Assessment of Background Radiation around Lagos State University Ojo, Lagos

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Abstract

Every effort aimed towards attainment and sustenance of Global Goal, SDG3-sound health and well-being is worth the while. Among all sources of background radiation exposure, eighty percent of the annual mean effective dose to man are due to naturally occurring radionuclides (NORs) and this could pose health threat. In order to make the living environment radiological safe for dwellers, it is needful to appraise the scale of exposure to habitat and man. This work appraised the scales of activities of natural radioisotopes in the environment, soil and sediment samples. The impact of NORs on the terrestrial and freshwater aquatic stations in LASU, Ojo LGA of Lagos State, Nigeria was assessed. Ambient gamma doses per unit time and specific activities of natural radioelements ^{40}K, ^{238}U, ^{232}Th were measured deploying mobile Radio Solution's RS-125 gamma spectrometer while soil and sediment samples were analysed using Hyper-Pure Germanium HP(Ge) gamma detector. Radiological risk indicators were evaluated from both measured andanalysed specific activities of NORs. For terrestrial station, Ojo-LASU-2nd-Gate, background gamma dose rates ranged from 9.64 - 26.98 nGyh^{-1} and their mean was 17.11 nGyh^{-1}. Activities per unit mass of ^{40}K, ^{238}U, ^{232}Th ranged from 0.0, 2.46 and 11.48 to 113.76, 10.82 and 25.99 Bqkg^{-1}, respectively; with the average value for each NOR being 59.41, 6.00 and 17.93 Bqkg^{-1}, correspondingly. For freshwater aquatic station, Ojo-LASU Fish Farm, ambient gamma doses per unit time ranged from 0.92 - 7.42 nGyh^{-1} with the mean being 4.29 nGyh^{-1}. Mean specific activities of ^{40}K, ^{238}U, ^{232}Th were 2.53, 2.61 and 4.64 Bqkg^{-1}, respectively. Measured mean activities per unit mass of the NORs and estimated mean radiological hazard indices due to the background radiation and those due to samples analyses were well below the threshold limits. Hence the study concluded that Ojo-LASUarea is radiologically safe.

Keywords: SDG3, Background radiation, Environment, NORs, Risk parameters, Ojo-LASU

Introduction

It was reported that out of 3 mSv annual mean effective dose to an individual, about 80% (2.4 mSv) comes from natural sources (UNSCEAR, 2008). Protection from radiological effects of radioactivity has evolved from a system that used to focus on man only, to an all-encompassing one covering the living surroundings as well as non-human ecosystem (Bréchignac et al., 2016). In view of the demands to attain and sustain the Sustainable Development Goal 3 - sound health and well-being for, it is crucial to ascertain the safety of the living environment, radiologically. The level of exposure due to natural radionuclides adds to the motivation for this study, as examining the natural radiation from naturally occurring radionuclides (NORs) and assessing radiation hazards are of utmost importance. NORs are useful in many applications such as tracers for processes, dating tools, isotope hydrogeology and sedimentology (Botwe et al., 2017). However, these radionuclides have harmful effects, and could pose a threat to both the ecosystem and human health (Botwe et al., 2017). Natural radionuclides can also undergo bioaccumulation and bio concentration and thereby impacting the health of humans and the ecosystem (Fonollosa et al., 2017).

^{238}U, ^{232}Th and ^{40}K, were adopted for studies because they are long-lived with very long half-lives and are prevalent in the environment due to their universal abundance in the earth's surface, sub surface and the air; the first two yield lots of decay products in their respective decay series. These three NORs are used in radiological impacts assessments for both the ecosystem and the human population. Work done by Botwe et al. (2017) revealed spatial fluctuations in the specific activities of radionuclides due to complicated dynamics of many mingled sources of sediments in Tema Harbour, Ghana. Though Nigeria may not have nuclear power facilities yet, the ecosystem may still be impacted due to oceanic and atmospheric dispersals and redistributions of natural radionuclides. Moreover, human activities such as mining, oil and gas exploration, industrialisation and agricultural activities all have the potential to contribute to the levels of radionuclides in the ecosystem. It is therefore important to monitor the level of radioactivity in the environment in order to estimate the radiological risk associated it.

