



# Radioactivity Concentrations and Their Radiological Significance in Sediments of Some Communities in Andoni, Rivers State, Nigeria

C. P. Ononugbo<sup>1\*</sup> and O. S. Amah<sup>2</sup>

<sup>1</sup>Department of Physics, University of Port Harcourt, Port Harcourt, Nigeria.

<sup>2</sup>Department of Physics, Ignatius Ajuru University of Education, Nigeria.

## Authors' contributions

This work was carried out in collaboration between both authors. Author CPO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author OSA managed the analyses of the study. Author CPO managed the literature searches. Both authors read and approved the final manuscript.

## Article Information

DOI: 10.9734/AJARR/2019/v6i330151

### Editor(s):

(1) Dr. Rachid Masrou, Professor, Department of Solid Physics, Faculty of Sciences, National School of Applied Sciences, University of Cadi Ayyad, Safi, Morocco.

### Reviewers:

(1) Fabiola Monroy-Guzmán, National Institute of Nuclear Research, Mexico.  
(2) R. D. Mavunda, University of Johannesburg, South Africa.

Complete Peer review History: <https://sdiarticle4.com/review-history/50456>

Original Research Article

Received 01 June 2019  
Accepted 04 August 2019  
Published 04 October 2019

## ABSTRACT

Quantification of naturally occurring radioactive materials in sediment provides information on geological characteristics, the possibility of petroleum and mineral exploration, radiation hazards to the dwelling populace and so on. The coastal sediment collected from the densely populated coastal area of Andoni, Rivers State Nigeria, were analyzed using a Sodium Iodide activated with thallium  $\gamma$ -ray spectrometer with low background radiation environment. The result showed an inhomogeneous distribution of radionuclides at different sampling points. The activity concentration of  $^{226}\text{Ra}$  ranges from  $9.82 \pm 3.41$  to  $33.37 \pm 3.27$  Bqkg<sup>-1</sup> with an average value of 22.64 Bqkg<sup>-1</sup> and  $^{232}\text{Th}$  ranges from BDL to 26.78 Bqkg<sup>-1</sup> with the average value of 8.45 Bqkg<sup>-1</sup>. The activity concentration of  $^{40}\text{K}$  was relatively higher than  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ , ranging from  $7.35 \pm 3.03$  to  $75.38 \pm 2.75$  Bqkg<sup>-1</sup> with an average value of 29.01 Bqkg<sup>-1</sup>. The average mass concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the sediments were found to be  $2.04 \pm 0.002$ ,  $2.08 \pm 0.001$  ppm and  $0.09 \pm 0.003$  % respectively. The  $^{232}\text{Th}/^{226}\text{Ra}$  ratio was found to be within the range of 0.00 to

\*Corresponding author: Email: [onochinyere66@yahoo.co.uk](mailto:onochinyere66@yahoo.co.uk), [onochinyere@yahoo.co.uk](mailto:onochinyere@yahoo.co.uk);

3.59 with a mean value of 1.02 which is far below the continental crustal average concentration of 3.82. There was also a poor correlation of radionuclides in the sediment showing differences in their origin. The mean values of AGED, D, AEDE, Hex, Raeq, RLI, I $\alpha$ , AUI and ELCR were below their recommended values. Thus the radioactivity levels in the studied sediments are generally of very little radiological concern for human health.

*Keywords: Radionuclide; spectrometer; mass concentration; Andoni; sediment.*

## 1. INTRODUCTION

The knowledge of natural radionuclide concentration levels in sediment and their distribution in the marine environment is of great concern in the field of science [1]. Natural radionuclides have been the component of the earth since its existence. It is widely distributed in the earth's environment and exists in soil, sediment, water, plants and air [2]. Radionuclides constitute an important source of ionizing radiation exposure to human and non-human populations which can cause harmful biological effects such as DNA damage and cancer [3].

Radionuclides are widely distributed in the environment as a result of their natural occurrence in the earth's crust or the atmosphere ref. In addition to their potential ionizing effects, radionuclides may be toxic and can undergo bioconcentration and bioaccumulation and adversely impact human health [4]. The human population worldwide receives an average annual radiation dose of 2.4 mSv<sup>-1</sup> about 80% of which comes from naturally occurring radionuclides, the remaining part is largely due to artificial sources ref.

The natural radioactivity in sediment comes from uranium and thorium series and natural potassium ref. Natural environmental radioactivity and associated external exposure due to gamma radiation depend primarily on the geological conditions of soil and sediment formations of each region in the world [2]. The study of natural radioactivity in marine and coastal environment is of significant importance for a better understanding of oceanographic and sedimentological processes.

The distribution of natural radionuclide in the seabed can be used as a tracer for both sediments and dredged soil dispersal and accumulation mechanisms. They also provide an estimation of the sedimentological composition of the seabed [5] usually the activity concentration of radionuclides increases inversely with the grain size and in proportion with the density of the sediment [6]. Sediment can act as both sinks

and sources of radionuclide in the marine environment ref. Following an input to marine systems, sediments represent the major sink for many radionuclides ref. However, when the primary sources have ceased, remobilization of radionuclides from previously contaminated sediment may increase in importance as diffused secondary source [7]. The secondary source also includes mobilization from contaminated land-based areas ref.

The partitioning of radionuclides between water and sediments is represented by the distribution coefficient or K<sub>d</sub> (ml/g) [5].

$$K_d = \frac{\frac{Bq}{g} \text{ Sediment}}{\frac{Bq}{ml} \text{ water}} \quad (1)$$

K<sub>d</sub> is one of the major parameters determining the fate of radionuclide in the environment: the higher the K<sub>d</sub>, the greater the proportion of contaminant that will be found in sediments ref. It follows that the mobilization of any radionuclide in a water-sediment system will be limited by the strength of sorption to the sediment, the reversibility of the sorption mechanism and the kinetics of the sorption /desorption process [7]. These factors will, in turn, depend on the physical and chemical properties of the radionuclides, the water and sediment [8]. Radionuclide can be transported from the water to the sediment phases by physical (sedimentation), chemical (ion-exchange) and biological (debris) process ref. The coastal communities can be contaminated as a result of the ocean and atmospheric dispersal and redistribution ref. Furthermore, anthropogenic activities within the seashore such as shipping, offshore oil and gas exploration and production, agricultural production and industrialization can potentially add to levels of radionuclides in marine sediment [9].

