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ARTICLE

Assessment of Naturally Occurring Radionuclides with Depths in the Soils of Selected Dumpsites, Ogun State, Southwestern Nigeria

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Abstract: The assessment of natural radionuclides in sixteen soil samples obtained across Saje, Oke-Diya, Premier and Ita-Oshin dumpsites, Ogun State, Southwestern Nigeria was carried out to determine the activity concentrations of ^{238}U, ^{232}Th and ^{40}K and to evaluate possible health hazards that these radionuclides may pose to inhabitants. The samples were collected at profile depths of 0-20, 20-40, 40-60 and 60-80 cm using soil auger. The samples were oven-dried for 24 hours and about 600 g post-sieved samples were sealed for thirty days before analysis using a high-purity germanium detector. The results revealed higher concentrations of ^{40}K compared to ^{232}Th and ^{238}U in the soil samples. Saje samples revealed mean concentrations of ^{238}U and ^{40}K above their global averages, while those of ^{232}Th were below the global averages. The mean concentrations of ^{238}U, ^{232}Th and ^{40}K were all above the global averages for Oke-Diya samples. Ita-Oshin and Premier samples recorded mean concentrations that were below the global averages. The estimated radiological parameters for the representative soil samples were all below the permissible limits, except for the absorbed dose rates of Oke-Diya samples. The study areas generally revealed a reasonably high level of soil radionuclides which may continue to increase with the dumpsites' age.

Keywords: Dumpsites, Soil, Natural radionuclides, Activity concentrations, Health risks.

1. Introduction

Radioactive elements are found naturally in the soil at low concentrations since the formation of the Earth [1, 2]. The most significant natural radionuclides are Uranium-238 (^{238}U) and Thorium-232 (^{232}Th) and their subsequent radioactive decay products, as well as Potassium-40 (^{40}K). They are found at varying degrees of concentrations all over the surface of the Earth [3, 4]. Traces of radionuclides are found in groundwater, ambient air, soil and human bodies. Human beings and other living organisms inhale and ingest radionuclides on a daily basis which have been ubiquitous on earth since its creation [5]. The presence of natural radionuclides in soil results in internal and external exposure of humans [6] and this could lead to increase both carcinogenic and non-carcinogenic health risks in man.

The deleterious radiological adverse health risks posed by human activities, such as solid-waste dumpsites, have attracted great concern and tremendous interest over the years in the field of radiation and health physics due to the enormous amounts of generated wastes, with large constituents of radionuclides being embedded in them [7-9]. According to Telford et al. [10], radionuclides can have both beneficial and adverse effects on all living organisms, but the latter are more, especially when radionuclides are available in excess. The staple food stuffs consumed in most parts of Nigeria contain traces of radionuclides in them [11] and

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as a result, the dumpsites in which food stuff leftovers were disposed are liable to be highly polluted with radioactive contaminants [11, 12]. Furthermore, [13] reported that the vegetation and most farmlands in Nigeria contain traces of natural radionuclides. Soils with high level of activity concentrations are considered as the main sources of natural background radiation [14, 15]. The need for precise and accurate information on the background ionizing radiation levels in the soils of dumpsites laid credence to this study.

Naturally occurring environmental radiations and radioactivity in soils have received appreciable attention in recent times due to human exposure to different levels of natural radioactive materials, depending on the mineral contents of each region of the earth and the degree of radionuclide pollutions on contaminated sites, such as solid-waste dumpsites [16, 17]. The knowledge of the distribution of natural radionuclides in soils plays an important role in radiation protection and measurement [12, 14, 18]. Gamma-ray measurement techniques are the backbone tool for radionuclide concentration estimation in environmental samples [1], because most radionuclides emit gamma ray. High penetration of gamma rays permits a comparatively simple source of preparation and gamma-ray spectrometry gives good selectivity in discriminating among radionuclides [9, 19]. Gamma-ray spectrometry based on high-purity germanium detectors is preferred for the determination of radionuclides in environmental samples, such as soils, because of its high resolving power, superior energy resolution, high-quality spectral capability, excellent peak symmetry, low-noise operation and efficiency in stopping and detecting high-energy gamma rays [20, 21].

In recent times, Abeokuta had consistently shown the highest level of natural radioactivity in southwestern Nigeria, while the location Jos has the highest level of natural radioactivity in Nigeria [12, 22, 23]. Odunaike et al. [24] studied the radiation dose in some dumpsites within Abeokuta, Ogun State and observed that the radiation doses were minimal compared to global average dose rates, but no matter how low, all levels of radiation still constitute a hazard. A survey of natural radionuclide levels with depth in dumpsite soils within Abeokuta was carried out by Bello and Farinre [7] and the activity concentrations of natural radionuclides indicated low significant health risks to inhabitants. This study therefore seeks to determine the activity concentrations of naturally occurring radionuclides in soils of four selected dumpsites within Abeokuta and Sagamu metropolises and to evaluate the radiological hazard parameters on man due to exposure to these naturally occurring radionuclides.

