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Natural Radioactivity Measurement and Evaluation of Radiological Hazards in Sediment of Imo River, In Rivers State, Nigeria by Gamma Ray Spectrometry

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Abstract: *The distribution of natural gamma ray emitting ^{238}U, ^{232}Th and ^{40}K radionuclides in River sediments along Imo river in Rivers State, Nigeria has been carried out using NaI (TI) gamma ray spectrometric technique. The mean activity concentration of radionuclides ^{238}U, ^{232}Th and ^{40}K were 187.12 Bq kg $^{-1}$, 38.62 Bq kg $^{-1}$ and 180.59 Bq kg $^{-1}$ respectively. Correlations made among these radionuclides prove the existence of secular equilibrium in the studied sediments. The total average absorbed dose rate in this study is 113.58 ± 7.62 nGyh^{-1}, whereas the annual effective dose rate (outdoor and indoor) are 139.29 µSvy^{-1} and 557.16 µSvy^{-1}The mean activity concentrations of measured radionuclides were compared with other literature values. The ratios between the detected radioisotopes have been calculated for spatial distribution of natural radionuclides in the studied area. . Also the radiological hazard of the natural radionuclide content, radium equivalent Raeq, radiation hazard indices (H_{ex}, H_{in}), gamma radiation representative level, annual gonadal equivalent dose and excess lifetime cancer risk of the sediment samples were calculated. Multivariante statistical analysis (pearson correlation, cluster and factor analysis) were carried out between the parameters obtained from radioactivity to know the existing relations.*

Keywords: *Sediments, radiological hazards, gamma ray spectrometry, gonald Radioactivity*.

I. Introduction

Natural radionuclide has been the components of earth since its existence. Living organisms are continuously exposed to a wide range of ionizing radiations from naturally occurring radioactive materials (NORMs) and radionuclides generated from human activities known as artificial radionuclides (El Samad et al., 2013, Isinkaye and Emelue, 2015). Soil and rocks are the major source of radiation exposure to the population and also a means of radionuclide migration into the environment (Felix et al., 2015).

Sediments are a major source of radiation exposure to aquatic biota, and it acts as a medium of migration for the transfer of radionuclides in the aquatic environment. The sediment deposited at the bottom of rivers, most frequently consist of sand and gravel of different grain sizes, which are very valuable for building constructions (Isinkaye and Emelue, 2015). River sediments are used extensively as major building materials, in construction of residential and office complexes in Nigeria. Studies have shown that internal radiation exposure is due to radiations from building materials, hence, the needs to determine the activity concentrations of natural radionuclides in sediments samples in order to accurately assess the radiological health implications to the members of the public.

Among the various geological formations, sediments play a very important part in the accumulation and transportation of contaminants within the geographic area. It is the basic indicator of radiological contamination in the environment (SureshGandhi *et al*, 2013). River sediments may be regarded as a temporary sink of many materials which pass through acquatic, 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 (El – Taher *et al*, 2012) or from natural sources like weathering and recycling of terrestrial minerals and rocks and also by anthropogenic activities. Natural radioactivity in the soil comes from uranium and thorium series and natural potassium. The study of the distribution of primordial radionuclide allows the understanding of the radiological implication of these elements due to the gamma ray exposure of the body and radiation of lung tissue from inhalation of radon and its daughters (Usoif *et al*., 2008).

The contribution of radiation from sediment to human exposure can either be whole body due to external radiation originating directly from primordial radionuclides present in sediment or internal due to inhalation of radon (Isinkaye and Emelue, 2015, Jibril and Okeyode, 2012, Ngachin *et al.,* 2007). The internal exposure to radiation, affecting the respiratory track, is due mainly to radon and its decay products which emanate from soil, sediment and building materials (Hameed *et al*., 2014). ^{222}Rn results from radioactivity of 238U and itself decays with a half life of 3.82 days (Felix et al., 2015). Long-term exposures to radioactivity and

inhalation of radionuclides have serious health effects such as chronic lung cancer and leukemia (Qureshi *et al*., 2014). Radiological studies on sediments and water in Nigeria especially in the Niger Delta region has been carried out because of the activities of oil exploration and exploitation industries. The result showed an increase in background radiation of some areas which include Akoko, Southwestern Nigeria (Ajayi 2008), Ogbomosho land, south water Nigeria (Ajayi *et al*, 2012), Aluu, Rivers State Nigeria (Avwiri *et al*, 2014), Imo state, Oguta lake (Isinkaye and Emelue, 2015). In the last two decades, the Niger Delta area has been exposed to intense hydrocarbon exploration and exploitation and the attendant contamination of the environment.

The objective of this study is to determine the natural radioactivity of river sediment and evaluate their radiological health risk to the populace associated with the use of sediments from Imo River as building material. The result obtained from this study will serve as radioactivity database for the area and will also be relevant in the radiological mapping of the area.