Methodology

Geographical Location of the Study Area

The study area covered Lagos State University in Ojo, Lagos State, Nigeria, as shown in Figure 1 and lies between latitude 6° 28' 4" - 6° 28' 13" N and longitude 3° 12' 1" - 3° 12' 20" E. According to City Population (2022), Ojo LGA, has a population of 941,523 by 2006 census with a landmass of 172.7 km^2 area. Each of the locations examined has quite an appreciable percentage of the LGA's population. The elevation and the respective coordinates of the locations were gotten through the GPS

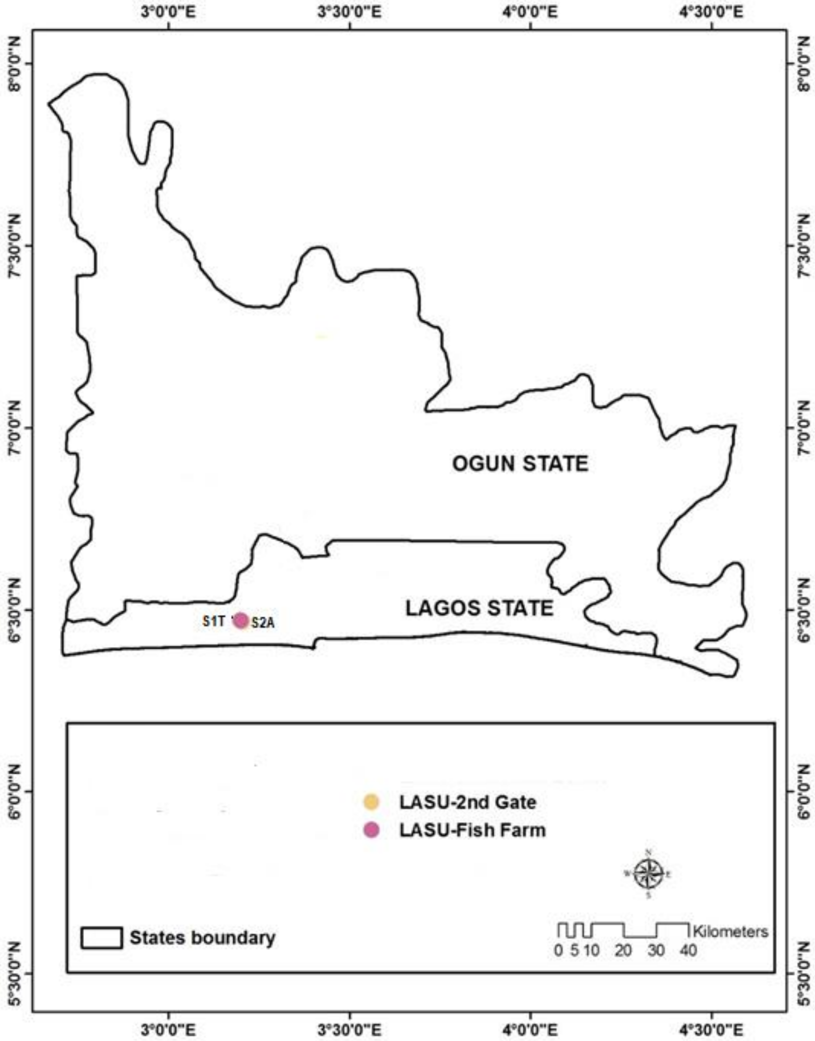

Figure 1: Map of the study area showing the two overlapping sampling stations

On the Spot Assay Measuring at Stations

In-situ assay measurements were taken from two locations: LASU 2nd Gate and LASU Fish Farm, respectively. A total of 50 readings were recorded from the two stations examined. At every station, an area is mapped out and in-situ readings of the assay mode readings of the mobile RS-125 gamma spectrometer were recorded after stabilised against the ambient gamma radiation. To have a full picture of NORs' distribution and propagation of ambient gamma radiation in an examined area, an adapted design of the envelope method was adopted due to the diversity in the dimensions of the studied stations (Kapanadze et al., 2019). 5 samples were taken at each sampling point, corners A, B, C, D and center E as shown in Figure 2. The samples were thoroughly mingled together and an average representative sample was taken for treatment and analysis. For the terrestrial station, a rectangular area was measured out and the GPS coordinates, the elevations and the assay mode recordings of RS-125 gamma spectrometer were recorded at each of the 5 station points, Figure 2. RS-125 gamma spectrometer was usually balanced upon a pipe which was 1.0 m high from the ground. By spanning 1.0 m from a central point to each of four cardinal directions: North, South, East and West, values were recorded at each point and at the center. At each sampling point, 5 assay mode values of the ambient dose rate, potassium (^{40}K), uranium (^{238}U) and thorium (^{232}Th) were taken after the RS-125 might have calculated the assay values after a duration of 120 seconds; during this time duration, it might have stabilised against the background radiation. RS-125's assay mode displays specific activities of NORs $^{40}K, ^{238}U, ^{232}Th$ in their respective native units. Same procedure was repeated at the freshwater aquatic station as the GPS coordinates, the elevations and the assay mode recordings of RS-125 were taken at the four corners of a fishpond and its center.

