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Assessment of Activity Concentrations of Radionuclide with Depth in Wasteland Soils in Abeokuta, Southwest Nigeria

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Author's contribution

This work was carried out in collaboration between both authors. Author BR designed the study, managed the literature searches and wrote the first draft of the manuscript. Author FOZ performed the statistical analysis, wrote the protocol and managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

A survey of natural radionuclide level with depth in wasteland soils in some locations in Abeokuta was carried out in February 2013. Samples were collected at 10 cm depth interval from each of the locations visited. They were collected into containers with length 9 cm and width 7 cm and then room dried. The different soil samples picked from different locations were not mixed together in order to avoid cross contamination of the soil samples. Analysis was carried out on each of the soil samples and the specific activity concentration of the radionuclides ^{40}K, ^{238}U and ^{234}Th was measured using the model 802 series thallium activated sodium iodide detector NaI (Tl). The average specific activity values obtained for the 0 cm depth (surface) were 428.91±15.05 Bq/kg for ^{40}K, 2.09±0.84 Bq/kg for ^{238}U and 54.60±2.00 Bq/kg for ^{234}Th. The gamma absorbed dose rate and effective dose equivalent were also calculated and an average of 55.5 nGy hr^{-1} and 0.136 mSv yr^{-1} were obtained. These obtained values were found to be below the recommended standard values by UNSCEAR which are 55.9 nGy hr^{-1} and 0.7 mSv yr^{-1}. The results indicate that the radiation level within the dumpsites pose no significant health risk on the people living close to

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the dumpsite. Also, it was observed that as radionuclides are leached down, activity concentration reduces but may be altered again by factors such as the type of radionuclide, composition of subsurface materials, rate of ground water movement and the soil particles with which the radionuclides are connected.

Keywords: Radionuclides; wasteland; activity concentration; depth; soil.

1. INTRODUCTION

In physics, radiation is a process in which energetic particles or energetic waves travel through a vacuum or through matter-containing media that are not required for their propagation. Radiation can be classified as either ionizing/non-ionizing according to whether it ionizes or does not ionize ordinary chemical matter. Ionizing radiation is the radiation with sufficiently high energy which can ionize atoms. Because living cells and more importantly the orbit in those cells can be damaged by this ionization, it can result in an increased chance of cancer. In Non-ionizing radiation, the kinetic energy of particles is too small to produce charged ions when passing through matter. For non-ionizing electromagnetic radiation, the associated particles (photons) have only sufficient energy to charge the rotational, vibrational or electronic valence configuration of molecules and atoms [1].

In 1895, the German physicist Wilhelm Roentgen identified penetrating radiation, which produced fluorescence, and which he named X-rays. In 1896 two months later, Henri Becquerel discovered that penetrating radiation, later classified as α, β and γ rays, were given off in the radioactive decay of uranium and thus opened a new field of study of radioactive substances and radiations they emit [2].

Soils are naturally radioactive, primarily because of their mineral content. The main radionuclides are ^{238}U, ^{232}Th and their decay products, and ^{40}K. The radioactivity varies from one soil type to the other depending on the mineral makeup and composition. The objective in the measurement of the radioactivity in soil is to asses the radionuclide concentrations; and these concentrations may be used to characterise substances and relate the radiometric properties to physical properties of the material. This may be of use in mineral separation for example [2].

According to the work of [3] in measuring natural radioactivity in environmental samples (soil, vegetation and water) from the (Idu) industrial district of Federal Capital Territory (FCT) Abuja, Nigeria was measured by means of gamma-ray spectrometer with NaI (Tl) detector to establish a baseline data for activity concentration of ^{40}K, ^{226}Ra and ^{232}Th. Results from the twelve field samples analysed also indicated that the activity concentration due to ^{40}K in the soil samples ranked highest against the lowest value obtained for sediments in the water samples.

[4] carried out analysis of alpha and beta activity concentration and heavy metal in soil and water in and around Imirigin oil field. The results showed that the level of the various metals obtained differs from location to location.

Man is continuously exposed to ionizing radiation from naturally occurring radioactive materials (NORM). The origin of these materials is the earth crust, but they find their way into the soil, building materials, air, water, food and the human body itself. In many parts of the world, building materials containing radioactive materials have been used for generations. The earth is naturally radioactive and about 90% of human radiation exposure arises from natural sources such as cosmic radiation, exposure to radon gas and terrestrial radionuclides [5]. However, it has been observed that the type and concentration vary considerably depending on the soil type. The effects of the radiation emitted by different radionuclides depend on the over lining soil material (thickness and type), its chelating agents and physio-chemical properties [6].