2. The Study Areas

Abeokuta is located on the basement complex of southwestern Nigeria, while Sagamu terrain is mainly sedimentary and located on the Ewekoro formation (Fig. 1). The study areas are Saje, Oke-Diya, Ita-Oshin and Premier dumpsites (Fig. 2). Saje is the largest dumpsite in Abeokuta and is located in Abeokuta south local government area within latitudes N07º11.201′-N07º11.480′ and longitudes E003º21.001′-E003º22.250′, covering an area of about 119,000 m^2. Oke-Diya is also the largest dumpsite in Sagamu and is located within Sagamu local government area. It has an area of about 60,000 m^2 and is bounded with latitudes N06º48.100′-E06º48.902′ and longitudes E003º35.520′-E003º36.655′. These two study areas have been in operation for the past twenty years. Ita-Oshin and Premier are located within Abeokuta north local government area, Abeokuta and cover approximate areas of 1,600 and 2,000 m^2, respectively. Ita-Oshin lies within latitudes N07º08.085′-N07º08.210′ and longitudes E003º18.351′-E003º18.544′ while Premier is bounded by latitudes N07º09.595′-N07º09.986′ and longitudes E003º18.201′-E003º18.581′. They have been in operation for the past ten years.

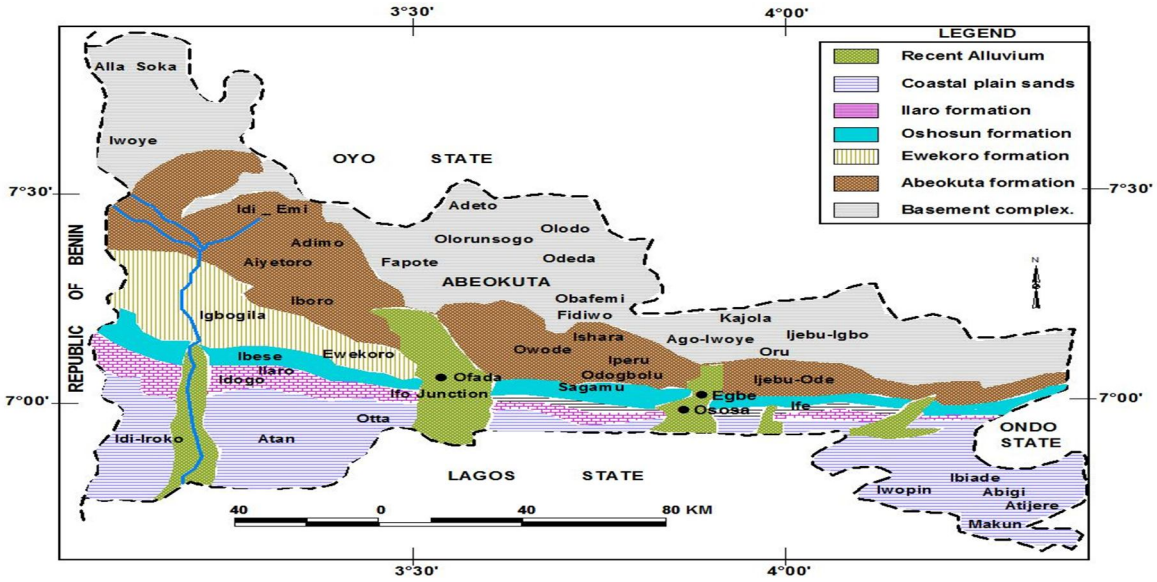

FIG. 1. Geological map of Ogun state showing Abeokuta and Sagamu terrains.

