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Radiological Risk Assessment of Primordial Radionuclides in Catfish Samples from Commercial Fish Ponds In Osogbo, Osun State, Nigeria

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Abstract— Fish is a primary protein source for most residents of Osogbo and Nigeria. This study verified the possibility of radioactive contamination in the study region due to catfish consumption. Using gamma spectroscopic assembly, the activity concentrations of the primordial radionuclides Uranium-238 (U-238), Thorium-232 (Th-232) and Potassium-40 (K-40) were assessed in catfish. Thereafter, the committed effective dose resulting from catfish consumption was determined from the measured activity concentrations of U-238, Th-232 and K-40 for the residents of the research region. The projected yearly committed effective doses found in this investigation were less than the public's allowed limit of 1.0 mSv/y, according to the findings. This suggests there is no significant harm to the population's radiological health from the radiation dosage obtained from consuming the examined catfish samples. However, the long-term health risks, particularly from uranium and thorium, remain a concern due to their carcinogenic and mutagenic properties. To mitigate these risks, it is recommended to implement radionuclide monitoring programmes by regulatory bodies and to create public awareness regarding potential risks associated with consumption of fish with elevated radionuclide concentrations.

Keywords: Radionuclides, Gamma spectroscopic assembly, Radiation dose, Contamination, Catfish

1. Introduction

Naturally occurring radionuclides (U-238(Ra-226), Th-232 and K-40) as well as releases from agricultural chemicals, research and medical facilities account for the majority of radionuclides found in water (Mollah & Ferdous, 2025; Pelić et al., 2023). Both natural and artificial sources can contribute to the occurrence of radionuclides in polluted settings. Radionuclides are naturally produced by weathered bedrock. Because of mineral leaching, these radionuclides have the potential to pollute the environment and harm human health. Artificial radionuclides are created by human activity, mostly as a result of mining and milling mineral ore, research, medicine and agriculture.

Radiation from artificial radionuclide use and natural radionuclide decay are identified to cause or promote cancer in the tissues. In order to determine the presence of concentrations of dangerous contaminants discharged into the environment or in living things, natural radioactivity is usually investigated (Adeola et al., 2023; Michalik et al., 2023). The geology and geography of a particular region mostly dictate the levels of these radionuclides in different environmental components, whereas the geochemistry of each element influences its movement from the soil (Dowell, 2024; Widya et al., 2025). Every source of radionuclides in the environment contributes to radiation exposures for both people and the environment at large; hence they should all be assessed.

Radioactivity measurement in the environment in Nigeria, is a relatively new endeavour, with the majority of studies concentrating on soil related materials, water and foodstuffs (Esan et al., 2022; Muhammad et al., 2024). The aquatic biota contains both naturally occurring and man-made radionuclides (Al-Sharif et al., 2024). ^{40}K and ^{238}U are the two most prevalent radionuclides in aquatic environments. Because of insolubility of Th-232 in water, products of thorium decay series are found in low quantities in aquatic media (Santofimia et al., 2022). Despite extensive media coverage of the consequential effects of eating milk related meat, fish still plays a significant role in Nigerian diets. About 75% of the animal protein consumed in rural and fishing communities comes from fish. The geology of the study region is known to consist primarily of basement rocks, specifically schist and migmatites, accompanied by quartzite ridges that provide the distinctive undulating topography.