Sediment contamination by naturally occurring radionuclides can form the basis for radiological assessment for the human population that feeds on seafood [2]. Currently there is no information on radioactivity levels in the coastal marine environment of Andoni community of the Niger

Delta region. Due to incessant oil spills, oil and gas production activities and urbanization in the area, monitoring of such coastal sediment is therefore essential to ensure that human health is protected and proper functioning of the coastal aquatic ecosystems is maintained. This study aimed to assess the radioactivity concentration and mass concentration of radionuclides in sediments from Andoni River and ascertain their radiological health implication.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

Andoni is a Local Government Area in Rivers State, Nigeria. Its headquarters is at Ngo Town. It has an area of over 233 km<sup>2</sup> and a population of over 311,500 at the last census [10]. Its surface geology consists of fluvial sediments. This includes the recent sediments transported by Niger River distributaries and other rivers, such as Andoni, Bonny and New Calabar. These materials deposited as regolith overburden of 30 m thickness are clays, peat, silts, sands and gravels.

The Western Andoni coastline Beaches about 33 Km long and 0.6 km wide from oyorokoto to Inyan- Open is one Nigeria's many barrier bar beaches along the Atlantic Ocean coastline. It lies in the east-central sector of the Niger Delta with latitudes 4°25'17.03" to 4°29'19.63"N and

longitudes 7°24'37.24" to 7°34'16.95" E. It is flanked by the Andoni and Imo rivers respectively to the west and east (Fig. 1). The semi-enclosed island is usually flooded during high tide which is semidiurnal up to 80% [11].

### 2.2 Sediment Sampling

Twenty-one (21) sediment samples were collected using grab sampler from Andoni River and two sediment samples from another river as a control. The sampling locations start from upstream to downstream cutting across seven (7) communities in Andoni. To minimize the potential loss of fine grain particles through leakage of water from the grab, it was ensured that only grabs that arrived firmly closed on the deck were sampled for analysis.

About 100 g wet weight portions of sediments were taken with clean plastic spoons into the polyethene bag and securely closed. With an extremely low potential for diffusion of materials across their surfaces [3]. Rilson bags are suitable for the collection and storage of sediment samples and they have been used in environmental monitoring programme [12]. To minimize contamination, from the grab, sediments in direct contact with the grab were not used and the sampling spoon was washed with deionized water after each sampling. All the sediment were transported to research institute laboratory for gamma analysis.

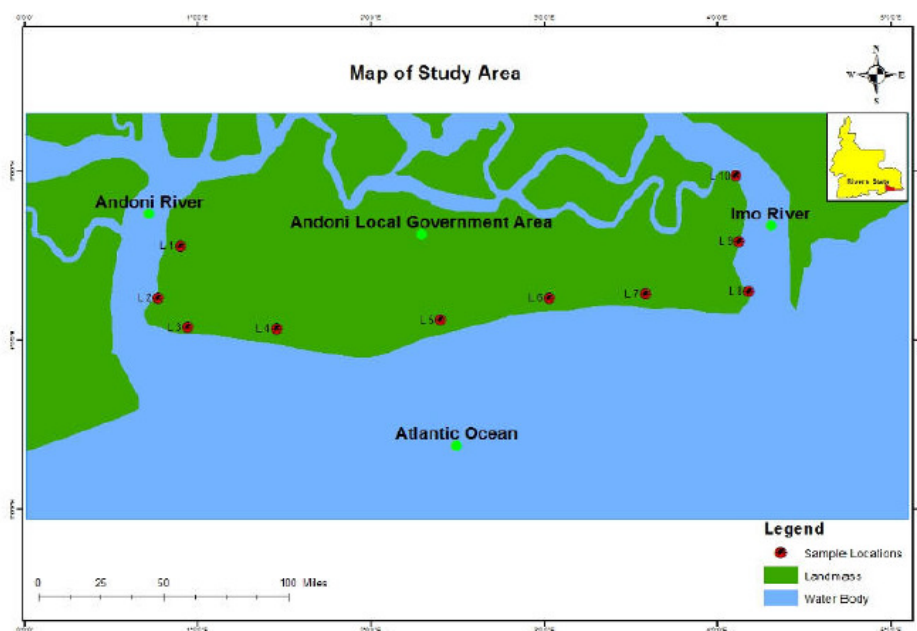


Fig. 1. Map of the study area

### 2.3 Gamma Analyses

For the analysis of the radioactivity levels in sediments, wet samples were oven-dried at 50°C till constant weight. Radiometric analysis of sediments samples was conducted at the University of Agriculture, research laboratory, Abeokuta with a gamma-ray spectrometry system with thallium activated 3" x3" Sodium iodide detector connected to ORTEC 456 amplifier. The sediments samples were ground and placed in 5 g plastic vials of standard geometry, closed and sealed airtight and stored for 28 days to ensure secular equilibrium between the parent nuclides and their short-lived daughter nuclides [13].

Prior to the sample radioactivity analysis, the gamma-ray detectors were calibrated for measurement of <sup>40</sup>K using the IAEA-385 certified reference materials while the calibration for <sup>238</sup>U series radionuclides were performed using the Canada Centre for mineral and energy Technology (CANMET) reference standard (DL 1a) being a U-Th ore in which <sup>210</sup>Pb and <sup>226</sup>Ra exists in secular equilibrium. Calibration for <sup>232</sup>Th was performed using the IAEA reference standard (RG Th-1) prepared by CANMET. Quality of all the results was routinely checked by analyzing IAEA -300 and IAEA -315 reference materials, as well as detector blanks (empty sample containers), processed similarly as the actual samples. Correction of measured activities for self – adsorption effects was done based on the measurement of attenuation of known <sup>210</sup>Pb gamma source by the samples.

