International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

ASSESSMENT OF RADIATION LEVEL IN RIVER WATER OF BONNY LOCAL GOVERNMENT AREA OF RIVERS STATE, NIGERIA.

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ABSTRACT :

The activity concentration of naturally occurring radionuclides (potassium-^{40}K, radium-^{226}Ra, and thorium- ^{232}Th in twenty samples of river water from Bonny Local Government Area of Nigeria was investigated using sodium iodide (NaI(TI)). The obtained results indicate that the mean activity concentrations were 311.35 ± 135.38 Bq/L, 21.93 ± 16.41 Bq/L, and 448.89 ± 78.46 Bq/L of ^{40}K, ^{226}Ra, and ^{232}Th respectively. These mean values exceeded the World Health Organization's (WHO) safety standards, indicating possible radioactive dangers. The absorbed dose rate, excess lifetime cancer risk, and annual gonadal equivalent dose were determined and compared to international acceptable standards. The mean absorbed dose rate of 287.94 mSv/y much exceeds the world standard limit of 1.5 mSv/y [1] while the excess lifetime cancer risk and annual gonadal equivalent dose are likewise above acceptable limits. Also, the committed effective dose for children of different age groups mean values were above 0.1 mSv/y (WHO's recommended limit), indicating potential health risks due to lengthened exposure.

Key words: River water, Committed effective dose, Activity concentration, Annual gonadal equivalent dose

INTRODUCTION

Human health, farming and commerce requires water as an essential resource. River water can be significantly affected by the presence of contaminants, including radionuclides. Radionuclides can have access into natural processes and human activities including disposal of radioactive waste improperly. Researches have shown that produced water contains an elevated concentration of ^{226}Ra and ^{228}Ra and is normally discharged with body of river waters. [2][3]. Consumed radioactive contaminant like ^{226}R. ^{40}K overtime accumulates in the body, increasing the chances of having cancer, organ damage etc. Having an understanding of behaviour, health impact and sources of radionuclides in river water is very important for developing remediation and monitoring strategies.

Coastal areas can be described as places surrounding bays, estuaries, or other waterways that are prone to tidal action and may experience flooding or increasing flood levels as a result of tidal actions, hurricanes surge or rising water caused by storms etc. However, coastal environments are extremely sensitive to environmental threats such as coastal erosion, pollution, and extreme weather occurrences. Effective management and conservation efforts are critical for preserving a balance between human usage and the preservation of these unique and vulnerable ecosystems.

This work investigates the determination of activity concentrations of radionuclides in river water samples, statistical analysis of the data acquired, and assessment of radiological health risk factors to the public associated with exposure to samples collected.

2. MATERIALS AND METHODS

2.1 Study Area

Bonny is a coastal town and island located in Rivers State, southern Nigeria, within the Niger Delta region. It lies on the Atlantic coast and is bordered by the Bonny River, which connects it to Port Harcourt, the capital of Rivers State. Positioned at approximately 4.43°N latitude and 7.17°E longitude, Bonny serves as an important maritime and industrial hub [4][5].

The town is historically significant as a former center of trade and is now home to the Nigeria Liquefied Natural Gas (NLNG) plant, making it a key player in Nigeria's oil and gas sector. Surrounded by creeks and mangrove forests, Bonny is also known for its rich cultural heritage, fishing activities, and vibrant local traditions. However, like many coastal areas, it faces challenges such as coastal erosion, environmental pollution, and limited infrastructure, necessitating efforts for sustainable development.

