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An Evaluation of Health Hazards Indices of Natural Radioactivity of the Sediments from Eko-Ende Dam, Osun State, Nigeria

Katherine Temitope Ogundele[1*], Emmanuel Ayodele Oluyemi[2], John Adekunle Oyedele Oyekunle[2], Oladotun Wasiu Makinde[1], Sejlo Temidayo Gbenu[1]

[1]Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria
[2]Department of Chemistry, Obafemi Awolowo University, Ile-Ife, Nigeria
Email: *kattyk20025@yahoo.com

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Abstract

This study measured the radioactivity level in the sediments of Eko-Ende Dam in Ifelodun Local Government Area, Osun State, Nigeria and assessed the radiological impact associated. Thirty six (36) sediment samples were collected from three different points within the Dam for a period of 12 months. The samples were analyzed using Gamma Ray Spectrometer. The radiological hazards due to natural radionuclides content, such as absorbed dose rate (D_R), annual effective dose rate (AEDE), effective life cancer risk (ELCR), activity utilization index (AUI), internal radiation hazard (H_{in}) and external radiation hazard (H_{ex}) in the sediment samples were calculated. The calculated radiological parameters were compared with recommended safety limits and internationally approved values. The radium equivalent activity, internal hazard index, annual effective dose equivalent and effective life cancer risk values of the sediment samples were lower than the permissible limit. Thus, the study area might not pose immediate health implications to the general public, but prolonged exposure could lead to radiation related health hazards.

Keywords

Natural Radioactivity, Radiological Parameters, Dam, Eko-Ende, Nigeria

1. Introduction

Naturally occurring radioactive materials (NORMs) contain insignificant amounts of radionuclides in the environment but when disturbed or altered from natural settings, their concentrations are usually enhanced above the background radiation levels. This may result in a relative increase in radiation exposures and risks to the public and the environment [1]. From time to time, every living creature is exposed to the ionizing radiation that comes from the earth. This radiation affects the general biota, food and air that we breathe, and makes them partially radioactive. As a result, people are exposed to this ionizing radiation on daily basis from the ground, building materials, air, food, sediment, water, the universe, and even elements in their own bodies [2].

The study of the radioactive components in sediment is a fundamental link in understanding the behavior of radionuclides in the ecosystem and contributes to the total absorbed dose via ingestion, inhalation and external irradiation [3]. Sediments have been widely used as environmental indicator and their ability to trace contamination sources and monitor contaminants is widely recognized [4]. Sediment plays a predominant role in aquatic radioecology and they are accumulating and transporting contaminants within the geographic area. Sediments may be regarded as a temporary sink of many materials which pass through aquatic, chemical and biological cycles operating on the earth's surface. Thus, sediments become an environmental host for many of the waste products discharged by society or from natural sources like weathering and recycling of terrestrial minerals and rocks and also by anthropogenic activities [5]. Hence, sediments are good indicators of radiological contamination in the environment [6]. The determination of naturally occurring radionuclides depends on the distribution of rocks from which they originate and the processes which result in their removal from the soil and migrate them [4]. The determination of these radionuclides gives the understanding of the radiological health implications to the populace.

Determination of the concentrations of the radionuclides as well as their associated health risks in an environment is important in order to make informed decisions by the stakeholders. Little is known about the concentrations of radionuclides in the sediments of Eko-Ende Dam located in Ifelodun local government area of Osun State. Thus in the present study, the radioactivity level of naturally occurring ^{40}K, ^{238}U and ^{232}Th in Eko-Ende Dam sediments and an evaluation of radiological health hazard indices were carried out in order to establish the baseline data for natural background radiation level in the study area.