The mass concentrations were determined from the activity concentration of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K radionuclides using equation 2 [14].

$$CE = \frac{M_E \times A_E \times 10^6}{\lambda_E \times N_A} \quad (2)$$

Where CE is the mass concentration of the radionuclide E in ppm (parts per million), ME is the atomic mass of the radionuclide of interest in g/mol, AE is the specific radioactivity of the radionuclide in Bq/g, λE is the decay constant of

the radionuclide and NA is the Avogadro's number (6.023 x 10<sup>23</sup> atoms/mol.).

The <sup>40</sup>K concentration as a percentage (%) of mass in the sample of the total potassium was calculated using equation 3.

$$\%C_K = \frac{M_K \times A_K \times 10^2}{N_K \times \lambda_K \times N_A} \quad (3)$$

Where C<sub>K</sub> is the % of total potassium of the investigated sample, MK is the atomic mass of <sup>40</sup>K in g/mol, AK is the specific radioactivity of <sup>40</sup>K in Bq/g, NK is the per cent of natural abundance of <sup>40</sup>K (0.0118%), wk. is the decay constant of <sup>40</sup>K, NA is the Avogadro's number.

The minimum detectable activity (MDA) was calculated for each radionuclide according to equation 3 [15]. The levels of MDA were calculated based on the counting conditions used for measuring the studied samples and listed in Table 1.

$$MDA = \frac{L_D}{T \times \text{Eff}(E) \times P_Y(E) \times M} \quad (4)$$

Where T, Eff (E) and Py (E) are the counting time, full energy peak efficiency at photon energy E and emission probability respectively. LD is the detection limit, calculated by using the following equation 5.

$$LD = LC + K \text{idd} \quad (5)$$

Where Lc is the critical level, below which no signal can be detected, σd is the standard deviation and K is the error probability [16].

After the attainment of secular equilibrium between <sup>232</sup>Th, <sup>238</sup>U and their daughter products, the samples were subjected to gamma-ray spectrometric analysis. Natural radionuclides of relevance for this work are mainly gamma-ray emitting nuclei in the decay series of <sup>232</sup>Th and <sup>238</sup>U and the single occurring <sup>40</sup>K. While the activity concentration of <sup>40</sup>K can be measured directly from its γ-rays, <sup>232</sup>Th and <sup>238</sup>U are not directly γ-ray emitters but it is possible to measure the γ-rays of their decay products.

**Table 1. The minimum detectable activity (MDA) for the radionuclides**

Radionuclides	Gamma energy (Kev)	MDA (Bq/kg)
K-40	1460.8	0.2
Ra-226	186.2	0.2
Ac-228	911.0	0.02

Decay products for  $^{238}\text{U}$  ( $^{214}\text{Pb}$ :295 and 352 keV and  $^{214}\text{Bi}$ : 609 keV) and  $^{232}\text{Th}$ , ( $^{228}\text{Ac}$ :338 and 911 Kev,  $^{212}\text{Pb}$ : 239 keV;  $^{212}\text{Bi}$ :727 keV and  $^{208}\text{Tl}$ :583 keV) were used by assuming the decay series to be in secular equilibrium [13]. The weighted average of several decay products was used to estimate activity concentrations of  $^{238}\text{U}$  and  $^{232}\text{Th}$ .

The activity concentration of  $^{40}\text{K}$  was measured directly by its gamma rays (1460.8 Kev). The measured activities were decay –corrected concerning the date of sediment sampling [4,3] and the associated errors were determined from 1-sigma counting statistics [9,17]. The activity of  $^{226}\text{Ra}$  was obtained from the activity of its daughter  $^{214}\text{Pb}$  and the average activity of  $^{228}\text{Ac}$  and  $^{212}\text{Pb}$  was used as a proxy for  $^{232}\text{Th}$  activity.

## 2.4 Radiological Risk Assessment

River sediments may be disposed on land or used for building purposes which can potentially result in human exposures to ionizing radiations and causes radiological effects. For human protection and appropriate handling of radioactively contaminated sediments, it is essential to characterize the associated potential radiological risks. Six radiological hazard indices were estimated following established formulae to characterize the potential radiation dose to humans resulting from exposure to sediment radioactivity.

### 2.4.1 Absorbed dose (D)

The total absorbed dose expresses the rate of exposure to gamma radiation in the air at 1 m above the ground due to the activities of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the sediment samples. D was calculated using equation 1 following [17].

$$D \text{ (nGyh}^{-1}\text{)} = 0.462A_{\text{Ra}} + 0.604 A_{\text{Th}} + 0.0417A_{\text{K}} \quad (6)$$

### 2.4.2 Radium equivalent dose (Raeq)

The radium equivalent (Raeq) activity represents a weighted sum of activity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in sediment samples which allows comparison with their  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  activity concentration [18]. It is based on the estimation that 1 Bq  $\text{kg}^{-1}$  of  $^{226}\text{Ra}$ , 0.7 Bq  $\text{kg}^{-1}$  of  $^{232}\text{Th}$  and 13 Bq  $\text{kg}^{-1}$  of  $^{40}\text{K}$  produce the same radiation dose rates. The radium equivalent activity index was estimated using the relation [19].

$$\text{Raeq} = C_{\text{Ra}} + 1.43C_{\text{Th}} + 0.077C_{\text{K}} \quad (7)$$

Where  $C_{\text{Cu}}$ ,  $C_{\text{Th}}$  and  $C_{\text{K}}$  are the activity concentration in Bq  $\text{kg}^{-1}$  or Bq  $\text{l}^{-1}$  of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ .