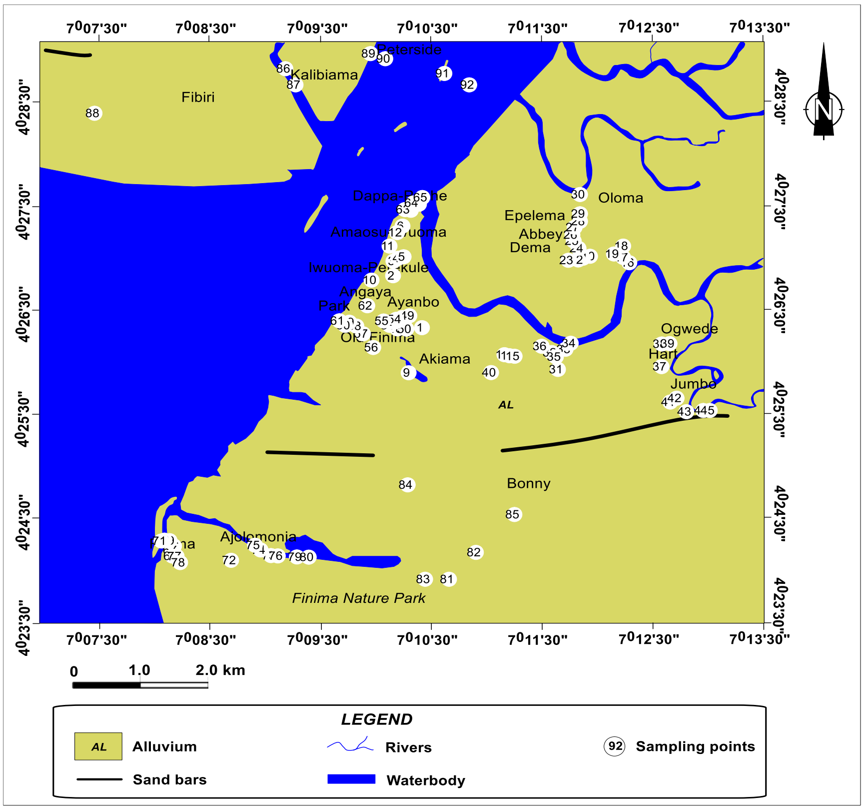


Fig. 1: Map of Bonny Island showing sampling points

2.2 Sampling

River water samples were collected from various locations in Bonny bottle. The bottles were carefully filled with water, ensuring that there was no bubble, after which they were tightened with a cap. The locations of sampling were recorded. The river water samples, locations and descriptions are displayed in Table 1.

Table 1: Details of sampling locations of Bonny River and collection plan.

S/N	Community	Water Site Code	Samples
1	Fibiri	WAF 2	**1**
2	Peterside	WAP 1	**1**
3	Light House	WALH 1	**1**
4	Park Community 1	WAPC 1	**1**
5	Park Community 2	WAPC 2	**1**
6	Agaya	WAAG	**1**
7	Oloma	WAO 1	**1**
8	Hart/LongJohn	WAL 1	**1**
9	Main Bonny Town	WAMB 1	**1**
10	Minima	WAM 1	**1**
11	Abalamabie	WAAB 1	**1**
12	Akiama	WAAK 1	**1**
13	Ajolomonia	WAAJ 1	**1**
14	Iwuoma	WAOG 1	**1**
15	Ayanbo 1	WAAY 1	**1**
16	Epelema	WAE 1	**1**
17	Kalabiama	WAK 1	**1**
18	Dappa-Poshe	WAAD-P	**1**
19	Ayanbo 2	WAAY 2	**1**
20	New Finima	WAFM 2	**1**

Sodium iodide NaI(TI) spectrometer was used to perform spectrometric analysis on twenty (20) river water samples. Before counting using a sodium iodide NaI(TI) detector, 200 ml of each water sample was placed into a 200 ml Marinelli beaker for gamma spectrometry and sealed for four weeks (30 days) to achieve secular equilibrium between the thorium and radium content of the sample and their daughters [6]. Each sealed sample was placed on the sodium-iodide detector and counted for 10800 seconds. The gamma-ray counting of the samples as performed on a lower gamma-ray spectrometer consisting of a detector called sodium iodide Thallium activated Canberra vertical high purity 2″×2″ Sodium iodide [NaI(TI)] coupled to ORTECMestro Software. which amplifies the incoming signals and integrates them to volts (0-10volts). The detector was shielded by 15cm thick lead on all four sides and 10cm thick on top. The standard International Atomic Energy Agency (IAEA) sources were used for calibration [7]. From the counting spectra, the activity concentrations of Uranium ^{238}U, Thorium ^{232}Th and Potasium ^{40}K was determined using the computer program [4].

An essential requirement for the measurement of gamma emitters is the exact identity of photo peaks present in a spectrum produced by the detector system. The energy calibration of detector system is made by measuring mixed standard sources of known radionuclide with well- defined energies provided by the IAEA Technology.

