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Evaluation of Natural Radioactivity And Radiological Health Implications Of Oniru Beach Lagos, South-Western, Nigeria

Jegede Oluwaseyi[a1], Suraju Kasali[b], Kolo Tikpangi Matthew[c]
[a] *Department of Physics, Federal University of Agriculture Abeokuta, Ogun State, Nigeria.P.M.B 2240, Abeokuta*
[b]*Department of Physics/Geology/Geophysics, Federal University Ndufu-Alike Ikwo, Ebonyi State, Nigeria. P.M.B 1010, Ebonyi,*
[c]*Department of Physics, Federal University of Technology Minna, Niger State, Nigeria. P.M.B 65, Minna*

Abstract: *This study assessed the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in beach sand samples of Oniru beach, south-western Nigeria and evaluated its radiological implications on human health. The samples were analysed by gamma spectrometric technique which employs a low background NaI (Tl) gamma detector. Mean specific activities of ^{226}Ra, ^{232}Th and ^{40}K were 56.65±18.7, 53.11±12.7 and 603.52±188.7 Bqkg^{-1} respectively, which were higher than the their respective safety limits prescribed by the United Nations Scientific committee on the Effects of Atomic Radiation. Calculated mean air absorbed dose rate at 1 m above ground was 83.42 nGhh^{-1}, with corresponding annual effective dose equivalent of 0.1 mSy^{-1}. These values were higher than the world precautionary safety limits, which therefore identified Oniru beach as a high background radiation area that demands urgent attention. Computed results of other radiation hazard parameters complimented the claim. Excess lifetime cancer risk (ELCR) recorded an average value of 0.35× 10^{-3} which is above the world safety limit. This point to the likelihood of cancer incidence among the exposed population. Multivariate statistical analysis involving Pearson correlation analysis, factor analysis and cluster analysis indicated that the concentrations of ^{226}Ra and ^{232}Th in the studied beach sand are principally responsible for the enhanced level of natural radioactivity of Oniru beach.*
Keywords: *Natural radioactivity; Radiological parameters; beach sand; Oniru beach; Gamma-ray spectrometry; Nigeria*

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I. Introduction

Naturally occurring radioactive materials (NORM) are ubiquitous in the human environment and commonly found in typical geological formations including rivers, riverbed soils, rocks, air, sands, sediments and even the human body (Ravisankar et al., 2015; UNSCEAR, 2000).Their origin could either be primordial, cosmogenic or anthropogenic (TE-NORM) and their existence in various geological formations is primarily governed by the weather, geological and geographical conditions, coupled with the prevailing technological activities(Chakraborty & Alam, 2014; Lu & Zhang, 2008). Though there exist some notable
similarities in activity concentrations of natural radionuclides of different areas, some regions are yet classified as high background radiation areas (HBRA) due to their peculiar geological and geochemical factors(Tari et al., 2013). NORM of primordial origin, mainly those of uranium and thorium (^{226}Ra, ^{232}Th and their decay products), together with radioactive potassium (^{40}K) are the principal external sources of terrestrial gamma radiation to which humans are constantly exposed (Saat et al., 2011). Exposure of humans to natural radiation could be external; directly from gamma-emitting radioisotopes contained in soils and sediments, or internal; as a result of radionuclide ingestion via the food chain and/or inhalation of radioactive radon (^{222}Rn) and its decay products (Isinkaye, 2013; Lu & Zhang, 2008). Long-term exposures to natural radiation can become detrimental to human health and the environment. Health related cases due to radiation exposures, which include chronic lung diseases, acute leucopoenia, anaemia, cancer of different kinds, internal organ damage and even death, have been reported by various authors (Aliyu et al., 2015; Qureshi et al., 2014; SureshGandhi et al., 2014; Taskin et al., 2009; Finkelman et al., 2002; UNSCEAR, 2000). It is therefore important that the concentration and distribution of NORM in environmental samples be studied in order to assess the radiological implications on human health and the environment.

Beach sands are naturally occurring inorganic coarse materials that are produced by natural environmental processes of weathering and erosion of geological formations and transported by fluvial processes to the shoreof

[1] Corresponding author. E-mail address: suraju.kasali@gmail.com

the beach (SureshGandhi et al., 2014; Saat et al., 2011; Lu & Zhang, 2008; Veiga et al., 2006). The amount of suspended sand sediments that is finally deposited at the sea shore is controlled by the resident time of water on the shore and the sand concentration of sea beaches (Chakraborty & Alam, 2014). Beach sands which are predominantly mineral deposits from weathering of underlying bedrocks contain naturally occurring radionuclides that contributes significantly to radiation background.