2. Materials and Methods

2.1. Geological Outline

Eko-Ende study area lies between Latitude 7˚54'30''N and 7˚57'0''N and Longitude 4˚33'30''E and 4˚35'30''E. The Dam on the Otin River was impounded in 1973 to form a reservoir with storage capacity of 5.5 MCM and improve existing water supply to the communities of Eko-Ende, Eko-Ajala, Ikirun, Iragbiji, Okuku and Oba [7]. The Dam serves as a source of drinking water, agricultural and fishing activities for the residents of the communities within its catchment area. Eko-Ende reservoir is located within a comparatively semi-urban to rural area and the regional relief of the study area is rugged with elevations ranging from 35 m to over 400 m above sea level [8]. The area constitutes a part of the basement complex of Southwestern Nigeria essentially of granite-gneiss complex and is largely monolithologic. The study area is under Koppen's Af humid tropical rainforest climate (**Figure 1**). The mean annual rainfall is about 1400 mm with the rainy season covering eight months (April to November) and its beginning and end marked by torrential rains and thunderstorms [9]. The geographical position and natural resources of Eko-Ende indicate the likelihood of radioactivity but information on radioactivity is scarce as systematic measurements have not being undertaken in this area so far.

2.2. Sampling and Sample Preparation

Thirty six sediment samples were collected from three (3) sampling points along Eko-Ende Damon a monthly basis (between November, 2013 and October, 2014). The sampling was done across the water body in the Dam in a perpendicular manner to the direction of flow of River Otin. The study area, apart from being close to residential homes, attracts activities such as fishing and other agricultural activities. The sampling points were identified using a Global Positioning System coordinates (GPS). Approximately 2 kg of sample was collected per site for each month. The samples were placed in an oven at a temperature of 60˚C until it was dried to a constant weight after about 72 h. It was there after pulverized, weighed and packed into pre-weighed plastic containers which were then hermetically sealed with the aid of PVC tape to prevent the escape of airborne ^{222}Rn and ^{220}Rn from the samples. Each of the covered and labeled container was then re-weighed. The samples were stored for a period of 28 days prior to measurement to attain secular equilibrium.