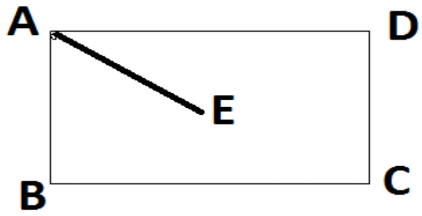

Figure 2: An adapted design of the envelope method depicting sampling points: A, B, C, D, E (Kapanadze et al., 2019).

Assay mode recordings of RS-125 displayed ^{40}K in percent (%) and each of ^{238}U with ^{232}Th in parts per million (ppm). These were translated to standard SI units, Bqkg^{-1} with translation factors from (The Medusa Institute, 2023).

Sample Collection and Preparation Procedures

For the terrestrial station, following the envelope method of Figure 2, a rectangular area was carved out for the measurements. Soil samples were collected at the same station, at each of the four corners of the rectangular area and at its center. Soil specimens were collected at a deepness of roughly 12 - 25 cm from the surface since the roots of grass/herbs are from 12 - 25 cm deep. Each sampling point was cleared of debris and vegetation before scooping the soil. The foremost processing of the soil samples took place on-site which involved the removal of stones, roots and debris. The soil sample was packed in a labeled polythene bag for further treatment at the Covenant University Civil Engineering Laboratory. The sediment samples were collected at each of these 5 points, homogeneously mixed, and a standard representative sample of each was taken for further processing. The initial preparation of the sediment samples took place at the site, which entailed removing rubbles, pebbles and roots. Each sediment and water sample was then packaged in a labelled polyethylene bag and 1 litre PET bottle, respectively. Fish samples were bought from the pond owner and were carefully packaged. Both sediment and fish samples were taken to the laboratory for heat treatment. A sum of 22 samples was taken from the two examined locations in the study area.

Samples of soil and sediment collected were sorted out carefully and kept for further processing for laboratory gamma spectroscopy counting. Appropriate measures were taken to separate the samples from one another to prevent cross-contamination as instruments, tools, and kits were thoroughly washed after packaging each sample. The soil and sediment samples were air-dried at the ambient temperature for a few days; and subsequently oven-dried at about 105°C to ensure total removal of moisture and were thereafter ground to powdery form with a 750W Rico MG 1803 Mixer Grinder blender (Eyebiokin et al., 2005). The powdery form was filtered through a 600-micron mesh sieve, loaded, and secured in a well labeled, impermeable PET bottles ready for gamma counting. The homogenized samples were put in 500 ml Marinelli beakers, closed for thirty days to attain secular equilibrium of radionuclides of interests and their progenies before radioactivity counting (Usikalu et al., 2015).

The laboratory-based Hyper-Pure Germanium HP(Ge) gamma detector used for samples analyses is a *p*-type CANBERRA (model: GC 8023) with 80% resolution and efficiency calibration using ^{60}Co at the energy range of 1.33 MeV and 2.3 keV (FWHM). The HP(Ge) gamma detector is coupled to a pre-amplifier 8k multi-channel analyser (model: 2002CSL). The detector uses Genie 2000 software for sample analysis which gathers as well as treats γ spectrum into widths of peak values, for computing the areas of peaks and eventual translation into the activity of a radioisotope. Each sample was counted for 288000 seconds and peak analysis was done with Genie 2000 software**.**

Estimating Average Radiological Health Indicators

In order to assess both immediate and future threats to man from ambient gamma radiation and NORs, radiological health indicators are usually estimated. Biological effects of gamma radiation could be indirect or direct. Therefore it is crucial to evaluate the scales of potential threats through their associated indices. 8 indicators will be calculated in this work.