Oniru beach, located at latitude 6^0 35' N and longitude 3^0 45' E, is one of the famous seaports and an exciting tourists' attraction sites in Lagos, south-western Nigeria. The beach which is known for its clean, quiet and clear atmosphere has played host to local and international tourists together with numerous holidaymakers who go there constantly for sea swimming and other recreational activities. The locals living around the beach have also been using the beach sand as aggregates of building construction material. It is therefore imperative to assess the radiological contents of Oniru beach and to evaluate its corresponding impacts on the tourists, holiday makers and the general public.

Numerous researches have been conducted on activity concentrations of natural radionuclides in beach sands and sediments and their corresponding radiological impacts on human health and the environment(Ravisankar et al., 2015; Chakraborty & Alam, 2014;Qureshi et al., 2014; Arnedo et al., 2013; Tari et al., 2013; Harb, 2008; Lu & Zhang, 2008). Although some beaches in Nigeria have been investigated for their radiological contents by (Ademola and Nwafor, 2013), documented reports on the concentration and distribution of natural radionuclides in Oniru beach are quit scarce. This investigation is therefore primarily aimed at measuring the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in beach sand samples Oniru beach. Radiological hazard parameters will also be evaluated from the measured activities in order to assess the radiological burden delivered to the visitors and the general public. Data from this investigation will serve as reference baseline for further radiological studies and constant monitoring of the beach.

II. Materials and methods

2.1. Sample collection and preparation

Ten beach sand samples were collected from the surface (5 – 10 cm) at random over long distances along the shore of Oniru beach. The samples were air-dried at ambient temperature for one week after which they were packed in well labelled polyethylene bags and transported to the Centre for Energy Research and Development (CERD), Obafemi Awolowo University Ile-Ife for radiometric analysis. At the laboratory, all samples were further oven dried at 110^0C for 48hours to attain constant weight, after which they were pulverized, sieved using 2 mm mesh and thoroughly homogenized. The dried samples (about 280±1 g each) were carefully packed into well labelled Marinelli beakers and tightly sealed to prevent escape of radon gas. Sealed samples were incubated for about 5weeks to bring the daughter radionuclides into circular radioactive equilibrium with their respective long-lived parents(Agbalagba & Onoja, 2011; Mehra et al., 2010).

2.1.1. Sample analysis

All beach sand samples were subjected to gamma spectrometric analysis which employs low-background 7.62 × 7.62cm thallium doped sodium iodide [NaI(Tl)] detector manufactured by Bircom and housed in a 10cm thick lead shield to suppress any interference from the surrounding environment(Kolo et al., 2015; Asaduzzaman et al., 2014). The detector was coupled to ADCM data acquisition system with multi-channel analyser (MCA, model 8075) and high voltage power supply system. The background spectrum which was used to correct for the activity concentrations of the samples was obtained by counting a clean empty beaker with the same geometry as the samples for 25,200seconds. Each sample was afterwards counted for the same counting time as the background. Specific activity of ^{226}Ra was assessed using the weighted mean gamma peaks of ^{214}Pb (351.93 keV, 609.31 keV) and ^{214}Bi (1120.30 keV). Activity concentration of ^{232}Th was calculated from the weighted average gamma peaks of ^{208}Tl (583.19 keV) and ^{228}Ac (911.07 keV), while ^{40}K activity was determined from its characteristic gamma-ray peak of 1460.822 keV. Specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the samples were computed from the acquired spectrum using the equation(Khandaker et al., 2012 Dabayneh et al., 2008):

$$A(Bqkg^{-1}) = \frac{CPS \times 1000}{\varepsilon_\gamma \times I_\gamma \times M} \qquad (1)$$

Where A ($Bqkg^{-1}$) is the specific activity, CPS is the net counts per second for each sample investigated, ε_γ (E) is the detector photo-peak efficiency at respective gamma-ray peak, I_γ is the corresponding gamma ray intensity and M the mass of sample in g.

III. Results and discussions

3.1. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in beach sand from Oniru beach

Activity concentrations of primordial radionuclides in beach sand samples collected along the shore of Oniru beach, together with their respective mean values and the calculated radium equivalent activity (Ra_{eq}) are presented in Table 1. All values were computed and presented in $Bqkg^{-1}$ of dry weight of samples.