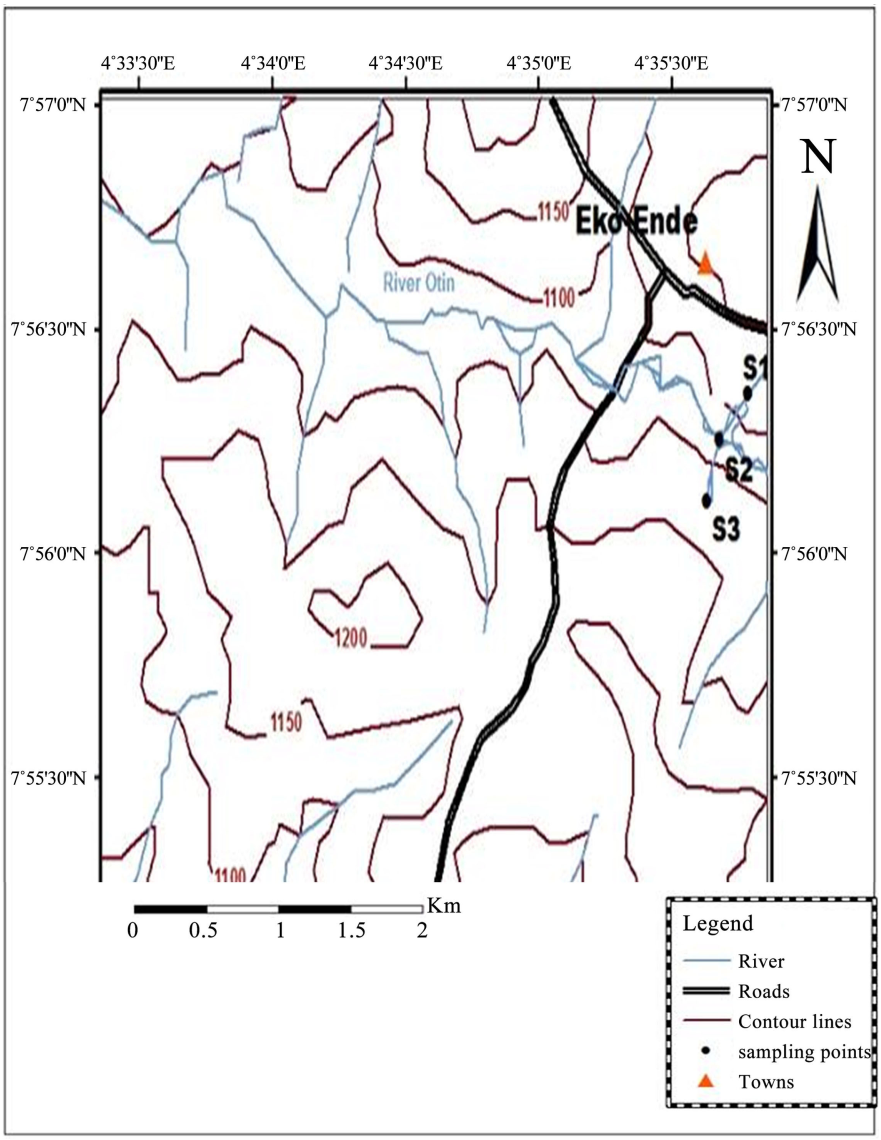
2.3. Gamma Spectrometric Analysis

Gamma ray spectrometry was used to determine and measure the concentration of radionuclides in the samples. Each sample was placed on the NaI detector enclosed in a thick lead shield and counted for 25,200s (7 h). The activity concentration in the sediment samples were determined using a 7.62 cm × 7.62 cm NaI (TI) detector surrounded with adequate lead shielding that reduces the background by a factor of approximately 95%. The activities of various radionuclides were determined in Bq/kg from the count spectra obtained from each of the samples using the gamma ray photo peaks corresponding to energy of 1120.3 keV (^{214}Bi), 911.21 keV (^{228}Ac) and 1460.82 keV (^{40}K) for ^{238}U, ^{232}Th and ^{40}K, respectively. For a counting time of 25,200 s, the detection limits of the NaI (TI) detector system were calculated as 6.77, 11.40, and 12.85 Bq/kg for ^{40}K, ^{232}Th, and ^{238}U, respectively.

2.4. Energy Calibration for Gamma Spectrometry

In order to properly identify various peaks in the spectrum, the NaI detector was calibrated in terms of absolute gamma ray energy. For the energy calibration of NaI detector system, standard sources: ^{241}Am (59.5 keV), ^{137}Cs (662.3 keV), ^{22}Na (511.0 keV) and ^{60}Co (1173.2 and 1332.5 keV), with known gamma-ray energies that are widely different from those to be measured in the unknown spectrum, prepared by the Isotope Products Laboratories, Burbank California, USA were used. The calibration sources were counted long enough to obtain a well defined photo peak. This ensured that the range of all radionuclides of interest was covered.

(a)



(b)

Figure 1. (a) The map of Nigeria showing Osun State; insetting Eko-Ende Dam; (b) Map of the sampling points in Eko-Ende Dam.

2.5. Activity Concentration Determination

The activity concentration of a certain radionuclide, C, in the sediment samples was calculated using the following equation:

$$C = \frac{A}{\varepsilon P\gamma TM} \quad (1)$$

where C is the activity concentration, A is the area under the graph, ε is the detector efficiency, $P\gamma$ is the probability that a peak will occur, T is time (in seconds) and M is the mass (in kg) of the sediment sample under consideration.

2.6. Radium Equivalent Activity Concentration Index (Ra_{eq})

Radium equivalent index in Bq/kg is a widely used radiological hazard index. It is a convenient index to compare the specific activities of samples containing different concentrations of ^{238}U, ^{232}Th and ^{40}K [10]. This radium equivalent concept was used to describe the gamma output from different mixtures of uranium, thorium and potassium in sediments from Eko-Ende Dam [11]. It was calculated using the formula:

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

where A_U, A_{Th} and A_K are the specific activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg respectively.

2.7. The Absorbed Gamma Dose Rate

The input of natural radionuclides to the absorbed dose rate in air (D_R) at the average height of one meter above the ground surface depends on the natural specific activity concentration of ^{238}U, ^{232}Th and ^{40}K. If a radionuclide activity is known, then, its exposure dose rate in air at 1 m above the ground can be estimated using the formular given by Kurnaz *et al.* [12] and Ravinsankar *et al.* [11]:

$$D_R\left(nGyh^{-1}\right) = 0.43A_U + 0.666A_{Th} + 0.042A_K \quad (3)$$

where D_R, A_U, A_{Th} and A_K are the absorbed dose rate, specific activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg respectively.