### 2.4.3 Annual gonadal equivalent dose (AGED)

Owing to their relatively higher sensitivity to ionizing radiation compared to other organs of the body, the gonads are considered to be at a high risk of radiation exposure and are therefore of great interest in radiological assessment [3]. An increase in AGED has been known to affect the bone marrow, destroying the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal. The AGED for the resident using such material for the building were evaluated using the equation [20].

$$\text{AGED (Sv./yr)} = 3.09C_{\text{Ra}} + 4.18C_{\text{Th}} + 0.314C_{\text{K}} \quad (8)$$

Where  $C_{\text{Ra}}$ ,  $C_{\text{Th}}$  and  $C_{\text{K}}$  are the activity concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in sediments samples.

### 2.4.4 Hazard index (Hex)

This is a measure of the indoor radiation dose rate associated with external gamma radiation exposure from natural radionuclides in building materials and it is important when considering the suitability of sediment as building materials [21]. For human health safety, the value of Hex must not exceed 1.0 [22].

The external hazard ( $H_{\text{ex}}$ ) and internal hazard ( $H_{\text{in}}$ ) indices were evaluated using the relations [23].

$$\text{Hex} = C_{\text{Ra}}/370 + C_{\text{Th}}/259 + C_{\text{K}}/4810 \leq 1 \quad (9)$$

### 2.4.5 Annual effective dose equivalent (AEDE)

The annual effective dose equivalent received by a member of the public is calculated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv./Gy and occupancy factor for outdoor and indoor was 0.2 and 0.8 respectively. AEDE is determined using the following equations [24].

$$\text{AEDE (outdoor) } (\mu\text{Sv/y}) = \text{Absorbed dose D (nGy/h)} \times 8760\text{h} \times 0.7\text{Sv/Gy} \times 0.2 \times 10^{-3} \quad (10)$$

The AEDE indoor occurs within a house whereby the radiation risks due to building materials are taken into consideration. AEDE outdoor involves a consideration of the absorbed dose emitted

from radionuclide in the environment such as  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ .

#### 2.4.6 Excess lifetime cancer risk (ELCR)

The Excess Lifetime cancer risk (ELCR) was calculated using the following equation [25].

$$\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \quad (11)$$

Where AEDE is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to be 70 years), 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 the public.

#### 2.4.7 Activity utilization index (AUI)

The samples are also examined whether it facilitates the dose criteria when it is used as a building material. For this reason, the activity utilization index is calculated using the equation given by [4].

$$\text{AUI} = \left( \frac{A_U}{50 \text{ Bqkg}^{-1}} \right) f_u + \left( \frac{A_{Th}}{50 \text{ Bqkg}^{-1}} \right) f_{Th} + \left( \frac{A_K}{1500 \text{ Bqkg}^{-1}} \right) f_K \quad (12)$$

Where  $A_{Th}$ ,  $A_U$  and  $A_K$  are activity concentrations in  $\text{Bqkg}^{-1}$  of  $^{232}\text{Th}$ ,  $^{238}\text{U}$  and  $^{40}\text{K}$  and  $f_{Th}$  (0.604),  $f_u$  (0.462) and  $f_K$  (0.041) are fractional contributions to the total dose rate in the air due to gamma radiation from the actual concentrations of these radionuclides.

#### 2.4.8 Gamma radiation representative level index

Estimation of the level of gamma radioactivity associated with different concentrations of some specific radionuclides is known as the representative level index which is given as:

$$\text{RLI} = \frac{A_U}{150 \text{ Bqkg}^{-1}} + \frac{A_{Th}}{100 \text{ Bqkg}^{-1}} + \frac{A_K}{1500 \text{ Bqkg}^{-1}} \leq 1 \quad (13)$$

Where  $A_U$ ,  $A_{Th}$  and  $A_K$  are the activity concentrations of  $A_U$ ,  $A_{Th}$  and  $A_K$  respectively.

### 3. RESULTS AND DISCUSSION

#### 3.1 Concentration of Radionuclides in River Sediments

The activity concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the sediments samples are shown in Table 2.

The result showed an inhomogeneous distribution of these elements at different sampling points. The activity concentration of  $^{226}\text{Ra}$  ranges from  $9.82 \pm 3.41$  to  $33.37 \pm 3.27 \text{ Bqkg}^{-1}$  with an average value of  $22.64 \text{ Bqkg}^{-1}$  and activity concentration of  $^{232}\text{Th}$  ranges from 0.00 to  $26.78 \text{ Bqkg}^{-1}$  with an average value of  $8.45 \text{ Bqkg}^{-1}$ . The activity concentration of  $^{40}\text{K}$  was relatively higher than those of the radionuclide ranging from  $7.35 \pm 3.03$  to  $75.38 \pm 2.75 \text{ Bqkg}^{-1}$  with an average value of  $29.01 \text{ Bqkg}^{-1}$ . Generally, the measured mean activity concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the studied samples show the following order:  $^{40}\text{K} > ^{226}\text{Ra} > ^{232}\text{Th}$ . Table 2 shows the activity concentration of  $^{226}\text{Ra}$  to be greater than that of  $^{232}\text{Th}$  in most of the samples contrary to the fact that the presence of thorium is 1.5 times greater than that of uranium in the earth's crust [26]. These elements have different behaviors in the sediments. Radium is more stable in water than thorium and will leak from the floor sediments. There is, therefore, a higher concentration of  $^{226}\text{Ra}$  near the ocean floor [26], where the samples were collected. This is an indication that the uranium content of the sediment might have been enhanced due to anthropogenic activities in the area.

It was observed that the activity concentration of  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  in the sediment samples were not uniform which represents the variations in the geological characteristics of the area under study. It was also observed that the measured mean activity concentration of  $^{40}\text{K}$  exceeded the values of both  $^{232}\text{Th}$  and  $^{226}\text{Ra}$  being both the most abundant radioactive element present in the environment and it also being noted that potassium is used extensively as part of a NPK fertilizer medium in intensive farming agricultural activities to promote the vigorous growth of crops. The overall mean activities of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the study samples were found to be lower than that of the world average values of 35, 30 and  $400 \text{ Bqkg}^{-1}$  respectively [20].