Solid waste other than hazardous or radioactive material are often referred to as municipal solid waste (MSW). Municipal solid waste is useless unwanted material discharged as a result of human activity. Human activity creates wastes and it is the way this waste is handled, stored, collected and disposed of that constitute risk to the environment and public health. In the urban area especially the rapidly urbanizing cities of the developing world, problems and issues of solid waste management are of immediate importance. However, rapid population growth of most municipal authorities is to provide even the

basic services when waste is collected. They are disposed of in uncontrolled dumpsites and/or burnt polluting water resources and air [7]. Municipal solid waste includes waste generated from residential, commercial, industrial institution, construction, demolition process and municipal services.

In most cases however, 'landfill' in developing countries is usually an unlined shallow hollow (often not deeper than 50cm). [8] referred to it as 'dumps' which receives solid wastes in a more or less uncontrolled manner, making a very uneconomical use of the available space and that which allows free access to waste pickers, animals and flies, and often produce unpleasant and hazardous smoke from slow-burning fires [9].

In Nigeria, open dump is almost the very option for solid waste disposal, millions of tons of these wastes from a variety of sources; industrial, domestic, agricultural find their way into the soil. These wastes end up interacting with the soil system waste disposal, even in the capital cities. Sanitary landfill however is rare and unpopular except perhaps among few institutions and few affluent people. The soil is the primary recipient of solid waste [10]; millions of tons of these wastes from a variety of sources; industrial, domestic thereby changing the physical and chemical properties [11].

Wastes constitute an environmental and public health nuisance in major cities all over the world. Thus, governments consider waste management as an essential social service whose budgetary provision is made in line with population projections [12]. Hazards posed by such dumpsite are not only in term of odour and presence of disease causing micro-organism, but can arise from the radiation emanating from such dumpsite [13]. It has also been established that vegetation and environmental fields in Nigeria contain traces of radionuclides [14].

Consequently, the radionuclide content in the waste dumpsite, if not properly managed emits mixed radiation to the environment [12]. Solid is an asset when properly managed and Nigerian government has been and is being invested much on solid municipal waste management in cities one of which is Abeokuta, a case study for this work, nevertheless the goal has not been met. Ideally wastes should remain immobile and unreactive but if water reaches the waste package, some radionuclides may dissolve or leach and move away from the disposal area. Radionuclides may be transported by water to the saturated zone and migrate with ground water flow depending on the type of radionuclide, the rate of ground water movement, the composition of subsurface materials, and time, a plum of contaminated wells and surface water.

2. MATERIALS AND METHODS

2.1 Sampling and Sample Preparation

This study was carried out in February 2013 with samples collected in four different locations across Abeokuta as depicted in Fig. 1. Table 1 shows the location of the dumpsites that were visited using the Global positioning system (GPS).

Abeokuta is the capital of Ogun state in south-west Nigeria. It is situated on the Ogun River; 64 miles North of Lagos by railway or 81 miles by water. It was founded in 1825 and has coordinates ranging 7.14993° N – 7.17635° N and 3.36268° E – 3.39997° E on the map. It has an elevation of 66 m (217 Ft). As of 2005, Abeokuta and the surrounding area had a population of 888,924. Abeokuta is an ancient city; therefore many of the dumpsites are illegal and are situated very close to the residential areas which are liable to pose more threats than when they are a far off.

The dumpsites visited have a very close proximity to the residential houses and have been in use for years. The soil samples were picked varying with depths of 0 cm, 10 cm, 20 cm, 30 cm and 40cm below the earth surface which implies that five soil samples were got from each location. The samples were collected into air tight containers of length 9 cm and width 7 cm and weighed 240 g each. A meter rule was used to measure the various depths from which the samples were picked. Each sample was crushed into finer particles and room dried. After collecting each of this soil samples from different dumpsites, the soil samples were not mixed together i.e. they were separately room dried in order to avoid cross contamination or pollution of the samples. In order to also enhance this, each of the containers was carefully labeled and left for 28days to ensure that the parent and daughter nuclide in the sample were at secular equilibrium. The analysis was done at The National Institute of Radiation Protection and research, University of Ibadan, Ibadan, South – West Nigeria.

