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Radioecological Characterization and Natural Radioactivity Levels in Fish From Kalokol and Long'ech Markets, Lake Turkana, Kenya

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Abstract
Radioecological assessments are vital for shielding human populations from the harmful impacts of radiation. They generate essential data to strengthen legal frameworks for radiation safety and raise public awareness. This study examined natural radioactivity levels in fish sourced from Lake Turkana, specifically the Long'ech and Kalokol markets. Using a high-purity germanium (HPGe) detector, the research measured the activity concentrations of ^{232}Th, ^{238}U, and ^{40}K in various fish species and evaluated radium equivalent activity. ^{40}K showed the highest activity concentrations across all fish species (mean 476.95 Bq/kg), while ^{238}U and ^{232}Th were significantly lower. Radium equivalent activity (Ra_{eq}) varied by species, with African Catfish recording the lowest value (66.87 Bq/kg), Nile Tilapia intermediate (94.93 Bq/kg), and Nile Perch the highest (106.93 Bq/kg) due to elevated ^{238}U. These differences reflect species-specific feeding habits, habitats, and metabolic processes influencing radionuclide bioaccumulation. Compared to other global water bodies, fish from Lake Turkana exhibit comparable or lower levels of ^{232}Th(15.00 Bq/kg) and ^{238}U (31.40 Bq/kg), but notably higher concentrations of ^{40}K (476.95 Bq/kg). Despite the elevated ^{40}K, the overall Ra_{eq} (89.58 Bq/kg) remains within safe comparative limits, aligning closely with regions like the Eastern Libyan Coast (103.40 Bq/kg).
Keywords: *Lake Turkana, Kalokol, Long'ech, Radioecology, Natural radioactivity, Radium equivalent activity.*

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I. INTRODUCTION

The radioecological characteristics of natural habitats have garnered increasing public interest due to the potential health and environmental risks associated with radionuclide contamination. Environmental radiation stems from both natural processes such as cosmic and terrestrial radiation and anthropogenic activities, including nuclear technology, industry, and mining (UNSCEAR, 2001). Among natural sources, primordial radionuclides like ^{40}K, ^{238}U, and ^{232}Th are the primary contributors to human exposure. The local distribution of these natural radiation levels is heavily influenced by the geophysical and geochemical properties of a region. Volcanic rocks (such as granite, tuffs, and pumice) and phosphate-rich deposits inherently contain radioactive components. As these geological formations weather and erode, their mineral contents including uranium, thorium, and potassium can wash into aquatic ecosystems, introducing potential radiation pollution (Kessaratikoon et al., 2007).

The Lake Turkana Basin, situated within the northern Kenyan Rift Valley, presents a unique geological environment shaped by extensive volcanic activity and complex tectonic structures. The basin is surrounded by volcanic formations and complexes, with its hydrology heavily driven by the Omo River which contributes over 90% of the lake's water alongside the Kerio and Turkwel rivers. The catchments for these rivers consist of vast volcanic (68%), alluvial (25%), and granite deposits (Feibel, 2011). Because these mineral-rich volcanic and granitic sediments continuously drain into and settle within the Lake Turkana ecosystem, there is an inherent risk that aquatic organisms may accumulate natural radionuclides.

Despite the ecological and economic importance of Lake Turkana, particularly through fisheries that support local and regional populations, data on the radiological safety of its aquatic life remains limited. Kalokol and Long'ech are key hubs for fish collection and trade on the lake. Given the basin's unique volcanic and sedimentary geology, coupled with regular human consumption of fish from these areas, assessing the activity concentrations of ^{232}Th, ^{238}U, and ^{40}K is vital. This study addresses this critical gap by evaluating radiation concentration levels in fish from the Kalokol and Long'ech markets, providing essential baseline data to ensure public health safety and strengthen regional radiation protection frameworks.

A cartographic representation of the study area showing the sampling locations is presented in Figure 1.1.