II. Materials and Methods

2.1 Study Area

The study area is located in the northern part of Rivers State. The present study area is the boundary between Abia state and Rivers State in the Niger Delta region. It lies between longitude $007^{o}\ 08^{1}\ 11.9^{11}$ and $007^{o}\ 11^{1}\ 35.5^{11}$ East of Greenwich meridian and latitudes $04^{o}\ 54^{1}\ 11.9^{11}$ and $04^{o}\ 51^{1}\ 37.8^{11}$ North of equator. This area is located in the tropical rain forest and the climate is tropical with sharp two seasons – the dry season and wet season. The sample location were recorded in terms of degree - minute and second (latitudinal and longitudinal position) using hand held Global Positioning System (GPS). Each location is separated by a flying boat ride of approximately 4 minutes.

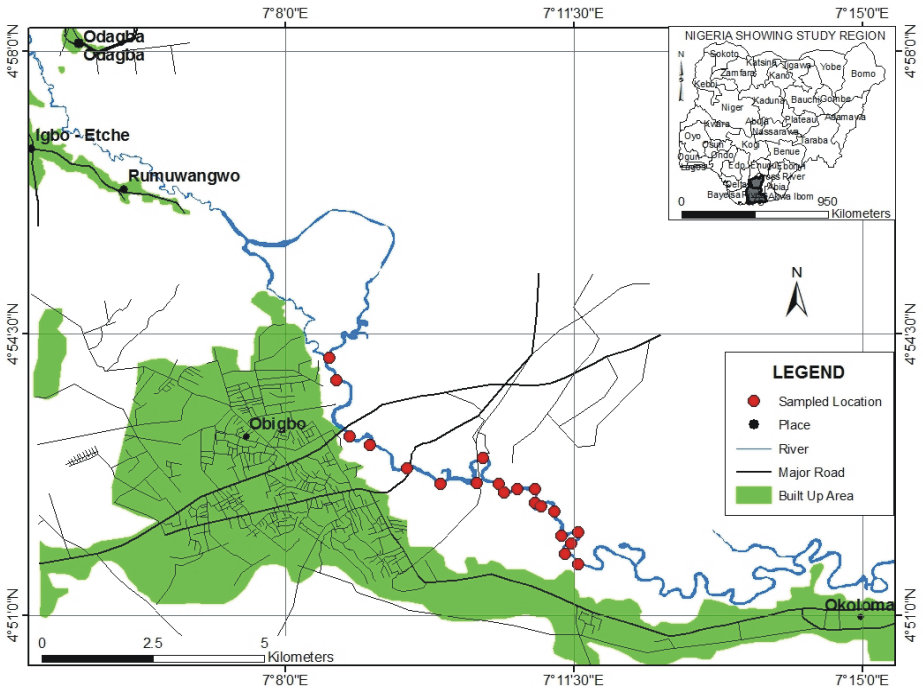


Fig. 1: Map showing sampling points and industrial study areas

2.2 Sample Collection and Preparation

Twenty sediment samples were collected randomly from various locations along the river bank. Samples were collected with the help of local fishermen using their fishing boat to transverse the whole length of the river. Surface sediments were collected from the depth of 0-5 cm at the floor of the river (Isinkaye and Emelue, 2015; Jibiri and Okeyode, 2012). 3kg of Sediment samples collected were placed in black nylon bags and properly labeled at the point of collection. The collected samples were transported to the National Institute of Radiation Protection and Research, University of Ibadan.

In sediment samples large stones and other objects were removed, then were oven dried at a temperature of 100 – 105^{o}c for 24 hours to a constant mass, then sieved through mesh 500 µm. All sediment samples were weighed and sealed in Marinelli containers (Mohsen *et al*., 2008). The samples were sealed hermitically and externally using cellophane tape and kept for about four weeks to reach secular equilibrium

where the rate of decay of ^{226}Ra becomes equal to that of their daughters before it is taken for gamma ray spectrometric analysis (SureshGandhi *et al.*, 2013).

2.3 Gamma Spectroscopy

All samples were subjected to gamma spectral analysis with a counting time of 10hrs (i.e. 36000 secs). An 8.5cm x 6.5cm NaI (Ti) detector model 802 was used and the detector was shielded in a 10cm thick and cylindrical in shape Canberra leads to reduce gamma ray background. The concentration of the various radionuclide of interest were determined in Bq kg^{-1} for sediment samples for the identification of the various radionuclide that may be present in the samples through gamma energies they emit, the system have to be efficiency collaborated using a set of International Atomic Energy Agency standard source of known radionuclide with well defined energies within the range of interest (0.511 – 2.615 Mev) (Ajibode et al., 2013, Ravisankar et al.,2014).

