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Health Risk Assessment of Radionuclides in Soil and Sediments of some Selected Areas of Pindiga, Nigeria

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Abstract: The knowledge of the concentrations and distributions of the radionuclides have common environmental concern along with the health hazards to human beings, animals as well as aquatic life. In this study, the Gamma-ray spectrometry technique has been employed to determine the activity concentrations of 238U, 232Th and 40K in 5 soil and sediment samples of selected areas of Pindiga, using Sodium Iodide-Thallium Gamma Spectrometry, NaI(Tl) detector. From the obtained results, the measured activity concentration of 40K vary from 124.3565 Bq/kg to 195.8387 Bq/kg with an average value of 155.9953 Bq/kg, the concentration of 226Ra vary from 27.2052 Bq/kg to 62.0805 Bq/kg with an average value of 40.79578 Bq/kg and the concentration of 232Th vary from 12.0709 to 45.9638 Bq/kg with an average value of 31.2664 Bq/kg. The average world average activity concentration of 40K, 226Ra and 232Th are 400 Bq/kg, 35 Bq/kg and 30 Bq/kg respectively. The results showed that the activity concentration of 40K in the study area is below the reference level assigned by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) while for 226Ra and 232Th are higher than the references levels. These results are of great importance for exploring the health risks due to activity concentrations of radionuclides in soil and in sediments and may pave the road to a baseline for future changes in environmental radioactivity due to naturally occurring radioactive materials and human activities.

Keywords: Radionuclides, Gamma Spectrometry, concentration, radiological hazard, indices, Pindiga.

1 Introduction

Radionuclides are unstable form of nuclides that disintegrate spontaneously into different daughter nuclides in order to achieve stable nuclide [1]. They occur naturally in ground water through contact with rocks or soils that have naturally occurring radioactive materials (NORMs) [2,3]. Most background waters have very low levels of naturally occurring radionuclides (e.g. ^{40}K, ^{232}Th, ^{235}U, ^{210}Pb and ^{226}Ra) with half-life comparable to the age of the earth, [4-6]. Radium-226 (^{226}Ra) was reported to be responsible for 98.5% of the radiological effects of uranium decay series [7]. Some human activities, for example mining, have led to increase in the relative concentration of radionuclides through extraction and disposal of large quantities of minerals containing ^{40}K and other radionuclides in the decay series of ^{232}Th and ^{235}U [8,9]. These radionuclides deserve special consideration due to the threat they may poses as environmental pollution, when they undergo radioactivity [1,10]. Their decay chain produces alpha and beta particles accompanied by gamma rays which are the strong source of radiation exposure in the environment and present the main external source of irradiation to human body [11-13].

Researchers, both at the developed and developing nations of the world have worked extensively in determining the activity concentration of radionuclides in various sources of water and different types of soil, as it affects community health [14]. High infections and mortalities especially children below the age of five were recorded in Nigeria due to exposure to radionuclides and water-related diseases [15-17]. Over the past half century, it has been recognized that the presence of NORMs in the environment with activity concentrations higher than the radiological reference levels assigned by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is hazardous to living organisms [11,12]. It is an established fact that the radioactivity is harmful to living organisms, however small it may be [18].

The knowledge of the concentrations and distributions of the radiological consequences have common environmental concern along with the health hazards to human beings, animals as well as aquatic life [19-21]. Tremendous investigations have been made worldwide to assess activity

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concentrations of NORMs in soil. This is of great importance for assessing the dose to the population, which plays a vital rule in exploring the health risks due to radioactivity and paving the road to a baseline for future changes in environmental radioactivity due to human activities [22]. The assessment of radionuclide activity levels in the environment provides us with essential information about the abundance of radionuclides in the local environment [12,23]. Many areas in the world such as Australia, Brazil, China, India, Iran, Japan etc., possess levels of natural radiation. Soil and sediment contain trace quantity of terrestrial radionuclides are the most important source of terrestrial gamma radiation and the activity concentrations depend on the local geology of each region in the world [24].

Therefore, this research is aimed at measuring the activity concentration of ^{232}Th, ^{226}Ra and ^{40}K in the soil and sediment of Pindiga. Pindiga is a city found in Gombe, North-eastern Nigeria having about 106,322 inhabitants. It is located 9.98° North latitude, 10.93° East longitude and it is situated at elevation 523 *m* above sea level [25]. These measurements may provide a clear picture about the radiological risk of such radionuclides on human in the area.

