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Research article

Radiometric survey of sediments and health risk assessments from the southern coastal area of Delta State, Nigeria

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ABSTRACT

Over the years, the release of potential radiological components around the oil exploration environment has increased with potential health implications.Yet; the mechanism and health associated assessment have remained fuzzy to most experimental scientists. The current study determines the activity concentration of radionuclides in sediments and the corresponding health risk assessments from the hydrocarbon exploration environment of the southern coastal area of Delta State, Nigeria. A Sodium-iodide NaI(Tl) detector, with a well-calibrated multichannel analyzer (MCA) to ensure efficiency and energy was utilized. A total of seventy-five sediment samples (Five sediment samples each per community) were collected from the southern coastal area of Delta State, Nigeria. The mean activity concentrations of ^{40}K, ^{238}U, and ^{232}Th of the sediment samples were 3361.48 ± 194.26 Bqkg^{-1}, 40.11 ± 16.17 Bqkg^{-1}, and 45.73 ± 19.27 Bqkg^{-1} respectively. The obtained mean values exceeded the world standard limit of 400 Bqkg^{-1}, 35 Bqkg^{-1}, and 30 Bqkg^{-1} respectively. Also, the computed mean radiological health hazard risk of radium equivalent activity (Raeq), representative level index (I_{yr}), external hazard index (Hex), internal hazard index (Hin), absorbed gamma dose rate (*D*), annual effective dose equivalent outdoor and indoor (AEDE) and lifetime cancer risk (ELCR) values are 363.94 ± 32.37 Bkgl^{-1}, 2.9657 Bkgl^{-1}, 0.9839, 1.0919, 175.82 nGyh^{-1}, 2.1556 mSvyr^{-1}, 0.8625 mSvyr^{-1}, and 7.5447 mSvyr^{-1} respectively. The values were found to be slightly higher than the world standard limit. Therefore, the residents that are using the sediments of the southern coastal area for the construction of buildings as well as dwelling in houses built with such sediments are exposed to these radiological materials. This may pose a radiological health risk concern. The obtained results will serve as radiation and radiological baseline data for sediments of the southern coastal area of Delta State, Nigeria.

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1. Introduction

Since the formation of the Earth, scientists have reported naturally occurring radioactive materials (NORM) (^{238}U, ^{232}Th, and ^{40}K) in soil, sediment, rocks, plants, water, building materials and houses [1–5]. These radioisotopes are classified into Primordial source, cosmogenic source and anthropogenic source [4,6–8]. Anthropogenic activities such as hydrocarbon exploration and production, agricultural activities, atomic bomb testing, and maritime activities may increase the activity concentration levels of radioactive components in the environment [9–11]. Hydrocarbon exploration and production activities has been taking place for decades in the Niger Delta area of Nigeria, and these are associated with the release of radioactive materials that may result in radiological pollution of the water, soil, sediments and air [9,10]. These radionuclides pollutants from oil exploration activity that ultimately sink to the water bed (sediments) may pose potential radiological health hazards to the residents who use the sediments as raw material for building and constructions purposes [4,9,11,12].

When human beings are exposed to ionizing radiation through inhalation and ingestion, radiological health challenges such as chronic effects, genetic effects, deterministic effects, and stochastic effects may result [13–22]. To ensure the radiological safety of building, it is important to know the activity concentrations of radionuclides in sediments which form major part of raw materials used for building or constructions purposes [23].

Over the years, scientists have studied the presence of radionuclides and their health effects on humans from sediment and other raw materials used for building and constructions in other parts of Nigeria and the world [2,6,7,24–35]. However, There exist little to no study done in the Southern region of the Delta State of Nigeria even though the region host several mining and exploration activities over the years.

The main objective of this present study was to investigate the concentrations of the primordial radionuclides ^{238}U, ^{232}Th, and ^{40}K in sediments samples collected from the southern coastal area of Delta State, Nigeria due to hydrocarbon exploration and production in the studied area. The outcome of the study will provide information whether the coastline and sediments have normal or high background radiation, and also form a baseline for the determination of natural radioactivity level in the Niger Delta region of Nigeria.

1.1. Study area description

The research area is situated in the Southern region of Delta State, Nigeria. The research area is bounded by the Atlantic Ocean to the south. This location has a coastline extending from the Warri River to the Forcados River. The area comprises of Burutu local government area, Warri South West local government area, Ogbe-Ijoh and Warri North local government area, Koko. The area is between latitudes 5°00 and 6°.30′ North and longitudes 5°00 and 6°.55′ East of Delta state, Nigeria, and it's tectonically stable and 3.0

Fig. 1. Map of the research area.

m above sea level [36] as shown in Fig. 1. The area plays host to multinational and other hydrocarbon servicing organizations which makes it one of the oil and gas producing regions in the state and country. It encompasses several coastal barrier islands, clean water swamps, saltwater mangrove swamps, estuaries, creeks, mangrove swamps, tidal channels, seaside ridges, and sand bars.

2. Material and methods

2.1. Sampling and sample preparation

A total of seven five sediment samples were collected from the southern coastal area of Delta State, Nigeria. Five sediment samples were collected from each community using a well acid-washed, cleaned, and distilled water rinsed grab sampler. The treated grab sampler was used to collect the sediment samples at 10 cm–15 cm at the bottom of the river (sea bed) at every sampling point. Immediately, the collected sediment samples were transferred into labeled black polythene bags before being transported to the laboratory for analysis using Sodium-iodide NaI (Tl) Detection at the National Institute of Radiation Protection and Research Center (NIRPR), University of Ibadan (Fig. 2).The sampled sediments were put in an oven at a temperature of 110 °C–120 °C eliminate moisture, and decrease the sample weight [24]. After drying all they samples were pulverized into fine grains and thoroughly mixed to obtain a homogeneous sample and sieved using 200 μm mesh size to remove macro-materials, pebbles, stones, wood and all unwanted materials [6,37]. The sieved, smooth, and dried sediments were accumulated into plastic cylindrical boxes and sealed for four (4) weeks to enable secular equilibrium to take place. After secular equilibrium is attained, all samples were subjected to gamma spectroscopy.

2.2. Sample analysis

The concentrations of radionuclides in the sediments was analyzed using Canberra thallium activated Sodium iodide detector 7.6 cm × 7.6 cm NaI(Tl). The detector had a lead shielding 10 cm thickness to reduce the background by a factor of about 95% [4]. The version of the detector used is 802 (3''x 3″), which was used for determination of ^{226}Ra, ^{232}Th, and ^{40}K concentrations in all the sampled sediments. The detector has a Multichannel Analyzer (MCA) through a pre-amplifier Model2007P with serial 13000742 bases. The Canberra thallium activated Sodium iodide detector NaI(Tl) undergo two form of calibration. The first was energy calibration that converted the channel numbers to γ-rays energy in MeV. This calibration (energy) of the detector was done using three-point sources ^{241}Am, ^{137}Cs, and ^{60}Co standard sources, which were purchased in the year 2010. The energy calibration was done before the sample measurement started and always checked daily to ensure that the peaks had not shifted. However, the second that is known as efficiency calibration converted the area under a photopeak to concentration of radionuclides in SI unit of Bq/kg. The efficiency calibration was done yearly using a mixed gamma source that supplied by the International Atomic Energy Agency (IAEA) in 2013. The detector efficiency calibration and the quality control were done by means of certified standard (IAEA-Sediment-315). The detector was last calibrated in January of 2023. The background band was accumulated for 36000s at 600 V to generate well-built gamma peaks emitting energies of radionuclides concentrations by (1764.5kev from gamma peak of ^{214}Bi) for ^{226}Ra, (2614 kev from gamma peak of ^{208}Tl) for ^{232}Th, and (1460.8 kev from gamma peak of ^{40}k) for ^{40}k. The detector energy resolution of ^{137}Cs and ^{60}Co standards were 7.5% and 6.5% at 662 keV and 1332 keV peaks respectively. The analyses of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K were achieved with the usage of a gamma-ray spectrum that was connected to GENIE 2000 software.

The specific activity A (Bq.kg^{-1}) of nuclide and peak energy E, is given in equation (1):

Fig. 2. Gamma ray NaI(Tl) Spectrometer.

$$A = \frac{NP}{T_I = I\,(E) \quad x \in (E)\; x\; M} \tag{1}$$

where NP is the number of peak counts, ε(E) is detection energy performance, I(E) is counting lifetime and M is mass in kg.