The specific activity concentrations (equation 1) of the samples were determined using the net area under the photo peaks from the energy and efficiency calibration.

$$C\ (BqKg^{-1}) = K\ C_n \qquad (1)$$

Where C ($BqKg^{-1}$) is the specific activity concentration of the radionuclide in the sample, C_n is the count rate under the corresponding peak, $K = 1/_\varepsilon P_\gamma M_s$, $_\varepsilon$ is the detector efficiency at the specific gamma ray energy, P_γ is the absolute transition probability of the specific gamma ray and M_s is the mass of the sample [8].

The peak corresponds to 1460 kev for ^{40}K, 1764.5 Kev (Bi-214) for ^{238}U and 2614.5 kev (Ti-208) for ^{232}Th were considered in arriving at the activity levels (Bqkg^{-1}). The activity concentration (C) of the radionuclide was calculated after subtracting decay correction using the following expression [9][10];

$$C_S \frac{C_S}{P_\gamma (M_s/V_s)\varepsilon_\gamma t_c}\left(BqKg^{-1}\right) \qquad (2)$$

Where Cs = Sample concentration, Ca= net peak area of a peak at energy, εγ= Efficiency of the detector for a γ-energy of interest, Ms/Vs= Sample mass/volume for soil/water, tc= total counting time, Pγ is the abundance of the γ-line in a radionuclide.

It has been noted that the natural radionuclides ^{40}K, ^{232}Th, and ^{226}Ra in water differ depending on the location. Therefore, the following formula was used to determine the radiation dangers associated with these radionuclides in river water.

Calculation of Radiation Hazard Indices

Table 2: Formulas for Calculating Radiation hazard risk of Community Drinking Water Implication [1][6][11]

S/N	Hazard Index	Formulas	
1	Absorbed Dose Rate (D)	$D\ (nGyh^{-1}) = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_K$	(3)
2	Annual Effective Dose Equivalent (AEDE)	AEDE ($mSvyr^{-1}$) = D(nGyrh-1) × 8760 h × 0.7Sv/Gy ×0.2	(4)
3	Annual Gonadal Equivalent Dose (AGED)	AGED (μSvy^{-1}) = 3.09 A_{Ra} + 4.18 A_{Th}+ 0.314 A_K	(5)
4	Excess Lifetime Cancer risk	Excess lifetime cancer risk (ELCR) = AEDE×DL×RF	(6)
5	Committed Effective Dose	$C_D = 50 \times E_D$	(7)

Where all parameters retained their usual meaning: D = absorbed dose rate, for AEDE the following constant values are 0.7 Sv/Gy conversion coefficient and 0.2 for outdoor factor of occupancy [1][12]. Where, AEDE is the annual effective dose rate. Also, for ELCR, AEDE is the annual effective dose Equivalent, DL is Duration of life (70 years) and RF is risk factor (Sv^{-1}), fatal cancer risk. ICRP 60 uses values of 0.05 for the public exposure [13][14][15][16]. For AGED, a gonad is a reproductive gland that produces gametes (sperm or eggs) and hormones. In males, the gonads are the **testes**, and in females, they are the **ovaries**. Gonads play a crucial role in sexual reproduction and hormone production, such as testosterone in males and estrogen/progesterone in females. An increase in Annual Gonadal Equivalent Dose (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 [Amiri, M. *et al*., 2011]. A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K,

respectively. The Committed Effective Dose to an individual (evaluated here for six age group of ≥1yr, 1yr, 5yrs, 10yrs, 15yrs and >15yrs age group for adults) over an average life span of 50yrs was estimated. Where E_D is the annual effective dose. The committed effective dose to the individuals in the space of 50years [17]

RESULTS AND DISCUSSION

ACTIVITY CONCENTRATION IN RIVER WATER (Bql^{-1})

The results of the activity concentrations of radionuclides ^{40}K, ^{226}Ra and ^{232}Th are presented in Table 3 while the comparison of the calculated radiation hazard indices with standards are presented in Table 4. Table 5 shows total committed effective dose in river water for different age group. Figure 5 shows the comparison of committed effective dose of all the age bracket in river water with standard in all the locations while Figure 6 shows the percentage distribution of the total effective dose of different age group in river water.

Table 3: Gamma Activity Concentration Results for River Water Bonny Local Government Area, Rivers State.