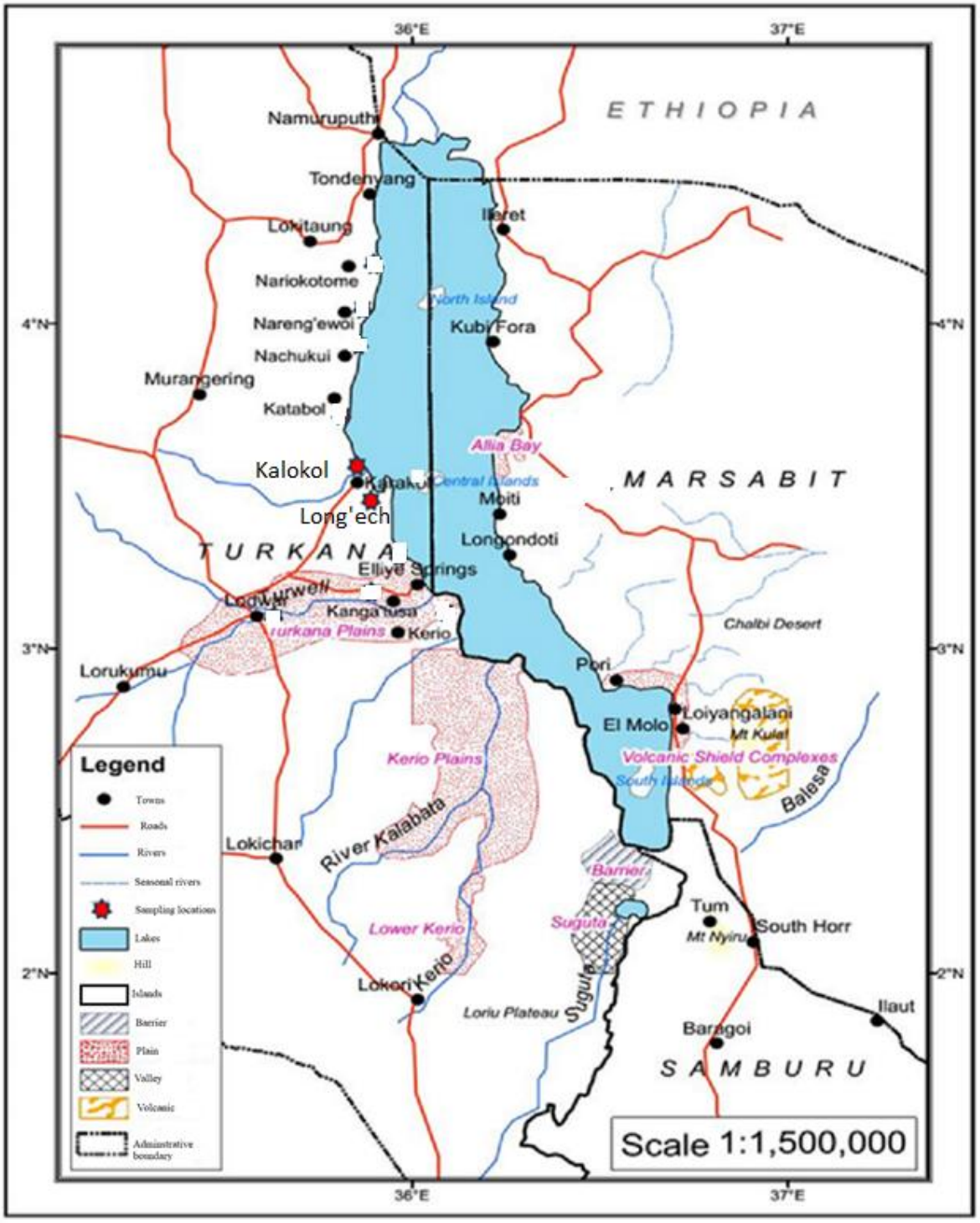


Figure 1.1: A cartographic representation of the Lake Turkana basin displaying sampling locations.