3. Results and discussions

3.1. Computation of radiological hazard indices

3.1.1 ^{40}K, ^{226}Ra and ^{228}Ra concentrations in the sediments.

The mean activity concentrations of ^{40}K, ^{238}U, and ^{232}Th evaluated and the corresponding computed radiological hazard index in sediments sampled from the coastal area of Delta State, Nigeria are shown in Table 1 and Table 2. The statistical comparison results and contour maps are shown in Figs. 3–18. The obtained mean values of ^{40}K ranged from 133.95 ± 10.05 Bqkg^{-1} in Okerenkoko community to 15098.1 ± 821.72 Bqkg^{-1} in Oporoza community with a mean result of 3361.48 ± 194.26 Bqkg^{-1} and a control result of 72.13 ± 22.06 Bqkg^{-1} gotten from community river sediment where hydrocarbon and its byproduct are not produced with a similar formation. The high ^{40}K value obtained maybe attributed to spilled (hydrocarbon) petroleum products, discharged in the water, contaminated drilling mud, oil sludge's and some abandoned oil pipe scales and scraps material. These possibly will affect the sediments due to sedimentation and seepage. The concentrations of ^{238}U ranged from 0.81 ± 0.20 Bqkg^{-1} in Tisum community to 88.79 ± 19.10 Bqkg^{-1} in Tebu community with a mean value of 40.11 ± 16.17 Bqkg^{-1}, and a control result of 9.26 ± 4.08 Bqkg^{-1}. The high value of ^{238}U obtained maybe attributed to the activities of the exploration for crude oil by mining companies in the region. Some observed activities of oil and gas multinational and services companies that may have led to these high values are gas flaring, transportation of crude hydrocarbon, discharge of contaminated effluents and soil from flow stations and oil terminals into the waters, and spillage of crude hydrocarbon from oil gas delivering pipelines in the studied region. The concentrations of ^{232}Th ranged from 11.53 ± 1.23 Bqkg^{-1} in Tisum community to 93.90 ± 28.01 Bqkg^{-1} in Okpele-Ama community with a mean value of 45.73 ± 19.27 Bqkg^{-1} and a control result of 14.55 ± 1.29 Bqkg^{-1}. The observed high levels of activity of ^{232}Th in the sediment samples maybe attributed to the anthropogenic sources of oil pollution activities from mining of petroleum products to the activities of illegal refining and illegal bunkers of crude hydrocarbon by locals in the region. The obtained means concentrations of ^{40}K, ^{238}U and ^{232}Th in the study area exceeded both the values of the control and world standard limit of 400 Bqkg^{-1}, 35 Bqkg^{-1} and 30 Bqkg^{-1} respectively [38]. Similarly, the concentrations of ^{40}K, ^{238}U and ^{232}Th in the present study was found higher than those reported elsewhere around the world [4–6,22,24–26,37,39–42] but compared favorably with results reported by Refs. [43,44].

3.1.1. Radium equivalent activity (Ra_{eq})

The disequilibrium of ^{226}Ra and its decay products has been the major cause of the inhomogeneous distribution of radionuclides (^{40}K, ^{238}U and ^{232}Th) in Sediments. To estimates the exposure level of these radionuclides, Radium equivalent activity' (Raeq) in Bqkg^{-1} was used to compute radiological hazard in sediment using equation (2) [45].

$$\mathbf{Ra_{eq}} = H_{Ra} + (1.43H_{Th}) + (0.077H_K) \tag{2}$$

where H_{Ra}, H_{Th} and H_K are the activity concentrations of ^{40}K, ^{238}U and ^{232}Th, respectively in Bqkg^{-1} [6,15,37,46,47].

The Radium equivalent computed values ranged from 48.69 ± 8.42 Bkgl^{-1} in Okerenkoko community to 1293.64 ± 77.25Bqkg^{-1} in Oporoza community with a mean value of 363.94 ± 32.37Bkgl^{-1} (Table 2). The obtained results are within the recommended global

Table 1
Mean Specific activity concentration of^{40} K,^{238}U, and^{232}Th (Bq/kg) Results in Sediment Samples.

S/N	COMMUNITIES	ACTIVITY		
		^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
1	Burutu	1825.83 ± 106.62	3.58 ± 0.95	31.49 ± 2.99
2	Yeye	5046.21 ± 350.31	64.47 ± 128.80	49.8 ± 197.74
3	Ogulagha	2954.11 ± 166.77	64.84 ± 14.41	38.46 ± 3.73
4	Forcados	3626.31 ± 205.31	59.30 ± 13.29	71.42 ± 6.73
5	Odimodi	3940.07 ± 219.96	46.60 ± 10.86	74.81 ± 7.03
6	Okerenkoko	133.95 ± 10.05	19.88 ± 5.16	17.07 ± 1.74
7	Kunukunuma	1535.4 ± 101.86	15.80 ± 4.12	9.57 ± 0.92
8	Benikurukuru	2368.76 ± 160.06	40.69 ± 10.33	51.00 ± 15.31
9	Oporoza	15098.1 ± 821.72	5.05 ± 1.35	88.14 ± 8.83
10	Okpele-Ama	9945.86 ± 555.23	39.10 ± 9.57	93.90 ± 28.01
11	Koko	257.44 ± 26.70	82.76 ± 20.70	41.89 ± 4.54
12	Abigborodo	704.29 ± 3.42	61.68 ± 1.65	24.87 ± 2.40
13	Tebu	1679.81 ± 98.61	88.79 ± 19.10	54.89 ± 5.17
14	Tisum	924.78 ± 59.82	0.81 ± 0.20	11.53 ± 1.23
15	Kolokolo	381.34 ± 27.44	8.31 ± 1.99	27.08 ± 2.63
	Mean	**3361.48 ± 194.26**	**40.11 ± 16.17**	**45.73 ± 19.27**
	Control	**72.13 ± 22.06**	**9.26 ± 4.08**	**14.55 ± 1.29**

Table 2
Computed Radiation Hazard Indices in Sediment samples.

S/No	Communities	Raeq	Iyr	Hex	Hin	D	AEDE (Outdoor)	AEDE (Indoor)	ELCR × 10^{-3}
1	Burutu	189.2 ± 13.44	1.5561	0.5109	0.5203	37.87	0.4644	0.1858	1.6254
2	Yeye	524.24 ± 44.54	4.2919	1.4156	1.5899	270.40	3.3113	1.3265	11.5896
3	Ogulagha	347.29 ± 32.58	2.7862	0.9379	1.1131	76.45	0.9376	0.3750	3.2816
4	Forcados	440.66 ± 38.72	3.5270	1.1899	1.3502	221.90	2.7214	1.0886	9.5249
5	Odimodi	456.97 ± 37.85	3.6855	1.2339	1.3599	231.16	2.8350	1.1340	9.9225
6	Okenrenkoko	48.69 ± 8.42	0.3925	0.1475	0.2012	25.11	0.3080	0.1232	1.0780
7	Kunukunuma	147.72 ± 13.29	1.2246	0.3988	0.4416	77.13	0.9459	0.3784	3.3107
8	Benikurukuru	296.01 ± 44.54	2.3604	0.7995	0.9093	148.49	1.8211	0.7284	6.3739
9	Oporoza	1293.64 ± 77.25	10.9805	3.4957	3.5065	685.33	8.4008	3.3620	29.4028
10	Okpele-Ama	939.21 ± 92.37	7.8302	2.5360	2.6417	489.70	6.0057	2.4023	21.0200
11	Koko	162.48 ± 29.25	1.1423	0.4378	0.6626	74.37	0.9121	0.3648	3.1924
12	Agigborodo	151.47 ± 5.34	1.1294	0.4092	0.5759	72.94	0.8945	0.3578	3.1308
13	Tebu	296.63 ± 34.08	2.2607	0.8011	1.0411	144.33	1.7701	0.7080	6.1954
14	Tisum	88.51 ± 6.57	0.7372	0.2390	0.2368	45.92	0.5632	0.2253	1.9712
15	Kolokolo	76.39 ± 7.26	0.5804	0.2063	0.2288	36.15	0.4433	0.1773	1.5516
	Mean	**363.94 ± 32.37**	**2.9657**	**0.9839**	**1.0919**	**175.82**	**2.1556**	**0.8625**	**7.5447**

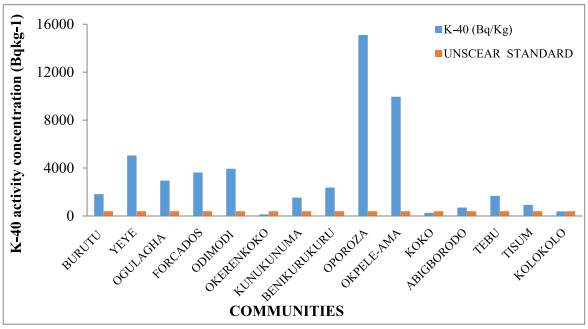

Fig. 3. Comparison of ^{40}k activity concentration (Bqkg^{-1}) in Sedimentwith standard in all the communities.

