A Study of Ambient Gamma Radiation in Agege Area, Lagos, Nigeria

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Abstract

Attainment and sustenance of SDG3-sound health and well-being is a worthy pursuit in ensuring a radiologically safe environment. It has been reported that of all sources of ambient radiation exposure, 80% of the annual average effective dose to man are caused by naturally occurring radionuclides (NORs) and this could pose risk health wise. It is pertinent to appraise the level of radiation exposure to humans and the habitat. This study measured radioactivity levels in the living environment and in soil and sediment samples in terrestrial Agege-Abattoir and freshwater aquatic Agege-Matogbun stations, respectively. The effect of NORs $^{40}K, ^{238}U, ^{232}Th$ on the study area was assessed. Ambient gamma doses per unit time and activities per unit mass of NORs were measured employing portable RS-125 gamma spectrometer from Radio Solution and gamma spectroscopy of soil and sediment samples were performed using Hyper-Pure Germanium HP(Ge) gamma detector from Canberra Industries. Radiological risk indices were estimated from gauged and analysed activities per unit mass of NORs. From the in-situ measurements, average values ambient gamma doses per unit time, activities per unit mass of NORs and radiological health risk indicators were found to be lower than their corresponding permissible limits. However, activity concentrations of ^{238}U and ^{232}Th in soil samples were higher than their permissible limits by factors of 1.42 and 1.81; while in sediment samples they were higher by 1.52 and 1.59 factors, accordingly. Specific activities of ^{40}K were lower than its permissible limit in both stations. Radiological health risk parameters from soil samples, outdoor and indoor gamma dose rates were higher than permissible limits by factors 1.31 and 1.29; while same indicators from sediment samples were higher than the allowed limit by 1.18 and 1.16 factors, respectively. Excess lifespan cancer risk values from NORs in samples of soil and sediment were almost at par with the permissible limit at both stations. Remedy actions and monitoring process are recommended for both stations in order to neutralise and curtail high levels of radioactivity so as to make the stations radiologically safe.

Keywords: SDG3, Gamma radiation, Environment, NORs, Risk parameters, Agege

Introduction

A lot of work has been done on investigating radioactivity and its effects both in Nigeria and other parts of the world (Ajani et al., 2020; Botwe et al., 2017; Ehsan et al., 2020; Júnior, Araújo, Fernandez, et al., 2021; Kapanadze et al., 2019; Orosun et al., 2020; Usikalu et al., 2022; Yang & Sun, 2022). There is a need for a concerted effort to be made to ensure the living environment is radiologically safe as the whole world moves towards achieving Sustainable Development Goal (SDG) 3 - sound health and well-being for all. It was reported that nearly 80.00% (2.40 mSv) comes from natural sources out of the 3.00 mSv annual average effective dose to an individual (UNSCEAR, 2008). Studies have shown that protection from radiological effects of radioactivity has grown from a system that usually focused on human solely, to an all-embracing one covering the living environment as well as non-human habitat (Bréchignac et al., 2016). Hence it is imperative to appraise how safe the living environment is, radiologically.

Man-made and naturally occurring radionuclides (NORs) and cosmic rays are sources of background radiation. Human activities such as mining, manufacturing, oil and gas exploration could increase the level of ambient or background radiation. Variations in the levels of background radiation can occur from location to location and over time in a location. For the good of mankind, radiation is used in medicine, academics, mining industry, nuclear power generation, agriculture and lots more (Botwe et al., 2017). However, radiation could be harmful to man and his environment as it has a tendency to be toxic. Hence the need to monitor the environment to appraise the levels of radioactivity therein and whether it is within the permissible limits. Where the level are higher than permissible, urgent remedy action should be taken to mitigate them in order to make the environment livable. In addition to their latent ionising effects NORs can undergo bioaccumulation and bio concentration and thereby impacting the health of humans and the ecosystem (Fonollosa et al., 2017).