		ACTITIVY CONCENTRATION		
S/N	**LOCATION**	**^{40}K (Bq/l)**	**^{226}Ra (Bq/l)**	**^{232}Th (Bq/l)**
1	WAAB 1	244.12	24.40	331.17
2	WAAD-P	401.91	11.48	464.54

3	WAAG	352.54	27.06	495.05
4	WAAJ 1	242.18	11.56	375.25
5	WAAK 1	111.49	5.35	212.49
6	WAAY1	397.07	2.25	497.31
7	WAAY 2	87.29	29.28	480.36
8	WAE 1	202.49	11.48	466.80
9	WAF 2	277.03	55.86	bdl
10	WAFM 1	468.71	24.40	498.45
11	WAK	341.89	29.72	551.57
12	WAL 1	36.95	7.57	437.41
13	WALH 1	367.06	28.83	446.45
14	WAM 1	195.71	11.48	501.84
15	WAMB 1	432.89	51.43	375.25
16	WAO 1	556.80	11.48	490.53
17	WAOG 1	324.47	11.48	431.76
18	WAP 1	343.83	55.86	489.40
19	WAPC 2	438.70	7.12	470.19
20	WAPC 1	403.85	20.42	513.14
	Mean	**311.35±135.38**	**21.93±16.41**	**448.89±78.46**
	WHO STD	**10**	**0.5**	**0.2**

bdl = below detectable limit

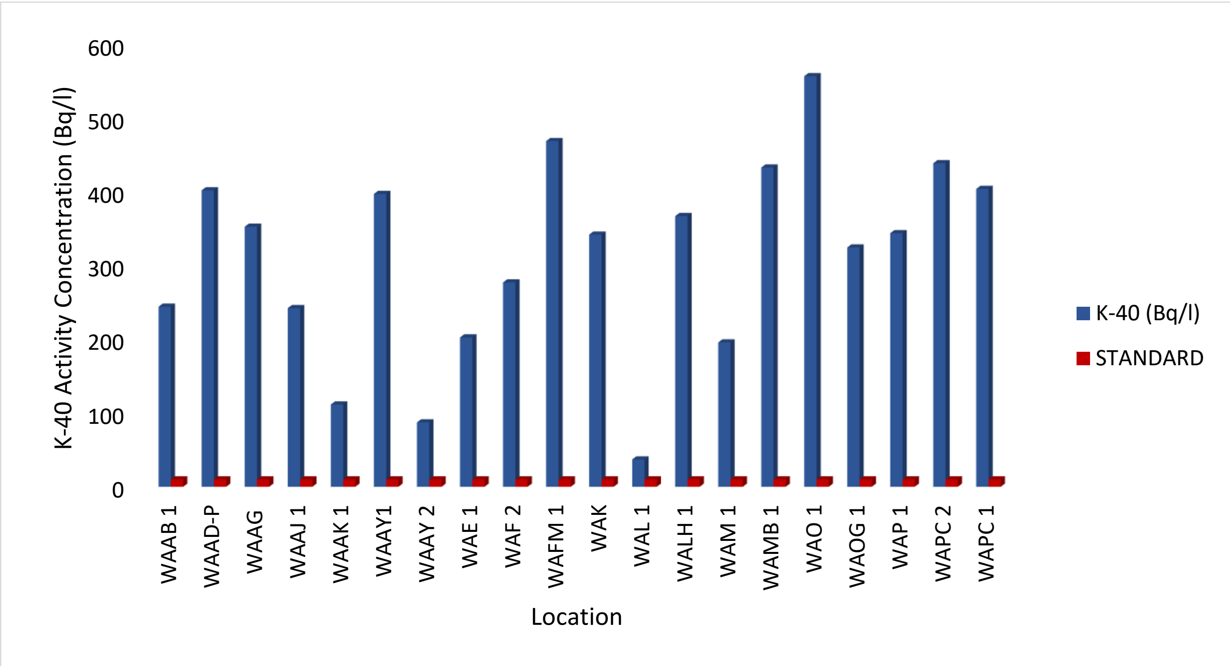


Fig. 2: Comparison of ^{40}k activity concentration (Bql^{-1}) in river water with standard in all the locations.