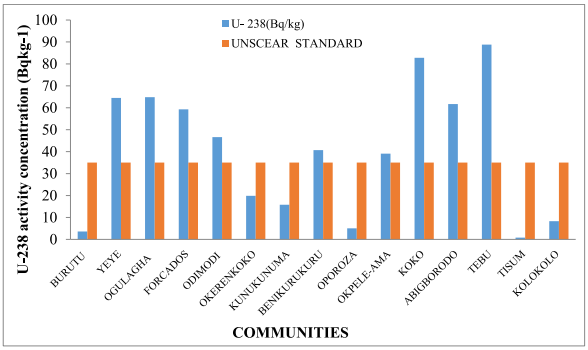

Fig. 4. Comparison of ^{238}U activity concentration (Bqkg^{-1}) in Sediment with standard in all the communities.

limit of 370 Bqkg^{-1} [45,48], except five communities where it exceeded the recommended global limit. It implied an insignificant radiological hazards associated with the sediments. The increase in the Radium equivalent of the five communities may be attributed to the geological formation (composition) of the different communities and oil and gas activities in the area. Fig. 9 shows the comparison of Radium equivalent activity (Raeq) of different communities with the recommended world limit. The mean value of this research work exceeded the values reported elsewhere in literatures [5,42,49,50].

3.1.2. Representative level index (I_{yr})

The I_{yr} is one of the indexes used to evaluate the level of radiological hazard linked with sediments. This index is a correlating factor used in terms of annual dose rate and excess gamma radiation which is caused by radioactive materials. It can also acts as screening devise for knowing if a construction materials carry any radiological risk [4,48,51]. The representative level index can be computed using equation (3):

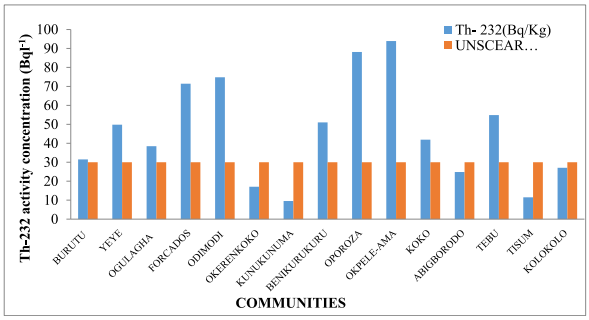

Fig. 5. Comparison of ^{232}Th activity concentration (Bqkg^{-1}) in Sediment with standard in all the communities.

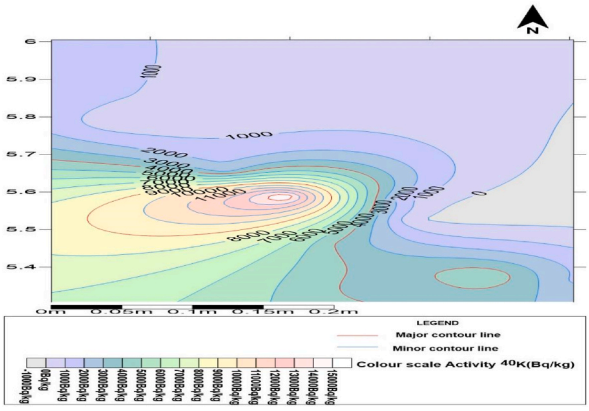

Fig. 6. Contour map of ^{40}K (Bq/kg) mean results for Sediment.

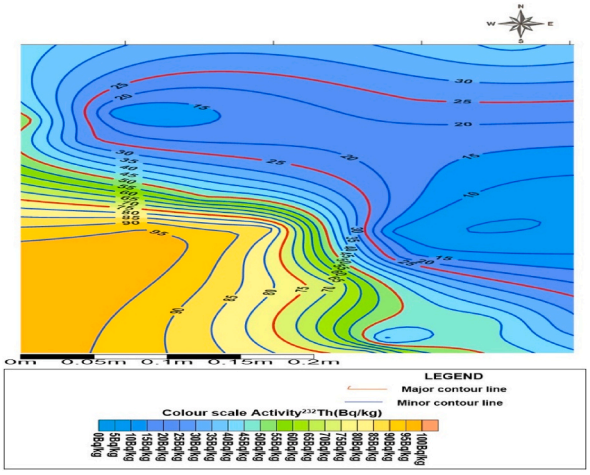

Fig. 7. Contour map of ^{232}Th (Bq/kg) mean results for Sediment.

$$I_{yr} = \frac{H_{Ra}}{150} + \frac{H_{Th}}{100} + \frac{H_K}{1500} \quad (3)$$

where H_{Ra}, H_{Th}, and H_k are the concentrations of ^{40}K, ^{238}U and ^{232}Th respectively in Bqkg^{-1}. The computed representative level index ranged from 0.3925 Bqkg^{-1}in Okerenkoko community to 10.9805 Bqkg^{-1} in Oporoza community with a mean value of 2.9657 Bqkg^{-1} (Table 2). The mean representative level index (Iyr) values for some assessed communities' exceeded unity while others had values within the world recommended limit of unity. Hence, the radiological effect may be insignificant. Fig. 10 shows the comparison of representative level index (Iyr) at different sampling communities with standard.

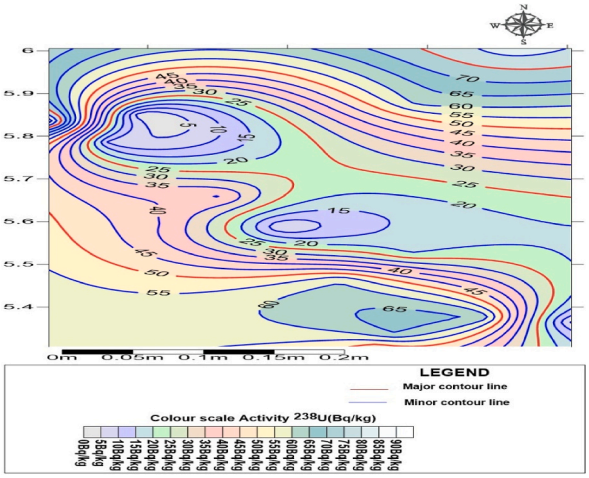

Fig. 8. Contour map of ^{238}U (Bq/kg) mean results for Sediment.

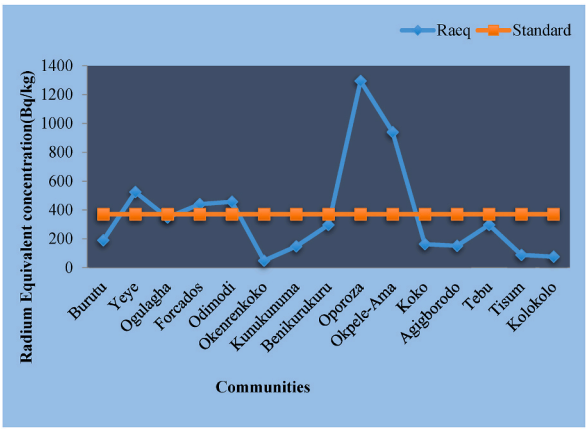

Fig. 9. Comparison of Raeq values in sediment with all the Communities.

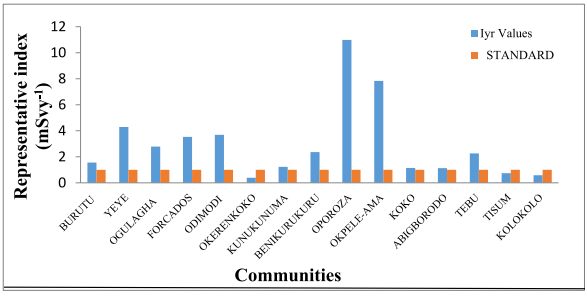

Fig. 10. Comparison of Iyr (mSvy^{-1}) in Sediment with Standard in all the communities.