Radiation health effects could be direct and indirect. Acute radiation syndrome, though rare, could result from great exposures to occurrences like nuclear blasts, mishandling or burst of a hugely radioactive material and nuclear wastes; while exposure to small scales of radiation does not result in sudden health issues, it can lead to an increment in the danger of having malignancy in a lifespan (Ostrom, 2022). Researches have shown that increment in radiation dose due to increment in exposure is correlated with increment in the probability of developing cancer.

NORs ^{238}U, ^{232}Th plus ^{40}K, were adopted for studies because they are long-lived with huge half-lives and are prevalent in the environment due to their natural abundance in the earth's surface and the air; the first two yield lots of decay progenies in their respective decay chains. The three NORs are used in radiological impacts assessments for both the human population as well as the ecosystem. Studying the ambient gamma radiation from naturally occurring radionuclides (NORs) and quantifying the associated radiological health hazards indicators are pointers to determining the level of exposure to these NORs. It is therefore paramount to monitor the level of radioactivity in the environment in order to assess the radiological risk associated with it.

Methodology

Geographical Location of Study Area

The study area encompassed Agege-Abattoir in Lagos State's Agege LGA in Southwest Nigeria, as shown in Figure 1 and lies on an elevation of 42 m with GPS coordinates: latitude 6º 38' 55" N and longitude 3° 18' 57" E. Using the 2006 census Agege LGA has a population of 461,743 (City Population, 2022). It is a hub of commercial activities boasting of a massive abattoir and a sprawling market, office, recreational and residential buildings. Matogbun (tagged in this work as Agege-Matogbun) is on an elevation of 20 m, with latitude 6º 43' 30" N and longitude 3° 19' 51" E, and is a sprawling settlement on Lagos/Ogun States boundary but in Ifo LGA of Ogun State. Ifo LGA has a 2006 population census of 539,170 (City Population, 2022). The mainstay of Agege-Matogbun dwellers is commercial fish production. Each of the locations examined has quite an appreciable percentage of the LGA's population. A GPS device was deployed to get the elevation and the coordinates of the examined locations.