II. MATERIALS AND METHODS

2.1 Fish samples

Nine fish samples comprising of African catfish (*Clarias gariepinus*), Nile tilapia (Oreochromis *niloticus*) and Nile perch (*Lates niloticus*) were bought from Kalokol town and Longéch Island. These two fish sampling sites provide a good representation of the entire lake basin considering that fishing boasts dock on these places. For each fish species, three samples were collected. At the time of collection, each sample was cut into tiny pieces using a knife that was cleaned before being used to cut the next sample, weighed, placed in a clean non-polythene paper bag that was properly labeled.

The fish samples were thoroughly sun-dried to remove initial moisture and individually pulverized into a fine powder using a cleaned mortar and pestle. The powder was transferred into pre-weighed plastic containers consistent with IAEA recommendations for radionuclide analysis. To achieve a constant dry weight, a secondary drying process was performed in a convection oven at 105°C for 24 hours. The containers were then covered with aluminum foil, tightly corked for an airtight seal, and re-weighed to determine the precise net sample mass. A durable sticker containing the sample ID, mass, and sealing date was affixed for tracking. Finally, the containers were stored for a minimum of 30 days before analysis to allow secular equilibrium to be established between parent radionuclides and their daughter products (Kessaratikoon *et al.,* 2007).

2.2 Gamma ray spectrometry

The radionuclide spectra in the samples were determined using a high resolution, p-type coaxial HPGe γ-ray spectrometer serial number 2489. The detector had a crystal of diameter 57.4mm, length 56.9 mm, active volume 144 mm^3, germanium dead layer thickness 600 microns and a detector to window distance $\leq 5mm$. The detector was housed inside a 10 cm thick lead shield internally lined with 2 mm Cu foils to effectively reduce the background gamma radiation within the laboratory. The energy resolution of the detector was 1.8 keV at energy of 1.33 keV for ^{60}Co and its efficiency was 31.6 %. Each sample was placed on the thin front window above the crystal detector for 28,800 seconds for spectrum acquisition. In order to maintain the high resolution of energy peaks during data collection and minimize non-linearity effects, the detector crystal was kept cool using liquid nitrogen at 77 K. Spectral data for all samples were collected and saved using Maestro-32 software.

2.2.1. Calibration of the Gamma Spectrometry System

To achieve meaningful outcomes from a gamma spectrometry system, such as isotope identification and both qualitative and quantitative analysis, it is essential to calibrate the system for both energy and efficiency. Reference gamma (RG) standard samples from International Atomic Energy Agency, IAEA (IAEA-RGU-1, IAEA-RGTh-1 and IAEA –RGK-1) were used for calibration. The energy calibration process links the spectrometer's channel numbers to the energy of the reference material. This calibration was done by aligning the primary gamma rays in the spectrum of the standard with their corresponding channel numbers.

2.3 Radionuclide Identification and Analysis

The radionuclide data for analysis were obtained by identifying significant energy peaks with statistical relevance. A region of interest (ROI) report was generated containing key details for further processing, such as gross and net peak areas, peak centroid energy and radionuclide library information which identifies the radionuclide species corresponding to each peak. The activity concentration of ^{238}U, ^{232}Th and ^{40}K were calculated from counts obtained from the following gamma lines ^{214}Pb (352 KeV), ^{214}Bi (609 Kev), ^{228}AC (911 KeV), ^{212}Pb (238 KeV) and ^{40}K (1460 KeV). The net characteristic count of the field samples was determined as the difference between the gross measured and the background count.

III. RESULTS AND DISCUSSIONS

3.1 Determination of activity concentration

Equation 3.1 was used to calculate the activity concentration from the measured counts (Radzali et al., 2018).

$$A = \frac{N}{\varepsilon_f P_\gamma t_s M} \qquad (3.1)$$

where $N = N_S - N_B$ is the γ-ray's net counts, N_S - sample spectrum's counts, N_B - counts of the background spectrum, ε_f - the γ-ray's detection efficiency, t_s – the sample spectrum's collection time in seconds, M - the mass of the sample (kg), P_s - emission probability of the γ-ray.