The samples were analyzed at National Institute of Radiation Protection and Research centre (NIRPR), University of Ibadan. Gamma Ray Spectrometry using a thallium activated 3"x3" Sodium iodide [NaI(TI)] detector connected to ORTEC 456 amplifier. The detector, enclosed in a 100mm thick lead shield, was connected to a computer program SAMPO 90 window that matched gamma energies to a library of possible isotopes. Since the accuracy of the quantitative measurements is depended on the calibration of the spectrometry system and adequate energy. Background measurement and efficiency calibration of the system was made possible using Cs-137 and Co-60 standard sources from IAEA, Vienna. Spectrum were accumulated for background for 29000s at 900volts to produce strong peaks at gamma emitting energies of 1460keV for ^{40}K; 609keV of 214Bi and 911keV of 228Ac, which were used to estimate the concentration of ^{238}U and ^{232}Th, respectively (Avwiri *et al*., 2015, Issa and Mustafa, 2015). The energy resolution of the detector using Cs-137 and Co-60 standards is 39.5% and 22.2% respectively while the activity of the standards at the time of calibration is 25.37KBq for Cs-137 and 4.84KBq for Co- 60. The background spectra, measured under the same conditions for both the standard and sample measurements, were used to correct the calculated sample activities concentration in accordance with Arogunjo *et al.*, (2005). The activity concentration (C) in Bq/kg of the radionuclides in the samples was calculated after subtracting decay correction using the expression (Tariq et al., 2006):

$$Cs = N_{Ey} \times \varepsilon E_{\gamma} / M_v \text{ x } t_c \text{ x } P_{\gamma} \text{ (Bq/kg)} \quad \text{----------} \quad (1)$$

Where Cs= Sample concentration, NEy= net peak area of a peak at energy, εEy= Efficiency of the detector for a γ-energy of interest, Mv = Sample volume, tc= total counting time, Pγ=Emission probability of radionuclide of interest.

III. Results and Discussion

The result of activity concentration of ^{40}K , ^{238}U and ^{232}Th with their radium equivalent values in the sediment are presented in Table 1. The associated radiation hazard parameters calculated are shown in Table 2.

Table 1: Specific activity of ^{226}Ra, ^{232}Th and ^{40}K and radium equivalent activity (Bq/kg) in sediment samples from Imo river environment of Rivers state.

SAMPLE ID	LOCATION DESCRIPTION	ACTIVITY CONCENTRATION Bq/kg(±SD)			Ra_{eq}
		^{40}K	^{228}U	^{232}Th	
SED1	NNPC- ALSCON PIPE	179.72±11.82	218.77±45.65	46.50±4.46	299.10
SED 2	OTAMIRI -RIVER	142.35±9.36	121.85±26.78	6.06±0.66	141.48
SED 3	OBIGBO BRIDGE	231.41±14.43	278.41±59.67	61.14±5.65	383.66
SED 4	**MAMA TOWN (OBIGBO)**	**212.76±13.33**	**158.90±35.20**	**46.33±4.38**	**241.53**
SED 5	OLD IMO RIVER BRIDGE	195.30±12.78	325.0±67.07	53.80±4.50	416.97
SED 6	IMO RIVER VILLAGE	178.87±11.42	213.64±44.83	23.79±2.44	261.43
SED 7	VILLAGE (BUNKERING	97.62±7.02	85.27±20.06	27.50±2.75	132.11
SED8	IMO RIVER RAILWAY	278.37±17.36	252.78±53.78	58.04±5.43	357.21
SED 9	NNPC PIPELINE CROSS	117.76±8.31	109.73±26.16	30.46±3.12	162.36
SED 10	IMO RIVER	108.92±7.94	106.00±24.94	41.99±3.94	174.43
SED 11	IMO RIVER DIVISION 1	47.53±3.37	108.57±23.80	30.46±2.87	155.79
SED 12	IMO RIVER DIVISION 3	198.38±12.98	123.24±28.80	42.09±3.97	198.70
SED 13	IMO RIVER DIVISION 5	233.64±14.40	178.93±38.74	30.98±3.10	241.22
SED 14	IMO RIVER DIVISION 7	121.47±8.34	116.72±25.66	39.00±3.69	181.84
SED 15	IMO RIVER BANKS 1	213.44±13.15	105.54±23.62	35.18±3.45	172.28
SED 16	IMO RIVER BANKS 2	207.45±13.80	199.66±45.25	35.56±3.45	266.48
SED 17	IMO RIVER BANKS 3	273.75±16.98	260.47±54.86	43.68±4.16	344.01
SED 18	IMO RIVER BANKS 4	256.12±15.69	331.06±67.83	37.87±3.68	404.94
SED 19	IMO RIVER BANKS 5	200.37±12.74	220.40±47.20	46.30±4.34	302.04
SED 20	MMIRI-NWAYI (IMO RIVER DIVISION 14)	116.50±8.02	227.39±47.09	35.60±3.47	287.27

MEAN	**180.59±15.04**	**187.12±54.82**	**38.62±4.82**	**256.24**

Table 2: Radiation hazard indices of sediment samples from Imo river of Rivers State.

