



Radiological Risk Assessment of Naturally Occurring Radionuclides in Commonly Consumed Stimulants in Akwa Ibom State, Southern Nigeria

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Abstract

This study aims at evaluating the presence and potential health risks of naturally occurring radioactive materials (NORM) such as Uranium-238 (^{238}U), Thorium-232 (^{232}Th), and Potassium-40 (^{40}K) in selected stimulants commonly consumed in Akwa Ibom State, Southern Nigeria. Ten representative stimulant samples, including kola nut, bitter kola, ginger, turmeric, marijuana, ginseng, cloves, cocoa seed, snuff, and wonder kola, were procured from local markets and analysed using gamma spectrometry with a sodium iodide (NaI(Tl)) detector. The specific activity concentrations of ^{238}U , ^{232}Th , and ^{40}K ranged from 16.06–31.47 Bq/kg, 1.54–3.76 Bq/kg, and 1.56–2.53 Bq/kg, respectively. Radiological indices such as absorbed dose, committed effective dose (CED), annual gonadal equivalent dose (AGED), excess lifetime cancer risk (ELCR), radium equivalent activity (Ra eq.), gamma index, and both internal and external hazard indices were computed. All measured values were below the safety thresholds established by UNSCEAR, ICRP, and WHO, indicating negligible radiological health risk from the consumption of these stimulants. The highest activity and associated risk indices were observed in cloves (CZ) and bitter kola (BK), while ginseng (G5) and ginger (GN) recorded the lowest. Pearson correlation and heat-map analyses demonstrated strong relationships between radionuclide activity and derived radiological parameters. This study provides essential baseline data for radiological food safety in the region and underscores the importance of routine monitoring to safeguard public health.

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1.0 Introduction

Food contamination with natural radioactivity has now become a major health risk for people. The human environment is naturally radioactive, and humans are exposed to radiation everywhere in the environment, whether from natural or artificial sources. Ionizing radiation may be released as a result of the decay of primordial radionuclides such as ^{238}U , ^{232}Th , and ^{40}K (García-León, 2022; Odede *et al.*, 2023; Jha *et al.*, 2024; Ndoma *et al.*, 2025). The major ways that radioactivity enters the human body are through ingestion of primordial radionuclides and their progeny, such as ^{238}U , ^{232}Th , and ^{40}K series radionuclides (Fisenne *et al.*, 1987; Shiraishi *et al.*, 2000; Skoko *et al.*, 2024), as well as inhalation of radon and thoron and their decay products (Ahmad *et al.*, 2021; Chang *et al.*, 2023; Misdaq *et al.*, 2001). Depending on their parent rock formation, geographic location, and geochemical processes, soils contain varying radionuclide contents (Ribeiro *et al.*, 2018; Tzortzis & Tsertos., 2004). Through plant absorption and other geochemical processes, radionuclides found in soils and fertilizers make their way to the human body through the food chain (Nieder *et al.*, 2018).

It is well known that foods, especially spices, contain both natural and synthetic radionuclides that, when consumed, provide an effective internal dose (George *et al.*, 2010; Saudi *et al.*, 2022). It is estimated that almost one-eighth of the mean yearly effective dose linked to natural sources is caused by food intake (UNSCEAR., 2000). About 60% of the total yearly effective dose from ingestion is caused by the K-40 (United Nations Scientific Committee on the Effects of Atomic Radiation, 2008). As a result, it is a radionuclide that is important for radiological protection as well as the environment (Zhu, 2001). Therefore, it is crucial to keep an eye on food radioactivity levels to determine the dose that the general public may consume.

The main thrust of this paper focuses on the measurement of radionuclides such as ^{238}U , ^{232}Th , and ^{40}K in common spices and nuts (stimulant) using gamma spectrometry (NAI) system and their radiological hazard indices are evaluated. This study will serve as the baseline for this region, with which future measurements can be compared to check for any changes in the radiological assessment of this region. Studies on natural radioactivity in food matrices have been reported from certain regions (Patra *et al.*, 2014; Brandhoff *et al.*, 2016; Garcez *et al.*, 2018; Kolapo *et al.*, 2018; Yadav *et al.*, 2018; Desideri *et al.*, 2019; Silva *et al.*, 2021), but there is little or no data for this part of the country.