3.1.2 Activity concentration of ^{238}U, ^{232}Th and ^{40}K in fish Samples

Table 3.1 presents the calculated activity concentrations of ^{232}Th, ^{238}U, ^{40}K and Ra_{eq} in the analyzed fish samples as well as the average concentration in each fish species. Additionally, the overall mean activity concentrations for the radionuclides across all fish samples are also included.

Table 3.1: Activity concentrations of ^{232}Th, ^{238}U, ^{40}K and Ra_{eq} in the fish samples.

Sample type	Sample ID	Radionuclide Activity (Bq/kg)			Ra_{eq} (Bq/kg)
		^{232}Th	^{238}U	^{40}K	
African cat fish	CF 1	1.45 ± 1.48	25.34 ± 4.22	557.65 ± 130.22	70.42
	CF 2	5.95 ± 0.28	26.70 ± 5.45	433.04 ± 169.08	68.55

	CF 3	2.67 ± 0.28	18.55 ± 3.02	510.24 ± 93.22	61.65
MEAN		3.36 ± 1.52	23.55 ± 4.23	500.31 ± 130.84	66.87
	NP 1	7.99 ± 5.80	42.98 ± 2.58	444.78 ± 76.28	88.66
Nile perch	NP 2	27.59 ± 6.90	56.72 ± 3.06	377.86 ± 95.48	125.27
	NP 3	15.13 ± 6.20	48.98 ± 2.77	470.81 ± 81.22	106.87
MEAN		16.90 ± 6.3	49.56 ± 2.81	431.15 ± 84.32	106.93
	NT 1	27.94 ± 9.05	19.16 ± 4.03	452.08 ± 125.66	93.93
Nile Tilapia	NT 2	24.41 ± 9.90	21.86 ± 3.39	526.36 ± 141 15	97.29
	NT 3	21.89 ± 9.27	22.26 ± 4.11	519.60 ± 133.86	93.57
MEAN		24.75 ± 9.41	21.09 ± 4.18	499.38 ± 133.56	94.93
OVERAL MEAN		15.00 ± 5.74	31.40 ± 3.74	476.95 ± 116.24	89.58
Minimum		1.45 ± 1.48	18.55 ± 3.02	377.86 ± 95.48	61.65
Maximum		27.94 ± 9.05	56.72 ± 3.06	557.65 ± 130.22	125.27
Standard deviation		9.20 ± 054	7.88 ± 1.25	68.81 ± 41.45	16.25