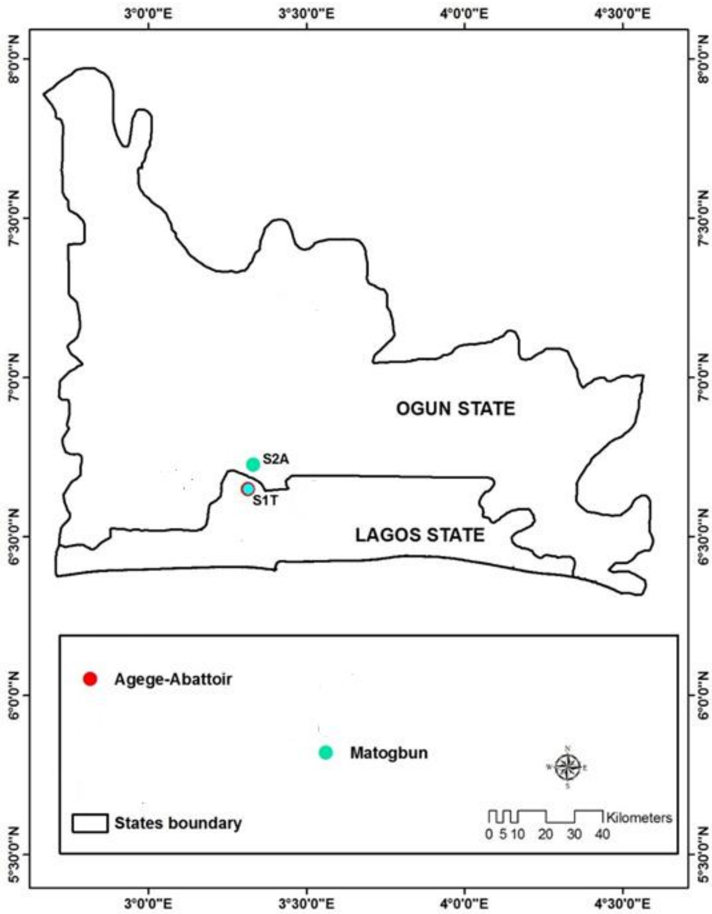

Figure 1: Study area showing the two sampling stations

In-situ Assay Measurements at Stations

On the spot assay readings were taken from two stations: Agege-Abattoir and Matogbun, respectively. A sum of 50 measurements were taken from the two stations. On each location, an area is charted out and in-situ readings of the assay mode recordings of the mobile gamma spectrometer RS-125 were read when it stabilised on the ambient gamma radiation. For a broad picture of NORs distribution and propagation of ambient gamma radiation in an examined area, an adapted model of the envelope design was used due to the diversity in the extents of the studied stations (Kapanadze et al., 2019). Five samples from a station's sampling point were taken from the corners D, C, B and A of a rectangular area and its center E as shown in Figure 2. A representative average sample was taken from a thorough mixture of the specimens. For the terrestrial station, a rectangular area was measured out and GPS coordinates, elevations and assay mode readouts of the RS-125 were recorded at each of the 5 station points: the four corners and the center of the station, Figure 2. To record the desired readings of the RS-125 gamma spectrometer, it was usually balanced on a 1 m pipe off the ground surface. Taking a 1 m stretch from a center point of four cardinal directions, five readouts were recorded: at the center and each of the four cardinal points. The gamma spectrometer's assay mode gave dose rate and specific activities of $^{40}K, ^{238}U, ^{232}Th$ readouts after a preset period of 120 seconds; during which it might have stabilised against the ambient gamma radiation. The gamma spectrometer gave specific activities of $^{40}K, ^{238}U, ^{232}Th$ in their respective native units: %, ppm and ppm. These were converted to standard SI units, Bq/kg by employing necessary translation factors (The Medusa Institute, 2023). Same procedure was repeated at the freshwater aquatic station as the GPS coordinates, the elevations and assay mode readouts of the gamma spectrometer were taken at the four corners of an earthen fish pond and its center.

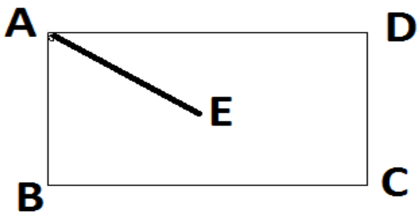

Figure 2: An adapted model of envelope design after (Kapanadze et al., 2019).

Sample Collection and Treatment

At the terrestrial station, following the envelope method of Figure 2, a rectangular area was charted out for measurements. Soil samples were scooped at the same location, at each of the four vertices of the rectangular area and its center. Soil samples were scooped at a depth of about 10-20 cm from the surface since the roots of grass/herbs are from 10 – 20 cm deep. Each sampling point was cleared of vegetation and debris before scooping the soil. The first step in processing the soil samples took place on-site which entailed the removal of roots, stones and debris. The soil sample was packaged in a labeled polythene bag for heat treatment at the Covenant University Civil Engineering Laboratory. The sediment specimens were scooped at each of the 5 points, homogeneously mingled, and a standard representative sample of each was packaged for further processing. The foremost preparation of the sediment samples took place at the site, which involved removals of roots, rubbles and pebbles. Each sediment sample was then packaged in a labelled polyethylene bag and taken to the laboratory for heat treatment.

Collected samples of soil and sediment were sorted out carefully and kept for further processing for laboratory gamma spectroscopy counting. Necessary 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 labeled, impermeable PET bottles ready for gamma counting. The homogenized samples were put in 500 ml Marinelli beakers, sealed for 30 days to reach secular equilibrium of radioisotopes of interests and their decay daughters 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**.**

Estimation of Average Radiological Hazards Indicators

Radiological health risks indicators were employed to assess the threats due to ambient gamma radiation and natural radioisotopes to man, now, in the near and far future, up to unborn generations. Biological effects direct or indirect could result. It is important to estimate the degree of the preponderance of these plausible harms through their associated indices. Consideration was given to 8 such indicators in this study.