The mass concentration of  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  in ppm in the sediments was calculated using equation 2 and the mass % concentration of  $^{40}\text{K}$  in sediment samples were calculated using equation 3. The average mass concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the sediments were found to be  $2.04 \pm 0.002$ ,  $2.08 \pm 0.001$  ppm and  $0.09 \pm 0.003$  % respectively as shown in Table 3. The  $^{232}\text{Th}/^{226}\text{Ra}$  ratio was found to be within the range of 0.00 to 3.59 with a mean value of 1.02 which is far below the continental crustal average

concentration of 3.82 [27]. It indicates that there is significant fractionation during weathering.

Correlation studies were made between each radionuclide pair to find their relationship/ origin of each. Figs. 2, 3 and 4 show the correlation of

$^{232}\text{Th}$  with  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  with  $^{40}\text{K}$  and  $^{226}\text{Ra}$  with  $^{40}\text{K}$  respectively. They all show poor correlation with a correlation coefficient of 0.022, 0.066 and 0.022 respectively. This result is lower than the values obtained in sediment samples of Potenga sea beach, Chittagong, Bangladesh [28].

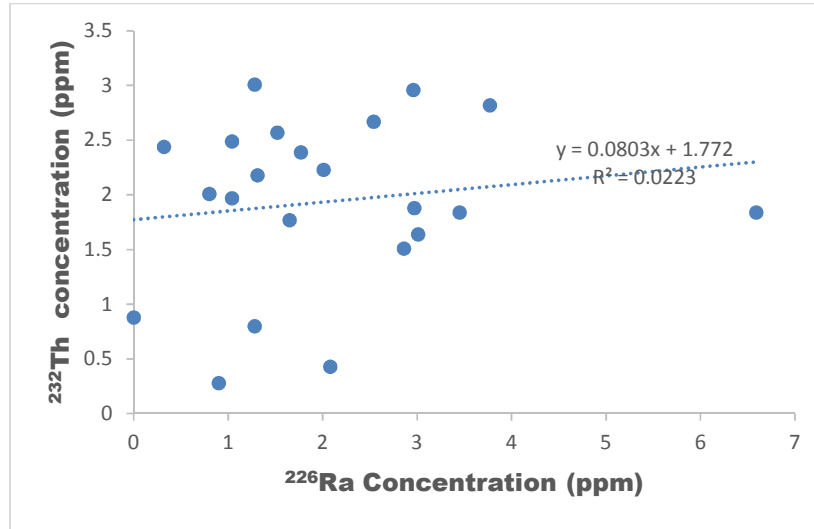


Fig. 2. Correlation of  $^{232}\text{Th}$  with  $^{226}\text{Ra}$  in sediment samples

Table 2. Specific activity concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in sediment samples and Radium equivalent

S/N	Sample location	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{40}\text{K}$	Raeq
		Bqkg <sup>-1</sup>	Bqkg <sup>-1</sup>	Bqkg <sup>-1</sup>	Bqkg <sup>-1</sup>
1	KAA 1	24.72±4.32	8.15±3.24	7.52±3.03	20.81
2	KAA 2	27.6±2.48	4.23±3.60	13.1±4.36	25.09
3	KAA 3	26.5±2.56	7.19±1.22	14.31±2.12	29.69
4	AKAJ 1	20.87±2.43	12.06±3.27	45.13±1.92	78.20
5	AJAK 2	21.83±3.95	4.23±3.47	34.21±2.38	54.83
6	AJAK 3	19.65±1.67	6.71±2.43	30.25±2.13	51.48
7	ATABA 1	27.12±4.00	1.29±0.34	24.5±2.54	38.41
8	ATABA 2	22.31±4.51	3.25±1.31	51.19±3.74	78.17
9	ATABA 3	24.22±1.43	5.32±1.24	28.23±1.23	47.55
10	AYA-ATABA 1	28.56±2.87	6.19±3.22	11.16±3.08	24.35
11	AYA-ATABA 2	32.89±2.43	12±3.27	23.29±1.81	47.84
12	AYA-ATABA 3	29.62±1.53	10.3±2.12	18.51±1.21	39.05
13	OTOKORO 1	20.39±3.39	26.75±2.24	25.72±2.80	65.10
14	OTOKORO 2	33.37±3.37	5.21±3.69	49.42±3.31	78.45
15	OTOKORO 3	31.25±1.22	15.3±2.12	33.5±2.61	65.61
16	OTOKORO-UP 1	20.39±3.81	14.02±3.29	16.01±2.83	38.48
17	OTORORO-UP 2	18.25±2.12	12.22±4.00	22.32±2.35	45.54
18	OTOKORO-UP 3	16.78±2.01	11.61±2.11	15.28±1.35	34.75
19	IBOT-ATABA 1	8.86±4.01	5.21±3.66	36.64±1.91	58.29
20	IBOT- ATABA 2	9.82±3.41	0	75.45±2.75	108.65
21	IBOT-ATABA 3	10.48±2.11	6.2±1.03	33.46±1.65	54.85
22	CONTROL	4.78± 1.01	3.67±2.42	7.44±1.23	14.68
23	CONTROL	3.18± 0.19	2.01±0.48	5.06± 1.52	9.49