2.8. External Hazard Index (Hex)

To limit the radiation exposure attributable to natural radionuclides in the samples to the permissible dose equivalent limit of 1 mSv/y, the external hazard index based on that criterion have been introduced using a model proposed by Krieger [13] which is given by;

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (4)$$

where A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. In order to keep the radiation hazard insignificant, the value of external maximum value of H_{ex} equal to unity corresponds to the upper limit of radium equivalent activity 370 Bq/kg.

2.9. Internal Hazard Index (H_{in})

The internal exposure caused by radon (^{222}Rn, the daughter product of ^{226}Ra) and thoron (^{220}Rn, the daughter product of ^{224}Ra) is hazardous to the respiratory organs. Using the relationship proposed by Harikrishnan *et al.* [6], this hazard can be quantified by the internal hazard index (H_{in}):

$$H_{in} = \frac{A_U}{185Bq/Kq} + \frac{A_{Th}}{259Bq/Kg} + \frac{A_K}{4810Bq/Kg} \quad (5)$$

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

2.10. The Representative Level Index (Iγr)

The representative level index (Iγr) is used to estimate the level of γ-radiation hazard associated with the natural radionuclides. According to Kinsara *et al.* [14], the radiation level index is defined as:

$$I_{\gamma r} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (6)$$

where A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively. $I_{\gamma r}$ may be used to estimate the level of gamma radiation hazard associated with natural radionuclides in the investigated sediment sample.

2.11. The Annual Effective Dose Equivalent

The annual effective dose equivalent received by a member of the public is calculated from the absorbed dose rates by using dose conversion factor of 0.7 Sv/Gy from absorbed dose in air to effective dose received by adults, the indoor to outdoor ratio (1:4), the outdoor occupancy factor 0.2 and the indoor occupancy factor 0.8 [15]. Therefore, the annual effective doses outdoors and indoors equivalent are calculated by using the relations:

$$D_{\text{outdoor}}(mSv/yr) = \left[D_R(mGy/hr) \times 24hr \times 365.25d \times 0.2 \times 0.7 Sv/Gy\right] \times 10^{-6} \quad (7)$$

$$D_{\text{indoor}}(mSv/yr) = \left[D_R(mGy/hr) \times 24hr \times 365.25d \times 1.4 \times 0.8 \times 0.7 Sv/Gy\right] \times 10^{-6} \quad (8)$$

The corresponding worldwide values of D_{out}, D_{ind} and D_{tot} are 0.08, 0.42 and 0.50 mSvy^{-1} respectively.

2.12. The Excess Lifetime Cancer Risk (ELCR)

The probability of developing cancer in a population within a life time after exposure to radionuclides was calculated using the following equation:

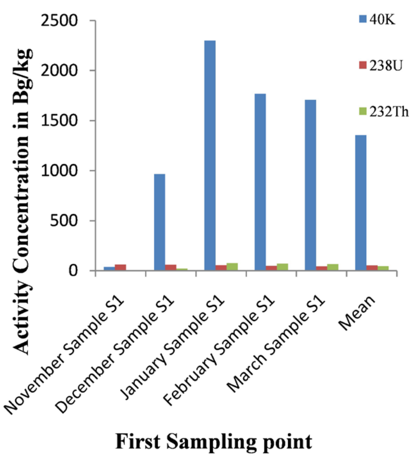
$$ELCR = AEDE \times DL \times RF \quad (9)$$

where, $AEDE$ is the Annual Equivalent Dose Equivalent, DL is the average duration of life, and RF is the Risk Factor (Sv^{-1}), *i.e.* fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public [16].