^{40}K consistently exhibited the highest activity concentrations across all fish species. The overall mean for ^{40}K was 476.95 ± 116.24 Bq/kg. This was an expected finding, as potassium is an essential element for all living organisms and its radioactive isotope, ^{40}K, is naturally abundant. In contrast, ^{238}U showed moderate activity concentrations, with an overall mean of 31.40 ± 3.74 Bq/kg, while ^{238}Th generally presented the lowest concentrations, having an overall mean of 15.00 ± 5.74 Bq/kg. African Catfish samples showed mean activity concentrations of 3.36 ± 1.52 Bq/kg for ^{232}Th, 23.55 ± 4.23 Bq/kg for ^{238}U, and 500.31 ± 130.84 Bq/kg for ^{40}K, resulting in a mean Ra_{eq} of 66.87 Bq/kg. These values were relatively consistent among the catfish samples, indicating a stable uptake pattern for these radionuclides in this species. Nile Perch samples, however, displayed notably higher mean concentrations for both ^{232}Th (16.90 ± 6.30 Bq/kg) and ^{238}U (49.56 ± 2.81 Bq/kg) compared to the African Catfish. The mean ^{40}K concentration in Nile Perch (431.15 ± 84.32 Bq/kg) was slightly lower than in African Catfish. The elevated concentrations of ^{238}U and ^{232}Th in Nile Perch contributed to a significantly higher mean Ra_{eq} of 106.93 Bq/kg for this species, indicating a greater radiological burden compared to the African Catfish. The variability, as indicated by the standard deviations, was also higher for ^{232}Th (6.30 Bq/kg) and ^{238}U (2.81 Bq/kg) in Nile Perch, suggesting more diverse individual uptake or environmental exposure. Nile Tilapia samples exhibited the highest mean ^{232}Th activity concentration at 24.75 ± 9.41 Bq/kg, while their mean ^{238}U concentration (21.09 ± 4.18 Bq/kg) was comparable to that of African Catfish but considerably lower than Nile Perch. The mean ^{40}K concentration for Nile Tilapia (499.38 ± 133.56 Bq/kg) was very similar to that of African Catfish. The Ra_{eq} for Nile Tilapia averaged 94.93 Bq/kg, placing it between African Catfish and Nile Perch. The standard deviations for ^{232}Th in Nile Tilapia (9.41 Bq/kg) were quite large, suggesting considerable variation in thorium uptake among individual tilapia samples.

Overall, the results highlighted that while ^{40}K was the most abundant radionuclide across all sampled fish, the concentrations of ^{238}U and ^{232}Th, and consequently the Ra_{eq} activity, varied significantly among different fish species. Nile Perch showed the highest accumulation of ^{238}U and the highest Ra_{eq}, while Nile Tilapia demonstrated the highest ^{232}Th levels. These variations likely reflected differences in the feeding habits, habitat preferences, and metabolic processes of each fish species within the Lake Turkana ecosystem. The reported standard deviations indicated a degree of natural variability in radionuclide uptake even within the same species. The overall standard deviations across all samples were 9.20 ± 0.54 Bq/kg for ^{232}Th, 7.88 ± 1.25 Bq/kg for ^{238}U, and 68.81 ± 41.45 Bq/kg for ^{40}K.The average abundance of ^{40}K in the studied fish was notably higher than that of ^{232}Th and ^{238}U (Figure 3.1a). The activity concentrations of the three radionuclides varied significantly across the fish species. The variation was attributed to differences in habitats where the fish live, feeding habits and individual fish metabolism which influence the bioaccumulation of radionuclides. The activity concentration of ^{40}K was relatively high across all species (Figure 3.1b). This was expected since potassium is a naturally occurring element in biological systems