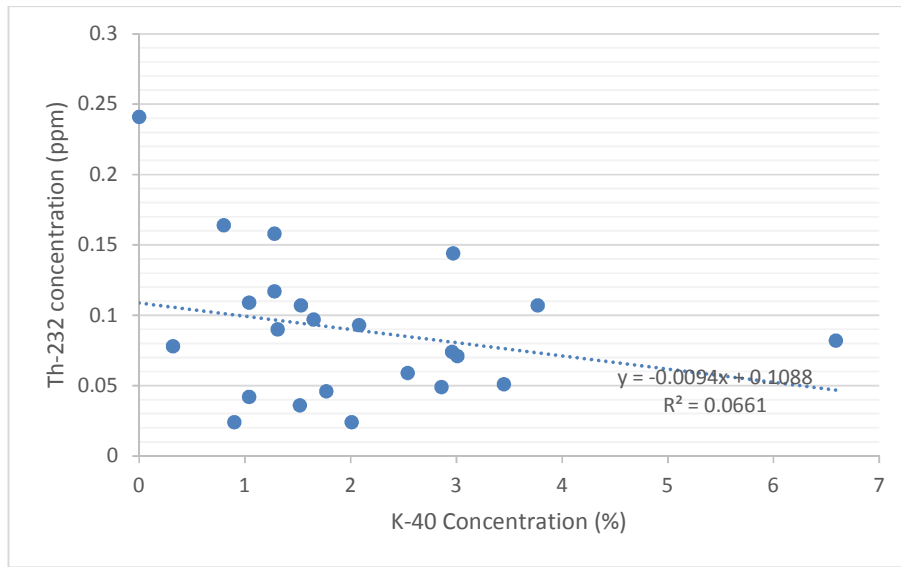


Fig. 3. Correlation of <sup>232</sup>Th with <sup>40</sup>K in Sediment samples

Table 3. Mass concentration of radionuclides, activity ratio and the Mass ratio of nuclides

S/N	Sample location	<sup>226</sup> Ra	<sup>232</sup> Th	<sup>40</sup> K	Activity ratio	Mass ratio
		ppm	ppm	%	Th/Ra	Th/Ra
1	KAA 1	2.23	2.01	0.024	0.33	0.90
2	KAA 2	2.49	1.04	0.042	0.15	0.42
3	KAA 3	2.39	1.77	0.046	0.27	0.74
4	AKAJ 1	1.88	2.97	0.144	0.58	1.58
5	AJAK 2	1.97	1.04	0.109	0.19	0.53
6	AJAK 3	1.77	1.65	0.097	0.34	0.93
7	ATABA 1	2.44	0.32	0.078	0.05	0.13
8	ATABA 2	2.01	0.80	0.164	0.15	0.40
9	ATABA 3	2.18	1.31	0.090	0.22	0.60
10	AYA-ATABA 1	2.57	1.52	0.036	0.22	0.59
11	AYA-ATABA 2	2.96	2.96	0.074	0.36	1.00
12	AYA-ATABA 3	2.67	2.54	0.059	0.35	0.95
13	OTOKORO 1	1.84	6.59	0.082	1.31	3.59
14	OTOKORO 2	3.01	1.28	0.158	0.16	0.43
15	OTOKORO 3	2.82	3.77	0.107	0.49	1.34
16	OTOKORO-UP 1	1.84	3.45	0.051	0.69	1.88
17	OTORORO-UP 2	1.64	3.01	0.071	0.67	1.83
18	OTOKORO-UP 3	1.51	2.86	0.049	0.69	1.89
19	IBOT-ATABA 1	0.80	1.28	0.117	0.59	1.61
20	IBOT- ATABA 2	0.88	0	0.241	0	0
21	IBOT-ATABA 3	0.94	1.53	0.107	0.59	1.62
22	CONTROL	0.43	2.08	0.093	0.77	2.10
23	CONTROL	0.28	0.90	0.024	0.64	1.74

**3.2 Radiological Risk Parameters**

The estimated radiological health risk parameters for Andoni River sediments are presented in Table 4. The range (mean) values of AGED, D, AEDE, Hex, RLI, Iα, AUI and ELCR for the sediment samples were 28.36-318.46 mSvy<sup>-1</sup>

(144.19 mSvy<sup>-1</sup>), 2.90 – 26.66 nGyh<sup>-1</sup> (15.66 nGyh<sup>-1</sup>), 0.001- 35.31 μSvy<sup>-1</sup> (12.69 μSvy<sup>-1</sup>), 0.042 -0.15 ( 0.093), 0.04- 0.42 (0.237), 0.016-0.167 Bqkg<sup>-1</sup> ( 0.11 Bqkg<sup>-1</sup>), 0.054-0.512 ( 0.335) and (0.003- 4.00) x 10<sup>-3</sup> ( 0.235 x 10<sup>-3</sup>). The mean values of AGED, D, AEDE, Hex, RLI, Iα, AUI and ELCR were below their recommended



values. Thus the radioactivity levels in the studied sediments are generally of very little radiological concern for human health.

Compared to the study, Benjamin et al. [3], reported higher mean values of D (39 nGyh<sup>-1</sup>),

Raeq (82.7 Bqkg<sup>-1</sup>), AEDE (273 μSvy<sup>-1</sup>) in sediments of Tema Harbour (Greater Accra), Ghana. Also, Amekudzie et al. [29] reported higher mean values of D (77 nGyh<sup>-1</sup>), Hex (0.5) but lower mean Raeq (9 Bqkg<sup>-1</sup>) values in sediments from Chorkor, James Town, Ghana.

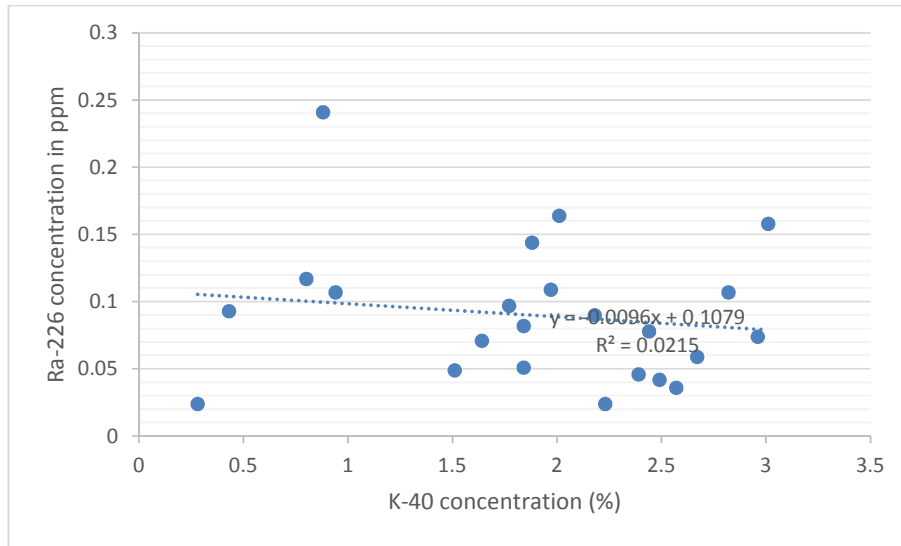


Fig. 4. Correlation of <sup>226</sup>Ra with <sup>40</sup>K in Sediment samples

Table 4. Radiological parameters estimated from radionuclides in sediment samples