S/N	SAMPLE ID	D ($nGyh^{-1}$)	I_γ ($Bqkg^{-1}$)	AGED ($mSvyr^{-1}$)	AEDE ($\mu Svyr^{-1}$)		ELCR x 10^{-3}	HAZARD INDEX	
					Outdoor	Indoor		H_{ex}	H_{in}
1	SED1	132.36±4.31	1.76	926.8	162.34	649.35	0.568	0.81	1.40
2	SED 2	62.29±11.77	0.93	446.55	76.39	305.56	0.267	0.38	0.71
3	SED 3	169.88±12.9	2.25	1188.51	208.34	833.35	0.729	1.04	1.79
4	SED 4	107.96±1.29	1.38	751.47	132.40	529.61	0.463	0.65	1.08
5	SED 5	183.46±16.0	2.5	1290.46	224.99	899.97	0.787	1.13	2.01
6	SED 6	115.01±0.33	1.64	815.75	141.05	564.18	0.494	0.71	1.28
7	SED 7	58.99±12.51	0.74	409.09	72.35	289.41	0.253	0.36	0.59
8	SED8	158.79±10.3	2.09	1111.11	194.74	778.95	0.681	0.97	1.65
9	SED 9	72.306±9.47	0.93	503.37	88.68	354.71	0.310	0.44	0.74
10	SED 10	78.01±8.16	0.94	537.26	95.68	382.71	0.334	0.47	0.76
11	SED 11	68.86±10.26	0.87	477.73	84.45	337.80	0.295	0.42	0.71
12	SED 12	89.23±5.58	1.12	619.04	109.44	437.75	0.383	0.54	0.87
13	SED 13	107.21±1.46	1.47	755.75	131.48	525.91	0.460	0.65	1.14
14	SED 14	81.15±7.44	1.01	561.83	99.52	398.08	0.348	0.49	0.81
15	SED 15	77.67±8.24	0.98	540.19	95.26	381.02	0.333	0.47	0.75
16	SED 16	118.05±1.03	1.61	830.73	144.78	579.11	0.506	0.72	1.26
17	SED 17	152.33±8.89	2.09	1073.39	186.82	747.27	0.653	0.93	1.63
18	SED 18	178±14.78	2.52	1261.69	218.30	873.21	0.764	1.09	1.99
19	SED 19	133.8±4.64	1.78	937.49	164.10	656.38	0.574	0.82	1.41
20	SED 20	126.15±2.89	1.73	888.02	154.71	618.86	0.541	0.78	1.39
MEAN		**113.58±7.62**	**1.52**	**796.31**	**139.29**	**557.16**	**0.487**	**0.69**	**1.20**

D = Absorbed dose ($nGyh^{-1}$), 1γ = Gamma Index ($BqKg^{-1}$), AGED = Annual Gonadal Equivalent dose ($mSvyr^{-1}$)

AEDE = Annual Effective dose Equivalents ($mSvyr^{-1}$), ELCR = Excess Lifetime Cancer risk

H_{in} and H_{ex} = Internal and External hazard Index

3.1 Specific Activity concentration of ^{238}U, ^{232}Th and ^{40}K in the sediments.

The activity concentration of ^{238}U, ^{232}Th and ^{40}K in the sediments samples are determined and shown in Table 1. The mean activities concentration ranges for ^{238}U, ^{232}Th and ^{40}K are 85.27 ±20.06 to 331.06 ±67.83 $Bqkg^{-1}$ with mean value of 187.12 ±54.82 $Bqkg^{-1}$, 6.06 ±0.66 to 61.14 ± 5.65 $Bqkg^{-1}$ with mean value of 38.62 ± 4.82 $Bqkg^{-1}$, and 47.53± 3.37 to 278.37±17.36 $Bqkg^{-1}$ with mean value of 180.59 Bq kg^{-1} respectively. The activity concentration of ^{238}U, ^{232}Th and ^{40}K in river sediment vary from site to site because bottom of a river can exhibit large variation in chemical and mineralogical properties (Krmar et al., 2009). In all the sampling points, mean activity concentration of the natural radionuclide is of the order $^{232}Th < {}^{238}U < 40K$. In SED 18 and SED 5, the activity concentration of ^{238}U is very high which may be due to the solubility and mobility of $U(VI)O_2$ and drift from the oil bunker site. The increasing concentration of ^{232}Th and ^{40}K may be due to the high content of monazite (Ramasamy et al., 2009). The increasing trend of ^{40}K is due to the presence of sandy and clay sediments.

The activity concentration of ^{238}U for all measured samples is higher than the world average value of 35.0 $Bqkg^{-1}$ while the mean activity concentration of ^{232}Th and ^{40}K are within their world values of 30.0 $Bqkg^{-1}$and 400.0 $Bqkg^{-1}$ respectively. However in some sampling points, concentration of^{232}Th is higher than the world average value which indicates areas with monazite deposit. The host community (Mama Town) samples (SED 4) recorded higher activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the sediment sample. Table 3 compares the activity concentration of ^{238}U, ^{232}Th and ^{40}K in river sediment of Imo River Rivers State, Nigeria and other studies in different parts of the world.