2 Materials and Methods

2.1 Sample Collection and Preparation

To measure radioactivity concentration of ^{232}Th, ^{226}Ra and ^{40}K in sediment and soil, a total of five samples were collected from Pindiga where mining activities are prominent, during wet season using Global Positioning System (GPS) to record the exact position of the sampling sites. Soil and sediment samples of about 1.00 *kg* each, were collected in indicated locations from Pindiga, Gombe state (Table 1).

Table 1: Sampling location sites with co-ordinates in the study area of soil and sediment sampling.

Name of the Location	Co-ordinates	
	Latitude	Longitude
Pindiga Dam	9°59'25.21" *N*	10°57'58.18" *E*
Madagaska Dam	9°59'6.76" *N*	10°56'50.22" *E*
Abbayo Quaters	9°59'0.79" *N*	10°57'7.76" *E*
Unguwar Baka I	9°59'7.63" *N*	10°57'8.82" *E*
Unguwar Baka II	9°59'16.94" *N*	10°56'47.74" *E*

Containers for the samples were washed with solution of detergent and then rinsed with distilled water, freshly distilled hydrochloric acid (*HCl*) to remove any inorganic material that might have stuck to the walls of the container before the samples were collected. Samples were collected with a metal sampler and stored into labeled plastic boxes. These samples were collected at the bank of the river an area where there is less dilution of the washout from the surrounding environment. Samples collected were put in a separate polythene bag to avoid cross contamination.

Activity measurements were performed at the Center for Energy Research and Training, CERT, Ahmadu Bello University Zaria, using gamma-ray spectrometry system based on a *NaI* detector. At the laboratory samples were homogenized, dried at 105 ℃ temperature, crushed, sieved and fractions lower than 2 *mm* were transferred to polyethylene beakers of 1 *litre* capacity used for analysis. The beakers were sealed tightly and wrapped with thick vinyl tape around their screw necks. Each of the samples collected were dried and crushed to fine powder with the use of pulverizer. The sealing process include smearing of the inner rim of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps between lid and container, and tight-sealing lid container with masking tape.

Radon and its short-life progenies were allowed to attain secular radioactive equilibrium by storing the sample for 30 *days* prior to gamma spectroscopy measurements. Packing of the samples into radon-impermissible cylindrical plastic containers which were selected based on the space allocation of the detector vessel which measures 76 *mm* by 76 *mm* in dimension (geometry) was also carried out. To prevent ^{222}Rd escaping, the packing in each case was triple sealed.

2.3 Evaluation of Radioactivity of the Samples

The analysis was carried out using a 76 × 76 *mm* $Na(Tl)$ detector crystal optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1 *kW* external source. The detector is enclosed in a 60 *mm* lead shield with cadmium and copper sheets. This arrangement is aimed at minimizing the effects of background and scattered radiation. The data acquisition software is **Maestro** by Canberra Nuclear Products. The samples were measured for a period of 29000 *seconds*, for each sample. The peak area of each energy in the spectrum was used to compute the activity concentrations of nuclides in each sample by the use of the following equation:

$$C(Bq/kg) = \frac{C_n}{C_{fk}} \quad (1)$$

Where C_n = count rate (count rate per second) and C_{fk} = calibration factor of the detecting system.

2.4 Calibration and Efficiency Determinations

Calibration of the system for energy and efficiency were done with two calibration point sources, ^{135}Cs and ^{60}Co. These were done with the amplifier gain that gives 72%

Table 2: The special energy windows used in the analysis

Radioisotope	Gamma Energy	Energy Window (*keV*)
^{40}K	1460.0	1380 – 1550
^{226}Ra	1764.0	1620 – 1820
^{232}Th	2614.5	2480 – 2820

The concentrations of ^{40}K, ^{226}Ra and ^{232}Th radionuclides in the samples were also measured in parts per millions (*ppm*) from the measured activity in *Bq*/*kg* (Table 5 and 6) using the following experimental formula [26,27]:

$$C(ppm) = C(Bq/kg)\lambda \quad (2)$$

And the conversion factor,

$$\lambda = \left(\frac{M_w}{N \ln 2}\right) T_{1/2} \times 10^6 \quad (3)$$

where M_w is the molar weight ($gmol^{-1}$), N is the Avogadro's number and $T_{1/2}$ is the half-life measured in seconds.