S/N	AGED mSvy <sup>-1</sup>	D nGyh <sup>-1</sup>	AEDE <sub>Out</sub> μSvy <sup>-1</sup>	H <sub>EX</sub>	RLI	Iα Bqkg <sup>-1</sup>	AUI	ELCR X 10 <sup>-3</sup>
1	64.38	16.66	7.76	0.100	0.251	0.123	0.327	0.027
2	76.50	15.85	12.10	0.094	0.235	0.138	0.306	0.042
3	90.35	17.19	5.86	0.102	0.258	0.132	0.332	0.021
4	232.46	18.82	2.59	0.112	0.289	0.104	0.340	0.009
5	162.92	14.08	35.31	0.082	0.211	0.109	0.254	0.124
6	153.34	14.40	28.76	0.085	0.218	0.098	0.263	0.101
7	114.91	14.34	29.94	0.083	0.210	0.136	0.267	0.105
8	231.02	14.42	28.43	0.083	0.215	0.111	0.247	0.100
9	142.04	15.59	14.10	0.092	0.233	0.1211	0.288	0.493
10	74.74	17.40	5.24	0.103	0.259	0.1428	0.339	0.183
11	144.76	23.42	3.61	0.140	0.354	0.164	0.450	0.013
12	118.50	20.68	1.11	0.123	0.312	0.148	0.399	0.004
13	196.57	26.66	0.113	0.164	0.420	0.101	0.512	4.000
14	233.15	20.64	1.13	0.120	0.307	0.167	0.373	0.004
15	197.12	25.09	10.95	0.150	0.383	0.156	0.474	0.007
16	116.65	18.56	2.93	0.113	0.287	0.102	0.358	0.010
17	136.79	16.74	7.38	0.101	0.259	0.091	0.317	0.026
18	105.01	15.41	15.67	0.093	0.238	0.084	0.296	0.055
19	172.04	8.78	24.74	0.052	0.136	0.044	0.146	0.009
20	318.46	7.71	0.008	0.042	0.116	0.049	0.093	0.028
21	162.31	9.99	0.0008	0.059	0.154	0.052	0.173	0.003
22	43.94	4.74	0.64	0.029	0.074	0.024	0.089	0.022
23	28.36	2.90	53.54	0.017	0.040	0.016	0.054	0.019
<b>Mean</b>	<b>144.19</b>	<b>15.66</b>	<b>12.69</b>	<b>0.093</b>	<b>0.237</b>	<b>0.105</b>	<b>0.335</b>	<b>0.235</b>

#### 4. CONCLUSION

The geologic formation of sediment collected from Andoni River of Rivers state, Nigeria were investigated through the determination of the mass concentration of natural radionuclide ( $^{232}\text{Th}$ ,  $^{226}\text{Ra}$  and  $^{40}\text{K}$ ) using Sodium Iodide activated with thallium gamma-ray spectrometry. It was observed that the concentrations of all the radionuclides are within their recommended values. The mass concentration of  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  corresponds to the formation of granite rocks (1-10 ppm) while the concentration of  $^{40}\text{K}$  obtained is in the range of the typical rocks (0.3 – 4.5 %). The ratio of  $^{232}\text{Th}$  with  $^{226}\text{Ra}$  was found in the range of 0 to 3.59.

The analysis of selective elemental abundance (Th/Ra ratios) showed reduction processes as a result of complex metamorphic alterations since the mean value of the ratio of the radionuclide is less than 3. There is an enrichment of radium while thorium was depleting. All the radiological health parameters assessed recorded lower values showing lower deposition of minerals which represents a safer radiological environment for dwelling place.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