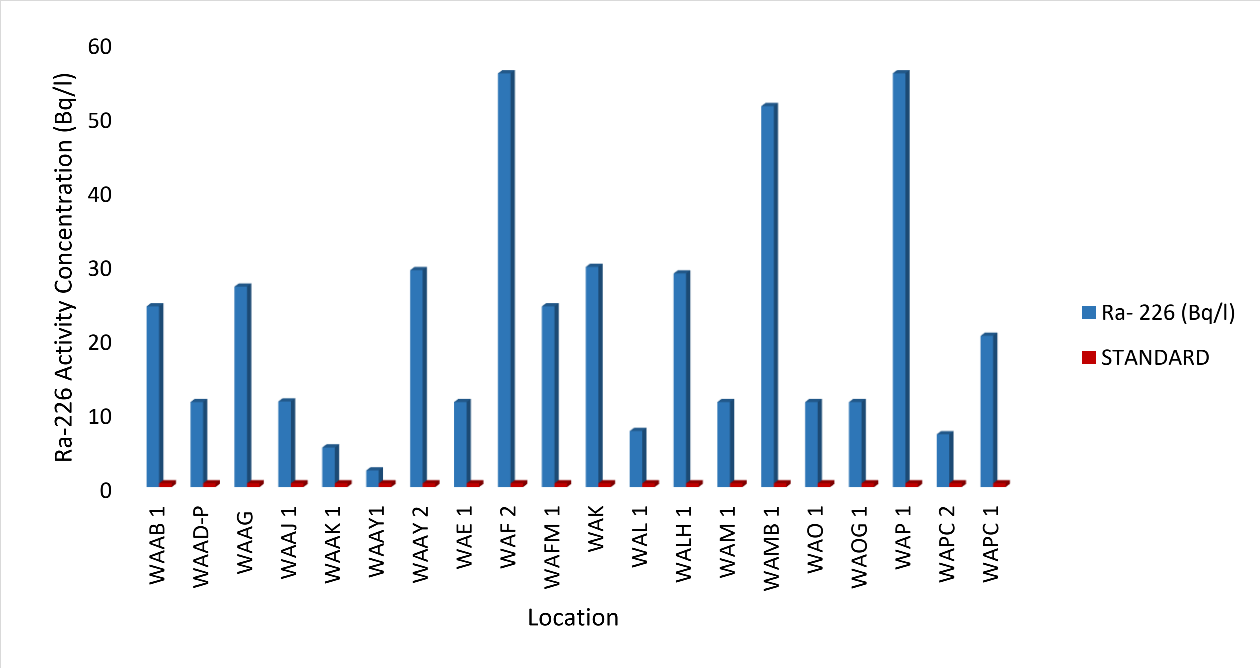


Fig. 3: Comparison of ^{226}Ra activity concentration (Bql^{-1}) in river water with standard in all the locations.