NORs ^{40}K, ^{238}U plus ^{232}Th are not uniformly distributed in soil and sediment as a result of loss of equilibrium among ^{238}U and its decay daughters (Ehsan et al., 2020). For homogeneity in exposure calculations, the activities per unit mass of natural radioisotopes are quantified in appellations of Ra_{eq} (radium equivalent activity in Bq/kg) (Ehsan et al., 2020). Ra_{eq} is the specific activity of a radioelement equal to 370 Bqkg^{-1} of ^{226}Ra, which releases to outdoors an external effectual dose rate of 1 mSv per annum, and is given by Equation 1 (Ajani et al. 2020; Omeje et al., 2018).

$$Ra_{eq} = (0.077)\times A_K + (1.430)\times A_{Th} + (1.000)\times A_U \quad (1)$$

A_K, A_{Th}, A_U are activities per unit mass of ^{40}K, ^{232}Th, ^{238}U , correspondingly.

Equation 1 was estimated assuming 1.00 $Bqkg^{-1}$ of uranium-238; 0.70 $Bqkg^{-1}$ of thorium-232, and 13.00 $Bqkg^{-1}$ of potassium-40 propagate equal γ radiation dose per unit time (Júnior et al., 2021).

External radiation hazard indicator (H_{ex}) is the exterior gamma radiation dose per unit time attributable to outdoor vulnerability towards γ emission. The external radiation hazards indicator, H_{ex} is given by Equation 2 (Ehsan et al., 2020):

$$H_{ex} = \frac{A_U}{370Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \leq 1 \quad (2)$$

A_U, A_{Th}, A_K are as previously defined, Equation 1.

Interior radiation hazard indicator (H_{in}) indicates the indoor subjection to cancer-causing radon plus its decay product of very small half-life as in Equation 3 (Ehsan et al., 2020):

$$H_{in} = \frac{A_U}{185Bqkg^{-1}} + \frac{A_{Th}}{259Bqkg^{-1}} + \frac{A_K}{4810Bqkg^{-1}} \leq 1 \quad (3)$$

A_U, A_{Th}, A_K are stated in Equation 1.

Gamma radiation aftereffects are usually expressed in relation to the absorbed dose per unit time in air. Inhaled dose per unit time in air, D_{out}, 1 meter from the ground due to NORs ^{238}U, ^{232}Th, ^{40}K in soil and sediment was quantified using Equation 4, (Omeje et al., 2018).

$$D_{out} = [0.0432] \times A_K + [0.662] \times A_{Th} + [0.427] \times A_U \quad (4)$$

A_K, A_{Th}, A_U are as defined in Equation 1.

For indoor environ, internal gamma dose per unit time, D_{in} is delivered by gamma radiation propagated by NORs ^{238}U, ^{232}Th, ^{40}K . D_{in} is related to D_{out} as expressed in Equation 5 (Ajani et al., 2020; Omeje et al., 2018).

$$D_{in} = (1.4) \times D_{out} \quad (5)$$

A building's walls, floors and ceilings contribute to indoor gamma radiation (Michael et al., 2010). Measurements of outdoor and indoor gamma doses per unit time using gamma spectrometry yielded the proportion of indoor to outdoor gamma doses per unit time as 1.40 ± 0.50 (Svoukis & Tsertos, 2007), hence the factor (1.4) in Equation 5.

With measured outdoors dose per unit time, D_{out}, yearly effective dose rate, outdoors, $AEDR_{out}$ was estimated using Equation 6 by using 0.70 Sv/Gy as a conversion factor (UNSCEAR, 2000) and 0.20 as factor of occupancy outdoors because people spent twenty percent of their lifespan outdoors on the average with $8.766 \times 10^{3} hours$ in one year $\left(3.6525 \times 10^{2} days\right)$ (UNSCEAR, 2000). The factor, 0.70 Sv/Gy is employed to translate absorbed dose in the atmosphere to effective dose delivered to a grown-up according to (Smith, 1991). Yearly dose delivered to man, outdoors, was estimated using Equation 6 (Ehsan et al., 2020; Raghu et al., 2017; Usikalu et al., 2017; Yang & Sun, 2022).

$$AEDR_{out} = D_{out} * \left(8766\right) * \left(0.2\right) * \left(0.7\right) * \left(10^{-4}\right) \qquad (6)$$

Gamma index (I_γ) was used to assess γ radiation threat associated with NORs in particular analysed specimens. Typical I_γ was calculated using Equation 7 (Usikalu et al., 2017). For γ radiation threat to be negligible, I_γ should be less than unity.

$$I_{\gamma} = \frac{A_U}{300 Bqkg^{-1}} + \frac{A_{Th}}{200 Bqkg^{-1}} + \frac{A_K}{3000 Bqkg^{-1}} \qquad (7)$$

A_U, A_{Th}, A_K are as indicated in Equation 1.