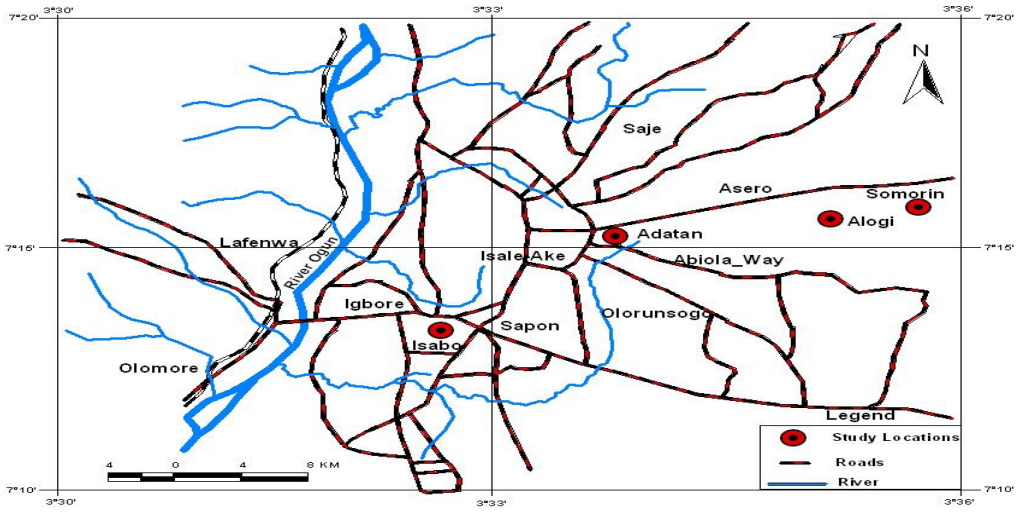

Fig. 1. Map showing locations of soil sample

Table 1. Locations covered with their positions using the global positioning system

Sites	Locations	Longitude (°E)	Latitude (°N)
1	Somorin	3.39997	7.17525
2	Alogi	3.39836	7.17635
3	Isabo	3.34736	7.14993
4	IsaleAbetu, adatan	3.36269	7.16719

2.2 Instrumentation and Evaluation of Activity Concentration

Sodium Iodide (thallium activated) scintillation detector Na(Tl)I, 802 series model was used to analyse the samples. The Model 802 Series Scintillation Detector is a hermetically sealed assembly which includes a high resolution NaI(Tl) crystal, a photomultiplier tube, an internal magnetic/ light shield, an aluminum housing, and a 14-pin connector. The 802 series of NaI(Tl) detectors provides high efficiency and uniform response on both the cylindrical and well configurations. These detectors have a proven record of long term reliability and stability [15].

The ^{232}Th-series, ^{238}U-series, and ^{40}K activities were estimated, as were the amounts of these radionuclides that would enter the air from the soil. A 3 inch × 3 inch NaI(Tl) detector was used, with adequate lead shielding. The system was calibrated in terms of both the energy response and the counting efficiency. Sample with a density of 1.3 g/cm3 was used for the calibration, which was the same as the mean density of the soil samples analyzed (1.24 g/cm3), the detector was very well shielded, and the counting time was 20,000s for each sample.

The concentrations of the radionuclides of interest were determined using the counting spectrum for each sample. Detectors that have been calibrated for photopeak detection efficiency were used to obtain the absolute gamma emission rates and quantitative analysis by NaI(Tl) gamma spectroscopy [16].

The reliability of any radiation measurement depends both on the inherent consistency of the measurement procedure as well as on the accuracy of the instruments used. In practice, all instruments have to be calibrated since the results typically appear as numerical multiples of some appropriate units [17].

The activity was calculated using the relation

$A = A_0 \exp(-\lambda t)$ where A = current activity of the source, A_0 = original activity of the source, λ = the decay constant and t = time elapsed

The decay constant is given by $0.693/T_{1/2}$ where $T_{1/2}$ = half life of the source.