3.2 Dose Calculations

3.2.1 Radium Equivalent Activity (Raeq)

The radium equivalent activity index (UNSCEAR, 2000) (Raeq) was calculated according to Equation

$$Raeq = A_U + 1.43A_{Th} + 0.0777A_K \quad \text{----------} \quad (2)$$

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

The radium activity concept allows a single index or number to account for the radiation hazards associated with the mixture of uranium, thorium and potassium in sediment samples in different locations (SureshGandhi *et al*., 2013). It has been assumed in this equation that 10 Bq kg^{-1} of ^{238}U, 7 Bq kg^{-1} of ^{232}Th and

130 Bq kg^{-1} of ^{40}K produce equal gamma doses (UNSCEAR, 2000). Raeq is related to external gamma dose and internal dose due to radon and its daughters. From Table1, the Raeq values for the sediment samples varied from 141.48 to 416.97 Bq kg^{-1}.with mean value of 256.24 $Bqkg^{-1}$.

3.2.2 Absorbed Dose Rate (D)

The mean activity concentration of ^{238}U, ^{232}Th and ^{40}K were converted to dose rate based on the conversion factor given by UNSCEAR (2000) and shown in Table 2.

$$D\ (nGyh^{-1}) = 0.462C_U + 0.604\ C_{Th} + 0.0417\ C_k \quad \text{---------- (3)}$$

Where D is the absorbed dose rate ($nGyh^{-1}$), C_U, C_{Th} and C_K are the activity concentrations ($Bqkg^{-1}$) of U, Th and K in river sediment respectively. The absorbed dose ranges from58.99 to 183.46 $nGyh^{-1}$ with a mean value of 113.58 ±7.62 $nGyh^{-1}$. The absorbed dose rate for all the samples was higher than the world average value of 60.0 $nGyh^{-1}$ (UNSCEAR, 2000).

3.2.3 Annual Effective Dose Equivalent (AEDE)

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 and the occupancy factor for outdoor and indoor was 0.2(5/24) and 0.8 (19/24) respectively (Ramasamy et al., 2009). The annual effective dose was determined using the following equations.

$$AEDE_{(outdoor)}\ (\mu Svy^{-1}) = D\ (nGyh^{-1}) \times 8760\ h \times 0.7Sv/Gy \times 0.2 \times 10^{-3} \quad \text{-------- (4)}$$

$$AEDE_{(indoor)}\ (\mu Svy^{-1}) = D\ (nGyh^{-1}) \times 8760\ h \times 0.7Sv/Gy \times 0.8 \times 10^{-3} \quad \text{--------- (5)}$$

The estimated AEDE for indoor and outdoor are presented in Table 2. The average, minimum and maximum values for outdoor and indoor AEDE are found to be 139.29, 72.35and 224.99 μSvy^{-1} respectively and 557.16, 289.41 and 899.97 μSvy^{-1} respectively. The mean indoor and outdoor annual effective dose equivalent is higher than the world average values of 70.0 μSvy^{-1} for outdoor and 450.0 μSvy^{-1} for indoor (Ramasamy et al., 2009).

3.2.3 Annual Gonadal Equivalent Dose (AGED)

The gonads, the bone marrow and the bone surface cells are considered as organs of interest by UNSCEAR (1988) because they are the most sensitive parts of human body to radiation. An increase in AGED has been known to affect the bone marrow and destroys the red blood cells which are then replaced by white blood cells. This situation results in a blood cancer (leukemia).

AGED is calculated with given activity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/kg) using the relation (Avwiri et al., 2015).

$$AGED\ (mSv/yr) = 3.09\ C_U + 4.18\ C_{Th} + 0.314\ C_K \text{……...……(6)}$$

Where, C_{Ra}, C_{Th}, and C_K are the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/kg) in soil samples respectively. AGED ranges from 409.09 to 1290.46 $mSvy^{-1}$ with an average value of 796.31 $mSvy^{-1}$. The annual gonadal dose recorded is 89 % higher than the world average of 300.0 $mSvy^{-1}$.

3.3 Radiological Hazard Indices

The gamma ray radiation hazards due to the specified radionuclide in river sediments are estimated by calculating different indices. Even though total activity concentration of radionuclides is determined, it does not provide the exact indication about the total radiation hazards. Also these indices are used to select the right materials for building.

3.3.1Radiation hazard indices (Hex, H_{in})

The external and internal hazard index is used for the evaluation of external exposure to gamma radiation in the outdoor air. The external and internal hazard that allowed maximum value (equal to unity) correspond to the upper limit of Raeq (370 Bq kg^{-1}). The external hazard index (Hex) and internal hazard index (H_{in}) can be calculated from the equation (Senthilkumar et al., 2010) and (UNSCEAR, 2000).

$$H_{ex} = \left(\frac{Au}{370Bqkg^{-1}}\right) + \left(\frac{Ath}{259Bqkg^{-1}}\right) + \left(\frac{Ak}{4810Bqkg^{-1}}\right) \leq 1 \qquad (7)$$

$$H_{in} = \left(\frac{Au}{185Bqkg^{-1}}\right) + \left(\frac{ATh}{259Bqkg^{-1}}\right) + \left(\frac{Ak}{4810Bqkg^{-1}}\right) \leq 1 \qquad (8)$$

Where A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively. The calculated external hazard values are 0.36 and 1.13 (Table 2). The mean, minimum and maximum value for Hex and Hin is found to be 0.69, 0.36 and 1.13 respectively and 1.20, 0.59 and 2.01 respectively. The mean external hazard index is lower than unity (permissible level) , though many sampling points exceeded unity while the mean internal hazard index exceeded unity slightly.