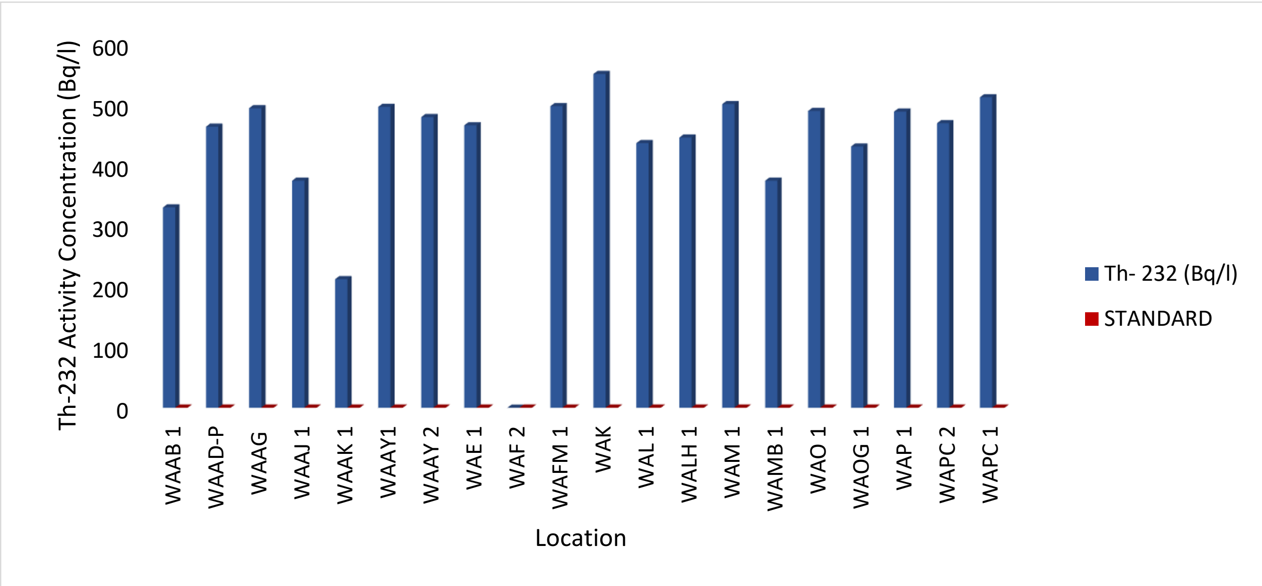


Fig. 4: Comparison of ^{232}Th activity concentration (Bql^{-1}) in river water with standard in all the locations

Table 4: Calculated Radiation Hazard Indices in River Water

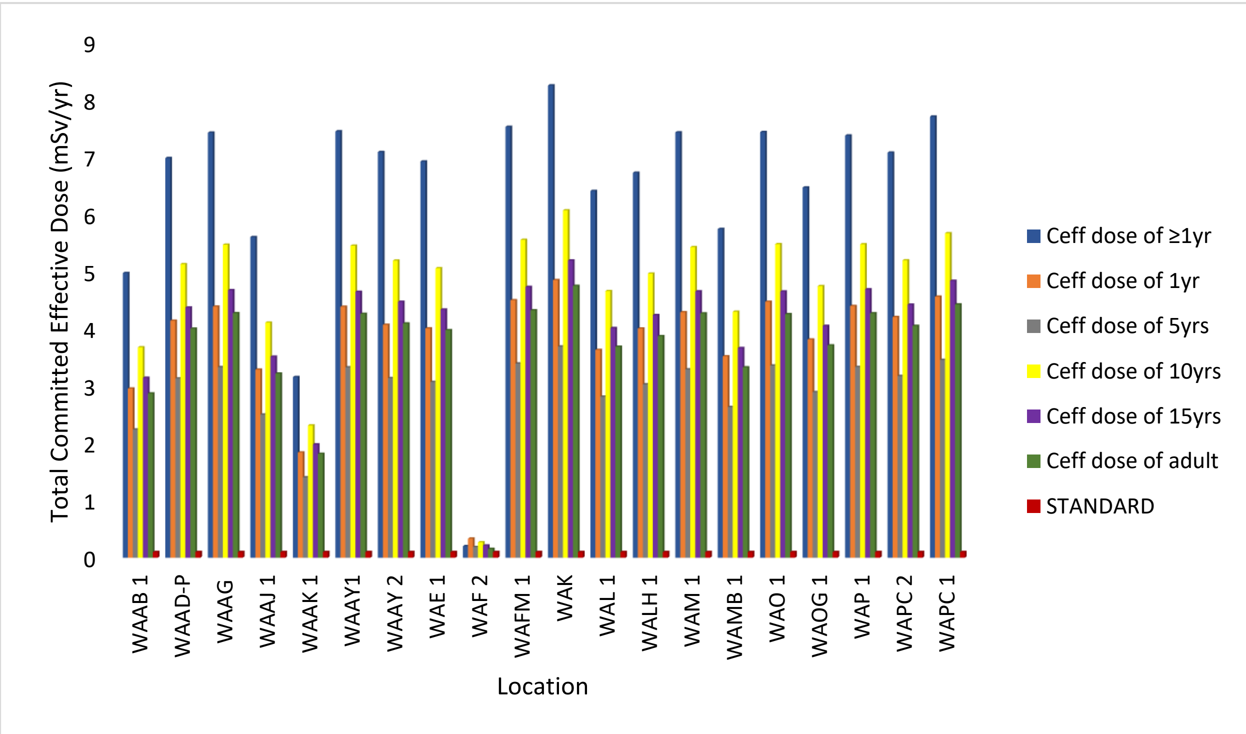
Location	D (nGyh^{-1})	AEDE (mSvy^{-1})	Gonadal (mSvy^{-1})	ELCR x 10^{-3}
WAAB 1	227.11	0.70	1.54	0.97
WAAD-P	310.54	0.95	2.10	1.33
WAAG	334.63	1.03	2.26	1.44
WAAJ 1	248.47	0.76	1.68	1.07
WAAK 1	139.08	0.43	9.40	0.60
WAAY1	326.43	1.00	2.21	1.40
WAAY 2	315.47	0.97	2.17	1.35
WAE 1	303.63	0.93	2.05	1.30
WAF 2	37.36	0.11	2.61	0.16