Table 1 Activity concentrations of primordial radionuclides with their uncertainties and radium equivalent activity ($Bqkg^{-1}$) of beach sand samples from Oniru beach

Sample ID	^{226}Ra	^{232}Th	^{40}K	**Ra_{eq}**
OB 01	38.45 ± 10.45	38.37 ± 11.07	632.78 ± 96.45	142.0
OB 02	50.14 ± 7.28	45.38 ± 19.76	543.87 ± 87.32	156.9
OB 03	49.16 ± 11.14	43.76 ± 19.11	901.12 ± 78.91	181.1
OB 04	58.08 ± 12.42	59.84 ± 14.76	498.56 ± 82.62	182.0
OB 05	19.60 ± 6.12	48.25 ± 12.25	392.23 ± 53.89	118.8
OB 06	84.91 ± 21.60	76.79 ± 18.11	433.68 ± 64.32	228.1
OB 07	60.61 ± 19.07	55.05 ± 17.15	355.73 ± 90.32	166.7
OB 08	72.77 ± 17. 10	72.27 ± 18.45	917.75 ± 95.83	246.8
OB 09	51.96 ± 18.06	37.69 ± 12.62	738.87 ± 97.02	162.7
OB 10	80.84 ± 23.63	53.73 ± 16.38	620.56 ± 86.45	205.5
Mean±SD	**56.65±18.7**	**53.11±12.7**	**603.52±188.7**	**179.1**

The activity concentrations of ^{226}Ra ranged from 19.60±6.12 to 84.91±21.60 $Bqkg^{-1}$ with a mean of 56.65±18.70$Bqkg^{-1}$. Activity concentrations of ^{232}Th and ^{40}K varied from 37.69±12.62 to 76.79±18.11 $Bqkg^{-1}$, and 355.73±90.32to 917.75±95.83 $Bqkg^{-1}$ respectively, with mean values of 53.11±12.7 $Bqkg^{-1}$ and 603.52±188.7 $Bqkg^{-1}$ in sequence. Considerable variations observed in activity concentrations of primordial radionuclides may be as a result of the geochemical, physical and chemical properties of the radionuclides and their respective availability in Marine environment (El Mamoney & Khater, 2004; SureshGandhi et al., 2014; El Mamoney & Khater, 2004). Furthermore, during high tides, water waves may extend to about 10m from the waterline as a result of increased wave action, thereby depositing heavy minerals along the seashore. This, according to Harb (2008), may be additional factor responsible for wide variations in radioactivity of beach sands. ^{40}K was found to have the highest activity concentration in the studied samples, which according to (Dar & El-Saharty 2013), may be due to its relative abundance in continental rocks. The results of this investigation showed that the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were higher than the world average values of 35 $Bqkg^{-1}$ for ^{226}Ra, 30 $Bqkg^{-1}$ for ^{232}Th and 400 $Bqkg^{-1}$ for ^{40}K documented by(UNSCEAR 2000) for sediments. The result of this study was compared with those of similar studies around the world as seen in Table 2.

3.1.1. Radium equivalent activity (Ra_{eq})

In order to effectively estimate the specific activities of ^{226}Ra, ^{232}Th and ^{40}K, an index known as radium equivalent activity (Ra_{eq}) has been presented. The idea is to enable a single index to define the radiation hazards associated with mixture of the radionuclides(Beretka & Mathew, 1985). Ra_{eq} was calculated from equation (1), with an assumption that 370 $Bqkg^{-1}$ of ^{226}Ra, 259 $Bqkg^{-1}$ of ^{232}Th and 4810 $Bqkg^{-1}$ of ^{40}K produce the same gamma-ray dose rate (Kolo et al., 2015; Ravisankar et al., 2014; NEA-OECD, 1979).

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

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively.

Table 2 Comparison of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in beach sand samples of Oniru beach, Lagos, Nigeria and similar studies around the world

	Activity concentrations (Bqkg-1)			
Location	^{226}Ra	^{232}Th	^{40}K	References
India-East coast of Tamilnadu	Bdl	14.29	360.23	Ravisankar et al. (2015)
India-North east coast of Tamilnadu	35.12	713.6	349.6	SureshGandhi et al. (2014)
Southwestern Nigeria (Lekki beach)	13.2	26.3	149	Ademola and Nwafor (2013)
Greater Accra, Ghana	-	108.6	29.78	Amekudzie et al. (2011)
Red sea coast, Egypt	23.1	7.2	338	Harb (2008)

Northwest Libya	4.5	7.5	28.5	El-Kameesy et al. (2008)
Beach sand, Egypt	-	177	815	Uosif and El-Taher (2008)
South-western Nigeria (Oniru beach)	56.65	53.11	603.53	Present study

Both external gamma dose and internal dose from exposure to radon and its daughter nuclides are related to Ra_{eq}(Ravisankar et al., 2015). Results presented in Table 1 showed that the Ra_{eq} values for beach sands from Oniru beach ranged from 118.8 to 246.8 $Bqkg^{-1}$ with average value of 179.1 $Bqkg^{-1}$. These values were less than the recommended world safety limit of 370 $Bqkg^{-1}$ (Ademola & Nwafor, 2013; UNSCEAR, 2000; Beretka & Mathew, 1985).