Table 3: The energy calibration for quantitative spectral analysis.

Radioisotope	Calibration Factors 10^{-3}		Conversion Factors (*Bq*/*Kg*)	Detection Limits	
	(*cps*/*ppm*)	(*cps*/*ppm*)		*ppm*	*Bq*/*kg*
^{40}K	0.026	64.31	0.032	454.54	14.54
^{226}Ra	10.500	86.32	12.200	0.32	3.84
^{232}Th	3.612	87.68	4.120	2.27	9.08

2.5 Absorbed Gamma Dose Rate (D_γ)

In order to assess the radiation hazards due to the concentrations of natural occurring radionuclides ^{238}U, ^{232}Th and ^{40}K in the samples, the absorbed gamma dose rate D (*nGy*/*h*), due to activity concentration of ^{238}U, ^{232}Th and ^{40}K was calculated using the following relationship [27-31]:

$$D_\gamma\left(\frac{nGy}{h}\right) = C_{Ra}A_{Ra} + C_{Th}A_{Th} + C_K A_K \quad (4)$$

Where A_{Ra}, A_{Th}, A_K are the radioactivity concentration in *Bq*/kg and C_{Ra}, C_{Th}, and C_k are dose conversion factors which are 0.427, 0.662 and 0.0432 for ^{238}U, ^{232}Th and ^{40}K respectively.

2.6 Annual Effective Dose Rate (AE)

The annual effective dose rate (A_E) from outdoor gamma radiation can be calculated using the following equation:

$$A_E\left(\frac{nGy}{h}\right) = \left(D_\gamma \times T \times O \times Q\right) \times 10^{-6} \quad (5)$$

Where D_γ is dose rate, T is time in hours in one year (24 × 365.25 *h*), Q is the conversion coefficient for an absorbed dose in air to effective dose in human body (0.7 *Sv*/*Gy*) with an outdoor occupancy of 20% and 80% for indoors, and O is outdoor occupancy factor. The mean numerical values of these parameters vary with the age of the population and the climate at the study location. Therefore, Outdoor occupancy factor depends on the living style of the people which is not the same in rural and urban area. Since the selected towns are rural area 0.3 which represent about 8 *h* out of 24 *h* of the day was used as outdoor occupancy factor [33,34,35,36]. Therefore, the annual effective dose rate measured in ($\mu Sv/y$) can take the form:

$$A_E\left(\frac{\mu Sv}{y}\right) = \left[D_\gamma\left(\frac{nGy}{h}\right) \times 8766 \times 0.7\left(\frac{Sv}{Gy}\right) \times 0.3\right] \times 10^{-3} \quad (6)$$

2.7 Radium Equivalent Activity (Raeq)

To ensure the uniformity in the distribution of naturally occurring radionuclides in the samples, a common radiological index, called radium equivalent activity (Ra_{eq}) has been introduced. This gives a single index which takes into account the gamma radiation hazards associated with the different mixture of ^{226}Ra, ^{232}Th and ^{40}Ra in the samples. The radium equivalent activity can be calculated by the expression [9,11,33]:

$$Ra_{eq}\left(\frac{Bq}{kg}\right) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (7)$$

Where A_{Ra}, A_{Th} and A_K are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}Ra respectively [35].

2.6 Gamma representative index (I_γ)

The gamma representative index, I_γ is a screening parameter generally applied to assess the possible hazardous level of radionuclides in the human body when exposed to an amount of annual effective dose of gamma

radiations decayed from radioactive nuclides in soils. It is very important in monitoring gamma radiation inside human body. The gamma radiation representative index associated with ^{232}Th, ^{226}Ra and ^{40}K in soil samples was calculated using the following equation [34]:

$$I_\gamma = \frac{A_K}{1500\ Bq/kg} + \frac{A_{Th}}{100 Bq/kg} + \frac{A_{Ra}}{150\ Bq/kg} \quad (8)$$

Where, the denominators of 100 *Bq*/*kg*, 150 *Bq*/*kg* and 1500 *Bq*/*kg* are the specific exposure rates for ^{232}Th, ^{226}Ra and ^{40}K respectively. To ensure the soil environment is generally safe, the assessed value must be less than or equal to 1 ($I_\gamma \leq 1$), the world wide permissible high dose values which corresponds to an annual effective dose of ≤ 1 *mSv* [12,37].