2.0 Materials and Methods

2.1 Samples Collection and Preparation for Radionuclides Assessment

The samples of stimulants that was used for this work were bought from the local market, and the stimulants that were used includes; kola nut, bitter kola, ginger, wonder kola, marijuana, cloves, ginseng, turmeric, snuff and cocoa seed.

After the samples were collected, the samples were processed according to standard methods by International Commission on the Effect of Atomic Radiation (IAEA). The samples were air dried first of all at room temperature for about twenty-four hours, then they were crushed, sieved and oven dried again to remove all traces of moisture. The individual sediments were sealed in a plastic bag, labelled accordingly and kept for twenty-one (21) days in order to attain secular equilibrium before undergoing gamma-spectrometric analysis for assessment of natural radionuclides present and associated concentration of activity.

2.2 Instrumentation Details and Calibration

The gamma spectrometry system used consist of a 3" x 3" NaI(Tl) detector, a product of Princeton Gamma Tech., USA. The detector is embedded in a cylindrical lead shield to attenuate the influx

of background radiation. The detector was coupled to Gamma Spectacular (model GS-2000 Pro) multichannel analyser and further linked to a computer for display. Data acquisition and analysis of gamma-ray spectra were achieved using Thermo software.

In order to derive a qualitative and quantitative relationship between the peak position in the spectrum and the corresponding gamma-ray energy, the spectrometry system was calibrated. Energy calibration of the detector was carried out using the RSS8 gamma source set traceable to Spectrum Techniques LLC, USA. It was accomplished by measuring the spectra of point sources emitting gamma-rays of precisely known energies. The efficiency calibration of the detector was also carried out using a reference source consisting of known radionuclide activities.

Counting Procedure

Prior to the sample measurement, an empty container was counted for 36000 s so as to determine the background gamma-ray distribution count. The sealed samples after attaining a state of secular equilibrium were each placed on the detector one after the other for analysis. Each sample was counted for the same period of time as that of the empty container. The photo peaks considered are: ^{214}Pb (295.3keV) and ^{214}Bi (1764.5keV) for ^{238}U ; ^{212}Pb (238.6keV), ^{228}Ac (911.1keV) and ^{208}Tl (2614.7keV) for ^{232}Th and that of ^{40}K (1460.0keV). The activity concentration A of each identified radionuclide in the sample was estimated using Eq. 1:

$$A = \frac{C_{\text{net}}}{P_{\gamma} \times \epsilon \times m \times t} \quad (1)$$

where C_{net} is the net peak count for each radionuclide present in the sample after subtracting the background count from the gross count, P_{γ} is the absolute gamma ray emission probability of the identified radionuclide, ϵ is the obtained full energy peak efficiency for each identified

radionuclide, m is the mass of the sample and t is the counting time.

The Minimum Detectable Activity (MDA) for each radionuclide was calculated using Eq. 2:

$$MDA = \frac{2.71 + 4.66 (\sigma)}{P_{\gamma} \times \epsilon \times m \times t} \quad (2)$$

where σ is the standard deviation of the background collected during time t over the energy range of interest. The Minimum Detectable Limit (MDL) are 5.42 Bqkg^{-1} , 0.58 Bqkg^{-1} , 0.21 Bqkg^{-1} for ^{40}K , ^{238}U , and ^{232}Th respectively

2.3 Radiological Health Indices

The activity concentration of ^{238}U , ^{232}Th , and ^{40}K was estimated for all samples through analysis using gamma spectrometry and Eq. (1), the results were subsequently used in Eq. (3) to (10) to evaluate the health impact and radiological risk parameters as outlined by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR., 2000).