The gamma absorbed dose rate D (nGy hr^{-1}) was calculated using the expression $0.043A_K + 0.427A_U + 0.662A_{Th}$ and annual effective dose equivalent A.E.D. (mSv yr^{-1}) was also calculated using the expression: Dose rate× 24hrs × 365.25 × 0.4 × 0.7Sv Gyr^{-1}× 10^{-6} where the occupancy factor used (outdoor) is 0.4.

Annual Effective Dose Equivalent at 0 cm Depth (Surface) using the formula:

$$A.E.D = (D \times 24hrs \times 365.25 \times 0.4 \times 0.7Sv\ Gyr^{-1} \times 10^{-6})\ mSv\ yr^{-1}$$

With occupancy Factor (Outdoor) – 0.4

3. RESULTS AND DISCUSSION

This section shows the result of the analysis carried out. The section comprises of tables and bar charts illustrating further how the various activity concentration of the radionuclides: ^{238}U, ^{40}K and ^{238}Th vary with depths 0, 10, 20, 30 and 40 cm.

Table 2 shows the concentrations of radionuclide ^{40}K, ^{238}U and ^{234}Th with their various depths in dumpsite 1. From Table 2, it was observed that ^{40}K is highest at depth 0 cm which is the surface, ^{238}U is highest at depth 20 cm and ^{234}Th is highest at 20 cm. This shows that the radionuclide after leaching down from the surface accumulated at the 20 cm depth.

Table 3 showed the concentrations of radionuclide with depth in dumpsite 2 (Adatan). From the table, it was observed that the concentrations of the radionuclide: ^{40}K, ^{238}U and ^{234}Th were highest at the 40 cm depth. This may be due to the fact that the radionuclide leached down from the surface and got accumulated at the 40 cm depth due to some physical and chemical processes. This gave a high tendency of getting surface water and wells contaminated.

Table 4 showed the concentrations of radionuclide with depth in dumpsite 3 (Isabo). The table showed that ^{40}K had highest at depth 20 cm, ^{238}U had highest at depth 40 cm and ^{234}Th had highest at depth 30 cm. This showed that the concentrations do not uniformly vary with depth and therefore no particular trend was followed.

Table 5 showed the concentrations of radionuclide with depth in dumpsite 4 (Somorin). The table showed that generally, the concentrations of ^{238}U, ^{234}Th and ^{40}K were low in dumpsite 4 compared to other locations visited, therefore the residents staying here are safe from the hazards posed by radionuclide from the dumpsites.

Table 2. Concentration of radionuclides in dumpsite 1

Location no	Depth (cm)	^{40}K Bq/kg	^{238}U (^{226}Rn) Bq/kg	^{234}Th (^{228}Ra) Bq/kg
1	0	344.77±13.86	1.41±0.08	44.68±1.75
2	10	296.40±12.03	1.02±0.07	46.28±1.61
3	20	339.26±13.41	1.68±0.07	50.37±2.05
4	30	308.32±14.82	1.54±0.08	45.04±1.74
5	40	322.37±12.90	1.19±0.07	43.01±1.73

Table 3. Concentration of radionuclides in dumpsite 2

Location no	Depth (cm)	^{40}K Bq/kg	^{238}U (^{226}Rn) Bq/kg	^{234}Th (^{228}Ra) Bq/kg
1	0	391.82±14.04	3.00±0.20	60.28±2.19
2	10	423.79±15.63	2.56±0.08	65.40±2.14
3	20	399.20±14.04	3.26±0.09	60.52±2.18
4	30	460.10±15.28	3.28±0.09	78.70±2.21
5	40	618.57±17.76	4.59±0.12	103.21±2.87

Tables 6 and 7 show the Gamma Absorbed Dose Rate D(Ngy/Hr) and Annual Effective Dose Equivalent. The gamma absorbed dose rate and effective dose equivalent were also calculated and an average of 55.5 nGy hr^{-1} and 0.136 mSv yr^{-1} were obtained. These obtained values were found to be below the recommended standard values by UNSCEAR which are 55.9 nGy hr^{-1} and 0.7 mSv yr^{-1}.

Bar charts were plotted for each depth : 0 cm, 10 cm, 20 cm, 30 cm and 40 cm where their concentrations were plotted against the various locations : Alogi, Adatan, Isabo and Somorin. Each bar was represented by the radionuclide ^{40}K, ^{238}U and ^{234}Th. These were plotted and presented in Figs 2 to 6.