2.7 External Hazard Indices (H_{ex})

The external hazard index (H_{ex}) due to gamma radiation was used to evaluate a potential hazard which is associated

with radiological effects and it was calculated using the equation given by:

$$H_{ex} = \frac{A_K}{4810 Bq/kg} + \frac{A_{Th}}{259 Bq/kg} + \frac{A_{Ra}}{370 Bq/kg} \quad (9)$$

The external hazard index, H_{ex}, due to gamma radiation was introduced to limit the external radiation exposure to natural radionuclides present in the samples to allowed dose equivalent limit of 1 *mSv*/*y*, which is below the dose limitof unity, in order for radiation hazard to be considered acceptable to the public. The external hazard index can be obtained from (Ra_{eq}) expression through the supposition that its allowed maximum value (equal to unity) correspond to the upper limit of Ra_{eq} (370 *Bq*/*kg*). The external hazard index is an additional criterion to assess the radiological suitability of a material [33,35,38].

2.8 Internal Hazard Indices (H_{in})

The internal exposure caused by radon ^{222}Rn (the daughter product of ^{226}Ra) is hazardous to the respiratory organs. This hazard can be controlled by the internal hazard index (H_{in}) and it is given by the relation:

$$H_{in} = \frac{A_K}{4810} + \frac{A_{Th}}{259} + \frac{A_{Ra}}{185} \quad (10)$$

This term quantified the internal exposure to radon and its short-lived decay products to the respiratory organs. This index value must be less than one ($H_{in} > 1$) for the radiation hazard to be insignificant [9,35,38].

3 Results and Discussion

With the obtained parameters, the net count life time and activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in the collected samples were determined using *NaI*(*Tl*) detector and the results are presented in Tables 4 and 5.

Table 4: The net count life time of ^{40}K, ^{226}Ra and ^{232}Th in soil and sediment samples .

Radioisotope	Count Rate (s^{-1})				
	Abbayo Quarters	Unguwar Baka I	Unguwar Baka II	Pindiga Dam	Piyau Dam
^{40}K	0.3043±0.0040	0.2659±0.0074	0.1933±0.0114	0.2094±0.0131	0.2392±0.0085
^{226}Ra	0.1018±0.0106	0.1295±0.0045	0.0684±0.0074	0.0690±0.0072	0.0568±0.0083
^{232}Th	0.0463±0.0041	0.0256±0.0012	0.0974±0.0031	0.0872±0.0026	0.0749±0.0033

Table 5: The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in soil and sediment samples.

Radioisotope	Activity Concentration (*Bq*/*kg*)				
	Abbayo Quarters	Unguwar Baka I	Unguwar Baka II	Pindiga Dam	Piyau Dam
^{40}K	195.8387±0.2574	171.1175±0.4773	124.3565±0.7347	134.7598±0.8419	153.9039±0.5470
^{226}Ra	48.8175±5.1934	62.0805±2.1572	32.7980±3.5554	33.0777±3.4356	27.2052±3.9949
^{232}Th	21.8220±1.9266	12.0709±0.5505	45.9638±1.4548	41.1276±1.2189	35.3477±1.5334