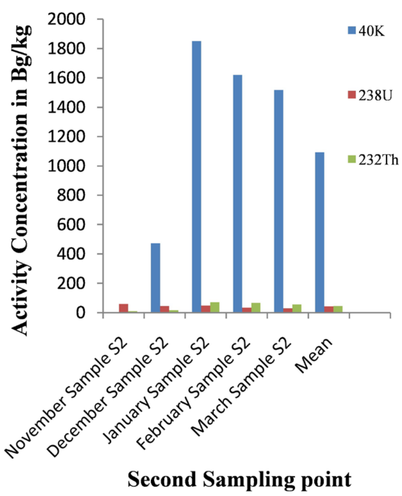
3. Results and Discussion

The activity concentrations of ^{40}K, ^{238}U and ^{232}Th in Eko-Ende sediment samples during dry and wet season for the three sampling points are presented in **Figures 2(a)-(c)** and **Figures 3(a)-(c)**. The range for the activity concentrations due to ^{40}K in the first sampling point during the dry season was 37.17 ± 5.10 to 2300.34 ± 24.62 Bg/kg with an average value of 1356.07 ± 18.87 Bq/kg, ^{238}U ranged from 43.94 ± 3.88 to 63.47 ± 8.90 having a mean value of 54.98 ± 6.61 Bq/kg and ^{232}Th from 4.00 ± 2.90 to 76.46 ± 12.55 Bg/kg with a mean value of 48.22 ± 7.76 Bq/kg. In the second sampling point, ^{40}K varied from BDL to 1850.35 ± 18.63 Bg/kg with a mean value 1092.23 ± 18.83, ^{238}U varied from 29.32 ± 3.32 to 58.91 ± 5.28 Bg/kg with an average value of 43.00 ± 5.76 and ^{232}Th varied from 10.63 ± 2.50 to 72.03 ± 6.82 Bg/kg having a mean value of 44.37 ± 5.72 while the third sampling point presented ^{40}K between 102.08 ± 7.21 to 1272.36 ± 20.81 Bg/kg with an average value of 677.50 ± 12.93, ^{238}U ranged from 4.82 ±

0.72 to 31.85 ± 5.43 Bg/kg with an average value of 20.12 ± 12.93 and ^{232}Th varied between BDL to 46.15 ± 4.77 with a mean value 24.78 ± 3.80. During the wet season presented in **Figures 3(a)-(c)**, ^{40}K ranged from 336.53 ± 12.11 to 1662.41 ± 21.22 Bg/kg with mean value of 1014.79 ± 19.42 Bq/kg in the first sampling point, in the second sampling point, ^{40}K ranged from 215.87 ± 9.47 to 1509.06 ± 17.09 Bg/kg having a mean value of 755.28 ± 15.75 and in the third point, ^{40}K varied from 202.38 ± 11.98 Bg/kg to 812.33 ± 9.75 Bg/kg with an average value of 510.42 ± 13.54, ^{238}U in the first sampling point during the wet season ranged from 10.74 ± 2.43 to 87.34 ± 4.33 Bg/kg with a mean value 41.10 ± 5.03, in the second sampling point, ^{238}U ranged from 4.00 ± 1.32 Bg/kg with an average value of 29.06 ± 4.29 and in the third sampling point, ^{238}U varied from 2.25 ± 0.23 to 56.46 ± 10.05 with a mean value of 23.19 while ^{232}Th varied from 30.28 ± 6.16 to 73.07 ± 10.51 Bg/kg with a mean value of 49.34 ± 7.33 in the first sampling point while in the second point, the value ranged between BDL to 58.71 ± 6.62 Bg/kg with an average value of 28.01 ± 3.94 Bg/kg and the third point presented ^{232}Th in the range 12.97 ± 3.52 to 42.07 ± 4.05 Bg/kg with an average value of 26.16 ± 4.98 Bg/kg.



(a)



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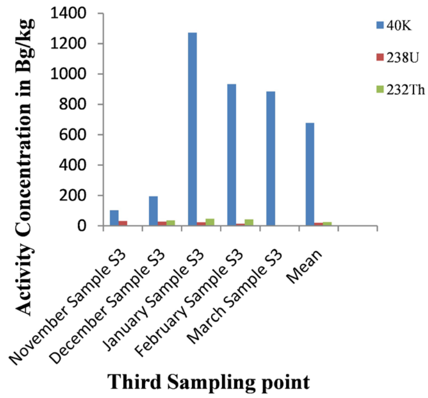
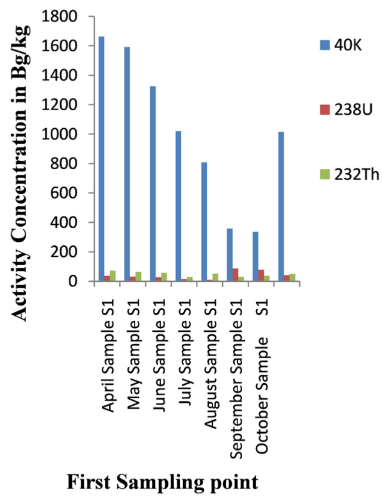


(c)

Figure 2. (a) and (b) Average activity concentrations of naturally occurring radionuclides in the first and second sampling point during dry season; (c) Average activity concentrations of naturally occurring radionuclides in the third sampling point during dry season.