IV. 4. Assessment of radiological hazard effects

Specific activities of radionuclides can provide very limited information on the radiation hazard effects of soils and sediments. Additional radiological parameters were therefore evaluated in order to gain a comprehensive insight into the radiological hazards that may be associated with the natural radioactivity of the studied beach sand samples.

4.1. Absorbed dose rate (D)

Outdoor air-absorbed dose rate (D) at 1 m above the ground was calculated from the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K in the studied beach sand samples. Contributions from other radionuclides to total dose from environmental background were neglected in this calculation since they were assumed to be very insignificant. D was calculated from the equation (UNSCEAR, 2008):

$$D\ (nGy\ h^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \qquad (3)$$

where A_{Ra}, A_{Th}, and A_K, are the activity concentrations in Bqkg-1, 0.462, 0.604 and 0.0417 are dose conversion factors provided in the (UNSCEAR, 2008) report for ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

D was assessed using equation 3 above and the results are presented in Table 3. The outdoor air absorbed dose rate varied between 54.6 and 115.5 $nGyh^{-1}$ with average value of 83.4 $nGyh^{-1}$. This value was found to be higher than the world average safety limit of 57 $nGyh^{-1}$ documented by (UNSCEAR,2000). Oniru beach can thus be categorized as a higher background radiation area (HBRA) that may demand further attention from radiation protection point of view.

4.1.1. Annual effective dose equivalent (AEDE)

Annual effective dose rate is a measure of radiation risk associated with the air absorbed dose rate. AEDE was calculated from D taking into cognisance two principal conversion factors provided by (UNSCEAR, 2000). These are (i) 0.7 $SvGy^{-1}$ which transforms absorbed dose in air into effective dose, (ii) 0.2 outdoor occupancy factor which presumes that people around the world spend 80% of their time indoors. AEDE in $mSvy^{-1}$ was calculated from the formula (UNSCEAR, 2000):

$$AEDE\ (mSv\ y^{-1}) = D(nGy\ h^{-1}) \times 8760(h\ y^{-1}) \times 0.7(Sv\ Gy^{-1}) \times 0.2 \times 10^{-6}$$

$$AEDE(mSv\ y^{-1}) = D \times 0.00123 \qquad (4)$$

Calculated annual effective dose equivalent, AEDE (Table 3) varied from 0.07$mSvy^{-1}$ to 0.14 $mSvy^{-1}$with an average value of 0.10 $mSvy^{-1}$, which is higher than the world precautionary limit of 0.07$mSvy^{-1}$(UNSCEAR, 2000).

Table 3 Radiological parameters of beach sand samples from Oniru beach

	Dose			Hazard indices				
Sample ID	D ($nGy\ h^{-1}$)	AEDE ($mSv\ y^{-1}$)	AGDE ($\mu Sv\ y^{-1}$)	AUI (≤ 1)	H_{ex} (≤ 1)	H_{in} (≤ 1)	$I_{\gamma r}$ (≤ 1)	ELCR (x 10^{-3})
OB 01	67.3	0.08	477.9	0.9	0.4	0.5	1.1	0.29
OB 02	73.3	0.09	515.4	1.1	0.4	0.6	1.2	0.31
OB 03	86.7	0.10	617.8	1.1	0.5	0.6	1.4	0.37
OB 04	83.8	0.10	586.1	1.3	0.5	0.6	1.3	0.35
OB 05	54.6	0.07	385.4	0.8	0.3	0.4	0.9	0.23
OB 06	103.7	0.13	719.5	1.7	0.6	0.8	1.6	0.44
OB 07	76.1	0.09	529.1	1.3	0.5	0.6	1.2	0.32
OB 08	115.5	0.14	815.1	1.6	0.7	0.9	1.8	0.49
OB 09	77.6	0.09	550.1	1.0	0.4	0.6	1.2	0.33
OB 10	95.7	0.12	669.2	1.4	0.6	0.8	1.5	0.41
Mean	83.4	0.10	586.6	1.2	0.5	0.6	1.3	0.35

4.1.2 Annual gonadal dose equivalent (AGDE)

Dose equivalent received per year by reproductive organs and other organs of interest as listed in (UNSCEAR,1988) report may become genetically significant to the exposed population. Annual gonadal dose equivalent (AGDE) which gives the measure of dose delivered to these organs due to specific activities of ^{226}Ra, ^{232}Th, and ^{40}K was calculated from the equation (Chandrasekaran et al., 2014; Morsy et al., 2012):

$$AGDE\ (\mu Sv\ y^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \qquad (5)$$

Calculated values for AGDE are presented in Table 3. The calculated average AGDE for the studied beach sand samples was 586.6 μSvy^{-1}.