Probability of having tumor in a lifetime for a risk level is assessed via excess lifespan cancer risk (ELCR). ELCR shows the figure of people with cancer expected among a given population on subjugation to a carcinogen for a stated dose. The rate at which a person can have bone, breast, blood, prostate, and other modes of tumor has a relationship with an increase in ELCR value (American Cancer Society, 2022). ELCR was obtained using Equation 8 (Penabei et al., 2018).

$$ELCR(\times 10^{-3}) = AEDR_{out} * DL * RF \qquad (8)$$

$AEDR_{out}$, yearly effective dose rate outdoor; *DL*, average lifespan (about 70 years); and *RF*, risk factor (per Sv), that is fatal cancer threat per Sievert. Considering stochastic effects, ICRP uses 0.05 Sv^{-1} as *RF* for public (Taskin et al., 2009) with the ELCR (UNSCEAR, 2000), standard being 0.29 x 10^{-3}.

Results and Discussion

Geographical Spread of Background Gamma Doses per Unit Time

Figure 3 displays the spatial distribution of the background γ dose rates in Ojo-LASU 2nd Gate. At the southern part of this station, the highest background gamma dose rate of 14.00 $nGyh^{-1}$ was recorded at OJL3, while the lowest background gamma dose rate of 8.00 $nGyh^{-1}$ was recorded at both station points OJL1 and OJL2, respectively. From the highest value noted at OJL3, the background gamma dose rate spread northwards. All the recorded background γ dose rates in the station were markedly lower than the permissible limit, 59.00 $nGyh^{-1}$ (UNSCEAR, 2008).

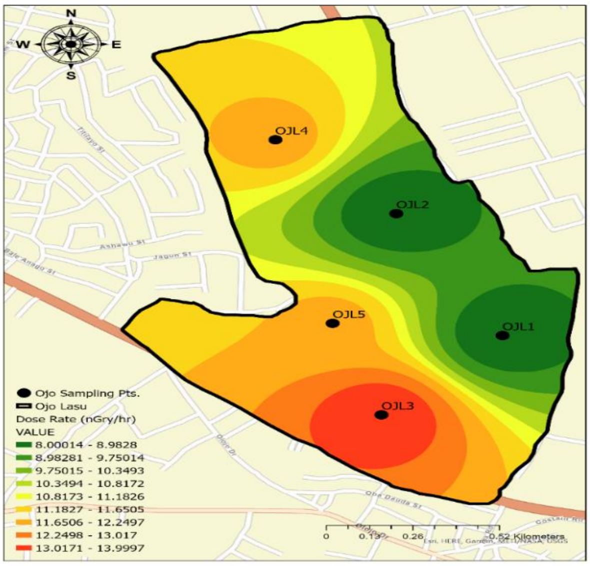

Figure 3: Geographical spread of ambient gamma doses per unit time in Ojo-LASU 2nd Gate (OJL)

Average Ambient Gamma Doses per Unit Time and Activity Concentrations of NORs in the Examined Stations

Ambient gamma doses per unit time and specific activities of ^{40}K, ^{238}U, ^{232}Th in Ojo-LASU-2nd-Gate terrestrial station, statistical summary and permissible limit for each of the parameters are displayed in Table 1 (UNSCEAR, 2008). Ambient gamma doses per unit time spanned from smallest value 9.64 $nGyh^{-1}$ at point E to the highest figure 26.98 $nGyh^{-1}$ at point C. Mean background gamma dose rates recorded at all the 5 sampling points was 17.11 $nGyh^{-1}$. Recorded figures for activity concentrations of NORs ^{40}K, ^{238}U, ^{232}Th changed from respective lowest figures 0.0, 2.46 and 11.48 $Bqkg^{-1}$ at points A, E to maximum figures 113.76, 10.82 and 25.99 $Bqkg^{-1}$ at points B, A plus C. Average values of the specific activities of NORs at all the sampling points were 59.41, 6.00 and 17.93 $Bqkg^{-1}$, respectively. All the average figures of ambient gamma doses per unit time and activity concentrations of NORs in this study area were appreciably below permissible limit for each (UNSCEAR, 2008). Table 2 displays the ambient gamma doses per unit time, activity concentrations of ^{40}K, ^{238}U, ^{232}Th in Ojo-LASU Fish Farm freshwater aquatic station plus statistical summary with permissible limit for each (UNSCEAR, 2008). Ambient gamma doses per unit time ranked from the least figure 0.92 nGy/h at point E to highest value 7.42 nGy/h at point A. Mean of all the ambient gamma dose rates recorded at all the sampling points was 4.29 $nGyh^{-1}$, which is lower than the acceptable threshold value, 59 $nGyh^{-1}$ (UNSCEAR, 2008) by a factor of 13.8. The average figures of specific activities of ^{40}K, ^{238}U, ^{232}Th at sampling points were 2.53, 2.61 and 4.64 $Bqkg^{-1}$, respectively, and these results, as well as that of the background gamma dose rates were very much below their corresponding permissible limits (UNSCEAR, 2008).