WAFM 1	340.35	1.04	2.31	1.46
WAK	370.51	1.14	2.50	1.59
WAL 1	276.67	0.85	1.86	1.19
WALH 1	305.88	0.94	2.07	1.31
WAM 1	325.11	1.00	2.19	1.40
WAMB 1	274.84	0.84	1.86	1.18
WAO 1	333.15	1.02	2.26	1.43
WAOG 1	286.96	0.88	1.94	1.23
WAP 1	344.06	1.05	2.33	1.48
WAPC 2	313.57	0.96	2.13	1.35
WAPC 1	344.93	1.06	2.33	1.48
Mean	**287.94**	**0.88**	**2.49**	**1.24**
UNSCEAR (2000)	**57**	**1**	**0.3**	**0.29**

Table 5: Total Committed Effective Dose in River water for different Age Group

Location	≥1	1yr	5yrs	10yrs	15yrs	Adult
WAAB 1	4.982040	2.960265	2.24451	3.68180	3.149292	2.87547
WAAD-P	6.987622	4.148228	3.13803	5.13634	4.378477	4.00961
WAAG	7.429645	4.395122	3.33678	5.47460	4.681346	4.28021
WAAJ 1	5.608277	3.292650	2.50657	4.11558	3.519564	3.22398
WAAK 1	3.162080	1.842246	1.40782	2.31538	1.982979	1.81787
WAAY1	7.452082	4.393483	3.33206	5.45807	4.65365	4.26851
WAAY 2	7.092090	4.075989	3.14450	5.19871	4.479106	4.10047
WAE 1	6.926000	4.013936	3.07604	5.06564	4.343785	3.98345
WAF 2	0.202814	0.334681	0.18773	0.27010	0.213457	0.15444
WAFM 1	7.530877	4.506190	3.39908	5.55901	4.738011	4.33060
WAK	8.253079	4.856895	3.69756	6.07433	5.200574	4.75659
WAL 1	6.413401	3.637133	2.81917	4.66631	4.020132	3.69286
WALH 1	6.729222	4.010996	3.03449	4.97144	4.246222	3.87840
WAM 1	7.434341	4.296492	3.29725	5.43330	4.661628	4.27606
WAMB 1	5.749710	3.526157	2.63788	4.30504	3.669983	3.33263
WAO 1	7.440660	4.480445	3.36344	5.48500	4.658658	4.26289
WAOG 1	6.472322	3.819681	2.89898	4.75264	4.057899	3.71691
WAP 1	7.379793	4.405102	3.33939	5.48212	4.697789	4.27810
WAPC 2	7.082017	4.213289	3.18186	5.20279	4.429589	4.05821
WAPC 1	7.709530	4.568411	3.46225	5.67387	4.844344	4.43272
Mean	**6.40188**	**3.78887**	**2.87527**	**4.71610**	**4.031324**	**3.68650**

Fig. 5: Comparison of committed effective dose ($mSvy^{-1}$) of all the age bracket in river water with standard in all the locations.



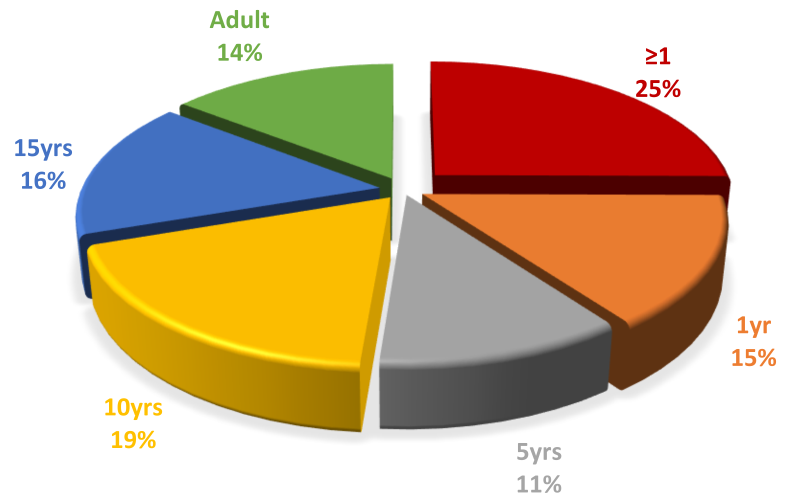


Fig 6: Percentage distribution of Total Effective Dose of different age group in River water