1. Feroz A. Mir, Sajad A. Rather. Measurement of radioactive nuclides present in soil samples of District Ganderbal of Kashmir Province for radiation safety purposes. *Journal of Radiation Research and Applied Sciences*. 2015;8:155-159.
2. Sivakumar A, Chandrasekaran A, Ravisankar R, Ravikumar SM, Prince Prakash Jebakumar J, Vijayagopal P, Vijayalakshmi I, Jose MT. Measurement of natural radioactivity and evaluation of radiation hazards in coastal sediments of East Coast of Tamilnadu using statistical approach. *Journal of Talbah University for Science*. 2014;8:375-384.
3. Benjamin O. Botwe, Antonio Schirone, Ivana Delbono, Peter Kelderman, Elvis Nyarko, Piet N. Lens. Radioactivity concentrations and their radiological significance in sediments of the Tema Harbour (Greater Accra, Ghana). *Journal of Radiation Research and Applied Sciences*. 2017;10:63-71.
4. Sirelkhatim D, Sam A, Hassona R. Distribution of  $^{226}\text{Ra}$ ,  $^{210}\text{Pb}$ ,  $^{210}\text{Po}$  in marine biota and surface sediments of the Red Sea, Sudan. *Journal of Environmental Radioactivity*. 2008;99(12):1825-1828.
5. Mabit L, Benmansour M, Abril J, Walling D, Meusburger K, Iurian AR, et al. Fallout  $^{210}\text{Pb}$  as a soil and sediment tracer in catchment sediment budget investigations: A review. *Earth-Science Reviews*. 2014;138:335-351.
6. Kpeglo D, Mantero J, Darko E, Emi-Reynolds G, Faanu A, Manj\_on G, et al. Radiochemical characterization of produced water from two production offshore oilfields in Ghana. *Journal of Environmental Radioactivity*. 2016;152:35-45.
7. Anne Liv Rudjord, Deborah Oughton, Tone D. Bergan, Gordon Christensen. Radionuclides in marine sediments - Distribution and processes. Norwegian Radiation Protection Authority, Agricultural University, As, 3IFE; 2007.
8. Kumar M, Varga E, Slivka J. Correlations of natural radionuclides in soil with those in sediment from the Danube and nearby irrigation channels. *J Environ Radioact*. 2013;117:31–35.
9. Nyarko E, Botwe B, Ansong J, Delfanti R, Barsanti M, Schirone A, et al. Determination of  $^{210}\text{Pb}$ ,  $^{226}\text{Ra}$  and  $^{137}\text{Cs}$  in beach sands along the coast line of Ghana. *African Journal of Environmental Pollution and Health*. 2011;9:17-23.
10. Chakraborty SR, Alam MK. Assessment of natural radioactivity in the sea beaches of Bangladesh. *Radiat Prot Environ*. 2014;37: 6–13.
11. Farai IP, Obed RI, Jibiri NN. Soil radioactivity and incidence of cancer in Nigeria. *J Environ Radioact*. 2006;90:29–36.
12. Serigstad B, Olsen M, Mørk T, Kristiansen J, Wolinski G, Gowing S. Marine environmental survey of bottom sediments in Cabinda and Soyo province, Angola. *Cruise Report No 4/2009*; 2010.
13. Keser R, Korkmaz Görür F, Alp İ, Okumusoğlu NT. Determination of radioactivity levels and hazards of sediment and rock samples in İközdere and Kaptanpasa Valley, Turkey. *International Journal of Radiation Research*. 2013;11(3).

14. Malain D, Regan PH, Bradley DA, Matthews M, Al-Sulaiti HA, Santawamaitre T. An evaluation of the natural radioactivity in Andaman beach sand samples of Thailand after the 2004 tsunami. *Appl Radia Isot.* 2012;70:1467–74.
15. El-Gamal AA, Saleh IH. Radiological and mineralogical investigation of accretion and erosion coastal sediments in Nile Delta Region, Egypt. *J. Oceanogr. Mar. Sci.* 2012;3(3):41–55.
16. Abdel-Halim AA, Saleh IH. Radiological characterisation of beach sediments along the Alexandria Rosetta Coasts of Egypt. *Journal of Talibah University for Science.* 2016;10:212-220.
17. El Mamoney M, Khater AE. Environmental characterization and radioecological impacts of non-nuclear industries on the Red Sea coast. *Journal of Environmental Radioactivity.* 2004;73(2):151-168.
18. Sugandhi S, Joshi VM, Ravi P. Studies on natural and anthropogenic radionuclides in sediment and biota of Mumbai Harbour Bay. *Journal of Radioanalytical and Nuclear Chemistry.* 2014;300(1):67-70.
19. Awwiri Go, Agbalagba EA. Assessment of natural radioactivity associated radiological health hazard indices and soil to crop transfer factors in cultivated area around a fertilizer factory in Onne, Nigerian. *Journal of Environmental Radioactivity.* 2013;4:56-63.
20. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources and effects of ionizing radiation, Report to General Assembly, with Scientific Annexes, United Nations, New York. 2000;91–125.
21. Xinwei L, Lingqing W, Xiaodan J. Radiometric analysis of Chinese commercial granites. *Journal of Radioanalytical and Nuclear Chemistry.* 2006;267(3):669-673.
22. Kurnaz A, Küçükömeroğlu B, Keser R, Okumusoglu N, Korkmaz F, Karahan G. Determination of radioactivity levels and hazards of soil and Sediment samples in Firtina Valley (Rize, Turkey). *Applied Radiation and Isotopes.* 2007;65(11):1281-1289.
23. Ravisankar R, Chandramohan J, Chandrasekaran A, Prince Prakash Jebakumar J, Vijayalakshmi I, Vijayagopal P, Venkatraman B. Assessment 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.* 2015;97:419–430.
24. Veiga R, Sanches N, Anjos RM, Macario K, Bastos J, Iguatemy M. Measurement of natural radioactivity in Brazilian beach sands. *Health Phys.* 2006;41:189–96.
25. Janković M, Todorović D, Savanović M. Radioactivity measurements in soil samples collected in the Republic of Srpska. *Radiation Measurements.* 2008;43:1448.
26. Papadopoulos A, Christofides G, Koroneos A, Stoulos S. Natural radioactivity distribution and gamma radiation exposure of beach sands from Sithonia Peninsula. *Central Eur J Geosci.* 2014;6(2):229–42.
27. National Council on Radiation Protection and Measurements (NCRP). Exposure of the Population in the United States and Canada from Natural Background Radiation, NCRP Report no. 94. Maryland; 1987.
28. Sabina Yasmin, Bijoysonker Barua, Mayeen Uddin Khandaker, Masud Kamal, Abdur Rashid SF, Abdulsani H, Ahmed Bijan Nikouravan, Braley DA. The presence of radioactive materials in soil, sand and sediment samples of Potenga sea beach area, Chittagong, Bangladesh: Geological characteristics and environmental implication. *Results in Physics.* 2018;8:1268-1274.
29. Amekudzie A, Emi-Reynolds G, Faanu A, Darko E, Awudu A, Adukpo O, et al. Natural radioactivity concentrations and dose assessment in shore sediments along the coast of Greater Accra, Ghana. *World Applied Sciences Journal.* 2011;13(11):2338-2343.

© 2019 Ononugbo and Amah; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*  
*The peer review history for this paper can be accessed here:*  
<https://sdiarticle4.com/review-history/50456>