Absorbed Dose (AD)

It is assumed that at 1m above the ground that the naturally occurring radionuclides will have a uniform distribution. The outdoor absorbed dose rate and indoor absorbed dose rate at 1m above the ground (UNSCEAR., 2000; Joel et al., 2018) is calculated using Eq. 3:

$$AD = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (3)$$

where A_U , A_{Th} and A_K are the activity concentrations of ^{238}U , ^{232}Th and ^{40}K respectively.

External Hazard Index (H_{ext})

The external hazard index (H_{ext}) is associated with the health risk assessment of outdoor exposure to natural radionuclides. For the radiation hazard to be small, H_{ext} has to be less than 1 and its calculated using the equation below (Nduka et al., 2022; Orosun et al., 2019).

$$H_{\text{ext}} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

where A_U , A_{Th} , and A_K are the specific activity concentrations of ^{238}U , ^{232}Th and ^{40}K in $Bqkg^{-1}$ respectively (Nduka *et al.*, 2022, Orosun *et al.*, 2019).

Internal Hazard Index (H_{In})

The Internal Hazard Index, H_{In} , which is calculated by Eq. 5 measures the inner exposure to radon and its daughter isotopes;

$$H_{In} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

Committed Effective Dose (CED)

The committed effective dose over one year was calculated using the relation shown in the Eq. 6

$$CED(Svy^{-1}) = \alpha \cdot C_s \cdot D_\eta \quad (6)$$

Where; α is the amount of food consumed in a year (Kgy^{-1}); C_s is the radionuclide specific concentration in the food ($Bqkg^{-1}$); D_η is the dose coefficient according to ICRP 119.

There is no Nigerian statistical data for the amount of seasoning and spices consumed annually, this may arise due to small consumption when compared to other food categories, such as cereals, meats, beverages, etc. (Lopes *et al.*, 2018). Therefore, the seasonings and spices consumption have regional and seasonal behaviour. So, the consumption if taken on the average could disagree with the committed effective dose value locally. Therefore, the annual consumption was estimated to be 1 kg for all seasonings and spices evaluated in this work.

Annual Gonadal Equivalent Dose (AGED)

The annual gonadal dose equivalent dose (AGED) is used to evaluate the potential effects of the specific activities of ^{238}U , ^{232}Th and ^{40}K on certain organs, such as reproductive organs (gonads), bone marrows and bone cells. (AGED) will be calculated using Eq. 7.

$$AGED(\mu Svy^{-1}) = 3.09A_U + 4.18A_{Th} + 0.314A_K \quad (7)$$

where A_U , A_{Th} , and A_K were earlier defined.

Excess Lifetime Cancer Risk (ELCR)

The Excess Lifetime Cancer Risk (ELCR) can be defined as the probability that an individual can develop cancer during his lifetime due to exposure level to radiation. The International Commission on Radiological Protection had proposed several models for calculating cancer risk from exposure to radionuclides either through ingestion or inhalation. ICRP proposed 0.05 as a value to calculate risk factors to the public from the ingestion of radionuclides (ICRP., 1990). Excessive Lifetime Cancer Risk (ELCR) from the ingestion of the stimulants (Taskin *et al.*, 2009) will be calculated

$$ELCR = CED \times LE \times RF \quad (8)$$

where CED is the Committed Effective Dose (Svy^{-1}), LE is life expectancy (70 years) (ICRP., 1990) and RF is a factor for risk estimation ($0.05Sv^{-1}$).

Radium Equivalent Activity (Ra_{eq})

This index is called Radium Equivalent Activity (Ra_{eq}) and is mathematically calculated to address the levels thus taking into account the radiological risks associated with them (Agbalagba & Onoja., 2011);

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \quad (9)$$

Gamma index (γ_I)

The Gamma index (γ_I) is expressed using (Reda *et al.*, 2018);

$$\gamma_I = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (10)$$

3.0 Results of the Study

The activity concentrations from radionuclides especially those of ^{238}U , ^{232}Th , and ^{40}K are presented as shown in Table 1, as well as the estimated radiological parameters derived from Eq. (2) to (10) displayed in Table 3.