The ratios of the specific activities of NORs are indicative of their distribution and relative abundance with respect to one another in a study area (Giwa et al., 2018). The ratios of the specific activities of NORs in examined stations is demonstrated in Table 3. In the terrestrial station, the degree of NORs abundance is of the form $^{40}K > ^{232}Th > ^{238}U$; while ^{40}K was more abundant than both ^{232}Th and ^{238}U that were at par, in the freshwater aquatic station. The associated mean radiological hazard indices due to the background radiation from examined stations were evaluated and presented in Table 4, and all values were very much below their respective permissible limits. The mean specific activities of NORs in soil and sediment samples from examined stations as analysed are presented in Table 5. The values from both stations were all below the permissible limits and the values from the freshwater aquatic stations are much lower than their counterparts from the terrestrial stations. The second trend is due the specific activities of NORs being reduced by complexation, oxidation and reduction chemical reactions coupled with diffusion processes (Omeje et al., 2016). The measured mean activity concentrations of NORs in soil samples were compared with similar works done in the study area (Southwest Nigeria), 5 – 9 years earlier, Table 6. The ratios of the specific activities of NORs in soil and sediment samples from examined stations were evaluated to appraise their relative abundance with respect to each other, Table 7. The results of the estimated radiological hazards indices due to NORs in soil and sediment samples from examined stations are shown in Table 8. All the estimated values of the indicators were all below the recommended limit given by (UNSCEAR, 2008).

Conclusion

In-situ measurements were made with portable Super Spec RS-125 gamma spectrometer and samples of soil and sediment were analysed with Hyper Pure HP(Ge) gamma detector. Spatial distribution of the background dose rate was plotted and eight associated radiological hazards parameters were evaluated both in-situ measurements and samples analysis. The measured dose rates, activity concentrations and the evaluated radiological parameters were well below the recommended limit. Hence, it could be concluded that the study area is radiologically safe.

Table 1: Background gamma dose rates and activity concentrations of radionuclides in Ojo-LASU-2nd Gate

Sampling Point	LAT. (^{0}N)	LONG. (^{0}E)	D_R (nGyh^{-1})	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
A	6.4676	3.2057	12.60±7.28	*BDL	13.53±3.41	11.81±3.49
B	6.4675	3.2055	20.74±3.60	113.76±53.72	10.46±1.32	21.57±3.61
C	6.4679	3.2054	26.98±3.12	107.44±56.88	11.99±3.24	25.99±6.23

D	6.4680	3.2055	15.58±3.68	50.56±15.80	7.38±2.01	18.78±5.66
E	6.4678	3.2055	9.64±2.43	31.60±0.00	3.08±0.95	11.48±2.46
UNSCEAR (2008)			**59.00**	**420.00**	**33.00**	**45.00**
Statistics Summary						
Mean			**17.11±6.88**	**75.84±40.96**	**9.29±4.15**	**17.93±6.28**
Minimum			9.64±2.43	BDL	3.08±2.95	11.48±2.46
Maximum			26.98±3.12	113.76±53.72	13.53±13.41	25.99±6.23

*BDL = below detection limit as the digital RS-125 returned 0.0 value

Table 2: Background gamma dose rates and activity concentrations of radionuclides in Ojo-LASU Fish Farm