^{40}K, ^{238}U and ^{232}Th are not uniformly distributed in the subsurface due to loss of equilibrium between ^{238}U and its progenies (Ehsan et al., 2020). For homogeneity in exposure estimations, activity concentrations of radioisotopes are expressed in terms of radium equivalent activity (Ra_{eq}) in Bq/kg, Equation 1 (Ehsan et al., 2020). Ra_{eq} is the activity concentration of a radioelement equal to 370 Bqkg^{-1} of ^{226}Ra, which releases to outdoors an external effectual dose rate of 1 mSv per year, and is given by Equation 1 (Ajani, Maleka, Usman & Penabei, 2020; Omeje et al., 2018).

$$Ra_{eq}(Bqkg^{-1}) = (1.000)A_U + (1.430)A_{Th} + (0.077)A_K \tag{1}$$

A_U, A_{Th}, A_K are the activity concentrations of ^{238}U, ^{232}Th, ^{40}K, in that order.

Equation 1 was estimated based on the assumption that 1.00 Bqkg^{-1} of ^{238}U; 0.70 Bqkg^{-1} of ^{232}Th plus 13.00 Bqkg^{-1} of ^{40}K produce the same gamma dose rate (Júnior et al., 2021).

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

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

All parameters as defined in Equation 1.

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

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

All parameters as stated in Equation 1.

Gamma radiation effects are normally expressed in terms of the absorbed dose per unit time in air. Inhaled dose per unit time in air, D_{out}, 1 m off the ground due to $^{238}U, {}^{232}Th, {}^{40}K$ in subsurface was estimated with Equation 4 (Omeje et al., 2018).

$$D_{out} = (0.4270) A_U + (0.6620) A_{Th} + (0.0432) A_K \quad (4)$$

All parameters as declared in Equation 1.

The internal gamma dose per unit time in indoors, D_{in} is delivered by radiation from $^{238}U, {}^{232}Th, {}^{40}K$. The connection between D_{out} in Equation 4 and D_{in} is given in Equation 5 (Ajani et al., 2020; Omeje et al., 2018).

$$D_{in} = (1.40) \times D_{out} \quad (5)$$

Indoor gamma radiation propagates not only from the floor, but simarly from ceilings and walls (Michael et al., 2010). In-situ gauging of indoor and outdoor gamma doses per unit time using high-resolution gamma spectrometry gave the proportion of indoor to outdoor gamma doses per unit time to be 1.40 ± 0.50 (Svoukis & Tsertos, 2007), hence the factor (1.40) in Equation 5.

With the measured dose rate D_{out} in the environment, the 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 an outdoor inhabitance factor, noting that human spent on average twenty percent of their lifespan outdoors with 8.766 x 10^3 hours in a year (3.6525 x 10^2 days) (UNSCEAR, 2000). The conversion factor, 0.70 Sv/Gy is used to convert the absorbed dose in air to effective dose received by an adult (Smith, 1991). The yearly dose received by humans, outdoors, was evaluated with Equation 6 (Ehsan et al., 2020; Raghu et al., 2017; Usikalu et al., 2017; Yang & Sun, 2022).

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

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

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

All parameters as defined in Equation 1.

Excess lifespan cancer risk (ELCR) is a measure of the probability of having cancer over a lifetime for a given threat level. It indicates the number of cancer patients expected in a given population on subjection to a carcinogen for a given dose. An increase in ELCR causes a corresponding growth in the rate at which an individual can have blood, prostate, breast, bone and other types of cancer (American Cancer Society, 2022). ELCR was obtained using Equation 8 (Penabei et al., 2018).

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

$AEDR_{out}$ is the yearly effective dose rate outdoors, DL is the average lifepan or life expectancy (estimated as 70 years), and RF is the risk factor (Sv^{-1}), that is, fatal cancer threat per Sievert. For stochastic effects, International Commission on Radiological Protection 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

Spatial Distribution of Ambient Gamma Dose Rates

Figure 3 presents the spatial distribution of the ambient γ dose rates in Agege-Abattoir. It shows the highest recorded background γ dose rate, 63.84 $nGyh^{-1}$ at sampling point AGA3 and this tends to spread out to both sampling points AGA4 and AGA5, towards the southwest and partially eastern portion of the study area, respectively. The lowest ambient gamma dose rate 20.71 $nGyh^{-1}$ was recorded at sampling point AGA1. The second highest background gamma dose rate of about 46.19 $nGyh^{-1}$ was recorded at sampling point AGA2. Topmost value, 63.84 $nGyh^{-1}$ found at AGA3 and was above the recommended limit, 59.00 $nGyh^{-1}$ (UNSCEAR, 2008) by a factor of about 1.1. The hot spot identified to be in AGA3 may be due to the presence of feldspathic sandstone associated with lateritic topsoil on the spatial distribution gave an indication of the effect of the underlying geological formation of the study area on the distribution of the ambient gamma dose rate.