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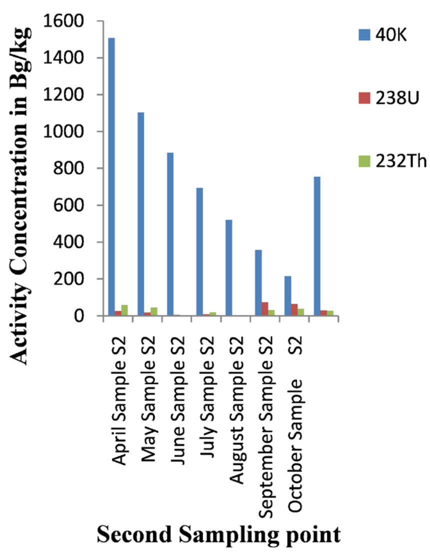

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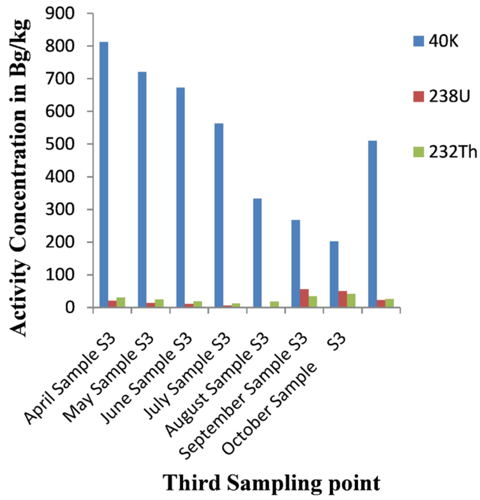

(c)

Figure 3. (a) and (b) Average activity concentrations of naturally occurring radionuclides in the first and second sampling point during wet season; (c) Average activity concentrations of naturally occurring radionuclides in the third sampling point during wet season.

It was observed that the activity concentrations of ^{40}K exceeded significantly the values of both ^{238}U and ^{232}Th in both seasons, thus it was the most abundant radioactive element among those under consideration. The average activity concentration of the radionuclides in the samples from the Dam was found to be lower than world average values, except ^{40}K (World average concentrations are 50 Bq kg^{-1}, 50 Bq kg^{-1} and 500 Bq kg^{-1} for ^{228}U, ^{232}Th and ^{40}K, respectively) [17]. The high concentration observed in the spread of ^{40}K could be as a result of anthropogenic activities such as fertilizer and manure application on farm land or as a contribution from background bedrock over which the water of the dam flows or settles.

The mean activity concentration of thorium in the samples was observed to be higher than that of uranium, probably because thorium is 1.5 times higher than that of Uranium in the earth's crust [18]. This indicates that the mean activity concentration of ^{238}U and ^{232}Th from the present study was less than the permissible values except for ^{238}U in the first sampling point during the dry season.

In the case of ^{238}U, it was observed that the highest values obtained in the first sampling point during the dry season could be as a result of low velocity of the river and as such the sediments could settle better and more fine-grained samples could settle. Radionuclides can accumulate better in these areas [19]. The solubility of thorium is constant and low, its mobility is low too and it mainly depends on the velocity of the river [19].

3.1. Evaluation of Radiological Hazard Effects

Radium Equivalent Activity

The radium equivalent activity (Ra_{eq}) in Eko-Ende sediment samples (**Table 1(a)** and **Table 1(b)**) ranged from BDL to 350.91 Bqkg^{-1} for the dry season and in the wet season; it ranged from 145.18 - 285.85 $Bqkg^{-1}$ with a mean value of 241.19 and 206.91 $Bqkg^{-1}$ respectively, the value detected were less than the safe limit (370 $Bqkg^{-1}$) recommended by UNSCEAR [20].