3.1.3. *External hazard index (H_{ex})*

The external hazard index **(H_{ex})** is used for assessment of radiological acceptability of a material. The index also reduce the limit of radiation dose to dose equivalent limit of unity [4,38,52,53]. The external hazard index is computed using equation (4) below:

$$H_{ex} = \frac{H_{Ra}}{370} + \frac{H_{Th}}{259} + \frac{H_K}{4810} \quad (4)$$

where H_{Ra}, H_{Th}, and H_k activity concentrations ^{40}K, ^{238}U and ^{232}Th respectively.

The calculated values of external hazard index (H_{ex}) ranged from 0.1475 in Okerenkoko community to 3.4957 in Oporoza

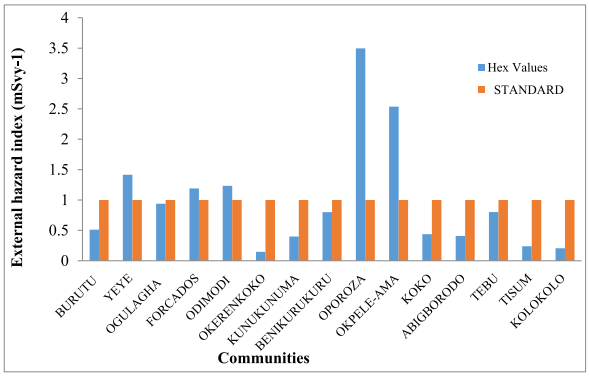

Fig. 11. Comparison of Hex values ($mSvy^{-1}$) in Sediment with Standard in all the communities.

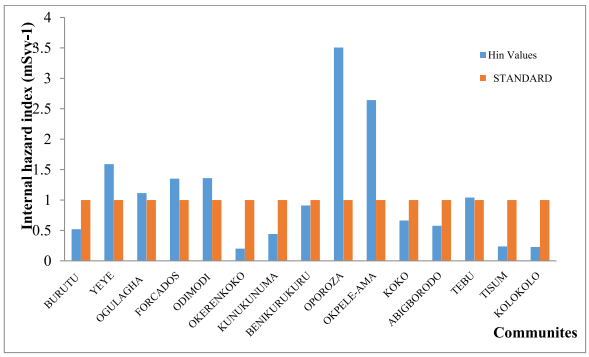

Fig. 12. Comparison of Hin values ($mSvy^{-1}$) in Sediment with Standard in all the communities.

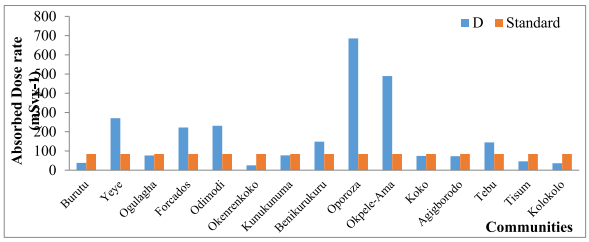

Fig. 13. Comparison of D ($mSvy^{-1}$) in Sediment with Standard in all the communities.

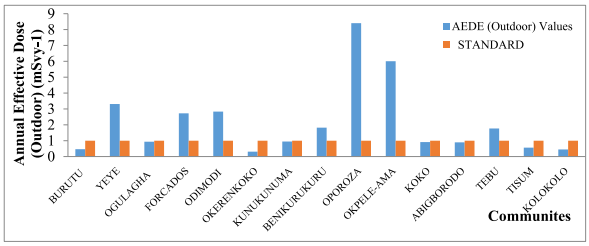

Fig. 14. Comparison of AEDE (Outdoor) ($mSvy^{-1}$) in Sediment with Standard in all the communities.

community with an average value of 0.9839 (Table 2). From Table 2 it is clear that the external hazard associated with the sediments usage by some communities may pose some radiological risk since their Hex values exceeded unity. However, some communities have results below the world recommended limit of unity [38]. This results from communities that has computed values less than unity implies that dwellers are relatively safe from radiation exposure risk; hence sediment of the study area can be used for construction. But

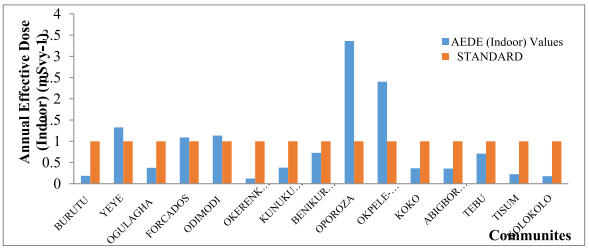

Fig. 15. Comparison of AEDE (Indoor) ($mSvy^{-1}$) in Sediments with Standard in all the communities.

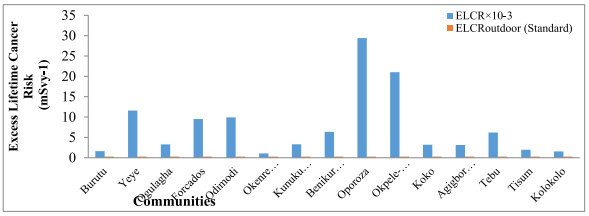

Fig. 16. Comparison of ELCR (outdoor) in Sediment with Standard in all the communities.

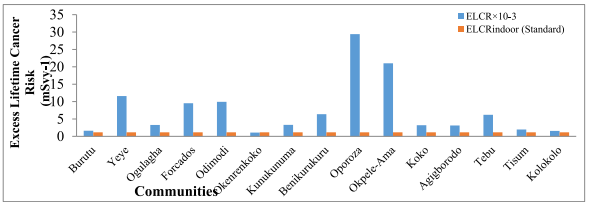

Fig. 17. Comparison of ELCR (indoor) in Sediment with Standard in all the communities.

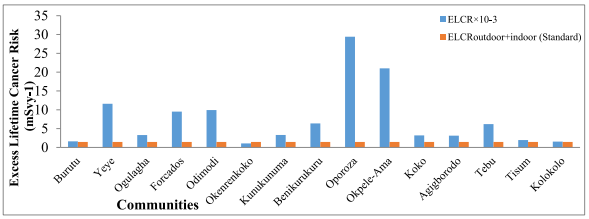

Fig. 18. Comparison of ELCR (outdoor + indoor) in Sediment with Standard in all the communities.

procuration should be taken to avoid increase in radionuclides concentration in the nearest further. The values obtained in comparison with similar coastal environment of other countries and part of Nigeria, shows that the values are in agreement with those reported in literatures [40,41,54]. Fig. 11 shows comparisons of Hex with different communities with standard.

3.1.4. *Internal hazard index (H_{in})*

The internal hazard index (Hin) is use to quantified radiological hazard in the respiratory organs due to inhalation of alpha particles that are given out by radionuclides of radon and thoron and their product. The internal hazard index is computed using equation (8) below [55,56].

$$H_{in} = \frac{H_{Ra}}{185} + \frac{H_{Th}}{259} + \frac{H_K}{4810} \quad 5$$

where H_{Ra}, H_{Th}, and H_k activity concentrations of ^{40}K, ^{238}U and ^{232}Th respectively.

The calculated results of the internal hazard index ranged from 0.2012 to 3.5065 with a mean value of 1.0919 (Table 2). The finding indicate that the mean value for Hin was comparable to the world acceptable limit of unity. This result implies that there is no significant radiation hazards associated with the sediments of the coastal area studied. Fig. 12 shows comparisons of H_{in} with different communities with standard.

3.1.5. Absorbed doss rate (D)

The Absorbed gamma dose rate, D (nGy/h) is the quantity of absorbed ionizing radiations energy gotten per unit mass per unit time from materials [15]. The sum of naturally occurring radionuclides activities of ^{226}Ra, ^{232}Th and ^{40}K amount to the total absorbed dose rate in environment. The dose conversion factors for converting the activity concentrations of ^{238}U, ^{232}Th and ^{40}K into doses (nGy.h^{-1} per Bqkg^{-1}) are 0.462, 0.621 and 0.0417 respectively [38]. The absorbed gamma dose rate was computed using equation (6) below:

$$D\ (nGyh^{-1}) = 0.462H_u + 0.621\ H_{Th} + 0.0417H_k \quad (6)$$

where D is the dose rate in nGyh^{-1} and H_u, H_{Th} and H_k are the concentrations of ^{40}K, ^{238}U and ^{232}Th respectively. Table 2 presents the results of the absorbed gamma dose rate, while Fig. 13 shows the variation of absorbed gamma dose rate in different communities with standard. The calculated values of D, in nGyh^{-1} ranged from 25.11 nGy/h in Okerenkoko community to 685.33 nGy/h in Oporoza community with a mean value of 175.82 nGy/h (Table 2). Clearly, the study showed that the mean value of D, in nGyh^{-1} is higher than the world average limit of 84 nGy/h [38,57] and slightly lower it in same communities. The computed values also did not compare favorably with those reported elsewhere and some part of Nigeria [58,59].