4.1.3. Activity utilization index (AUI)

There is a high tendency among the locals for the usage of the beach sands as aggregates of building construction materials. Hence activity utilization index is constructed to enable effective evaluation of dose rates in air due to varying combinations of ^{226}Ra, ^{232}Th, and ^{40}K in building construction materials. AUI was therefore assessed using the equation (Chandrasekaran et al., 2014; Ramasamy et al., 2011):

$$AUI = \left(\frac{A_{Ra}}{50Bq/kg}\right) f_U + \left(\frac{A_{Th}}{50Bq/kg}\right) f_{Th} + \left(\frac{A_K}{500Bq/kg}\right) f_K \qquad (6)$$

where A_{Ra}, A_{Th}, and A_K, are the measured specific activities of ^{226}Ra, ^{232}Th, and ^{40}K, inBqkg^{-1} respectively. f_U, $f_{Th}$and f_K, with numerical values of 0.462, 0.604 and 0.041 respectively, represents fractional contributions of ^{226}Ra, ^{232}Th, and ^{40}K, to the total gamma dose rate. (NEA-OECD 1979) proposed 500, 50 and 50 Bqkg^{-1} as typical activity per unit mass of ^{40}K, ^{232}Th, and ^{226}Ra in soils respectively. Calculated values of AUI as presented in Table 3, ranged between 0.8 and 1.7 with a mean value of 1.2.

4.1.4 Representative gamma index ($I_{\gamma r}$)

Representative gamma index is a screening criterion for distinguishing building construction materials that could pose any radiological threat (Jibiri & Okeyode, 2012). It correlates effectively with enhanced annual effective dose rate from superficial materials (Ravisankar et al., 2015). $I_{\gamma r}$ was calculated using the relation (Jibiri et al., 2014; NEA-OECD, 1979):

$$I_{\gamma r} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \qquad (7)$$

where A_{Ra}, A_{Th}, and A_K, are the specific activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively, in Bqkg-1. $I_{\gamma r}$ must be ≤ 1 for radiation hazard to be completely insignificant. Computed values of $I_{\gamma r}$ as presented in Table 3 ranged from 0.9 to 1.8 with a mean value of 1.3. The mean value slightly exceeded the prescribed safety limit of unity which indicated that beach sand samples from the study area have been enhanced in their radiological content, thus confirming Oniru beach as HBRA.

V. Radiation hazard indices

5.1. External and internal hazard indices (H_{ex} and H_{in})

External hazard index (H_{ex}), and the internal hazard index (H_{in}) are radiation criteria used to evaluate external hazard from natural gamma radiation and internal hazard due to exposure to radon and its decay progeny (Chandrasekaran et al., 2014) respectively. H_{ex} was calculated from the equation (UNSCEAR, 2000):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (8)$$

Similarly, internal exposure to radon and its radioactive decay daughters is controlled by the internal hazard index, $H_{in}$and calculated from the formula (UNSCEAR, 2000):

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (9)$$

where A_{Ra}, A_{Th}, and A_K, are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

Both H_{ex} and H_{in} must have values lower than unity for the radiation hazard to be termed insignificant (UNSCEAR, 2000). It can be seen from Table 3 that computed mean values for H_{ex} and H_{in} were 0.5 and 0.6 respectively, which were both below the precautionary limit of unity.

5.1.1. Excess lifetime cancer risk (ELCR)

The probability of occurrence of cancer in any given population for a given lifetime exposure is measured by the excess lifetime cancer risk (ELCR). ELCR was calculated from the estimated AEDE using the equation (Qureshi et al., 2014):

$$ELCR = AEDE \times DL \times RF \qquad (10)$$

where DL is the life expectancy of 70 years, and RF is risk factor given to be 0.05Sv^{-1} for stochastic effects (Taskin et al., 2009). From the results presented in Table 3, the computed ELCR values varied from 0.29 × 10^{-3} to 0.49 × 10^{-3} with an average value of 0.35 × 10^{-3}. This average value was slightly higher than the world recommended safety limit of 0.29 × 10^{-3}(UNSCEAR, 2000), which thus gave an indication of the likelihood of occurrence of cancer among the exposed population.

VI. Multivariate statistical analysis

6.1. Descriptive statistics of radiological data

For the purpose of understand the nature and validity of the distribution of natural radioactivity in beach sand samples from Oniru beach, the measured radioactive data in this study were quantitatively and qualitatively analysed statistically using the statistical software SPSS 22.0. Descriptive statistical data which include the minimum, maximum, mean, standard deviation, skewness and kurtosis of the measured and computed radiological parameters are presented in Table 4.