From Figs. 2 to 6, it could be observed that ^{40}K has the longest bar followed by ^{234}Th. ^{238}U was almost not detectable i.e. low concentration and this may be due to weathering and alteration caused by metamorphic process. It could also be observed that Adatan had the highest activity concentrations in all the depths as it had the longest bars in all the depths therefore one could conclude that the people staying at Adatan are at greater risk of being affected by the threats posed by natural radionuclide.

Table 4. Concentration of radionuclides in dumpsite 3

Location no	Depth(cm)	^{40}K Bq/kg	^{238}U (^{226}Rn) Bq/kg	^{234}Th (^{228}Ra)Bq/kg
1	0	627.25±18.30	2.56±0.08	63.27±2.14
2	10	616.36±17.31	2.70±0.09	70.32±2.14
3	20	663.21±18.98	2.92±0.10	75.11±2.27
4	30	611.47±17.119	3.12±0.09	84.62±2.37
5	40	573.92±17.42	3.41±0.11	82.52±2.47

Table 5. Concentration of radionuclides in dumpsite 4

Location no	Depth (cm)	^{40}K Bq/kg	^{238}U (^{226}Rn) Bq/kg	^{234}Th (^{228}Ra)Bq/kg
1	0cm	351.79±14.00	1.40±0.08	50.18±1.93
2	10cm	307.70±13.32	0.88±0.07	44.11±1.66
3	20cm	294.68±12.35	0.78±0.07	41.74±1.61
4	30cm	320.86±12.68	1.00±0.06	42.69±1.58
5	40cm	317.55±14.96	0.74±0.06	37.32±1.59

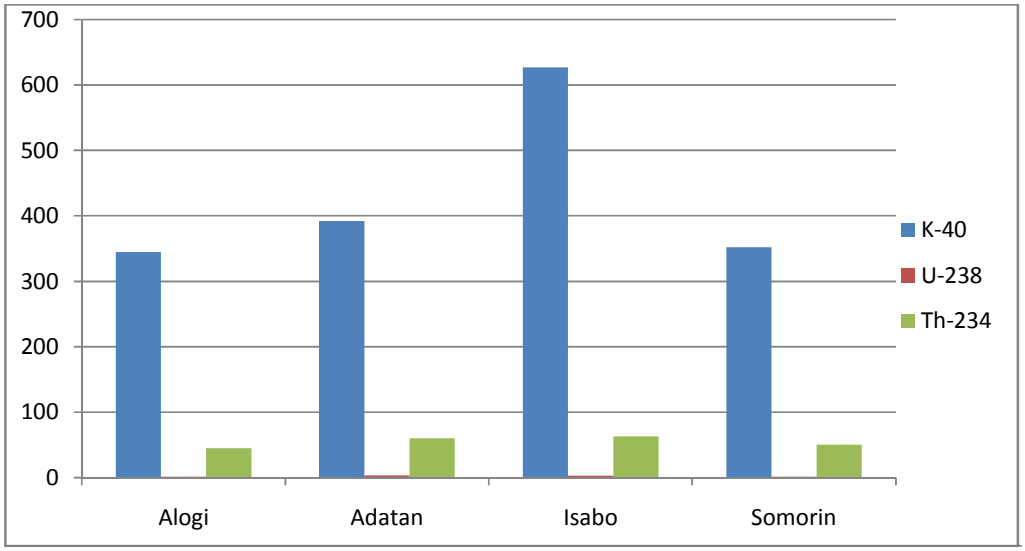

Fig. 2. Activity concentration against location at 0 cm depth (surface)

Table 6. Gamma absorbed dose rate D (Ngy/Hr) at 0cm depth (surface)

Location	Depth(cm)	K-40 Bq/kg	$0.043 \times A_K$	U-2238Bq/kg	$0.427 \times A_U$	Th-234Bq/kg	$0.662 \times A_{Th}$	D (nGy hr^{-1})
Alogi	0	344.77±13.86	14.82±0.60	1.41±0.08	0.60±0.03	44.68±1.75	29.58±1.15	45.00±1.78
Adatan	0	391.82±14.04	16.85±0.60	3.00±0.20	1.28±0.04	60.28±2.19	39.90±1.45	58.03±2.09
Isabo	0	627.25±18.30	26.97±8.02	2.56±0.08	1.09±0.03	63.27±2.14	41.89±1.42	69.95±9.47
Somorin	0	351.80±14. 01	15.13±0.60	1.40±0.08	0.60±0.03	50.18±1.94	33.20±1.28	48.93±1.91