3.3.2Gamma radiation representative level index (Iγ)

Estimation of gamma radiation hazard associated with the natural radionuclide in specific investigated sample is called gamma representative level index (European Commission, 1999) which is given as: -

$$I\gamma = \left(\frac{A_U}{150}\right) + \left(\frac{A_{Th}}{100}\right) + \left(\frac{A_K}{1500}\right) \qquad (9)$$

Where A_U, A_{Th} and A_K are the average activity concentration of ^{238}u, ^{232}Th and ^{40}k respectively. The calculated value of the representative index varies from 0.74 to 2.52 with an average of 1.52. Values of representative index ($I\gamma$) $\leq$ 1 correspond to annual effective dose of less or equal to 1mSv. Fifteen locations (75%) have the representative index of their samples exceeding unity.

3.3.3Excess lifetime cancer risk (ECLR)

The probability of developing an extra cancer in a population within a life time after exposure to radionuclides can be estimated in terms of excess lifetime cancer risk. It is calculated using the equation (Taskin et al, 2009) and shown in Table 2.

ECLR = AEDE x D.L x RF ---------- (10)

Where AEDE is Annual effective dose equivalent, DL is duration of life (70yrs), RF is risk factor (0.05 Sv^{-1}). For stochastic effects, ICRP 60 uses values of $0.05Sv^{-1}$. The excess lifetime a cancer risk value ranges from 0.253×10^{-3} to 0.787×10^{-3} with a mean value of 0.487×10^{-3}. The average excess lifetime cancer risk (ELCR) calculated for all the samples is higher than the world average value of 0.29×10^{-3} (Taskin et al.,2009).

Table 3: Comparison of activity concentration of ^{238}U, ^{232}Th and ^{40}K in river sediment of Imo River of Rivers State, Nigeria and other studies in different parts of the world**.**

S/N	Location	$^{238}U(Bqkg^{-1})$	$^{232}Th\ (Bqkg^{-1})$	$^{40}k\ (Bqkg^{-1})$	References
1	World	35	30	400	UNSCEAR, 2000
2	India	28.67	63.83	327.6	UNSCEAR, 2000
3	Beach sand Egypt	-	177	815	Uosif et al., 2008
4	Red sea coast Egypt	23.1	7.2	338	Harb, 2008
5	Hungary	28.67	27.96	302.4	UNSCEAR, 2000
6	Kuwait	36	6	227	Saad & Al-Azml 2002
7	Nigeria	16	24	35	Arogunjo et al., 2004
8	Kalpakkam in Tamilnadu, India	112	1455.8	351	Kannan et al., 2002
9	Ula in Karnataka,India	374	358	158	Radhakrishna et al., 1993
10	North east coast of Tamilnadu, India	35.12	713.6	349.6	SureshGandhi et al., 2014
11	**Imo River, Nigeria**	**187.12**	**38.62**	**180.59**	**This present study**

IV. Statistical Analysis

In order to understand the distribution and characteristics of ^{238}U, ^{232}Th and ^{40}K measured in sediment samples from Imo river, basic descriptive statistics was applied using using the commercial statistics software package SPSS version 16.0 for windows. Statistical parameters such as standard deviation, mean, variance, geometric mean, skewness, kurtosis, minimum and maximum values were estimated and presented in Table 3. Frequency histogram and the associated distribution curves for ^{238}U, ^{232}Th and ^{40}K are shown in Figure 2 (Isinkaye and Emelue, 2015).

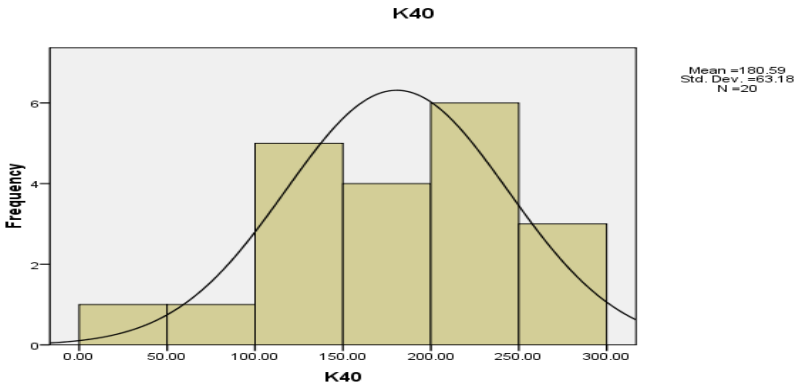
In statistics, skewness depicts the degree of asymmetry of distribution around its mean (suresh Gandhi et al., 2014, Isinkaye and Emelue, 2015). From Table 4 and Figure2, all the radiological parameters have positive skewness which shows an asymmetric distribution of the three radionucldes. ^{40}K and ^{238}U have negative