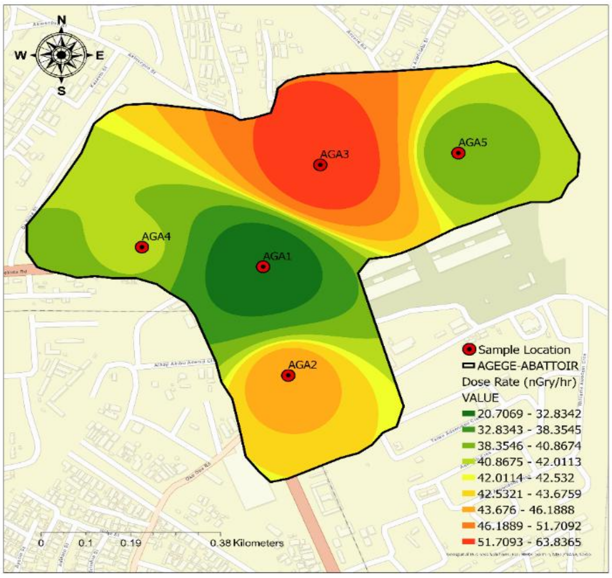

Figure 3: Distribution map for ambient gamma dose rates in Agege-Abattoir (AGA)

Ambient Gamma Dose Rates and Specific Activities of NORs in the Locations

Table 1 shows ambient gamma dose rates and specific activities of ^{40}K, ^{238}U as well as ^{232}Th in Agege-Abattoir terrestrial station with statistical summary and the permissible level for each of the measured parameters (UNSCEAR, 2008). The background gamma dose rates spanned from a minimum value 20.70 $nGyh^{-1}$ at sampling point A to a maximum value 63.84 $nGyh^{-1}$ at sampling point C. The mean of the ambient gamma dose rates recorded at the 5 sampling points was 42.14 $nGyh^{-1}$. The recorded values of the specific activities of the 3 NORs ^{40}K, ^{238}U plus ^{232}Th ranged from: 0.00, 17.71 and 1.48 $Bqkg^{-1}$ at sampling points A, C and A to maximum values: 202.24, 44.77 and 69.37 $Bqkg^{-1}$ at sampling points C, A and C, respectively. The mean values at all 5 sampling points in Agege-Abattoir were 84.69, 26.81 and 40.77 $Bqkg^{-1}$ for ^{40}K, ^{238}U and ^{232}Th, respectively. All the mean figures of the ambient gamma dose rates and the specific activities of the NORs were all below the permissible level for each of the parameters (UNSCEAR, 2008).