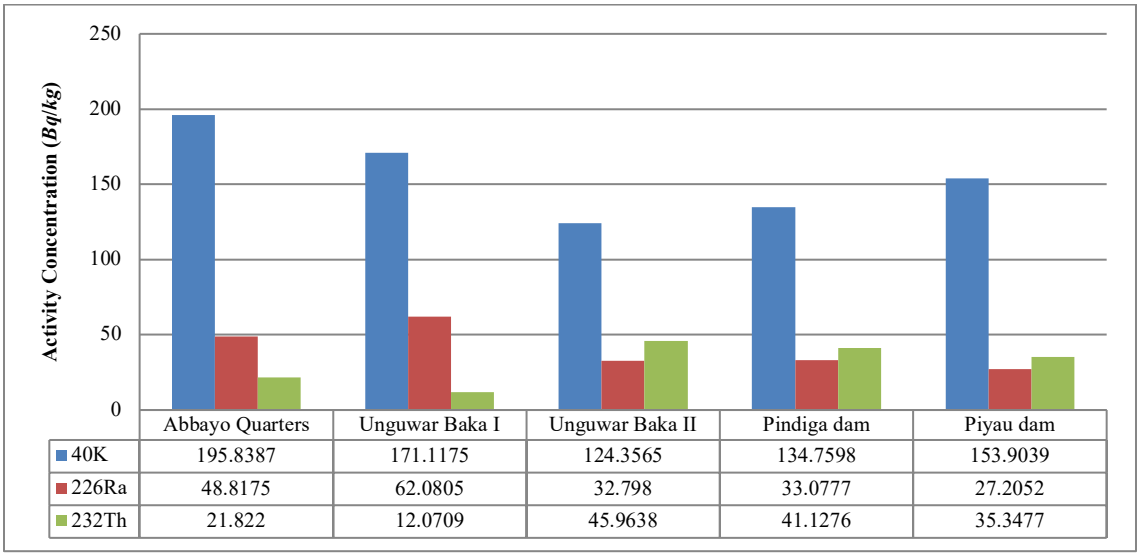

Fig.1: The variation of activity concentration of ^{40}K, ^{226}Ra and ^{232}Th with different sampling locations.

It can be observed from Figure 1 that the activity concentration of ^{40}K is highest at Abbayo Quarters and lowest in Unguwar Baka II. Unguwar Baka I showed the highest concentration of ^{226}Ra and lowest concentration of ^{232}Th. The lowest concentration of ^{226}Ra occurred at Piyau Dam.

The average world average activity concentration of ^{40}K, ^{226}Ra and ^{232}Th are 400 *Bq/kg*, 35 *Bq/kg* and 30 *Bq/kg* respectively. As shown in Table 5, the average activity concentration of ^{40}K, ^{226}Ra and ^{232}Th are 155.9953 *Bq/kg*, 40.79578 *Bq/kg* and 31.2664 *Bq/kg* respectively. It can be seen that the activity concentration of ^{40}K is below the reference level assigned by UNSCEAR while for ^{226}Ra and ^{232}Th are higher than the references levels.

Table 6: The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in the samples.

	Activity Concentration (*Bq/kg*)		
Radioisotope	**Maximum**	**Minimum**	**Average**
^{40}K	195.8387	124.3565	155.9953
^{226}Ra	62.0805	27.2052	40.79578
^{232}Th	45.9638	12.0709	31.2664

The conversion factors λ calculated from equation (3) for each radionuclide has been listed in Table 7. Table 8 showed the measured activity concentration of ^{40}K vary from 0.47942 *ppm* to 0.75499 *ppm* with an average value of 0.60139 *ppm*, the concentration of ^{226}Ra vary from 7.9771 $\times 10^{-7}$ *ppm* to 1.8203 $\times 10^{-6}$ *ppm* with an average value of 1.1962 $\times 10^{-6}$ *ppm* and the concentration of ^{232}Th vary from 2.97209 *ppm* to 11.3172 *ppm* with an average value of 7.69841 *ppm*.

Table 7: The values of λ for ^{40}K, ^{226}Ra and ^{232}Th radionuclides.

Radionuclides	$T_{1/2}$ **(years)**	M_w **(*g/mol*)**	**λ**
^{40}K	1.277×10^{9}	39.96399	3.8552×10^{-3}
^{226}Ra	1.600×10^{3}	226.02541	2.9322×10^{-8}
^{232}Th	1.405×10^{10}	232.03806	2.4622×10^{-1}

Table 8: The activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in converted in *ppm*.

Sample Location	**Activity Concentration in *ppm***		
	^{40}K	^{226}Ra	^{232}Th
Abbayo Quarters	0.7550	1.4314×10^{-6}	5.3730
Unguwar Baka I	0.6597	1.8203×10^{-6}	2.9721
Unguwar Baka II	0.4794	9.6990×10^{-7}	11.317
Pindiga Dam	0.5195	9.6170×10^{-7}	10.126
Piyau Dam	0.5933	7.9771×10^{-7}	8.7033

Average	0.6014	1.1962×10^{-6}	7.6984

The measured absorbed radiation dose rate in the air at 1 *m* above the ground (average gonadal height) is presented in Table 9. The values of absorbed dose rate delivered by ^{40}K, ^{226}Ra and ^{232}Th as shown in Table 9, ranges from 41.6655 *nGy/h* in Piyau Dam to 49.8049 *nGy/h* in Unguwar Baka II. The average absorbed dose produced by ^{40}K, ^{226}Ra and ^{232}Th are 44.8572 *nGy/h*. This is below the reference level 51 *nGy/h* assigned by UNSCEAR, (2000).