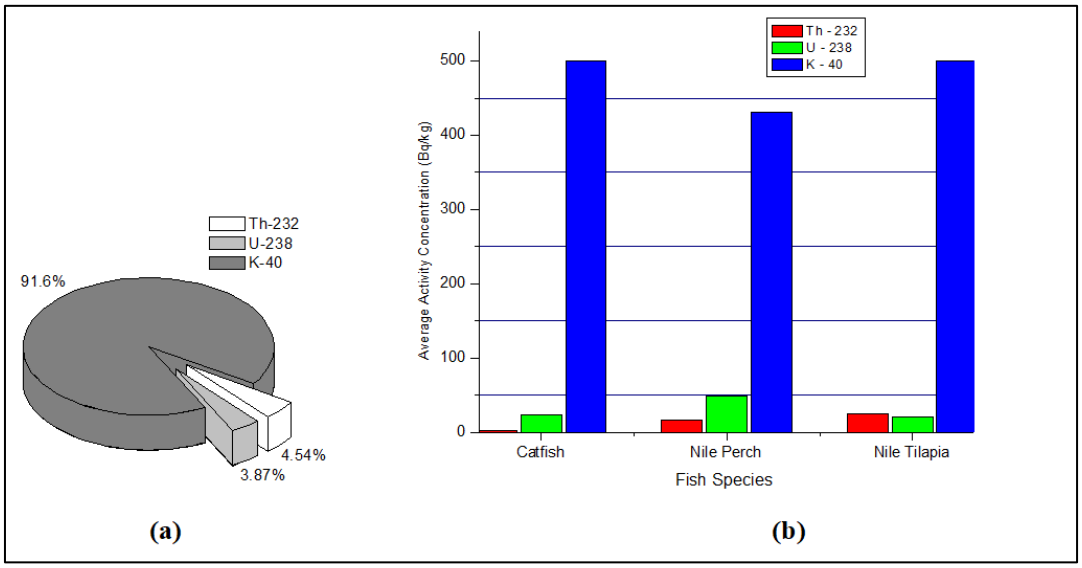


Figure 3.1: (a) Average percentage activity concentration of primordial radionuclides in fish; (b) Activity concentration levels of radionuclides in the fish.

Table 3.2 presents calculated average radionuclide activity in fish samples from various global locations. In summary, Lake Turkana's radionuclide values are relatively moderate when compared to other regions. The variability in activity concentrations is influenced by factors such as local geology, environmental conditions and the ecological characteristics of the regions.

Table 3.2: Average radionuclide concentration and radiation Ra_{eq} in fish samples of this study and the values of similar studies from other regions.

Location	Average Radionuclide Activity in fish samples (Bq/kg)				
	^{232}Th	^{226}Ra	^{238}U	^{40}K	Ra_{eq} (Bq/kg)
Eastern Libyan Coast (R. Hamad et al., 2023)	16.84±0.92	86.40±0.98	….	146.63±0.05	103.40 ±3.64
River Kubanni in Nigeria (Adigun & Sodipo, 2024)	77.24	46.86	….	270.14	….
Bay of Bengal Chattogram, Bangladesh (Biswas et al., 2021)	67 ± 9	5 ± 2	….	250 ± 50	….
Epe Waterside Region of Lagos, Nigeria (Olurin, 2024)	245.80 ± 7.7	80.15 ± 65.40	….	282.7 ± 17.9	….
Jeddah-Saudi Arabia (Safia H. Q & Jameelah H, 2016)	1.66	1.6	1.63	208.13	…..
Hong Kong (Yu et al., 1997)	0.47	0.005	0.018	86.65	….
Kainji lake (Adamu et al., 2013)	94.82	37.22	….	384.98	….
Lake Turkana (This work)	15.00 ± 5.74	….....	31.40 ± 3.74	476.95 ± 116.24	89.58

In summary, the data in Table 3.2 revealed significant variability in radionuclide concentrations in fish across different geographical locations, which likely stemmed from diverse geological backgrounds, environmental conditions, and specific aquatic ecosystem characteristics. The fish samples from Lake Turkana generally exhibited moderate to high concentrations of the measured primordial radionuclides, particularly for ^{40}K and ^{238}U, when compared to the available global data.

Figure 3.2 a-c displays histograms showing the frequency distribution for all the radioactive variables measured in the analyzed fish. These histograms approximate the probability distribution of these continuous variables. Notably, the graphs for ^{232}Th and ^{40}K suggest that these radionuclides follow a normal, or bell-shaped, distribution (Raghu et al., 2017) while that of ^{238}U has minimal skewness to the right.