The buildup of radionuclides in catfish from radiation exposure as a result of radioactivity in their diet and in their natural environments is a rising source of worry. Numerous research conducted in Nigeria and across the world have looked at the radionuclide levels in fish and the possible health consequences of eating them. For example, Jibiri & Eke, (2022) study on the radionuclide concentrations in fish from Nigerian water bodies found detectable levels of 40K, Th-232, and U-238, which sparked worries about potential long-term health impacts. Similarly, research was conducted in various parts of the world. The concentration of naturally occurring radionuclides in aquatic species has been recorded throughout Europe and Asia, for instance, Asaduzzaman et al., (2024) highlighting the necessity of keeping an eye on radiation levels in areas where fish farming is practiced. A significant vacuum in localized data on radioactive concentrations in the area has been left by the paucity of research that have addressed Osogbo and its fish farming operations. By evaluating the radiation levels in Osogbo catfish, this study seeks to close that knowledge gap and advance knowledge of radionuclide contamination in farmed fish worldwide. Additionally, people of Osogbo, the capital of Osun State, consume a lot of fish as part of their daily diet, making it a quickly expanding metropolitan center. Because fish farming is so common in the area, it is a perfect place to research radiation exposure in fish. This study will give a more precise evaluation of radiation exposure in Osogbo by examining the levels of U-238, Th-232, and K-40 in cat fish. As a result, it will provide useful information for Nigerian public health and regulatory agencies. Research on the radiation levels in fish samples from the study area is therefore essential. The resulting internal radiation would be calculated using the information gathered. Consumption of catfish resulted in the residents receiving a certain dose of natural radionuclides. Finding out the population's health risk from ionizing radiation intake from fish resources in the research region will be made easier with the use of the data collected. This study aimed at evaluating the levels of naturally occurring radionuclide particles (U-238, Th-232 and K-40) in catfish and the potential risks of consuming them in fish farms located in Ososgbo, Osun State, Southwest Nigeria.

2. Methodology

2.1 Collection of Samples and Sample Preparation

Mature catfish (Clarias heterobranchus) samples- numbering to 140, were randomly selected from ten fish farms in the city of Osogbo. Fourteen samples of mature catfish were taken from each fish farm using fishing nets for the collection. The sampling method, which involved collecting fourteen (14) fish samples from each farm, was designed to ensure fair representation of each location. Ten (10) Farm locations were considered adequate for this study (Biswas et al., 2021). The samples were collected in plastic containers that were properly labeled with the sample location. After that, they were brought to the lab to be prepared. After being killed, the fish samples were rinsed with clean water to get rid of any dust or other debris that might have accidentally been collected.

To eliminate the water content, each sample was cut into pieces and oven dried at 80°C until the mass of the samples remained constant (Sadeghi et al., 2024). To create a fine powder, the dried samples were pulverized. In order to maintain the same geometry configuration for the gamma activity analysis, each powder sample was sieved through a 2 mm sieve and hermetically sealed in an uncontaminated cylindrical plastic container that was 70 x70 mm^2 in dimension. The samples were labeled appropriately.

The container was filled to a height of 70 mm with around 150 g of the prepared samples for the gamma activity assay. To prevent the distribution of decay products that produce gamma radiation in the space above the sample mass, the sample was made to occupy the whole container. Before gamma spectroscopy observations, the samples were stored in the sealed containers for a minimum of 28 days to give room to secular equilibrium between radon and its transient offsprings.

2.2 Measurements of radioactivity

A 7.62 × 7.62 cm^2 Sodium Iodide activated with Thallium (NaI(Tl)), type 802 detector in conjunction with a gamma ray spectrometric apparatus was used to do the gamma spectrometric measurement because of its higher detection efficiency over high-purity germanium (HPGe) detector (Hesham et al., 2024). The peaks of the radionuclides of interest are not too close to affect the sorting from NaI(Tl) detector (Chambon et al., 2024). The detector is encased in a large lead shield to lower background radiation from the system, and it is positioned vertically in conjunction with an 8K PC-based Multi-Channel Analyzer (MCA). Point sources ^{60}Co, ^{137}Cs, ^{241}Am and ^{22}Na were used to calibrate the detector's energy, and the International Atomic Energy Agency, IAEA-385 volume source was used to calibrate the detector's efficiency. Using Genie 2000 as its operational software, the detector was properly calibrated for investigations of different energies of ^{238}U, ^{232}Th and ^{40}K. To lower the statistical uncertainty, each sample was positioned symmetrically on top of the detector and counted for 10,800 seconds (Asaduzzaman et al., 2024; Wais et al., 2025). According to Nabil et al., (2024), the detector is with a sufficient lead shield, which has capacity to lower the background radiation. A pulverised standard sample, prepared from Rocketdyne Laboratories, California, USA which is traceable to a mixed standard gamma source (No 48722 – 356) by Analytics inc., Atlanta, Georgia was used in validation to ensure reliability of the results obtained. In order to calculate the level of background radiation of the laboratory setting, which was then subtracted from that of the observed sample, gamma counting was also carried out for an equivalent period of 10,800 seconds for the previously cleaned empty Marinelli beaker under identical geometry.