Table 4 Descriptive Statistics of radioactive variables of soil samples from Oniru beach

Variables	Minimum	Maximum	Mean	Standard Deviation	Skewness	Kurtosis
^{226}Ra	19.60	84.91	56.65	19.68	-0.30	0.09
^{232}Th	37.69	76.79	53.11	13.35	0.72	-0.44
^{40}K	355.73	917.75	603.52	198.95	0.51	-0.90
Ra_{eq}	118.80	246.78	179.07	38.89	0.38	-0.27
D	54.55	115.54	83.42	17.91	0.33	-0.03
AEDE	0.07	0.14	0.10	0.02	0.59	-0.56
AGDE	385.41	815.12	586.57	124.59	0.35	0.10
AUI	0.80	1.75	1.21	0.32	0.46	-0.88
H_{ex}	0.32	0.67	0.48	0.11	0.41	-0.24
H_{in}	0.37	0.86	0.64	0.15	0.03	-0.38
$I_{\gamma r}$	0.87	1.82	1.31	0.28	0.38	0.03
ELCR	0.23	0.49	0.35	0.08	0.32	-0.06

The standard deviations of the measured primordial radionuclides, ^{226}Ra, ^{232}Th, and ^{40}K were lower than their respective mean values, which suggests a significantly high level of uniformity in their distribution (Ravisankar et al., 2015). Data variability of the measured radionuclides showed normal distribution sequence as reflected by the frequency distribution histograms in Fig. 1, which is corroborated by the values of skewness and kurtosis (Table 4).

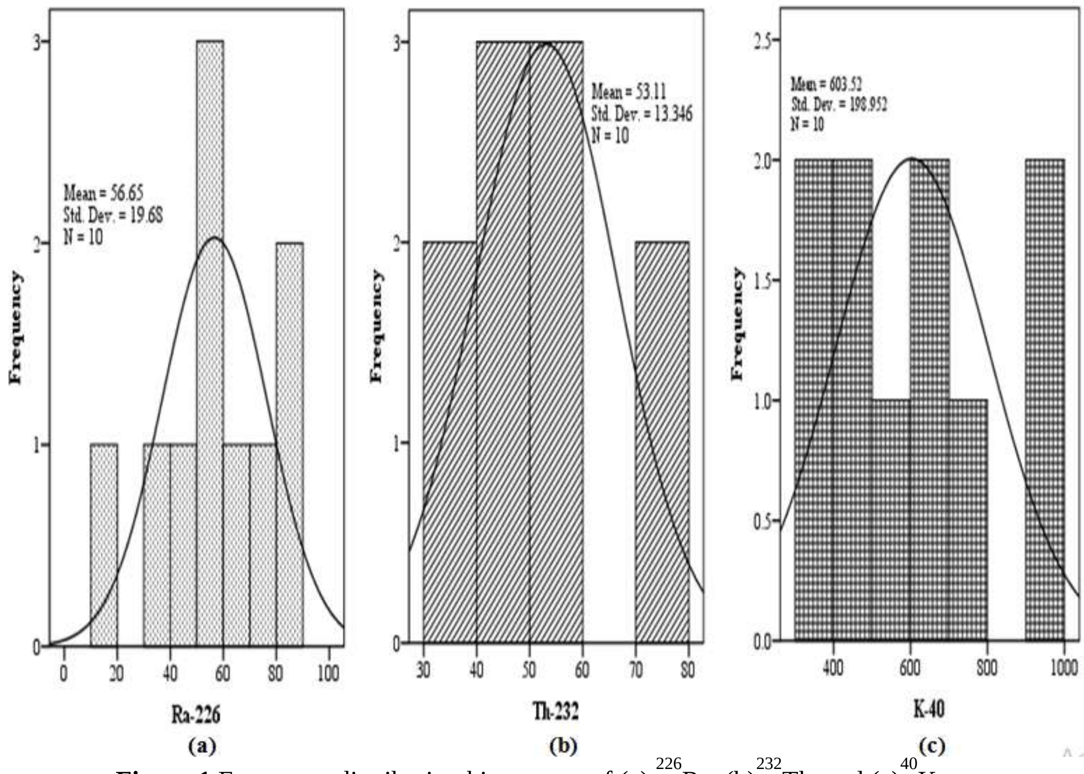

Figure 1 Frequency distribution histograms of (a) ^{226}Ra, (b) ^{232}Th, and (c) ^{40}K

6.1.1 Pearson's correlation analysis

Degree of association and possible relationships that may exist between the primordial radionuclides and the calculated radiological variables were evaluated using Pearson's correlation analysis. Calculated linear Pearson correlation coefficients are presented in Table 5. Strong positive correlation was observed between ^{226}Ra, and ^{232}Th, with correlation coefficient value r = +0.699. This implied that ^{226}Ra, and ^{232}Th in the beach sand samples have the same origin and coexists commonly in nature (Chandrasekaran et al., 2015; Tanasković et al., 2012). Very weak relationship between ^{40}K and ^{226}Ra (r = +0.124), and ^{40}K and ^{232}Th (r = -0.125) suggested that ^{40}K originated from a different source in the beach sand samples.