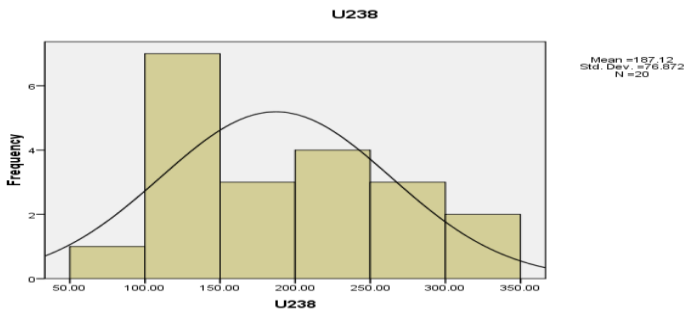
kurtosis indicating a relatively flat distribution. Cluster analysis and pearson correlation were also carried out to determine the mutual relationships and association between pairs of variables through the calculation of the linear Pearson correlation coefficient. In CA, the average linkage method along with correlation coefficient distance was applied and the derived dendrogram was shown in Figure 3. From this cluster analysis, external hazard index in this studied area is due to concentration of ^{238}U, and ^{40}K while the absorbed dose by human beings due to high concentration of ^{232}Th.

A strong positive correlation among variables indicates similar source and behavior in the environment (Isinkaye and Emelue, 2015). Results of the Pearson correlation coefficient among all the studied radiological parameters are shown in Table 5. It can be observed from Table 5, that positive correlation exist among the three radionuclides ^{238}U, ^{232}Th and ^{40}K and all the radiation hazard parameters. Strong correlation was however observed between ^{238}U and ^{40}K while ^{232}Th is weakly correlated with ^{40}K and ^{238}U. The strong relationship between ^{238}U and ^{40}K shows that their origin and behavior in the river are the same whereas the weak positive relationship between ^{232}Th and the other two radionuclides, ^{40}K and ^{238}U shows that they may have the same origin but their behavior in the river environment differs.

Table 4: Basic Statistics of the measured data**.**

	40K	*228U*	*232Th*	*Raeq*	*D*	*I*	*AGED*	*AEDEout*	*AEDEind*	*ELCR*	*Hex*	*Hin*
Mean	180.5865	187.1165	38.6165	256.2425	113.5753	1.517	796.3115	139.291	557.1595	0.48715	0.6935	1.1985
Standard Error	14.12752	17.18899	2.795929	20.36648	8.925954	0.127031	63.23999	10.94657	43.78649	0.038315	0.055142	0.10111
Median	196.84	189.295	38.435	251.48	111.485	1.54	785.75	136.725	546.895	0.4785	0.68	1.2
Mode	#N/A	#N/A	30.46	#N/A	#N/A	0.93	#N/A	#N/A	#N/A	#N/A	0.65	0.71
Standard Deviation	63.18018	76.87152	12.50378	91.08168	39.91808	0.5681	282.8179	48.95455	195.8192	0.17135	0.246604	0.452179
Sample Variance	3991.736	5909.23	156.3444	8295.873	1593.453	0.322738	79985.94	2396.548	38345.14	0.029361	0.060813	0.204466
Kurtosis	-0.58801	-0.96931	1.379274	-1.10566	-1.11243	-1.09577	-1.11606	-1.11257	-1.11251	-1.11177	-1.11853	-1.05602
Skewness	-0.34983	0.412676	-0.50557	0.341006	0.328561	0.346662	0.333426	0.328474	0.328536	0.328302	0.337521	0.385644
Range	230.84	245.79	55.08	284.86	124.47	1.78	881.37	152.64	610.56	0.534	0.77	1.42
Minimum	47.53	85.27	6.06	132.11	58.99	0.74	409.09	72.35	289.41	0.253	0.36	0.59
Maximum	278.37	331.06	61.14	416.97	183.46	2.52	1290.46	224.99	899.97	0.787	1.13	2.01
Sum	3611.73	3742.33	772.33	5124.85	2271.506	30.34	15926.23	2785.82	11143.19	9.743	13.87	23.97
Count	20	20	20	20	20	20	20	20	20	20	20	20





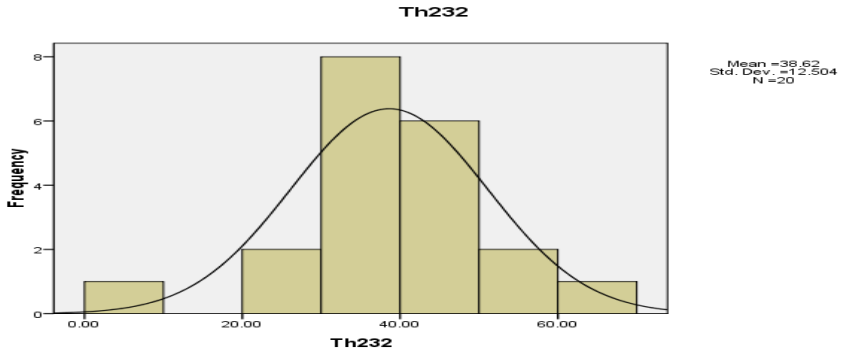


Fig. 2: Frequency distribution of ^{40}K, ^{238}U and ^{232}Th in river sediments

Positive correlation coefficient was also observed between ^{238}U, ^{232}Th and ^{40}K with all the radiological parameters. This implies that very strong relationship exist between the radionuclides and radiological parameters, that is all the three radionuclides contributes significantly to gamma radiation in all the sampling locations.