Gamma-ray lines of ^{214}Bi at 609.3 keV and ^{214}Pb at 351.9 keV were used to assess the particular activity of ^{226}Ra and gamma-ray lines of ^{212}Pb at 238.6 keV and ^{228}Ac at 911.1 keV were used to assess the specific activity of ^{232}Th. The 1460.8 keV gamma-ray line of ^{40}K was used to directly measure its specific activity and the relation shown in equation 3.1 was used to assess the activity concentrations in each sample. According to Mahdi et al., (2025) the radioactivity concentration of Ra-226, Th-232 and K-40 was computed in units of Bq/kg.

$$C = \frac{A}{mt\gamma\mathcal{E}} \quad (1)$$

Where:

C: Activity concentration of the radionuclide ($Bqkg^{-1}$)

A: Net area under the peak of the radionuclide

m: Mass of the sample (kg)

t: Counting time (sec)

γ: Gama yield of the detector

Ɛ: Detector efficiency

2.3 Determination of Effective Dose (D)

The effective dose (D) is calculated using the relation in equation 2, which is useful in estimating the internal radiation dose received by individuals of the study area in order to determine the eventual internal radiation dose received by the dwellers of the study area due to the consumption of catfish from the selected catfish farms. By evaluating the effective dose, the posed health challenge to the local population, arising from radiation exposure through catfish consumption, can be assessed. The overall dose from ingestion of catfish is determined by adding the individual doses from each radionuclide (K-40, Ra-226 and Th-232).

The formulae for the effective dose due to dietary intake is provided below (Billa et al., 2016)

$$D_{ingestion} = \sum\sum(C_f \; X \; M_f \; X \; H_j) \quad (2)$$

Where $D_{ingestion}$ (μSv) represents the effective dose, C_f (Bq/kg) is the radioactivity of radionuclide j in fish f, M_f (kg) is the average daily intake of fish f, and H_j is the effective dose coefficient. The dose coefficients for ^{40}K, ^{238}U and ^{232}Th are 6.2 x 10^{-9} Sv/Bq, 2.8 x 10^{-7} Sv/Bq, and 2.3 x 10^{-7} Sv/Bq, respectively. According to Food and Agricultural Organization (FAO), (2020), the average daily fish consumption rate in Nigerian is about 13.3 kg/y.

3. Results and discussion

3.1 Activity concentrations of 40K, 238U and 232Th in catfish

The activity concentrations of the primordial radionuclides (238U, 232Th and 40K) in catfish samples from selected fish ponds in Osogbo, Osun State, are summarised in Table 1 presented in colour-coded bars for easy comparison). It shows the mean and range of values for each radionuclide. From Table 1, it can be observed that 40K exhibits the highest mean activity concentration of 857.21±2.58 Bq/kg with Farm 7, whereas samples from Farm 3 had the lowest value at 370.83±2.57 Bq/kg. For 232Th, the highest mean activity concentration of 8.20±1.03 Bq/kg was noticed with fish from Farm 5, whereas Farm 4 had the lowest mean values of 5.61±1.01 Bq/kg. It is evident from the same Table 1 that the lowest of 238U was observed with Farm 6 and with value12.67±1.11 Bq/kg and Farm 10 exhibited its lowest value of 7.06±0.57 Bq/kg. The mean activity concentrations of 238U, 232Th and 40K in the catfish across all farms were 10.52±0.83 Bq/kg, 6.73±0.96 Bq/kg and 603.33±2.64 Bq/kg, respectively.

Comparing to similar studies, the mean activity concentrations in this study are notably higher than those reported in countries outside Nigeria, but they fall within the activity concentration ranges reported in other Nigerian studies. These comparisons are highlighted in Table 2, which illustrates the broader context of global radionuclide levels in aquatic life.

The heavy metals Uranium (238U) and thorium (232Th) are known to accumulate in fish tissues under specific environmental conditions. Uranium, in particular, is more toxic and carcinogenic, which poses significant health risks over prolong exposure, especially when accumulated through regular fish consumption. Thorium also presents environmental concerns, though its toxicity is less pronounced than uranium's. On the other hand, potassium (40K), which is essential for cellular functions, is more uniformly absorbed by fish and does not pose significant health concerns at the typical levels found in the environment.