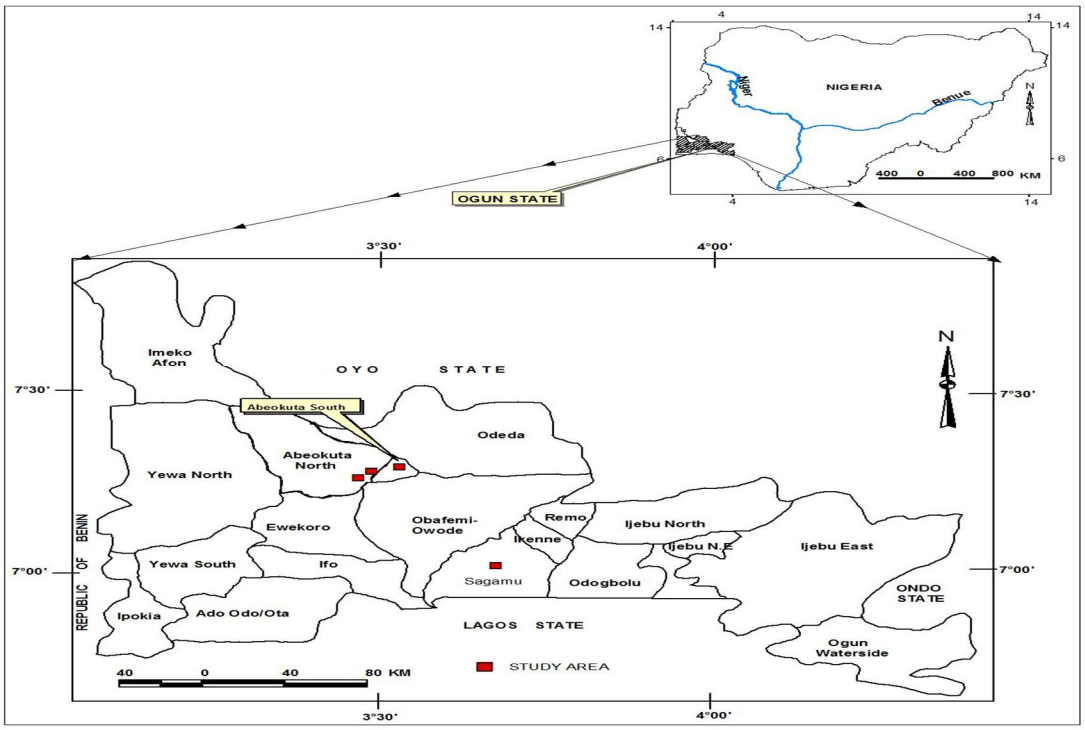

FIG. 2. Map of Ogun state showing the study areas.

3. Methodology

In order to collect sufficient soil samples for radionuclide measurements, about 1 kg of soil was collected at depths of 0-20, 20-40, 40-60 and 60-80 cm at each study area using a soil auger. The depths were measured using a meter tape, while the adequate records of the sampling locations were recorded by the Global Positioning System. Hand disposable gloves were worn to avoid soil contamination. Each sample was first transferred into a 2-mm sieve collecting pan to remove all extraneous materials that could introduce errors into the results. The sixteen post-sieved soil samples were then oven-dried for 24 hours at 100°C to remove significant moisture from the samples [25]. A 100-µm mesh was then used to sieve approximately 600 g of the dried samples to obtain uniform homogenous particle sizes for effective and efficient counting and the samples were parked and sealed in air-tight Marinelli beakers to prevent the escape of gaseous radon [17, 19]. Finally, the samples

were stored for thirty days in order to reach radioactive secular equilibrium [16, 26].

Gamma-spectrometry analysis was performed at the environmental unit, National Institute of Radiation Protection and Research, University of Ibadan, Nigeria, using a p-type coaxial high-purity germanium (HPGe) gamma-ray detector (GEM-25) which has a diameter of 57.5 mm and thick crystals of 51.5 mm and was coupled with a multi-channel analyzer for data acquisition. The spectrometer was set at 2800 volts, 1.67 keV energy resolution, 28.2% relative efficiency and full width at half maximum of 1.33 MeV. In order to avoid interferences of background radiations in the measurements from terrestrial sources, a well-designed suitable cylindrical lead shield was used to cover the detector. Energy calibration was carried out before sample measurement and was repeated prior to the measurements of new samples in order to reduce any changes as a result of subsequent measurements. Also, the counting efficiency of the detector was considered and number of pulses counted was determined to estimate the two significant values of detection efficiencies; the absolute total efficiency and the intrinsic total efficiency. The samples were counted for 86,400 seconds to achieve minimum photo-peak fitting errors [17]. The system was calibrated for photo peak efficiency using multi-gamma ray standard. The spectral data was analyzed using the Genie 2K Canberra software. The container used for the analysis was counted before being filled with the samples and the counts were subtracted from the total counts so as to determine the background radiation distribution [27].

The counting rate is proportional to the amount of radioactivity in a sample, so the activity concentration (A_c) in Bqkg^{-1} for a specific full-energy peak is given by the following Equation:

$$A_c = \frac{C}{\gamma \times \varepsilon(E_\gamma) \times m} \quad (1)$$

where C is the net peak count, γ is the absolute gamma decay intensity for the specific energy peak, m is the mass, and $\varepsilon(E_\gamma)$ is the absolute full-energy peak efficiency of the HPGe detector at this particular gamma-ray energy [28]. The activity concentrations of the soil samples were measured by considering the peaks of ^{238}U, ^{232}Th and ^{40}K at 1764.5, 2614.5 and 1460 KeV, respectively, on the spectra. These concentrations were used to estimate the radiological parameters, such as radium equivalents, gamma absorbed dose rates, annual effective dose equivalents, external hazard index and internal hazard index for individuals living around the study areas.