3.1.6. Annual effective dose equivalent

The number of time adults spend outdoor or indoor is a factor of radiation exposure quantity. Most adults use an average of 20% and 80% of their time outdoor and indoor respectively and they are being exposed to outdoor and indoor environmental radiation both in their houses and outside their houses. The annual effective dose equivalents, AEDE (mSv/year) for both outdoor and indoor were computed using equations (7) and (8) below respectively [38]:

$$AEDE_{outdoor}\ (mSvyr^{-1}) = D(\eta Gyrh^{-1}) \times 8760hyr^{-1} \times 0.2 \times 0.7\ (Sv/Gy) \times 10^{-6} \quad (7)$$

$$AEDE_{indoor}\ (mSvyr^{-1}) = D(\eta Gyrh^{-1}) \times 8760hyr^{-1} \times 0.8 \times 0.7\ (Sv/Gy) \times 10^{-6} \quad (8)$$

where D is the absorbed dose rate, 0.7 Sv/Gy is the recommended absorbed dose conversion coefficient, 0.2 and 0.8 is the outdoor and indoor occupancy factor respectively and 8760h is the total time (in hours) in a year [38].

The computed minimum, maximum and average values of AEDE (outdoor and indoor) were found to be 0.3080, 8.4008 and 2.1556 μSvy^{-1} and 0.1232, 3.3620 and 0.8625 μSvy^{-1}respectively (Table 2). The mean values of outdoor and indoor factor of AEDE indicated that the world allowed limits were exceeded having showed that the calculated results were above 1 μSvy^{-1} [38,60,61]. The outdoor mean results exceeded the recommended limit while indoor mean result is within the limit. This implied that the coastal environment is relatively safe for habitation.

3.1.7. Excess lifetime cancer risk (ELCR)

ELCR is the probability of developing cancer during one's lifetime due to exposure to ionizing radiation. It becomes important to determine the excess cancer risk over a lifetime (ELCR) of the people in the oil and gas producing coastal area of Nigeria. The ELCR of

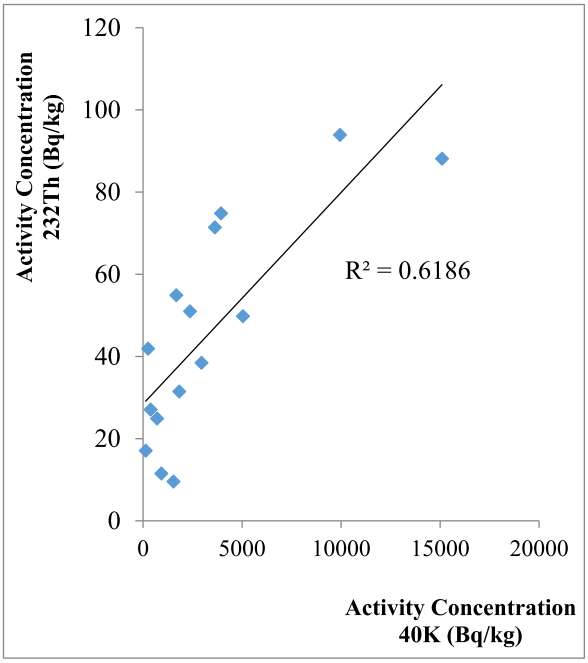

Fig. 19. Correlation between ^{232}Th and ^{40}K.

both outdoor and indoor were computed using equation (9) below.

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

where AEDE, DL and RF is the annual effective dose equivalent, duration of life (70 years) and risk factor (Sv^{-1}), fatal cancer risk per sievert. For stochastic effects, ICRP 60 uses values of 0.05 for the public [5,31,32]. The computed ELCR value ranged from 1.0780 x 10^{-3} to 29.4028 x 10^{-3} with a mean value of 7.5447 x 10^{-3} (Table 2). The ELCR computed for all the sediment samples exceeded the globe average limit of 0.29 $\times$ 10^{-3} for outdoor, 1.16 $\times$ 10^{-3} for indoor and 1.45 $\times$ 10^{-3} for outdoor + indoor [3,38] except for Okerekoko community where the results for indoor and outdoor + indoor are slightly lower than the recommended standard. These results revealed that there is a high probability of developing cancer by the local inhabitant during their life time.

4. Data statistical analyses

The correlation of activity concentrations have been presented in Figs. 19–21. A positive correlation was observed among ^{238}U, ^{232}Th and ^{40}K. The correlation between ^{232}Th and ^{40}K, ^{238}U and ^{40}K were found to be strongly positive correlated at $R^2 = 0.6186$ and $R^2 = 0.0632$ respectively while the correlation between ^{238}U and ^{40}K indicated a weak positive correlation at $R^2 = 0.0296$. The observed strong positive correlation indicates that ^{232}Th and ^{40}K, ^{238}U and ^{40}K have some similarities in teams of environmental origin and behavior. The observed weak positive correlation between ^{238}U and ^{40}K indicate that ^{238}U and ^{40}K has similar environmental origin but different behavior [62–64]. This implies a relationship among ^{40}K, ^{238}U, and ^{232}Th and they all contributed significantly to gamma radiation in the sediment samples. Figs. 22–24 shows the histogram frequency distribution which is indicative of the statistical distribution of activity concentrations of ^{40}K, ^{238}U, and ^{232}Th in the sediment samples analyzed in this study.

5. Conclusion

Oil exploration and release of radioactive elements into the environment have impacted on the regions and has resulted in radiological concerns amongst population in the study area. The determination of the level of radionuclide activity concentrations and its radiological health hazard on sediments is of great importance considering the place of sediment in construction and building of houses.This study analyzed activity of radionuclide in sediment samples from the southern coastal area of Delta State, Nigeria using a Sodium-iodide NaI(Tl) detector. The measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th results ranged from 133.95 $\pm$ 10.05 $Bqkg^{-1}$ to 15098.1 $\pm$ 821.72 $Bqkg^{-1}$with a mean value of 3361.48 $\pm$ 194.26 $Bqkg^{-1}$, 0.81 $\pm$ 0.20 $Bqkg^{-1}$ to 88.79 $\pm$ 19.10 $Bqkg^{-1}$ with a mean value of 40.11 $\pm$ 16.17 $Bqkg^{-1}$ and 11.53 $\pm$ 1.23 $Bqkg^{-1}$ to 93.90 $\pm$ 28.01 $Bqkg^{-1}$ with a mean value of 45.73 $\pm$ 19.27 $Bqkg^{-1}$ respectively.The obtained mean values exceeded the world standard limit of 400 $Bqkg^{-1}$, 35 $Bqkg^{-1}$, and 30 $Bqkg^{-1}$ respectively [38]. The computed mean radiological hazard parameters of radium equivalent activity (Raeq), representative level index (I_{yr}), external hazard index (Hex), internal hazard index (Hin), absorbed gamma dose rate (*D*), annual effective dose equivalent outdoor and indoor (AEDE) and lifetime cancer risk (ELCR) values are 363.94 $\pm$ 32.37 $Bkgl^{-1}$, 2.9657 $Bkgl^{-1}$, 0.9839, 1.0919, 175.82

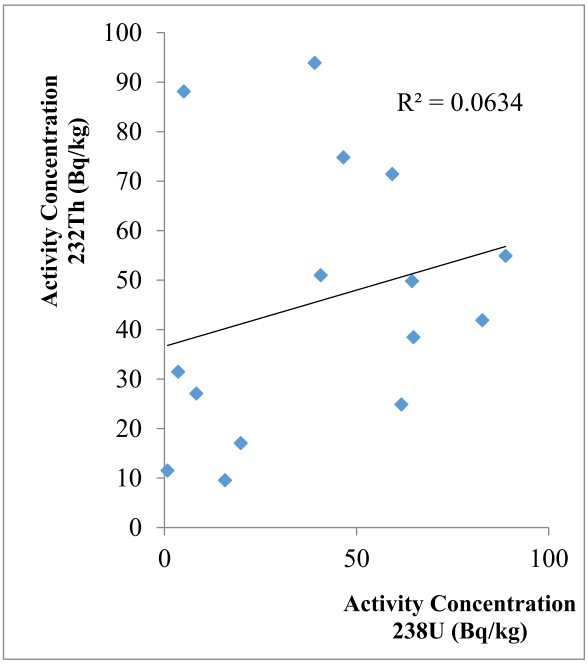

Fig. 20. Correlation between ^{232}Th and ^{238}U.