Table 5: Pearson Correlation between the radioactive variables in sediments

	40K	*228U*	*232Th*	*Raeq*	*D*	*I*	*AGED*	*AEDEout*	*AEDEind*	*ELCR*	*Hex*	*Hin*
40K	1											
228U	0.6525	1										
232Th	0.4835	0.5351	1									
Raeq	0.6990	0.9839	0.6738	1								
D	0.7064	0.9812	0.6829	0.9999	1							
I	0.7040	0.9949	0.6027	0.9956	0.9945	1						
AGED	0.7075	0.9845	0.6682	0.9999	0.9998	0.9964	1					
AEDEout	0.7064	0.9812	0.6829	0.9999	1.0000	0.9945	0.9998	1				
AEDEind	0.7064	0.9812	0.6829	0.9999	1.0000	0.9945	0.9998	1.0000	1			
ELCR	0.7065	0.9812	0.6825	0.9999	1.0000	0.9946	0.9998	1.0000	1.0000	1		
Hex	0.6987	0.9833	0.6763	0.9999	0.9998	0.9953	0.9998	0.9998	0.9998	0.9999	1	
Hin	0.6803	0.9951	0.6139	0.9967	0.9954	0.9993	0.9969	0.9954	0.9954	0.9954	0.9964	1

Dendrogram using Average Linkage (Between Groups)

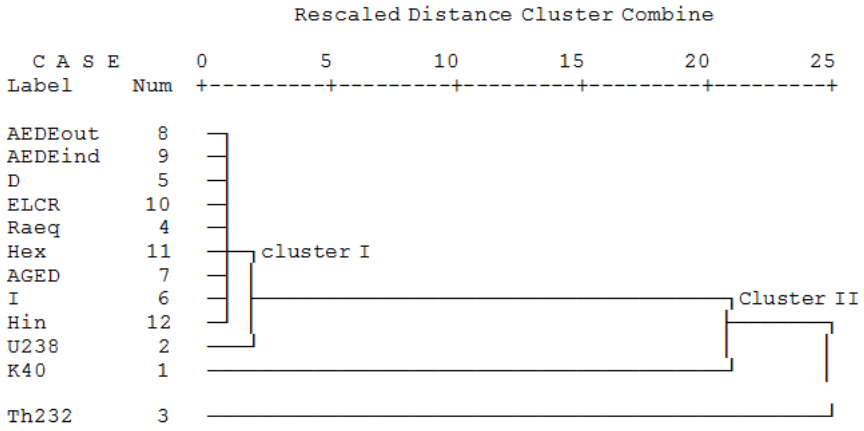


Fig. 3: Dendrogram shows the Clustering of radionuclide

V. Conclusion

The specific activity concentration of natural radionuclide ^{238}U, ^{232}Th and ^{40}K in sediment of Imo river were measured using NaI(TI) gamma ray spectrometer. The mean activity concentration of ^{40}K within the world average while that of ^{238}U and ^{232}Th exceeded their permissible value. The samples from the host community (Mama town) recorded higher activity concentration of ^{238}U, ^{232}Th and ^{40}K . measured activity concentration of ^{238}U, ^{232}Th and ^{40}K were used to calculate all the radiological parameters. The calculated average outdoor absorbed gamma dose rate was found to be **113.58±7.62 nGyh^{-1}** and annual effective dose

equivalent (outdoor and indoor) were higher than the world permissible values. The mean annual gonadal equivalent dose of 796.31 $mSvy^{-1}$ is higher than the world average value of 300 $mSvy^{-1}$. The gamma activity index, external and internal hazard indices were higher than unity.

Statistical analysis of the data shows that positive correlation exists between the ^{238}U, ^{232}Th and ^{40}K indicating same origin. Similar behavior of ^{238}U and ^{40}K in the river environment was observed due to strong correlation that existed between them while different behavior was exhibited by ^{232}Th due to its weak correlation. The results of this study show that the oil bunkering activity and sediment excavation in Imo River, together with the geological composition of the river has enhanced the concentration of the natural radionuclide in the sediment, hence making the sediment unsafe for use as building materials. There may be no immediate health implication to the general populace especially in Mama town but prolonged exposure could lead to radiation related health hazard, therefore Government should monitor the activities of this oil bunkering and other industrial activities along the Imo river and its environ. This result serves as a radiological baseline data of the area.

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