3.2. Absorbed Gamma Dose Rate (D_R)

The estimated absorbed dose rates for Eko-Ende sediment during the dry season ranged from BDL—171.84 $nGyh^{-1}$ with a mean value of 101.52 $nGyh^{-1}$ and in the wet season, the absorbed dose rate ranged from BDL to 134.21 $nGyh^{-1}$ having an average value of 65.32 $nGyh^{-1}$. The values were higher in the dry season and within the permissible limit when compared with the world average value of 84 nGy/h [6]. The absorbed dose rate itself does not give an indication of possible biological effects until it is converted to the effective dose equivalent measured in Sieverts (Sv) [21].

3.3. Annual Effective Dose Equivalent

The annual effective dose equivalent of the sediments varied from BDL to 0.21 μSv (average = 0.13 μSv) in the dry season and in the wet season, it varied from BDL to 0.16 having a mean value 0.08 μSv. The calculated values were found to be lower than the recommended value of 1 μSv [21] implying that the radiation hazard was insignificant for the population in Eko-Ende community.

3.4. Internal and External Hazard Indices

The calculated internal (H_{in}) during the dry season varied from BDL to 7.27 with a mean value 3.80 while during the wet season, it ranged from BDL to 1.21 with an average value 0.64. The external (H_{ex}) hazard indices for the investigated sediment samples in the dry and wet season varied from BDL to 2.77 with an average value 1.45 and BDL to 1.60 with a mean value of 0.92 respectively. The calculated mean internal (H_{in}) hazard was within permissible value, while the mean external (H_{ex}) hazard indices during the dry season were outside the range of less than 1 [6].

Table 1. (a) Calculation of Ra_{eq}, dose rate, annual effective dose equivalent (AEDE), and Effective life cancer risk (ELCR) of Eko-Ende sediment samples during dry season; (b) Calculation of dose rate, Ra_{eq}, annual effective dose equivalent (AEDE), and effective life cancer risk (ELCR) of Eko-Ende sediment samplesduring wet season.

(a)

Sample Identity	D_R (Abs. gamma dose nGy/h)	Ra (eq) Bq/kg (rate)	External Hazard Index for Sediment	Internal Hazard Index for Sediment	The Representative Index (I_{yr})	AEDE $mSvy^{-1}$	ELCR Male 10^{-3}	ELCR Female 10^{-3}
November Sample S1	38.18	183.59	0.57	0.44	1.43	0.05	0.13	0.30
November Sample S2	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.24
November Sample S3	BDL	156.97	BDL	BDL	BDL	BDL	BDL	0.20
December Sample S1	81.08	252.40	0.88	0.44	2.33	0.10	0.27	0.34
December Sample S2	50.08	198.09	0.81	0.64	2.09	0.06	0.17	0.26

Continued

December Sample S3	43.97	159.99	1.15	1.41	2.89	0.05	0.15	0.20
January Sample S1	171.84	350.91	2.77	2.85	7.27	0.21	0.56	0.36
January Sample S2	146.19	307.43	2.11	2.12	5.53	0.18	0.48	0.28
January Sample S3	94.33	238.84	1.56	1.42	4.09	0.12	0.31	0.25
February Sample S1	143.50	303.64	1.85	1.34	4.90	0.18	0.47	0.33
February Sample S2	127.58	276.67	1.56	1.04	4.15	0.16	0.42	0.27
February Sample S3	72.51	201.70	1.06	0.59	2.79	0.09	0.24	0.20
March Sample S1	135.62	292.76	1.69	1.18	4.49	0.17	0.44	0.30
March Sample S2	113.31	263.44	1.36	0.80	3.62	0.14	0.37	0.26
March Sample S3	BDL	190.26	BDL	BDL	BDL	BDL	BDL	0.18
Mean	101.52	241.19	1.45	1.19	3.80	0.13	0.33	0.27

(b)