Three naturally occurring radionuclides ^{40}K, ^{226}Ra and ^{232}Th were determined in all the samples (river water) and the results are as shown in Table 3. The mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in river water from the studied area are 311.35 ± 135.38 Bql^{-1}, 21.93±16.41 Bql^{-1} and 448.89 ± 78.46 Bql^{-1} respectively. The highest contribution of activity concentration in river water is 448.89±78.46 (^{232}Th) while the lowest concentration is 21.93±16.41 (^{226}Ra). The obtained mean values of river water of ^{40}K, ^{226}Ra and ^{232}Th, when compared with WHO standard, all exceeded the standard values limit of 10 Bql^{-1}, 0.5 Bql^{-1} and 0.2 Bql^{-1} for ^{40}K, ^{226}Ra and ^{232}Th respectively as shown in Table 3. From the obtained results, the mean values exceeded that reported by results of [18] and [19]. The high concentrations of the obtained results can be attributed to the geological formation of the area and also to drilling chemical (drilling mud), well logging etc used during oil and gas exploration, exploitation and production by the companies operating and the spilling of fuel on river water during filling of boat engines used for transportation in the studied area. The absorbed dose rate was calculated using equation 3. The samples have their mean result as 287.94 $nGyh^{-1}$. The obtained results when compared with standard of 57 $nGyh^{-1}$ [1] as shown in Table 4 revealed that the mean values of all the absorbed dose rate in all the Communities are all higher than world standard limit. This can also be attributed to drilling chemical, well logging equipment etc used during oil and gas activities and the maritime activities in the area. Table 4 shows the mean results of the calculated excess lifetime cancer risk as 1.24 x 10^{-3}. When compared with permissible allowed world average standard (0.29 x 10^{-3}) [13][20], it was observed that the obtained mean is higher than the standard. Table 4 shows the mean result of the calculated annual gonadal equivalent dose as 2.49 $mSvy^{-1}$. When compared with permissible allowed world average standard of 0.30 $mSvyr^{-1}$ [21], it was observed that the obtained values of all samples are higher than the world allowable average. This could be attributed to the high activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th that are present in the measured samples. These high concentrations pose significant threat to both human system and the environment. Also, the committed effective dose of river water for different age group (≥1yr, 1yr, 5yrs, 10yrs, 15yrs and adults) was calculated using equation 7 from ^{40}K, ^{226}Ra, ^{232}Th. The total committed effective dose values obtained when compared with [22] standard of 0.1 $mSvy^{-1}$ are above the maximum permissible limit therefore contact with the samples can lead to radiation dose intake. The high dose values could be attributed to the activities of oil and gas companies operating in the area. This is also illustrated in Figure 6 showing the percentage distribution of total effective dose of different age group in river water

CONCLUSION

The study assessed the activity concentrations of naturally occurring radionuclides ^{40}K, ^{226}Ra, and ^{232}Th in river water from Bonny Local Government Area of Rivers State, Nigeria, revealing significantly high levels that exceeded WHO safety limits. The mean concentrations of these radionuclides, along with the calculated absorbed dose rate, excess lifetime cancer risk, and annual gonadal equivalent dose, were all above internationally recommended thresholds, indicating potential radiological health risks. The committed effective dose across different age groups also surpassed the WHO permissible limit of 0.1 mSv/y, suggesting a heightened risk of radiation exposure for individuals consuming or coming into contact with the river water.
The elevated radiation levels can be attributed to the geological composition of the area and human activities such as oil and gas exploration, the use of drilling chemicals, well-logging operations, and fuel spills from maritime transport. These findings highlight the urgent need for environmental monitoring, regulatory intervention, and remediation strategies to mitigate the adverse health and ecological effects of radioactive contamination in the region's water bodies.

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Consent

It is not applicable.

Ethical Approval

It is not applicable.

Competing Interests

Authors have declared that no competing interests exist.