Table 1: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th in Catfish from fish farms

Fish from farm	No	Statistics	Activity Concentration (Bq/kg)		
			^{238}U	^{232}Th	^{40}K
Farm 1	14	Range	10.91 – 12.22	6.14 – 9.25	330.46 – 443.71
		Mean	11.67±1.10	7.04±1.01	383.41±1.40
Farm 2	14	Range	10.87 – 13.53	5.05 – 7.12	434.63 – 572.62
		Mean	12.06±1.22	5.91±1.02	525.21±1.58
Farm 3	14	Range	9.55 – 13.01	5.84 – 6.27	326.07 – 400.83
		Mean	10.36±1.08	6.01±1.01	370.83±2.57
Farm 4	14	Range	8.78 – 11.51	4.70 – 7.63	526.51- 701.57
		Mean	9.92±1.11	5.61±1.01	652.71±2.53
Farm 5	14	Range	9.74 – 12.73	7.11 – 9.43	436.39 - 622.37
		Mean	10.46±0.64	8.20±1.03	527.07±2.24
Farm 6	14	Range	11.54 – 14.67	5.74 – 9.41	422.46 - 615.50
		Mean	12.67±1.11	7.04±1.01	524.41±4.40
Farm 7	14	Range	10.87 – 13.41	3.56 – 8.44	734.63 - 1112.18
		Mean	11.66±1.12	6.16±1.03	857.21±2.58
Farm 8	14	Range	9.82 – 12.91	6.61 – 11.32	656.07 - 883.78
		Mean	10.36±0.17	8.11±0.71	740.83±2.57
Farm 9	14	Range	6.54 – 14.55	6.14 – 10.52	532.46 - 935.50
		Mean	8.97±0.20	7.04±0.92	724.41±4.40
Farm 10	14	Range	4.87 – 10.43	4.64 – 8.53	632.63 – 885.77
		Mean	7.06±0.57	6.16±0.80	727.21±2.58

Table 2: The mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th in fish samples obtained in previous studies

Location	Activity Concentration (Bq/kg)			References
	^{40}K	^{238}U	^{232}Th	
Ibadan (Nigeria)	41.04	10.15	4.39	(Jibiri et al., 2023)

Kainji (Nigeria)	618.2	37.2	94.8	(Adamu, R. et al., 2013)
Niger Delta (Nigeria)	37.4	85.9	11.0	(Bolaji et al., 2015)
Ado-Ekiti (Nigeria)	533.3	17.8	3.5	(Fasae & Isinkaye, 2018)
Lagos (Nigeria)	1767.19 – 2305.84	54.42 – 74.75	10.43 – 299.33	(Adeleye et al., 2020)
Peninsular (Malaysia)	31.2 – 42.6	0.50 – 1.67	0.47 – 1.35	(Khandaker et al., 2015)
Gujarat, India	142.90	49.98	405.65	(Pandion et al., 2024)
Vizag (India)	13.36 – 41.27	0.002 – 0.66	0.002 – 1.05	(Patra et al., 2014)
Mediterranean Cost of Turkey	132.99	1.13	1.91	(Ozmen & Yilmaz, 2020)
Lake Van (Turkey)	319	0.57	0.022	(Erenturk et al., 2014)
Mississippi (USA)	99	0.41	0.89	(Billa et al., 2016)
Bangladesh	405.51–749.80	2.76 – 22.02	1.78 – 21.53	(Asaduzzaman et al., 2024)
China	103	0.62	0.39	(Ghajarbeygi et al., 2024)
Osogbo (Nigeria)	603.33±2.64	10.52±0.83	6.73±0.96	Present Study

Table 3: Mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th in fish samples and the committed effective does