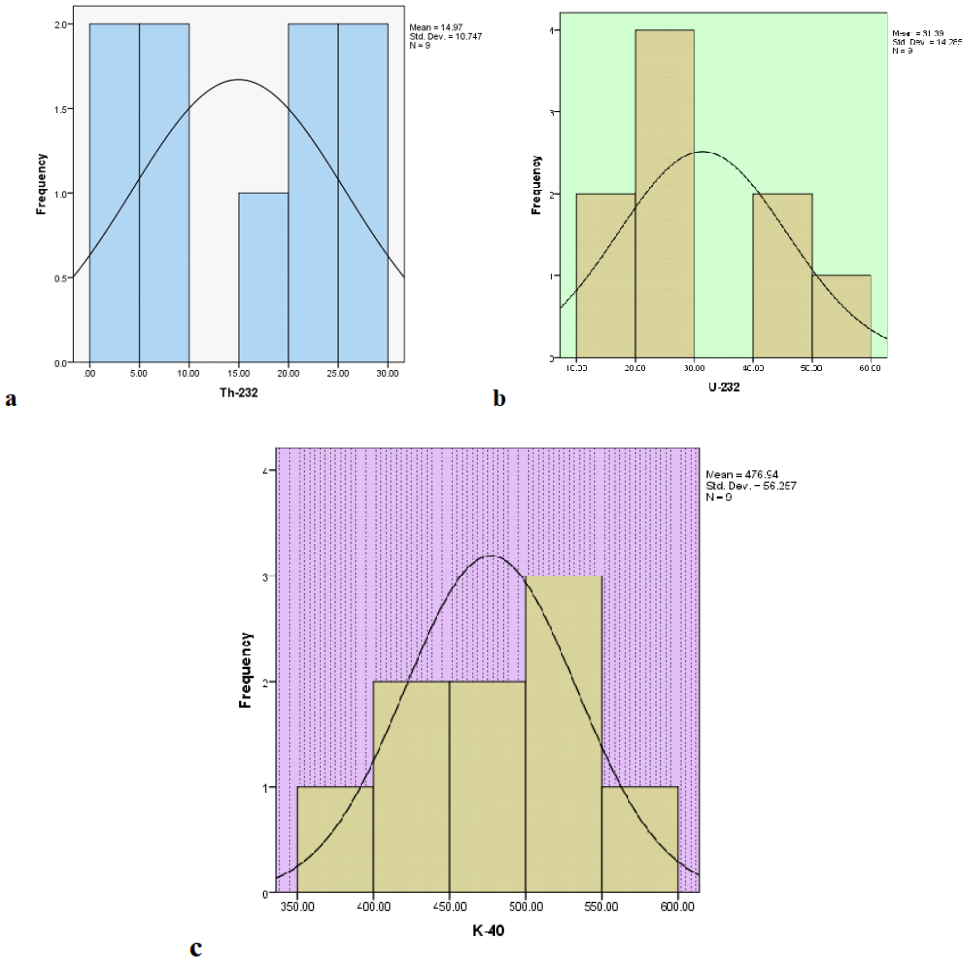


Figure 3.2: (a) Frequency distribution of ^{232}Th; (b) Frequency distribution of ^{238}U; and (c) Frequency distribution of ^{40}K.

IV. Conclusion

This study successfully evaluated the activity concentrations of primordial radionuclides ^{232}Th, ^{238}U, and ^{40}K and the associated radium equivalent activity (Ra_{eq}) in major fish species from Lake Turkana using high-resolution gamma-ray spectrometry. ^{40}K consistently exhibited the highest activity concentrations across all species, with an overall mean of 476.95 Bq/kg, whereas ^{238}U and ^{232}Th showed lower overall means of 31.40 Bq/kg and 15.00 Bq/kg, respectively. Significant variations in bioaccumulation were observed among the species due to differences in feeding habits, habitats, and metabolic processes: Nile Perch showed the highest accumulation of ^{238}U, Nile Tilapia demonstrated the highest ^{232}Th levels, and African Catfish displayed the most stable and lowest overall uptake patterns. Consequently, the overall mean Ra_{eq} was 89.58 Bq/kg, with Nile Perch presenting the highest radiological burden (106.93 Bq/kg) and African Catfish the lowest (66.87 Bq/kg). When compared to other global water bodies, Lake Turkana fish exhibit moderate radionuclide levels. Overall, these findings confirm that while natural primordial radionuclides are present in the studied fish from Long'ech and Lalokol markets, their Ra_{eq} is moderate.

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CONFLICT OF INTEREST

I declare no conflict of interest regarding the research presented in this study.

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