The radium equivalent (Ra_{eq}) assesses the risks associated with samples containing natural radionulides ^{238}U, ^{232}Th and ^{40}K. The spreads of these radionuclides in soils are not equal and in order to estimate the hazards caused due to the exposure to these radionuclides, their activity concentrations were combined together as given in Eq. (1) to give the radium equivalent in Bqkg^{-1} [15,29]. The universal maximum permissible limit of Ra_{eq} is 370 Bqkg^{-1} [3].

$$Ra_{eq} = (A_K \times 0.077) + (A_u) + (A_{Th} \times 1.43) \quad (2)$$

where A_u, A_{Th} and A_K are the activity concentrations in Bqkg^{-1} of ^{238}U, ^{232}Th and ^{40}K, respectively.

The absorbed dose rate (D) of the soil samples can be deduced from the following equation [30], where the universal maximum permissible limit is 55 nGyh^{-1} [3].

$$D = 0.042\, A_K + 0.429\, A_U + 0.666\, A_{Th} \quad (3)$$

In order to estimate the annual effective dose rate (E) in air, a conversion coefficient of 0.7 SvGy^{-1} for environmental sample exposure to gamma rays of moderate energy must be considered [30], as well as the absorbed dose in air to effective dose received by an adult and the outdoor occupancy factor of about 0.2. The annual effective dose equivalent is then given by Eq. (4) and the global average annual effective dose rate for outdoor or indoor terrestrial gamma radiation is 0.460 mSvy^{-1} [3].

$$E(mSvy^{-1}) = D \times 24hours \times 365.25 \times 0.2 \times 0.7SvGy^{-1} \times 10^{-6} \quad (4)$$

The external hazard index (H_{ex}) and internal hazard index (H_{in}) are deduced from the following Eqs. (5) and (6), respectively [16,17]. The prime objective of these indices is to limit the radiation dose to the admissible permissible dose equivalent limit of 1 mSvy^{-1} [3,30]. The external and internal hazard indices should be ≤ 1.

$$H_{ex} = \left(\frac{A_u}{740}\right) + \left(\frac{A_{Th}}{520}\right) + \left(\frac{A_K}{9628}\right) \leq 1 \quad (5)$$

$$H_{in} = \left(\frac{A_U}{185}\right) + \left(\frac{A_{Th}}{259}\right) + \left(\frac{A_K}{4810}\right) \leq 1 \quad (6)$$

where A_u, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K, respectively.

4. Results and Discussion

4.1 Activity Concentrations of Natural Radionuclides in the Soils

The activity concentrations of naturally occurring radionuclides in the sixteen representative soil samples collected from different depths into the soil profiles across the study areas were analyzed to determine the activity concentrations of ^{238}U and ^{232}Th natural decay chains and the long-lived naturally occurring radionuclide ^{40}K (Table 1). Table 2 presents the mean activity concentrations of each radionuclide in comparison with their global averages. Also, Fig. 3 shows the activity concentrations of each radionuclide at various depths. The determination of the specific activity of individual radionuclides in the representative soil samples revealed that ^{40}K had the highest activity concentrations in all the soil samples. Higher concentrations of ^{40}K were also observed in previous research [2, 19, 24, 26].

Saje samples (S1-S4) revealed that the activity concentrations of ^{238}U, ^{232}Th and ^{40}K increased with depth (Fig. 3A) and the highest concentrations of 63.83±8.54, 16.6±2.06 and 600.13±42.43 Bqkg^{-1}, respectively, were observed at depths of 60-80 cm. This probably indicates that the radionuclides had leached down into the subsurface and got accumulated at depths above 80 cm. The leaching action may be due to physical, metamorphic and chemical activities in these study areas, which gives a high tendency of the shallow aquifer getting contaminated. At depths 20-40 and 40-60 cm, the activity concentrations were very close and this probably indicates the migration of radionuclides into the subsurface. The mean activity concentrations of ^{238}U and ^{40}K were above their global averages, while that of ^{232}Th was below its global average.