Sample Fish	**Activity Concentration (Bq/kg)**			**Effective dose, D (µSv/y)**
	^{238}U	^{232}Th	^{40}K	
Farm 1	11.67±1.10	7.04±1.01	383.41±1.40	139.68±13.48
Farm 2	12.06±1.22	5.91±1.02	525.21±1.58	142.46±14.03
Farm 3	10.36±1.08	6.01±1.01	370.83±2.57	124.31±13.50
Farm 4	9.92±1.11	5.61±1.01	652.71±2.53	142.25±13.61
Farm 5	10.46±0.64	8.20±1.03	527.07±2.24	157.67±12.44
Farm 6	12.67±1.11	7.04±1.01	524.41±4.40	155.03±13.44
Farm 7	11.66±1.12	6.16±1.03	857.21±2.58	170.64±13.84
Farm 8	10.36±0.17	8.11±0.71	740.83±2.37	174.10±7.34
Farm 9	8.97±0.20	7.04±0.92	724.41±4.10	157.75±9.53
Farm 10	7.06±0.57	6.16±0.80	727.21±2.58	142.79±9.68
Overall mean	10.52±0.83	6.73±0.96	603.33±2.64	150.69±12.12

3.2 Effective Dose

Table 3 represents the estimated total effective dose (the colour-coded bar) from the consumption of catfish by residents in the study region. Farm 3 exhibited the lowest mean effective dose of 124.31±13.50 μSv/y, while Farm 7 had the highest mean effective dose of 170.64±13.84 μSv/y. The overall average committed effective dose for the study was 150.69±12.12 μSv/y, with average individual contributions of 238U, 232Th and 40K being 39.18±3.09 μSv/y, 61.76±8.81 μSv/y and 49.75±0.22 μSv/y, respectively. These dose values and their breakdown are presented in Figure 1, showing the percentage contributions of each radionuclide to the average total dose.

Of the total committed effective dose, 41% was attributed to thorium-232 (232Th), followed by 40K (33%) and 238U (26%). The total committed effective dose of 150.69±12.12 μSv/y in this study is below the projected global average effective dose of 290 μSv/y, which is the global average from consuming radionuclides from the uranium and thorium decay series.

Chronic exposure to these radionuclides, even at low concentrations, can accumulate over time and potentially exceed safety thresholds if not monitored appropriately. Cultural preferences and frequency of fish consumption are factors that influence the level of exposure, with those who consume fish more frequently being at a higher risk. Long-term consumption of fish with elevated radionuclide concentrations can pose health risks, especially from uranium and thorium, which are known to be carcinogenic and mutagenic.

Monitoring and controlling the levels of uranium, thorium, and potassium in fish populations is essential due to the possible health hazards linked to long-term exposure to radionuclides. Increasing knowledge of these dangers and putting monitoring programs in place can help reduce exposure to dangerous radiation and guarantee that populations that depend on fish as their main source of protein don't consume more radionuclides than is safe. Frequent monitoring of fish radionuclide levels could greatly lower the dangers associated with these exposures.

Conclusion

Using gamma spectroscopy techniques, the activity concentrations of major naturally occurring radioactive particles (Ra-226, Th-232 and K-40) were determined in catfish from selected fish farms in Osogbo, Osun State, Nigeria. The results showed that the highest mean concentration of 40K was 603.33±2.64 Bq/kg, while the concentrations of 238U and 232Th were 10.52±0.83 Bq/kg and 6.73±0.96 Bq/kg, respectively. The estimated committed effective dose due to human consumption of catfish in the area is 150.69±12.12 μSv/y, with 232Th accounting for 41% of the total dose.

The annual committed effective dose obtained in the catfish investigated in this study is less than the maximum permissible limit of 1.0 mSv/y, so the catfish are deemed not posing any radiological hazard to their consumers. Though the average effective dose from consuming these fish is below the global average, the long-term health risks, particularly from uranium and thorium, remain a concern due to their carcinogenic and mutagenic properties. To mitigate these risks, it is recommended to implement radionuclide monitoring programmes by regulatory bodies and to create public awareness regarding potential risks associated with consumption of fish with elevated radionuclide concentrations.

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HOE (hoefunwole@gmail.com)- Collected and prepared samples, interpreted activity concentration measurements, perform statistical analysis and contributed to the writing of the manuscript.
OAO (orisadareoluseyi@yahoo.com)- Assisted with sample collection, Carried out input of sample data and contributed to the writing of the manuscript.

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