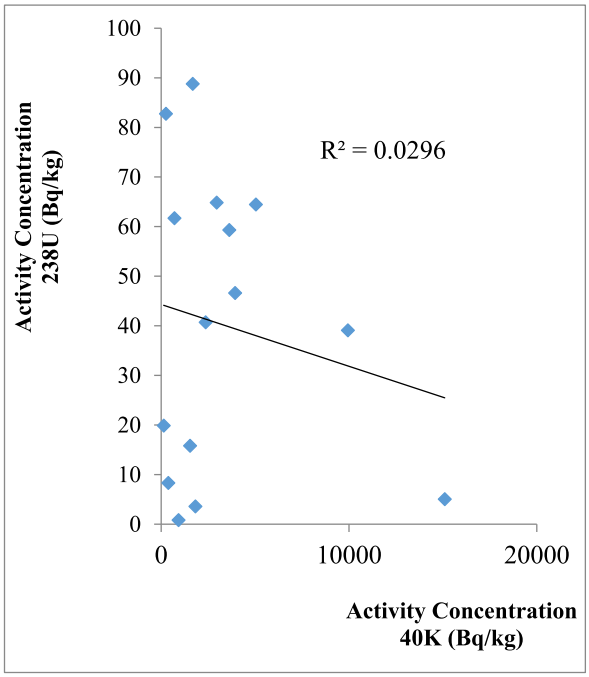

Fig. 21. Correlation between ^{238}U and ^{40}K.

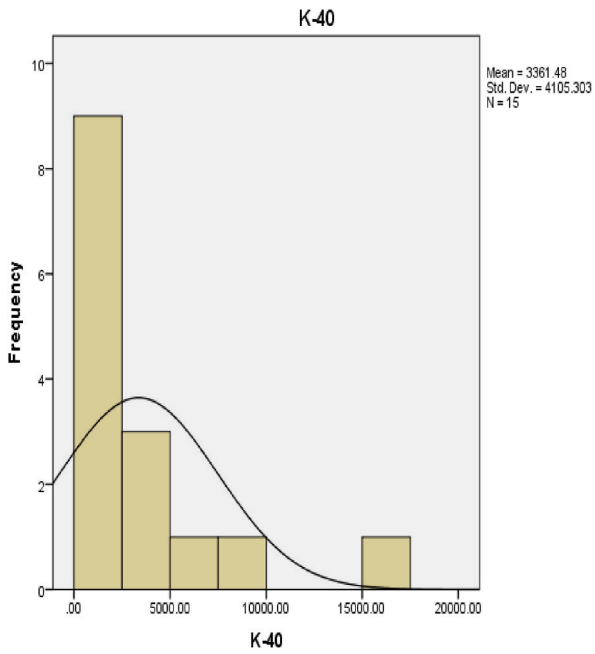

Fig. 22. The frequency distribution of ^{40}K.

$nGyh^{-1}$, 2.1556$mSvyr^{-1}$, 0.8625$mSvyr^{-1}$ and 7.5447$mSvyr^{-1}$ respectively. The study concludes that sediments from the coastline of the study area are radiologically not safe for use as building material. Therefore, there is need for proper management of hydrocarbon waste in the coastal area. The obtained results will contribute to the environmental radioactivity database of the Niger Delta region of Nigeria.

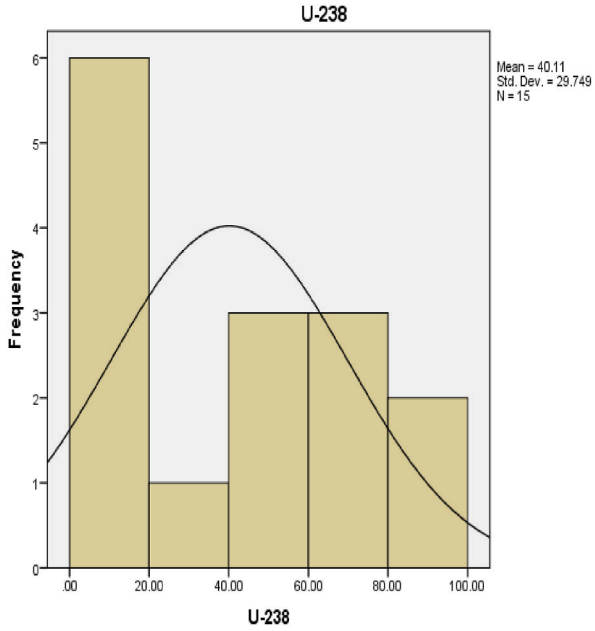

Fig. 23. The frequency distribution of ^{238}U.

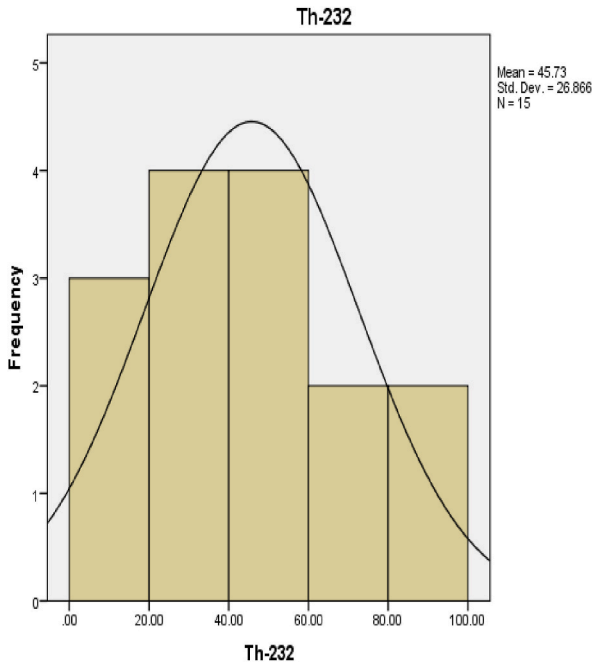

Fig. 24. The frequency distribution of ^{232}Th.

Data availability statement

Further details of the article would be made available on specified and relevant request from corresponding author.

Declaration

Data generated from the study originated solely from authors during our experimental assessment and have not been submitted for publication to any other journal or publishing house for the purpose of publication.

CRediT authorship contribution statement

Oghenevovwero E. Esi: Writing – original draft, Methodology, Formal analysis, Conceptualization. **Gregory O. Avwiri:** Writing – original draft, Methodology, Formal analysis. **Onjefu A. Sylvanus:** Writing – review & editing, Formal analysis. **Damian C. Onwudiwe:** Writing – review & editing, Formal analysis.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The corresponding author is an Associate Editor for Heliyon Materials.

References

[1] M.M. Orosun, T.B. Ajibola, F.C. Akinyose, O. Osanyinlusi, O.D. Afolayan, M.O. Mahmud, Assessment of ambient gamma radiation dose and annual effective dose associated with radon in drinking water from gold and lead mining area of Moro, North-Central Nigeria, J. Radioanal. Nucl. Chem. 328 (2021) 129–136.

[2] A.A. Essiett, I.E. Essien, M.C. Bede, Measurement of surface dose rate of nuclear radiation in coastal areas of AkwaIbom State, Nigeria, Int. J. Phys. 3 (2015) 224–229.

[3] H. Taskin, M. Karavus, P. Ay, A. Topuzoglu, Hindiroglu, G. Karajan, Radionuclide concentrations in soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli, Turkey, J. Environ. Radioact. 100 (2009) 49–53.

[4] R. Ravisankar, J. Chandramohan, A. Chandrasekaran, J. Prince Prakash Jebakumar, I. Vijayalakshmi, P. Vijayagopal, B. Venkatraman, Assessments of radioactivity concentration of natural radionuclides and radiological hazard indices in sediment samples from the East coast of Tamilnadu, India with statistical approach, Mar. Pollut. Bull. 97 (2015) 419–430.