Table 2 presents ambient gamma dose rates and specific activities of NORs in Agege-Matogbun freshwater aquatic station along with statistical summary and the permissible limit for each of the measured parameters (UNSCEAR, 2008). The ambient gamma dose rates ranged from a minimum value 25.72 $nGyh^{-1}$ at sampling point A to a maximum value 54.20 $nGyh^{-1}$ at sampling point B. The mean of all ambient gamma dose rates posted at all sampling points was 36.71 $nGyh^{-1}$. The recorded values of the specific activities of NORs ^{40}K, ^{238}U and ^{232}Th ranged from: 0.00, 23.12 and 0.41 $Bqkg^{-1}$ at points A, B and D, C and A to maximum values: 37.92, 57.81 and 49.45 $Bqkg^{-1}$ at sampling points C, A and C, in that order. The mean values of recorded specific activities of NORs at all sampling points were: 12.64, 43.39 and 25.90 $Bqkg^{-1}$, respectively. The mean value of ambient gamma dose rates, 36.71 $nGyh^{-1}$ was less than the allowed limit, 59 $nGyh^{-1}$ (UNSCEAR, 2008) by 1.6 times. Average figure of the specific activity of ^{40}K, 12.64 $Bqkg^{-1}$, was much less than the world average, 420 $Bqkg^{-1}$ (UNSCEAR, 2008), so also for ^{232}Th, 25.90 $Bqkg^{-1}$ was less than the world average, 45.00 $Bqkg^{-1}$ (UNSCEAR, 2008) by a factor of about 1.7. However, the mean value of the activity concentrations of ^{238}U, 43.39 $Bqkg^{-1}$ was higher than the world average limit, 33.00 $Bqkg^{-1}$ (UNSCEAR, 2008) by a factor of 1.3. 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 Agege-Abattoir, the degree of NORs abundance is of the form $^{40}K > ^{232}Th > ^{238}U$; while the form of abundance of NORs is of the trend $^{40}K > ^{238}U > ^{232}Th$ in Agege-Matogbun.

The associated mean radiological hazard indices due to the ambient 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 shown in Table 5. The values for ^{238}U and ^{232}Th were higher than their respective permissible limits in both examined stations and these exceedances are of a great concern. However, the activity concentrations of ^{40}K in both examined stations are much less than the permissible limit. The measured mean activity concentrations of NORs in soil samples were compared with earlier (5 – 9 years) parallel works done in the study area (Southwest Nigeria), Table 6. The proportions 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 trend for relative abundance in Agege-Abattoir is $^{232}Th > ^{40}K > ^{238}U$, while it is $^{232}Th > ^{238}U > ^{40}K$ in Agege-Matogbun. It is observed that ^{232}Th contributed more to the ambient radiation dose in both locations. The study also revealed that the in-situ measurement were quite lower than the values obtained from analysed samples from HP(Ge) in both locations. This should be expected because the result from HP(Ge) was directly from the soil samples while the handheld gamma was measured at a distance of 1m from the soil and sediment samples.

The results of the evaluated radiological hazards indicators due to NORs in soil and sediment samples from examined stations are displayed in Table 8. Both outdoor and indoor dose rates returned values higher than their respective permissible limits. Values for excess lifetime cancer risk were at par in both stations and were marginally higher than the permissible limit.

To curtail the undesirable high radioactivity in both examined stations, agencies can adopt methods of pollution reduction like 2-dimensional particles based on nanoparticles or titanium carbides that can help in the reduction of high levels of radioactivity due to ^{238}U and ^{232}Th and their decay daughters (Penabei et al., 2022).

Conclusion

In-situ measurements were made with portable RS-125 gamma spectrometer and samples of soil and sediment were analysed with Hyper Pure HP(Ge) gamma detector. Spatial distribution of ambient dose rates was plotted and eight radiological hazards parameters were calculated for both in-situ measurements and samples analysis. The measured dose rates, activity concentrations and the evaluated radiological parameters were well below the recommended limits for in-situ measurements. However, activity concentrations of ^{238}U and ^{232}Th in soil samples were higher than their permissible limits by factors of 1.42 and 1.81; while in sediment samples they were higher by 1.52 and 1.59 factors, accordingly. Specific activities of ^{40}K were lower than its permissible limit in both stations. Radiological health risk parameters from soil samples, outdoor and indoor gamma dose rates were higher than permissible limits by factors 1.31 and 1.29; while same indicators from sediment samples were higher than the allowed limit by 1.18 and 1.16 factors, respectively. Excess lifetime cancer risk values due to NORs in soil and sediment samples were at par both stations, but were marginally higher than the permissible limit. Remedy actions and monitoring process are recommended for both stations in order to neutralise and curtail high levels of radioactivity so as to make the stations radiologically safe.