TABLE 1. Activity concentrations of the soil samples

Locations	Samples	Depths (cm)	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
Saje	S1	0-20	13.83±2.54	7.02±1.07	216.38±16.33
Saje	S2	20-40	39.58±6.51	14.70±1.99	461.04±32.03
Saje	S3	40-60	59.05±8.20	15.58±2.05	464.71±32.26
Saje	S4	60-80	63.83±8.67	16.68±2.16	600.13±42.43
Oke-Diya	S5	0-20	37.06±6.12	34.91±4.31	751.29±51.14
Oke-Diya	S6	20-40	44.51±7.38	37.52±4.23	797.85±47.50
Oke-Diya	S7	40-60	56.83±9.06	50.22±6.34	982.86±64.06
Oke-Diya	S8	60-80	25.94±4.40	52.77±6.33	1043.00±68.02
Ita-Oshin	S9	0-20	44.85±7.26	13.25±1.79	819.40±54.36
Ita-Oshin	S10	20-40	40.56±6.40	12.98±1.73	516.05±35.61
Ita-Oshin	S11	40-60	38.53±6.40	5.21±0.45	460.00±32.42
Ita-Oshin	S12	60-80	9.90±2.11	0.16±0.04	69.16±6.67
Premier	S13	0-20	38.69±6.24	35.89±4.65	626.09±50.76
Premier	S14	20-40	26.31±3.40	32.20±6.32	521.16±25.65
Premier	S15	40-60	20.19±6.14	24.10±3.44	245.40±14.56
Premier	S16	60-80	12.54±3.34	12.90±2.11	95.76±7.89

TABLE 2. The mean activity concentrations compared with the global averages

Study Area	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
Saje	44.07±6.48	13.50±1.82	473.57±30.76
Oke-Diya	41.09±6.74	43.85±5.30	893.75±57.68
Ita-Oshin	33.46±5.54	7.90±1.00	466.30±32.27
Premier	24.43±4.78	26.27±4.13	372.10±24.72
Global Averages [3]	35	30	400

Oke-Diya samples (S5-S8) showed that the activity concentrations of the soil samples increased with depth (Fig. 3B), except for ^{238}U that had its highest concentration at depths of 40-60 cm. The soil samples had the highest concentrations of 56.83±9.06, 52.77±6.33 and 1043±68.02 Bqkg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively. The mean activity concentrations were all above their respective global averages. The high concentrations observed could be attributed to the age, geology and nature of the materials dumped on this site, which were mostly industrial and domestic municipal wastes as well as contraband goods. The highest and lowest concentrations of ^{238}U were at depths 40-60 and 60-80 cm respectively. The radionuclide had probably leached down into the subsurface due to the high infiltration nature of the terrain and got accumulated at depths of 40-60 cm. The highest concentrations ^{232}Th and ^{40}K were at depths of 60-80 cm, and the pattern in which the concentrations increased with depth indicated migration of these radionuclides into the subsurface. The pattern also indicated the high tendency of the shallow water aquifer being polluted.

Ita-Oshin samples (S9-S12) revealed the highest concentrations of 44.85±7.26, 13.25±1.79 and 819.40±54.36 Bqkg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively, at surface depths of 0-20 cm. The radionuclide concentrations decreased with depth (Fig. 3C) and the mean activity concentrations of ^{238}U and ^{232}Th were below their global averages, while the mean concentration of ^{40}K was above the global average. Ita-Oshin samples generally revealed low concentrations of radionuclides at depths above 60 cm and relatively high concentrations at depths below 60 cm. Premier samples (S13-S16) revealed low concentrations of radionuclide compared to other study areas and moreover, the concentrations decreased with depth (Fig. 3D). The low concentrations could be due to the age of the dumpsite and the nature of wastes dumped on it, which were majorly domestic municipal wastes. The highest concentrations of ^{238}U, ^{232}Th and ^{40}K at the surface depths (0-20 cm) were 38.69±6.24, 35.89±4.65 and 626.09±50.76 Bqkg^{-1}, respectively. Also, the mean activity concentrations of the radionuclides were all below the global averages. The observations in Ita-Oshin and Premier samples suggested that these radionuclides had not leached to depths above 60 cm in the subsurface; therefore, they may not be posing much havoc to the surface water and shallow aquifer.