Table 9 showed the values of Annual Effective Dose Rate (A_E) ranged between (91.6838 *μSv/y*) in Unguwar Baka II to (76.7003 *μSv/y*) in Piyau Dam with the mean value of (82.57571 *μSv/y*). The present study have shown that the values of A_E in the soil and sediment sample of Pindiga were less than 1000 *μSv/y* recommended by UNSCEAR, (2000).

It can be observed from Table 9 that the Radium Equivalent Activity (Ra_{eq}) of ^{40}K, ^{226}Ra and ^{232}Th is comparable high, 108.1017 *Bq/kg*, in Unguwar Bka II, while the Ra_{eq} value is comparably low of value 89.60301 *Bq/kg* in Piyau Dam. The average value of 97.51838 *Bq/kg* was found in Pindiga. Thus, the values of Ra_{eq} of ^{40}K, ^{226}Ra and ^{232}Th found in the soil and sediment sample of Pindiga were less than the upper limit of Ra_{eq} is 370 *Bq/kg* [35].

Table 9: The measured values of Absorbed Gamma Dose Rate (D_γ), Annual Effective Dose Rate (A_E) and Radium Equivalent Activity (Ra_{eq})

Sample Location	D_γ**(nGy/h)**	A_E**(μSv/y)**	Ra_{eq}**(Bq/kg)**
Abbayo Quarters	43.7515	80.5404	95.10254
Unguwar Baka I	41.8915	77.1164	92.51793
Unguwar Baka II	49.8049	91.6838	108.1017
Pindiga Dam	47.1723	86.8376	102.2667
Piyau Dam	41.6655	76.7003	89.60301
Average	44.8572	82.57571	97.51838

The information on measured values of absorbed gamma dose rate, annual effective dose rate and radium equivalent activity presented on Table 9 was depicted using figure 2.

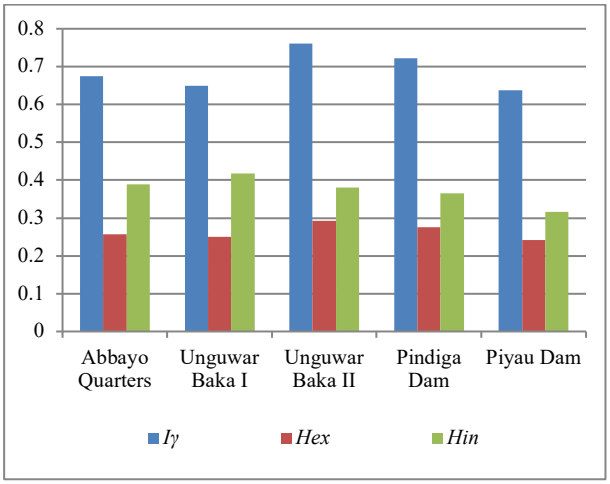

Fig. 2: The plots of The measured values of Absorbed Gamma Dose Rate (D_γ), Annual Effective Dose Rate (A_E) and Radium Equivalent Activity (Ra_{eq}).

Figure 2 showed the highest value of absorbed gamma dose rate (D_γ), annual effective dose rate (A_E) and radium equivalent activity (Ra_{eq}) in Unguwar Baka II, while Piyau Dam has the lowest value of absorbed gamma dose rate (D_γ), annual effective dose rate (A_E) and radium equivalent activity (Ra_{eq}).

Table 10 showed the highest value of gamma representative index (I_γ) of 0.7612, found in Unguwar Baka II, while the lowest value of I_γ is 0.6374 and was found in Piyau Dam. The average value of I_γ calculated from this study was 0.6886 and is below the recommended value of one (1) given by UNSCEAR, (2000). The values of external hazard indices (H_{ex}), due to gamma radiation, calculated from equation (9) showed the highest value of 0.2919 in Unguwar Baka II and the lowest value of 0.2420 in Piyau Dam, H_{ex} has the average value of 0.2634. The Table also showed the values of Internal Hazard Indices (H_{in}) ranging from 0.4177 in Unguwar Baka I to 0.3155 in Piyau Dam and the average value of H_{in} is 0.3737. It can be observed that all the radionuclides in the soil and sediment samples of Pindiga has the values of H_{ex} and H_{in} that is less than the value of one ($H_{ex} > 1$; $H_{in} > 1$) as recommended by UNSCEAR, (2000).