Sample Identity	D_R (Abs. gamma dose nGy/hr)	Ra (eq) Bq/kg (rate)	External Hazard Index for Sediment	Internal Hazard Index for Sediment	Activity Concentration Index ($I\gamma$)	AEDE $mSvy^{-1}$	ELCR Male 10^{-3}	ELCR Female 10^{-3}
April Sample S1	134.21	281.85	1.60	1.10	4.27	0.16	0.44	0.27
April Sample S2	114.06	260.39	1.57	1.14	4.16	0.14	0.37	0.23
April Sample S3	63.40	200.90	0.98	0.59	2.57	0.08	0.21	0.17
May Sample S1	122.73	272.40	1.46	0.95	3.89	0.15	0.40	0.24
May Sample S2	85.00	221.13	1.13	0.68	2.98	0.10	0.28	0.31
May Sample S3	53.16	186.85	0.88	0.50	2.30	0.07	0.17	0.18
June Sample S1	106.77	248.02	1.34	0.88	3.55	0.13	0.35	0.18
June Sample S2	BDL	190.26	BDL	BDL	BDL	BDL	BDL	0.15
June Sample S3	45.91	180.37	0.75	0.37	1.96	0.06	0.15	BDL
July Sample S1	69.05	209.88	1.11	0.68	2.93	0.08	0.23	0.16
July Sample S2	46.57	180.62	0.80	0.42	2.10	0.06	0.15	BDL
July Sample S3	35.16	167.29	0.92	0.58	2.38	0.04	0.12	0.07
August Sample S1	73.19	190.30	0.98	0.58	2.57	0.09	0.24	0.12
August Sample S2	BDL	161.39	BDL	BDL	BDL	BDL	BDL	0.08
August Sample S3	27.21	145.18	0.65	0.33	1.66	0.03	0.09	0.05
September Sample S1	73.61	232.26	0.85	0.72	2.17	0.09	0.24	0.37
September Sample S2	68.57	219.33	0.87	0.76	2.22	0.08	0.23	0.31
September Sample S3	58.76	194.35	0.86	0.78	2.17	0.07	0.19	BDL
October Sample S1	67.41	220.77	1.10	1.21	2.78	0.08	0.22	0.34
October Sample S2	68.08	198.19	0.76	0.60	1.93	0.08	0.23	0.28
October Sample S3	58.79	183.30	0.78	0.63	1.96	0.07	0.19	0.23
Mean	65.32	206.91	0.92	0.64	2.41	0.08	0.24	0.18

BDL: Below Detection Limit.

3.5. The Representative Level Index ($I_{\gamma r}$)

The gamma activity index (Iγ) used to assess safety requirement for building materials was evaluated and presented in **Table 1(a)** and **Table 1(b)**. The obtained values for the dry period ranged from BDL to 7.27, having a mean value of 3.80 mSv/y and for the wet season, it ranged from BDL to 4.27 with a mean value 2.41. The calculated values for the sediment samples were outside the exemption dose criterion (<1.0 mSv/y) [22].

3.6. Excess Lifetime Cancer Risk (ELCR)

The possible human carcinogenic effect was carried out by estimating the likelihood of cancer occurrence in a population of individuals for a specific lifetime from projected intakes (and exposures). The calculated values of the excess lifetime cancer risk (ELCR) for males during dry season varied from BDL to 0.56×10^{-3} with a mean value of 0.33×10^{-3} and in the wet season, it varied from BDL to 0.44×10^{-3} having an average value of 0.24×10^{-3}. In the females during the dry season, the excess lifetime cancer risk varied from 0.18×10^{-3} to 0.36×10^{-3} with an average value of 0.27×10^{-3} and during the wet season, the value ranged from BDL to 0.37×10^{-3} with an average value of 0.18×10^{-3}. When compared with the United Nations Scientific Committee on the Effect of Atomic Radiation [17] who recommended safe limit of 0.29×10^{-3}, it could be inferred that the values would not lead to respiratory diseases such as asthma, cancer and external diseases such as erythema, skin cancer and cataracts [22], except in dry season for males thus, the probability of people in the study area developing cancer cases for females and even males during wet season was low while serious caution should be taken during the dry season.

4. Conclusion

This study indicated that the sediment samples of Eko-Ende in both seasons had radioactivity with significant variations at various times. The mean uranium and thorium radionuclide activity was within permissible values, while mean potassium radionuclide activity was higher than the generally acceptable range. The radium equivalent activity, internal hazard index, annual effective dose equivalent and effective life cancer risk values of the sediment samples were lower than the permissible limit. However, the absorbed dose rates, external hazard index and representative level index ($I_{\gamma r}$) of the sediment samples during the dry season were higher than the permissible limit and it can be concluded that the study area may not pose immediate health implication to the general populace especially Eko-Ende town but prolonged exposure could lead to radiation related health hazard.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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