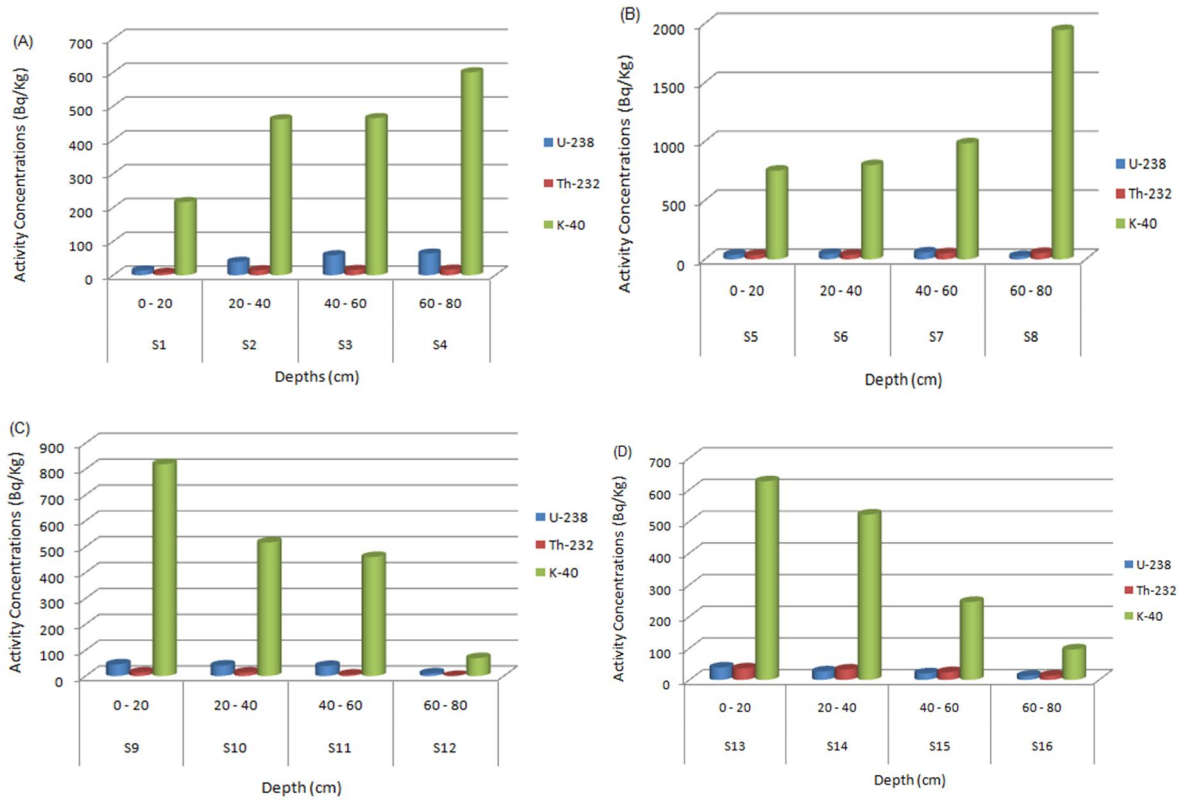

FIG. 3. Radionuclide concentrations with depths:(A) Saje (B) Oke-Diya (C) Ita-Oshin (D) Premier.

The mean activity concentrations of radionuclides ^{238}U, ^{232}Th and ^{40}K obtained in this study were within the ranges obtained by previous studies in Abeokuta (54.60, 2.09 and 426.91 Bqkg^{-1}) [7]; (43, 84 and 329 Bqkg^{-1}) [12]; Port-Harcourt (25.58, 10.97 and 326.47 Bqkg^{-1}) [19]; Agbara (26.3, 38.1 and 531.1 Bqkg^{-1}) [26]; Ibadan (26, 54 and 619 Bqkg^{-1}) [31]; Igbokoda (19.76, 31.98 and 494.64 Bqkg^{-1}) [32]; India (24, 55 and 549 Bqkg^{-1}) [33] and Georgia (53.57, 53.18 and 879.76 Bqkg^{-1}) [34].

4.2 Estimation of Radiological Parameters

The activity concentrations for the naturally occurring radionuclide distributions in the representative soil samples at different depths into the soil profile were used to estimate the radiological parameters for individuals living around the study areas (Tables 3).

4.2.1 Radium Equivalent (Ra_{eq})

The radium equivalent (Ra_{eq}) gives a single index used to describe the gamma absorbed output from different mixtures of uranium, thorium and potassium in the soil samples. The mean value of radium equivalent (Ra_{eq}) in the representative soil samples (S1-S16) from Saje, Oke-Diya, Ita-Oshin and Premier study areas were 96.91±11.45, 172.62±18.76, 80.65±9.46 and 90.65±12.59 Bqkg^{-1}, respectively. These values were considered to be normal, because they were all less than the permissible limit of 370 Bqkg^{-1}. Oke-Diya samples, S5-S8, had the highest values of 144.83±16.22, 159.60±17.09, 204.32±23.06 and 181.71±18.69 Bqkg^{-1}, respectively. Ita-Oshin soil samples, S9-S12, had the least values of 126.89±14.01, 98.86±11.62, 81.40±9.54 and 15.45±2.68 Bqkg^{-1}, respectively.