Table 5 Pearson's correlation matrix between radioactive variables of soil samples from Oniru beach

Variables	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}	D	AEDE	AGDE	AUI	H_{ex}	H_{in}	$I_{\gamma r}$	ELCR
^{226}Ra	1.000											
^{232}Th	0.699	1.000										
^{40}K	0.124	-0.125	1.000									
Ra_{eq}	0.898	0.795	0.395	1.000								
D	0.879	0.747	0.470	0.996	1.000							
AEDE	0.891	0.798	0.382	0.993	0.989	1.000						
AGDE	0.863	0.726	0.506	0.992	0.999	0.984	1.000					
AUI	0.932	0.908	0.054	0.938	0.907	0.936	0.889	1.000				
H_{ex}	0.892	0.800	0.395	1.000	0.996	0.992	0.992	0.938	1.000			
H_{in}	0.955	0.781	0.308	0.988	0.979	0.981	0.970	0.959	0.986	1.000		
$I_{\gamma r}$	0.867	0.747	0.482	0.995	1.000	0.987	1.000	0.901	0.995	0.974	1.000	
ELCR	0.878	0.730	0.486	0.994	0.999	0.988	0.999	0.898	0.993	0.977	0.999	1.000

All the evaluated radiation hazard variables were positively correlated with one another positively and also with ^{226}Ra, and ^{232}Th (r > +0.72). This suggested that the concentration of ^{226}Ra, and ^{232}Th in the beach sand samples were principally responsible for the radiation hazard effects of Oniru beach.

6.1.2. *Factor analysis*

The radiological parameters analysed in this study were subjected to principal component analysis (factor analysis) to further assess the inter-relationships between the radiological variables. By applying varimax rotation with Kaiser Normalization, eigen values and eigen vectors were extracted from the correlation matrix and the number of significant factors and percentage of variance were computed. The results of the factor analysis presented in Table 6 identified two principal components which could explain 97.57% of the total variance (Ravisankar et al.,2014), and (Zhang et al.,2005) stated that the principal component give a good representation of the data if total variance ≥ 70%.

Table 6 Rotated factor loadings of radiological parameters in beach sand samples from Oniru beach

Variables	Component-1	Component-2
^{226}Ra	0.91	-0.20
^{232}Th	0.80	-0.49
^{40}K	0.37	0.93
Ra_{eq}	1.00	0.03
D	0.99	0.11

AEDE	0.99	0.02
AGDE	0.99	0.15
AUI	0.95	-0.32
H_{ex}	1.00	0.03
H_{in}	0.99	-0.05
$I_{\gamma r}$	0.99	0.12
ELCR	0.99	0.13
% of variance	86.70	10.87
Cumulative %	86.70	97.57

Looking at Table 6, component-1 accounted for 86.70% of the total variance and is heavily loaded positively on ^{226}Ra, and ^{232}Th together with all the computed radiological variables. This indicated that ^{226}Ra, and ^{232}Th are principally responsible for the total radioactivity of the studied beach. Component-2 which is mainly loaded positively on 40K (0.93) accounted for 10.87% of the total variance showing that the contribution of potassium to the total radioactivity of Oniru beach was insignificant. The result of factor analysis, thus, corroborates Pearson's correlation analysis. Graphical representation of the principal components is shown in Fig. 2.

6.1.3. Cluster analysis (CA)

Cluster analysis was conducted on the radiological variables that were evaluated in this study. Euclidean distance between the variables was computed using average linkage method. This is to enable all the radiological variables to be grouped into distinct clusters based on their identical characteristic features and similarities. The dendrogram derived from the CA is presented in Fig. 3.