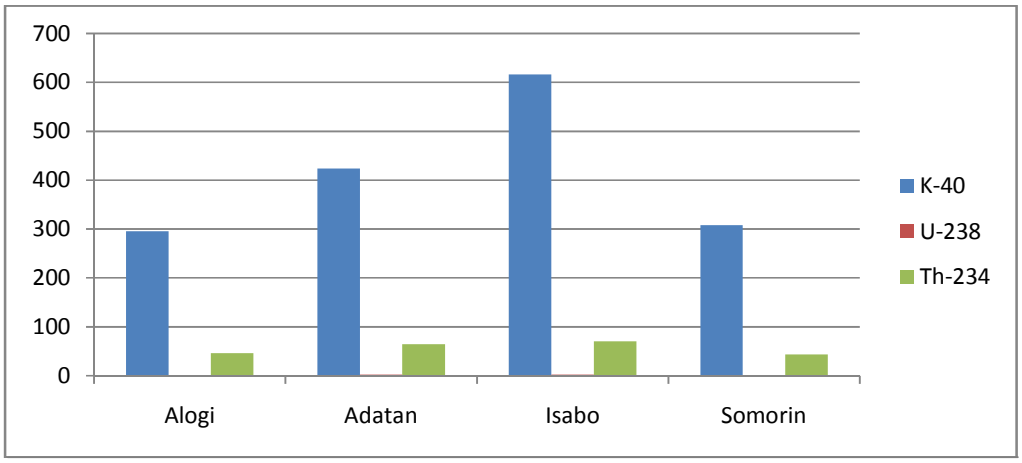

Fig. 3. Activity concentration against location at 10 cm depth

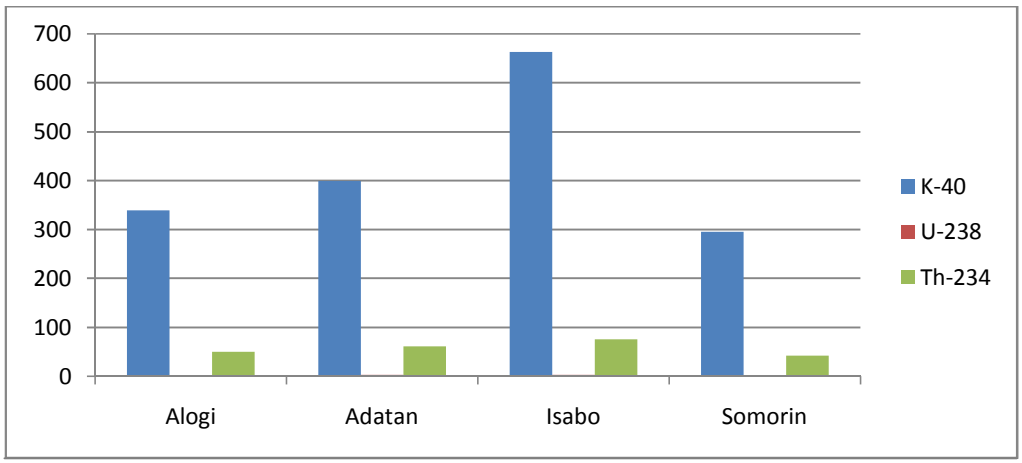

Fig. 4. Activity concentration against location at 20 cm depth

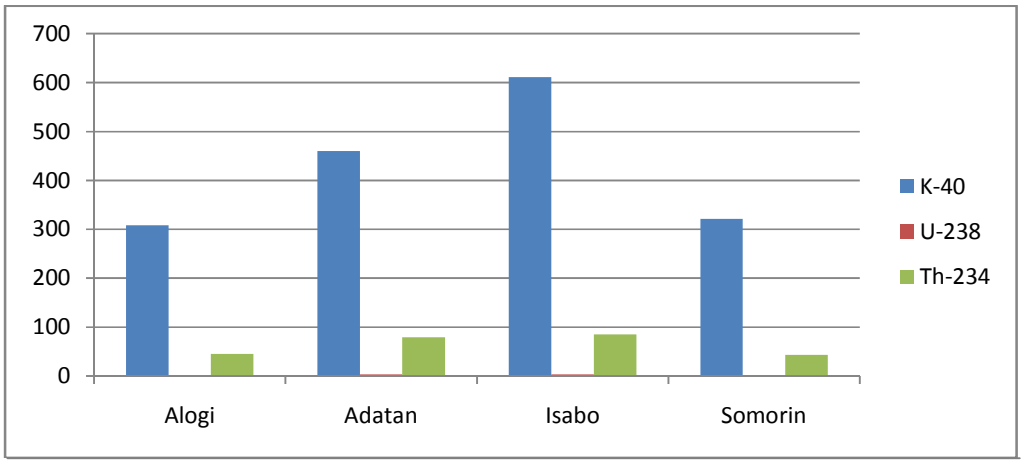

Fig. 5. Activity concentration against location at 30 cm depth

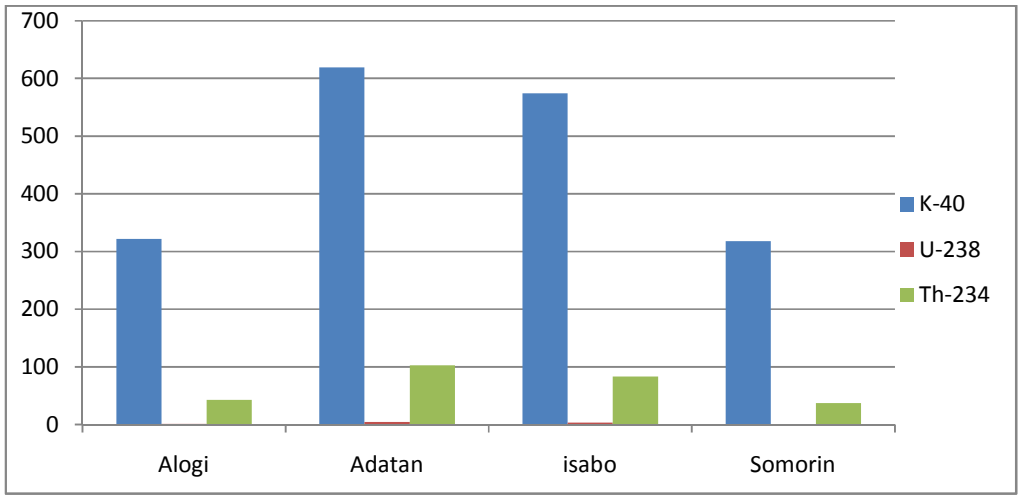

Fig. 6. Activity concentration against location at 40 cm depth

Table 7. Annual effective dose equivalent at 0cm depth (surface)

Location	A.E.D. (mSv yr^{-1})
Alogi	0.11±0.01
Adatan	0.14±0.01
Isabo	0.17±0.02
Somorin	0.12±0.01

4. CONCLUSION

From the analysis carried out, it was observed that all the samples analyzed at 0 cm depth (surface) from the dumpsites met the safety criteria by [18] and hence did not pose any threat or radiological hazard to the human health. This conclusion was made because the mean absorbed dose equivalent for soil obtained was 55.5 nGy hr^{-1} and the mean annual effective dose obtained was 0.136 mSv yr^{-1} and both were found to be below the recommended standard values by [18] which were 55.9 nGy hr^{-1} and 0.7 mSv yr^{-1}. It should also be mentioned that radionuclides are inclined to accumulate in the upper (0 - 20 cm) and lower soil layers as this was the area of homogenous lithology where a high correlation among natural radionuclide activity concentration is expected. Retention of uranium in the upper and lowest layers is connected with sorption of bivalent uranyl ions to the negative charged surfaces of clay minerals [19]. It has been noticed that radionuclide distribution is connected with particle size distribution which was related to the water infiltration in the 20 - 40 cm layer. Therefore it could be said that radionuclides were moving through the soil column along which the soil particles with which they were connected. This brings us to the final conclusion that radionuclides may be transported by water to the water table and migrates with ground water flow depending on the type of radionuclide, the composition of the subsurface materials and the rate of groundwater movement which may spread and contaminate wells and surface water. Ideally, as radionuclides leached down, activity concentrations reduces but may be altered again by factors mentioned earlier thereby causing accumulation in some fractions beneath the soil profile which tends to increase activity concentrations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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