4.2.2 Gamma Absorbed Dose Rate (D)

The gamma absorbed dose rates of Saje samples (S1-S4) had values ranging from 19.70±2.49 to 63.70±6.94 nGyh^{-1} with the mean dose rate of 46.19 nGyh^{-1}. The absorbed dose rates of S3 and S4 obtained at depths of 40-80 cm were higher than the published maximum admissible limit of 55 nGyh^{-1}, while S1 and S2 dose rates were below the limit. Generally, the gamma absorbed dose rates increased with depth. Oke-Diya samples (S5-S8) had gamma dose rates above the admissible limit at all depths. The dose rates ranged between 70.70±7.64 (depths of 0-20 cm) and 99.12±10.80 nGyh^{-1} (depths of 40-60 cm) and the mean gamma dose rate was 84.37 nGyh^{-1}. Oke-Diya had the highest values of gamma dose rates and this could pose a threat to the local aquifer and agricultural production if the site is used for growing crops. Ita-Oshin samples (S9-S12) dose rates ranged between 7.26 (depths of 60-80 cm) and 69.48 nGyh^{-1} (depths of 0-20 cm). The gamma dose rates decreased with depth and the mean value was 40.94 nGyh^{-1}. The dose rate of S9 was higher than the admissible standard, while the other samples had values within the permissible limits. Premier samples (S13-S16) revealed the highest absorbed dose rate of 66.80±7.91 nGyh^{-1} at depths of 0-20 cm and the lowest absorbed dose rate of 17.99±3.17 nGyh^{-1} at depths of 60-80 cm. The mean gamma dose rate was 43.64 nGyh^{-1}. At depths of 0-20 cm, S13 had a dose rate above the standard limit, while samples at depths above 20 cm (S14-S16) had lower dose rates when compared to the limits.

TABLE 3. The gamma dose rate (D), radium equivalent (Ra_{eq}), annual effective dose equivalent (E), external hazard index (H_{ex}), and internal hazard index (H_{in}) of the radionuclides in the soil samples compared to their permissible limits

Samples	Depths (cm)	Ra_{eq} (Bqkg^{-1})	D (nGyh^{-1})	E (mSvy^{-1})	H_{ex} (mSvy^{-1})	H_{in} (mSvy^{-1})
S1	0-20	40.53±5.33	19.70±2.49	0.024±0.003	0.054±0.007	0.147±0.021
S2	20-40	96.10±11.82	46.13±5.46	0.057±0.007	0.128±0.016	0.368±0.050
S3	40-60	117.11±13.62	55.23±6.24	0.068±0.008	0.156±0.018	0.477±0.059
S4	60-80	133.89±15.03	63.70±6.94	0.078±0.009	0.178±0.020	0.536±0.064
S5	0-20	144.83±16.22	70.70±7.64	0.087±0.009	0.192±0.022	0.494±0.061
S6	20-40	159.60±17.09	77.59±7.97	0.095±0.010	0.212±0.022	0.554±0.066
S7	40-60	204.32±23.06	99.12±10.80	0.122±0.013	0.271±0.031	0.709±0.087
S8	60-80	181.71±18.69	90.08±8.96	0.111±0.011	0.241±0.025	0.565±0.062
S9	0-20	126.89±14.01	69.48±6.59	0.085±0.008	0.168±0.019	0.466±0.058
S10	20-40	98.86±11.62	47.72±5.39	0.059±0.007	0.131±0.016	0.378±0.049
S11	40-60	81.40±9.54	39.32±4.41	0.048±0.005	0.108±0.013	0.325±0.043

Samples	Depths (cm)	Ra_{eq} ($Bqkg^{-1}$)	D ($nGyh^{-1}$)	E ($mSvy^{-1}$)	H_{ex} ($mSvy^{-1}$)	H_{in} ($mSvy^{-1}$)
S12	60-80	15.45±2.68	7.26±1.21	0.009±0.001	0.021±0.004	0.069±0.013
S13	0-20	138.33±16.80	66.80±7.91	0.082±0.010	0.184±0.022	0.480±0.062
S14	20-40	112.49±14.41	54.62±6.74	0.067±0.008	0.149±0.019	0.377±0.048
S15	40-60	73.55±12.18	35.14±5.54	0.043±0.007	0.098±0.016	0.255±0.050
S16	60-80	38.36±6.96	17.99±3.17	0.022±0.004	0.051±0.009	0.138±0.028
Limits [3]		370	55	0.460	1	1

The mean absorbed dose rate in dumpsite soils from different locations within Abeokuta was estimated by Bello and Farinre [7] as 55 $nGyh^{-1}$. This value was higher than the mean values obtained in Saje, Ita-Oshin and Premier, but lower than the mean value of Oke-Diya. Also, Odunaike et al. [24] obtained a mean absorbed dose rate of 36 $nGyh^{-1}$ for soils from a dumpsite in Abeokuta; this value was lower than the values obtained in this study. Again, Obed et al. [12] estimated a mean absorbed dose rate of 88 $nGyh^{-1}$; this value was higher than the mean absorbed doses obtained in this study. In dumpsites in Agbara and Port-Harcourt, mean absorbed doses of 62.4 and 52.49 $nGyh^{-1}$ were obtained, respectively [1, 26]; these values were higher than the mean values estimated for Saje, Ita-Oshin and Premier, but lower than the Oke-Diya values. The mean absorbed dose rates in dumpsites from Osogbo and Port-Harcourt were 28.80 and 31.98 $nGyh^{-1}$, respectively [19, 35]. These values were lower than the values obtained in this study. The mean absorbed dose rates estimated in this study were relatively high (especially for Oke-Diya results) compared to these similar studies.