Table 10: The measured values of Gamma representative index (I_γ), External Hazard Indices (H_{ex}) and Internal Hazard Indices (H_{in}).

Sample Location	I_γ	H_{ex}	H_{in}
Abbayo Quarters	0.6742	0.2569	0.3889
Unguwar Baka I	0.6486	0.2499	0.4177

Unguwar Baka II	0.7612	0.2919	0.3806
Pindiga Dam	0.7216	0.2762	0.3656
Piyau Dam	0.6374	0.2420	0.3155
Average	0.6886	0.26341	0.3737

Figure 3 showed the highest value of gamma representative index (I_γ) of the radionuclides ^{40}K, ^{226}Ra and ^{232}Th in the entire sample collected from Pindiga, while External Hazard Indices (H_{ex}) shoed the lowest values.

A comparison of the results of activity concentration of ^{40}K, ^{226}Ra and ^{232}Th obtained from some selected areas of Pindiga, present study and other countries are showed in Table 11

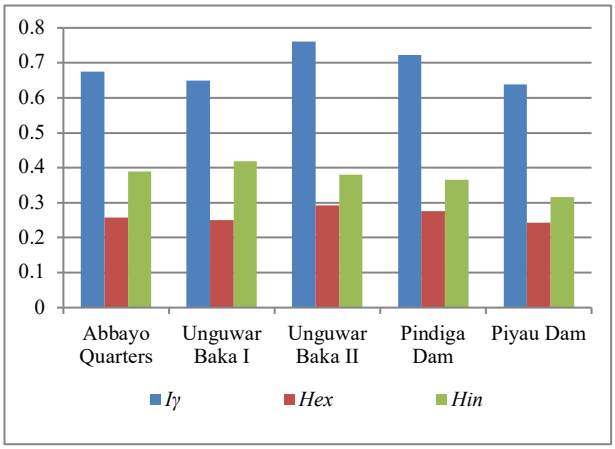

Fig. 3: The measured values of gamma representative index, external hazard indices and internal hazard indices.

Table 11: Comparison of the average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th obtained in present study with that reported for other country.

Country	**Activity Concentration in *Bq/kg***			**Reference**
	^{40}K	^{226}Ra	^{232}Th	
Nigeria	974.7±6.8	-	110.3±24.8	[9]
Nigeria	403.63±7.2	32.52±4.65	56.23±2.3	[39]
Nigeria	125.94±1.55	-	12.48±0.03	[2]
Nigeria	27.38	8.18	6.97	[38]
Nigeria	337.08	-	10.28	[33]
Nigeria	147.6	-	7.86	[29]
Libya	517.92	66.32	56.07	[40]
India	298.47	-	17.64	[39]
India	940+742	20+14	114+97	[41]
Palestine	113.3	-	19.5	[12]
Iraq	170.206	-	15.505	[42]
Nigeria	155.9953	40.79578	31.2664	[Present Study]
UNSCEAR	400	35	30	[11]

4 Conclusions

The results showed that the activity concentration of ^{40}K in the study area is below the reference level, 400 *Bq*/*kg* assigned by United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR, (2000) while ^{226}Ra and ^{232}Th have the activity concentration higher than the UNSCEAR references levels of 35 *Bq*/*kg* and 30 *Bq*/*kg* respectively. The calculated value of the average absorbed dose produced by ^{40}K, ^{226}Ra and ^{232}Th is 44.8572 *nGy*/*h*. This value is below the 51 *nGy*/*h* recommended by UNSCEAR, (2000). Other parameters (Gamma representative index, External Hazard Indices and Internal Hazard Indices) calculated from the present work were found to be less than the value of one ($I_\gamma > 1$; $H_{ex} > 1$; $H_{in} > 1$) as recommended by UNSCEAR, (2000) and hence will pose relatively none series health risk due to ^{40}K, ^{226}Ra and ^{232}Th exposure. These results are of great importance for exploring the health risks due to activity concentrations of radionuclides (to ^{40}K, ^{226}Ra and ^{232}Th) in soil and in sediments of mining area of Gombe and may pave the road to a baseline for future changes in environmental radioactivity due to naturally occurring radioactive materials and human activities in Pindiga.

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