Sampling Point	LAT. (^{0}N)	LONG. (^{0}E)	D_R (nGyh^{-1})	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})
A	6.4703	3.2003	7.42±1.57	31.6±0.00	3.69±2.46	9.35±1.85
B	6.4701	3.2003	5.44±2.36	BDL	6.97±1.48	6.66±5.90
C	6.4701	3.2001	5.44±3.47	BDL	4.51±1.85	6.48±5.66
D	6.4703	3.2001	2.22±0.93	BDL	4.92±1.72	1.23±0.00
E	6.4702	3.2002	1.15±0.87	BDL	BDL	1.64±1.44
UNSCEAR (2008)			**59**	**420**	**33**	**45**
Statistics Summary						
Mean			**4.33±2.58**	**31.6±0.00**	**5.02±1.40**	**5.07±3.51**
Minimum			1.15±0.87	BDL	BDL	1.23±0.00
Maximum			7.42±1.57	31.6±0.00	6.97±1.48	9.35±1.85

Table 3: Ratios of (in-situ) activity concentrations of NORs in examined stations

Station	^{40}K (Bqkg^{-1})	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{238}U:^{40}K	^{238}U:^{232}Th	^{232}Th:^{40}K
Ojo-LASU 2nd Gate	75.84	9.29	17.93	0.12	0.52	0.24
Ojo-LASU Fish Farm	31.60	5.02	5.07	0.16	0.99	0.16

Table 4: Mean radiological hazard indices due to the (in-situ) background radiation

Station No.	Ra_{eq} (Bqkg^{-1})	H_{ex}	H_{in}	D_{out} (nGyh^{-1})	D_{in} (nGyh^{-1})	$AEDR_{out}$ (mSvy^{-1})	I_γ	ELCR (x10^{-3})
Ojo-LASU 2nd Gate	36.21	0.1	0.11	17	23.79	0.02	0.13	0.07
Ojo-LASU Fish Farm	9.44	0.03	0.03	4.3	6.01	0.01	0.03	0.02
Permissible limits	**370**	**1**	**1**	**59**	**84**	**1**	**1**	**0.29**

Table 5: Mean specific activities of NORs in soil and sediment samples

Station	Sample	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
Ojo-LASU 2nd Gate	Soil	21.12 ± 1.09	29.69 ± 1.57	76.51 ± 4.05
Ojo-LASU Fish Farm	Sediment	9.31 ± 0.51	7.38 ± 0.44	*BDL
UNSCEAR, 2008	**-**	**33.00**	**45.00**	**420.00**

Table 6: Comparison of measured mean specific activities of NORs in soil samples with similar works in the study area (Southwest Nigeria)

	Specific activities of NORs (Bqkg^{-1})			
Location	**^{238}U**	**^{232}Th**	**^{40}K**	**Reference**
Ojo-LASU 2nd Gate	21.12	29.69	76.51	This work
Lagos	40.42	3.07	251.23	(Giwa et al., 2018)
Abeokuta	64.5	22.6	234.58	
Ifonyintedo	38.2	65.1	93.9	(Adagunodo et al., 2018)
Itagunmodi	55.3	26.4	505.1	(Ademola et al., 2014)
Ile-Ife	8.64	19.38	220.35	(Oluyide et al., 2019)
Permissible limit	**33.00**	**45.00**	**420.00**	(**UNSCEAR**, **2008**)

Table 7: Ratios of specific activities of NORs in soil and sediment samples

Station	Sample	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	^{238}U:^{40}K	^{238}U:^{232}Th	^{232}Th:^{40}K
Ojo-LASU 2nd Gate	Soil	21.12	29.69	76.51	0.276	0.711	0.388
Ojo-LASU Fish Farm	Sediment	9.31	7.38	0.08	116.375	1.262	92.250

Table 8: Radiological hazards indices due to NORs in soil and sediment samples

Station (*Sample*)	Ra_{eq} (Bqkg^{-1})	H_{ex}	H_{in}	D_{out} (nGyh^{-1})	D_{in} (nGyh^{-1})	$AEDR_{out}$ (mSvy^{-1})	I_{γ}	ELCR (x10^{-3})
Ojo-LASU 2nd Gate (*Soil*)	69.47	0.19	0.24	31.98	44.77	0.04	0.24	0.14
Ojo-LASU Fish Farm (*Sediment*)	19.87	0.05	0.08	8.86	12.41	0.01	0.068	0.04
UNSCEAR	**370**	**1**	**1**	**59**	**84**	**1**	**1**	**0.29**

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