4.2.3 Annual Effective Dose Equivalent (E)

The annual effective dose equivalents estimated ranged from 0.009±0.001 to 0.122±0.013 $mSvy^{-1}$. The minimum annual effective dose of 0.009 $mSvy^{-1}$ was obtained in Ita-Oshin sample S12 (depths of 60-80 cm), while the maximum annual effective dose of 0.122 $mSvy^{-1}$ was obtained in Oke-Diya sample S7 (depths of 40-60 cm). The mean annual effective dose equivalents obtained for Saje, Oke-Diya, Ita-Oshin and Premier samples were 56.7, 103.8, 50.2 and 53.5 μSvy^{-1}, respectively. These values were higher than the mean effective dose of 24.6 μSvy^{-1} obtained in samples from some selected dumpsites in Port-Harcourt, Rivers State, Nigeria by [9] and also higher than the mean annual effective dose of 36.0 μSvy^{-1} obtained in some dumpsites in Abeokuta, Ogun State, Nigeria [24], but lower than the annual effective dose of 80.0 μSvy^{-1} for the surface soil in some Southwestern cities of Nigeria [36], except for Oke-Diya study location with higher values. The high effective dose obtained in Oke-Diya may be due to its sedimentary terrain and the nature of the waste materials dumped on the site, which are mostly associated with industrial and domestic (household, animal bones and related wastes, charcoal, … and so on) wastes, as well as contraband goods and other market wastes which contain high amounts of potassium. In general, the average annual effective dose equivalents for all the representative soil samples were below the global average annual effective dose limit of 460 μSvy^{-1} and the study areas can then be considered to have permissible levels of background radiation.

4.2.4 External and Internal Hazard Indices

The external hazard index (H_{ex}) for the representative soil samples for Saje, Oke-Diya, Ita-Oshin and Premier ranged from 0.054±0.007-0.178±0.020, 0.192±0.022-0.271±0.031, 0.021±0.004-0.108±0.013 and 0.051±0.009-0.184±0.022 $mSvy^{-1}$, respectively. Also, the internal hazard index (H_{in}) ranged from 0.147±0.021-0.536±0.064, 0.494±0.061-0.709±0.087, 0.069±0.013-0.466±0.058 and 0.138±0.028-0.480±0.062 $mSvy^{-1}$ for Saje, Oke-Diya, Ita-Oshin and Premier, respectively. The external and internal hazard indices for all the representative samples were within the normal range, as they were all below unity and these low values were also obtained in similar studies by Sowole and Egunjobi [32], and Taqi et al. [37]. The external hazard index values of the soil samples were very low compared to the standard permissible limit of 1 $mSvy^{-1}$. Moreover, the internal hazard index values for Oke-Diya soil samples were relatively high compared to the other study areas; most of the values obtained were higher than 0.5 $mSvy^{-1}$.

5. Conclusion

The activity concentrations associated with ^{238}U and ^{232}Th natural decay chains and the long-lived naturally occurring radionuclide ^{40}K in sixteen representative soil samples collected from different depths into the soil profiles across the study areas were determined. Saje samples revealed an increase in the activity concentrations with depth, probably indicating leaching of the radionuclides into the subsurface. Oke-Diya samples revealed the highest concentrations of radionuclides, which may be due to geologic, hydro-geologic and anthropogenic effects. The radionuclide concentrations increased with depth, indicating the accumulation of these radionuclides at deeper depths. Ita-Oshin and Premier samples had their highest radionuclide concentrations at the surface depths and the radionuclide concentrations decreased with depth. The radionuclides had not leached into deeper depths of the subsurface and therefore may not pose much threat to soil and aquifer. Premier samples revealed low concentrations of the radionuclides when compared to the other study areas. The gamma absorbed dose rate, radium equivalent, external and internal hazard indices and annual effective dose equivalent for the complete set of samples were all below the recommended standards, except for the mean gamma absorbed dose rate of Oke-Diya samples. These parameters showed a radiation burden on the environment and the study areas could be regarded to have a relatively high level of natural background radiation which may increase overtime as the dumpsites age.

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