[5] R. Ravisankar, S. Sivakumar, A. Chandrasekaran, J Prince Prakash Jebakumar, I. Vijayalakshmi, P. Vijayagopal, B. Venkatraman, Spatial distribution of gamma radioactivity levels and radiological hazard indices in the East coastal sediments of Tamilnadu, India with statistical approach, Radiat. Phys. Chem. 103 (2014) 89–98.

[6] Akpan E. Anthony, Ebong D. Ebong, Stephen E. Ekwok, Joseph O. Eyo, Assessment of radionuclide distribution and associated radiological hazards for soils and beach sediments of Akwa Ibom Coastline, southern Nigeria, Arabian J. Geosci. 13 (2020) 753, https://doi.org/10.1007/s12517-020-05727-7.

[7] E.O. Agbalagba, R.A. Onoja, Evaluation of natural radioactivity in soil, sediment and water samples of Niger Delta (Biseni) flood plain lakes, Nigeria, J. Environ. Radioact. 102 (2011) 67–71.

[8] S.A.M. Issa, S.M. Alaseri, Determination of natural radioactivity and associated radiological risk in building materials used in Tabuk Area, Saudi Arabia, Int J Adv Sci Technol 82 (2015) 45–62.

[9] S.O. Oluyide, P. Tchokossa, M.M. Orosun, F.C. Akinyose, H. Louis, S.O. Ige, Natural radioactivity and radiological impact assessment of soil, food and water around iron and steel smelting area in Fashina Village, Ile-Ife, Osun State, Nigeria, J. Appl. Sci. Environ. Manag. 23 (1) (2019) 135–143.

[10] S.A. Onjefu, C. Kamunda, J. Abah, Health risk assessment of natural radioactivity in wasteland soils in Okakarara, Namibia, Arab J. Nuclear Sci. Appl. 54 (2) (2021) 143–150.

[11] Sylvanus Ameh Onjefu, Aina Nancy Iyaloo Kauluma, Munyaradzi Zivuku, Emmanuel Ejembi, Roswita Hambeleleni Hamunyela, Bismark Mzubanzi Tyobek, Assessment of radioactivity levels in shore sediments along the coastline of the Orange River, Oranjemund, Namibia, Heliyon 8 (2022) e10579.

[12] D. Porcelli, M. Baskaran, An overview of isotope geochemistry in environmental studies, in: M. Baskaran (Ed.), Handbook of Environmental Isotope Geochemistry, Springer, Heidelberg, 2011, pp. 11–33.

[13] A. Binesh, S. Mohammadi, A.A. Mowlavi, P. Parvaresh, Evaluation of the radiation dose from radon ingestion and inhalation in drinking water, Int. J. Water Resour. Environ. Eng. 2 (7) (2010) 174–178.

[14] P.P. Povinec, K. Hirose, Fukushima radionuclides in the NW Pacific, and assessment of doses for Japanese and world population from ingestion of seafood, Sci. Rep. 5 (2015) 9016.

[15] Y. Raghu, N. Harikrishnan, A. Chandrasekaran, R. Ravisankar, Assessment of natural radioactivity and associated radiation hazards in some building materials used in Kilpenathur, Tiruvannamalai District, Tamilnadu, India, Afr. J. Basic Appl. Sci. 7 (1) (2015) 16–25.

[16] O. Agbalagba Ezekiel, E. Esi Oghenevovwero, Occupational and public risk assessment of NORMs in soil of the Niger Delta region of Nigeria after six decades of hydrocarbon exploitation, Arabian J. Geosci. (2023), https://doi.org/10.1007/s12517-022-11151-w.

[17] UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionizing Radiation: Sources (Report Volume I), United Nations Publications, 2013.

[18] C. Busby, Aspects of DNA damage from internal radionuclides, in: New Research Directions in DNA Repair, IntechOpen, 2013.

[19] F.B. Masok, P.L. Masiteng, R.D. Mavunda, P.P. Maleka, H. Winkler, Measurement of radioactivity concentration in soil samples around phosphate rock storage facility in Richards Bay, South Africa, J. Radiat. Res. Appl. Sci. 11 (2018) 29–36.

[20] E. Chad-Umoren Yehuwdah, Margaret A. Briggs-Kamara, Environmental ionizing radiation DistributionIn rivers state, Nigeria, J. Environ. Eng. Landsc. Manag. 18 (2) (2010) 154–161.

[21] P. Kessaratikoon, R. Boonkrongcheep, S. Benjakul, S. Youngchauy, Specific activities and radioactive contour maps of natural and anthropogenic radionuclides in beach sand samples (Patong, Kamala, Kata, Karon and Nai Yang) after tsunami disaster in Phuket Province Thailand, J. Radioanal. Nucl. Chem. 297 (2013) 247–255, https://doi.org/10.1007/s10967-012-2384-8.

[22] Sivakumara, A. Chandrasekaran, R. Ravisankar, S.M. Ravikumar, J. Prince Prakash Jebakumar, P. Vijayagopal, I. Vijayalakshmi, M.T. Jose, Measurement of natural radioactivity and evaluation of radiation hazards in coastal sediments of east coast of Tamilnadu using statistical approach, J. Taibah Univ. Sci. 8 (2014) 375–384.

[23] R. Ravisankar, A. Chandrasekaran, P. Eswaran, A. Rajalakashmi, P. Vijayagopal, N. Meenakshisundaram, Natural radioactivity measurement in riverbed samples in and around Manaloorpet Riverbed Area Tamilnadu India, Int. J. Sci. Technol. 1 (1) (2017) 38–42, https://doi.org/10.4103/rpe.RPE_65_16.

[24] D.O. Jegede, I.A. Gbadamosi, O.O. Banjoko, J.A. Adeyoye, M.R. Gbadamosi, A.L. Ogunneye, T.E. Bakare, O.J. Oyewola, Radiometric and Spatial distribution of natural radionuclides concentrations and excessive lifetime cancer risks in sediments from selected rivers in Ilobi and Erinja communities, Southwest, Nigeria, Niger. Res. J. Chem. Sci. 6 (2019) 58–78.

[25] Omeje Maxwell, O. Adewoyin Olusegun, S. Joel Emmanuel, B. Ikechukwu Ijeh, A. Omeje Uchechukwu, Ayanbisi Oluwasegun, E. Iyanuoluwa Ogunrinola, M. Timothy Terhile Angbiandoo, A. Oha Ifeany, Mohammad Alam Saeed, Spatial distribution of gamma radiation dose rates from natural radionuclides and its radiological hazards in sediments along river Iju, Ogun state Nigeria, MethodsX 7 (2020) 101086.

[26] G.O. Avwiri, J.M. Egieya, C.P. Ononugbo, Radiometric assay of hazard indices and excess lifetime cancer risk due to natural radioactivity in soil profile in ogba/egbema/ndoni local government area of rivers state, Nigeria, Acad. Res. Int. 4 (2013) 54–65.

[27] Katherine Temitope Ogundele, Emmanuel Ayodele Oluyemi, John Adekunle Oyedele Oyekun, Oladotun Wasiu Makinde, Sejlo Temidayo Gbenu, An evaluation of health hazards indices of natural radioactivity of the sediments from eko-ende dam, osun state, Nigeria, Open J. Ecol. 8 (2018) 607–621.

[28] C.P. Ononugbo, G.O. Avwiri, C.A. Ogan, Natural radioactivity measurement and evaluation of radiological hazards in sediment of imo river, in rivers state, Nigeria by gamma ray spectrometry, IOSR J. Appl. Phys. 8 (3) (2016) 75–83.

[29] Qureshi Aziz Ahmed, Tariq Shahina, Din Kamal Ud, Manzoor Shahid, Calligaris Chiara, Abdul Waheed, Evaluation of excessive lifetime cancer risk due to natural radioactivity in the rivers sediments of Northern Pakistan, J. Radiat. Res. Appl. Sci. 7 (2014) 438–447.