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	6.6484	3.3158	20.70	*BDL	44.77	1.48
B	6.6485	3.3160	45.80	82.16	22.39	49.69
C	6.6489	3.3159	63.84	202.24	22.88	69.37
D	6.6488	3.3156	41.48	126.40	22.14	44.53

E	6.6486	3.3158	38.86	63.20	26.32	38.79
UNSCEAR (2008)			**59.00**	**420.00**	**33.00**	**45.00**
Statistics Summary						
Mean			**42.14**	**118.50**	**27.70**	**40.77**
Minimum			20.70	BDL	22.14	1.48
Maximum			63.84	202.24	44.77	69.37

Table 1: Ambient gamma dose rates and specific activities of NORs in Agege-Abattoir

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

Table 2: Ambient gamma dose rates and specific activities of NORs in Agege-Matogbun

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	6.7249	3.3309	25.72	*BDL	57.81	2.05
B	6.7250	3.3308	54.2	BDL	51.17	48.13
C	6.7250	3.3309	44.34	63.2	23.12	49.45
D	6.7250	3.3309	28.7	BDL	49.45	16.95
E	6.7250	3.3308	30.58	63.2	35.42	35.53
UNSCEAR (2008)			**59.00**	**420.00**	**33.00**	**45.00**
Statistics Summary						
Mean			**36.71**	**63.2**	**43.39**	**30.42**
Minimum			25.72	BDL	23.12	2.05
Maximum			54.20	63.2	57.81	49.45

Table 3: Ratios of gauged specific activities of NORs in examined stations (in-situ)

Stations	^{40}K ($Bqkg^{-1}$)	^{238}U ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	$^{238}U{:}^{40}K$	$^{238}U{:}^{232}Th$	$^{232}Th{:}^{40}K$
Agege-Abattoir	118.5	27.7	40.77	0.23	0.68	0.34
Agege-Matogbun	63.2	43.39	30.42	0.69	1.43	0.48

Table 4: Mean radiological risk indices due to ambient radiation from examined stations (in-situ)

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 ($x10^{-3}$)
Agege-Abattoir	91.64	0.25	0.32	42.10	58.94	0.05	0.32	0.18
Agege-Matogbun	81.40	0.22	0.34	36.22	50.71	0.05	0.28	0.16
Permissible limits	**370.00**	**1.00**	**1.00**	**59.00**	**84.00**	**1.00**	**1.00**	**0.29**

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

Table 6: Comparison of measured mean activity concentrations of NORs in soil samples with parallel works in the study area (Southwest Nigeria)

Location	**Specific activities of NORs ($Bqkg^{-1}$)** ^{238}**U**	^{232}**Th**	^{40}**K**	**Reference**
Agege-Abattoir	46.83	81.43	76.43	This work
Lagos	40.42	3.07	251.23	(Giwa et al., 2018)
Abeokuta	64.5	22.6	234.58	(Giwa et al., 2018)
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)**

Station	Sample	**^{238}U ($Bqkg^{-1}$)**	**^{232}Th ($Bqkg^{-1}$)**	**^{40}K ($Bqkg^{-1}$)**
Agege-Abattoir	Soil	46.83 ± 2.41	81.43 ± 4.32	76.43 ± 4.05
Agege-Matogbun	Sediment	50.05 ± 2.57	71.63 ± 3.77	16.38 ± 0.89
UNSCEAR, 2008	**-**	**33.00**	**45.00**	**420.00**

Table 7: Ratios of mean activity concentrations of NORs in soil and sediment samples

Station	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})	^{238}U:^{40}K	^{238}U:^{232}Th	^{232}Th:^{40}K
Agege-Abattoir (*soil*)	46.83	81.43	76.43	0.613	0.575	1.065
Agege-Matogbun (*sediment*)	50.05	71.63	16.38	3.056	0.699	4.373

Table 8: Radiological risks indicators due to NORs in soil and sediment samples

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})
Agege-Abattoir (*soil*)	169.16	0.46	0.58	77.2	108.09	0.09	0.59	0.33
Agege-Matogbun (*sediment*)	0.09	0.42	0.55	69.50	97.30	0.09	0.53	0.30
UNSCEAR	**370.00**	**1.00**	**1.00**	**59.00**	**84.00**	**1.00**	**1.00**	**0.29**

Acknowledgement: The authors hereby acknowledge the financial support of Covenant University CUCRID for this work.

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