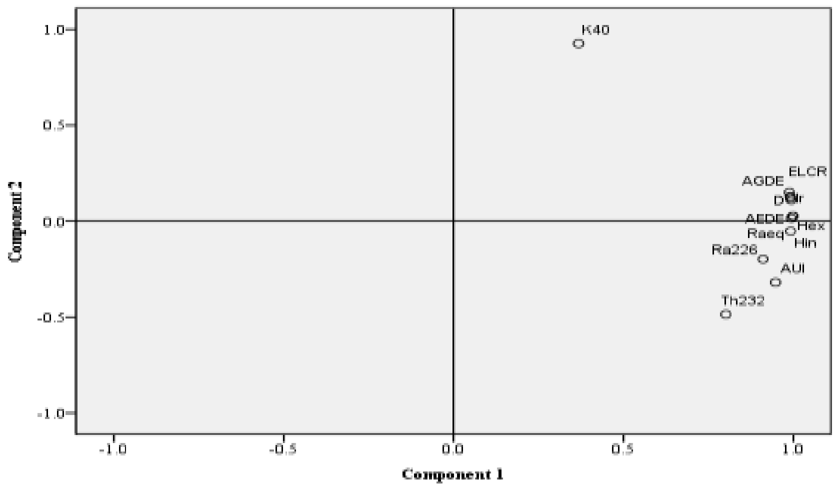

Figure 2 Graphical representation of rotated factor loadings of component -1 (86.70%) and component-2 (10.87%)

All 12 radiological variables were grouped into two statistically distinct clusters as seen in the dendrogram. Ra_{eq}, D_R, AEDE, AUI, H_{ex}, H_{in}, $I_{\gamma r}$, and ELCR, were grouped together in Cluster I along with ^{226}Ra, and ^{232}Th, while AGDE was linked together with ^{40}K at high Euclidean distance in Cluster II. The results of the cluster analysis showed that all the assessed radiological variables were a direct consequence of ^{226}Ra and ^{232}Th activity concentrations in the beach sand samples from Oniru beach. The results are in good conformity Pearson correlation and factor analysis.

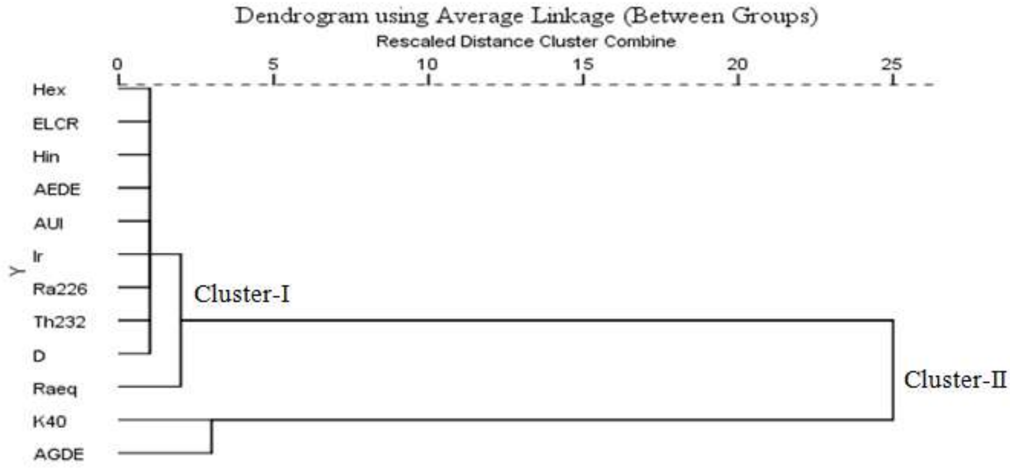

Figure 3 Dendrogram showing the clustering of radiological variables

VII. Conclusion

Beach sand samples along the shore of Oniru beach Lagos, south-western Nigeria were analysed for their radioactivity content using gamma-ray spectrometry with NaI(Tl) detector. Radiological hazard parameters were computed from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the beach sand samples in order to assess the radiological impacts of Oniru beach on the health of the public, tourists and visitors to the beach. Specific activities of ^{226}Ra, ^{232}Th and ^{40}K were found to be higher than the world precautionary limits set by the United Nations Scientific Committee on the Effects of Atomic Radiation. Consequently, all the computed radiological hazard parameters were above their respective limits of safety, which therefore identified Oniru beach as a high background radiation area. Multivariate statistical analysis involving Pearson correlation analysis, factor analysis and cluster analysis indicated that the concentrations of ^{226}Ra and ^{232}Th in the studied beach sand are principally responsible for the enhanced level of natural radioactivity of Oniru beach. The results of this investigation suggest possible radiation health effects after long period of exposure on the tourists who visits the beach for recreational activities. Sailors and the fishermen who ply their trade along the shores of the beach may also be in danger of long time exposure. The results of this study calls for continuous monitoring of environmental background radiation along the shore of Oniru beach and to implement policies that will keep radiation dose as low as reasonably achievable (ALARA) for the tourists, visitors to the beach and the general public. Data obtained in this study can serve as reference baseline for future monitoring of the beach from the point of view of radiation protection.

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