[30] Dizman Serdar, Tolga Akdemir, Cafer Mert Yeşilkanat, Vagif Nevruzoglu, Esra Bal, Recep Keser, Radiometric mapping and radiation dose assessments in sedimentsfrom Şavşat Black Lake, Turkey, J. Radioanal. Nucl. Chem. 331 (2022) 2533–2544, 2022.
[31] M. Tholkappian, ChandrasekaranA, Durai Ganesh, J. Chandramohan, N. Harikrishnan, R. Ravisankar, Determination of radioactivity levels and radiation hazards in coastal sediment samples of Chennai coast, tamilnadu, India using gamma ray spectrometry with statistical approach, J. Rad. Nucl. Appl. 3 (No. 3) (2018) 171–182.
[32] V. Ramasamy, G. Suresh, V. Meenakshisundaram, V. Gajendran, Evaluation of natural radionuclide content in river sediments and ExcessLifetime cancer risk due to gamma radioactivity, Res. J. Environ. Earth Sci. 1 (1) (2009) 6–10.
[33] M.M. Orosun, M.R. Usikalu, K.J. Oyewumi, A.T. Adagunodo, Natural Radionuclides and radiological risk assessment of granite mining field in Asa, North-central Nigeria, MethodsX 6 (2019) 2504–2514.
[34] M.M. Orosun, M.R. Usikalu, K.J. Oyewumi, J.A. Achuka, Radioactivity levels and transfer factor for granite mining field in Asa, North-central Nigeria, Heliyon (2020) e04240.
[35] M.M. Orosun, M.R. Usikalu, K.J. Oyewumi, Radiological hazards assessment of laterite mining field in Ilorin, North -central Nigeria, Int. J. Radiat. Res. 18 (4) (2020) 895–906.
[36] UNDP, Niger Delta Human Development Report UNDP Abuja, 2006.
[37] M.D. Murad Ahmed, Sariful Suranjan Kumar Das, Selina Yeasmin, Natural radioactivity and dose assessment in sand andSediment samples from kuakata beach, Bangladesh, J. Bangladesh Acad. Sci. 40 (1) (2016) 45–55.
[38] UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionizing Radiation: Sources, vol. 1, United Nations Publications, 2000.
[39] R.T. Newman, R. Lindsay, K.P. Maphoto, N.A. Mlwilo, A.K. Mohanty, D.G. Roux, R.J. de Meijer, I.N. Hlatshwayo, Determination of soil, sand and ore primordial radionuclide concentrations by fullspectrum analyses of high-purity germanium detector spectra, Appl. Radiat. Isot. 66 (6–7) (2008) 855–859.
[40] S.İ.R.İ.N. Murat, Evaluation of radioactive pollution in sediment samples of Borçka Dam Lake, Turkey, Cumhuriyet Sci. J. 40–3 (2019) (2019) 624–639.
[41] A. Al-Mur Bandar, Gad Ahmed, Radiation hazard from natural radioactivity in the marine sediment of Jeddah Coast, Red Sea, Saudi Arabia, J. Mar. Sci. Eng. 10 (2022) 1145, https://doi.org/10.3390/jmse10081145.
[42] D.I.P. Putra, W.R. Prihatiningsih, M. Makmur, M.N. Yahya, Y. Priasetyono, Untara, Distribution of some natural and anthropogenic radionuclides in the sediments and seawater along the coastal areas of North Sulawesi, 2nd International Conference on Fisheries and Marine IOP Conf. Series: Earth and Environmental Science 890 (2021) 012005, https://doi.org/10.1088/1755-1315/890/1/012005.
[43] Ayman A. El-Gamal, Ibrahim H. Saleh, Radiological and mineralogical investigation of accretion and erosion coastal sediments in Nile Delta Region, Egypt, J. Oceanogr. Mar. Sci. 3 (3) (2012) 41–55.
[44] M.I. Chowdhury, M.N. Alam, S.K.S. Hazari, Distribution of radionuclides in the river sediments and coastal soils of chittagong, Bangladesh and evalution of the radiation hazard, Appl. Radiat. Isot. 51 (1999) 747–755.
[45] I. Beretka, P.I. Mathew, Natural radioactivity of Australian building materials, waste and byproducts, Health Phys. 48 (1985) 87–95.
[46] M. AlamMN, M.I. Chowdhury, M. Kamal, S. Ghose, M. IslamMN, M.S.R. Miah, Radiation dose stimation from the radioactivity analysis of lime and cement used Bangladesh, J. Environ. Radioact. 42 (1999) 77–85.
[47] A.G.E. Abbady, Estimation of radiation hazard indices from sedimentary rocks in upper Egypt, Appl. Radiat. Isot. 60 (2004) 111–114.
[48] NEA-OECD, Exposure to Radiation from Natural Radioactivity in Building Materials, Report by NEA Group of Experts of the Nuclear Energy Agency. OECD, Paris, France, 1979.
[49] S. Murugesan, S. Ravichandran, Radioactive heat production rate and excess lifetime cancer risk of sand from two major rivers in India – a comparative study, Int. J. Radiat. Res. 21 (1) (2023), 187- 124.
[50] H.A. Al-Trabulsy, A.E.M. Khater, F.I. Habbani, Radioactivity level sand radiological hazard indices at the Saudi coastline of the Gulf of Aqaba, Radiat. Phys. Chem. 80 (2011) 343–348.
[51] N.N. Jibiri, I.C. Okeyode, Evaluation of radiological hazards in the sediments of Ogun river, South-Western Nigeria, Radiat. Phys. Chem. 81 (2012) 103–112.
[52] M. SureshGandhi, R. Ravisankar, A. Rajalakshmi, S. Sivakumar, A. Chandrasekaran, D.P. Anand, Measurements of natural gamma radiation in beach sediments of north east coast of Tamilnadu, India by gamma ray spectrometry with multivariate statistical approach, J. Radiat. Res. Appl. Sci. 7 (2014) 7–17.
[53] I.F. Al-Hamarneh, M.I. Awadallah, Soil radioactivity levels and radiation hazard assessment in the highlands of northern Jordan, Radiat. Meas. 44 (2009) 102–110.
[54] R.L. Njinga, V.M. Tshivhase, Lifetime cancer risk due to gamma radioactivity in soils from Tudor Shaft mine environs, South Africa, J. Radiat. Res. Appl. Sci. 9 (3) (2016) 310–315, https://doi.org/10.1016/j.jrras.2016.02.003.
[55] L. Xinwei, Natural radioactivity in some building materials of Xi'an, China, Radiat. Meas. 40 (2005) 94–97.
[56] M. Iqbal, M. Tufail, M. Mirza, Measurement of natural radioactivity in marble found in Pakistan using a NaI(Tl) gamma-ray spectrometer, J. Environ. Radioact. 51 (2000) 255–265.
[57] R. Ravisankar, A. Chandrasekaran, P. Vijayagopal, B. Venkatraman, G. Senthilkumar, P. Eswaran, A. Rajalakshmi, Natural radioactivity in soil samples of Yelagiri Hills, TamilNadu, India and the associated radiation hazards, Radiat. Phys. Chem. 81 (2012) 1789–1795.
[58] Mahmoud A. Dar, Mohamed A. Uosif, Lamia I. Mohamedein, Amany G. Madkour, Hesham M.H. Zakaly, Radiation hazards and the cancer risk assessments in the sediments of timsah lake, Egypt, JKAU: Mar. Sci. 30 (1) (2020) 1–16.
[59] Jegede Oluwaseyi, Suraju Kasali, Kolo Tikpangi Matthew, Evaluation of natural radioactivity and radiological HealthImplications of oniru beach lagos, south-western, Nigeria, IOSR J. Environ. Sci. Toxicol. Food Technol. 11 (10) (2017) 65–74.
[60] Who, Guideline for Drinking Water Quality. Radiation Quality of Drinking, World Health Organization, Geneva, Switzerland, 2004.
[61] L.I. Nwankwo, O.O. Olubo, Assessment of terrestrial 40k, 238u and 232th activities in soil within the basement complex terrain of west central part of Nigeria, Zimbabwe J. Sci. Technol. 11 (2016) 1–11.
[62] A. Chandrasekaran, R. Ravisankar, N. Harikrishnan, K. Satapathy, M. Prasad, K. Kanagasabapathy, Multivariate statistical analysis of heavy metal concentration in soils of Yelagiri Hills, Tamilnadu, India–Spectroscopical approach, Spectrochim. Acta Mol. Biomol. Spectrosc. 137 (2015) 589–600.
[63] M.H. Mamoney, El Ashraf, E.M. Khater, Environmental characterization and radioecological impacts of non-nuclear industries on the Red Sea coast, J. Environ. Radioact. 73 (2004) 151–168.
[64] I. Tanasković, D. Golobocanin, N. Miljević, Multivariate statistical analysis of hydrochemical and radiological data of Serbian spa waters, J. Geochem. Explor. 112 (2012) 226–234.