These parameters can be used to assess the expected effects of the specific activity that has been detected on both the human health and the ecosystem Ndoma *et al.*, 2024. The computed

parameters include Absorbed Dose (AD), External Hazard Index (H_{ext}), Internal Hazard Index (H_{in}), Committed Effective Dose (CED), Annual Gonadal Equivalent Dose (AGED), Excess Lifetime Cancer Risk (ELCR), Radium Equivalent Activity (Ra_{eq}), and Gamma index (γ_I).

A comparison of the outcome with other research conducted on ingested substances and the recorded specific radioactivity from various locations around the world is illustrated in Table 5. Furthermore, statistical data including Mean, Minimum (Min), Maximum (Max), Standard Deviation (SD), and Coefficient of Variation are presented in Tables 2 and 4 for radioactivity concentration and radiological indices respectively. Table 6 shows the Pearson Correlation of radiological parameters with relevant figures (Figures 1-5).

4.0 Discussion of the Results

4.1 Activity Concentration of ^{238}U , ^{232}Th , and ^{40}K and Health Radiological Indices

Table 1 shows the measured activity concentration of ^{40}K with ranges from $16.060 \pm 1.08 \text{ Bqkg}^{-1}$ to $31.470 \pm 2.92 \text{ Bqkg}^{-1}$, ^{238}U with ranges from $1.548 \pm 0.14 \text{ Bqkg}^{-1}$ to $3.760 \pm 0.56 \text{ Bqkg}^{-1}$, and ^{232}Th with ranges from $1.560 \pm 0.24 \text{ Bqkg}^{-1}$ to $2.530 \pm 0.48 \text{ Bqkg}^{-1}$ with average values of 22.190 Bqkg^{-1} , 2.450 Bqkg^{-1} , and 1.950 Bqkg^{-1} respectively as shown in Table 2. When compared with similar studies from other regions, the mean activity of ^{40}K was found to be 22.19 Bqkg^{-1} , which is considerably lower than values reported for South-West Nigeria (493.19 Bqkg^{-1}), Rio de Janeiro, Brazil (467.35 Bqkg^{-1}), Pacos de Caldas (254.81 Bqkg^{-1}), and Vizag, India (43.78 Bqkg^{-1}). The mean activity of ^{238}U was found to be 2.450 Bqkg^{-1} and comparable to South-West, Nigeria (2.990 Bqkg^{-1}), and lower than Vizag, India (5.300 Bqkg^{-1}). The mean activity of ^{232}Th was found to be 1.950 Bqkg^{-1} , which is higher than that of Vizag, India

(0.80 Bqkg^{-1}) but lower than the value for South-West, Nigeria (3.570 Bqkg^{-1}) as shown in Table 5.

The Box plot in Fig. 1 further illustrates the distribution of the measured activity concentrations (Bqkg^{-1}) of ^{40}K , ^{238}U and ^{232}Th . For ^{40}K , the activity concentration was within the range of 16 to 32 Bqkg^{-1} , with a median value of around 21 Bqkg^{-1} and lower and upper quartile around 18 and 26 Bqkg^{-1} respectively. For ^{238}U , the activity concentration was within 1.6 to 3 Bqkg^{-1} , a median value of around 2.5 Bqkg^{-1} , with the lower quartile of around 2 Bqkg^{-1} and upper quartile around 3 Bqkg^{-1} . For ^{232}Th , the activity concentration is within the range of 1.6 to 2.7 Bqkg^{-1} , with a median of around 2.1 Bqkg^{-1} and the lower quartile of Bqkg^{-1} and upper quartile of about 2.4 Bqkg^{-1} .

From Fig 2., ^{40}K has the highest concentration in all samples compared to ^{238}U and ^{232}Th , WK has the lowest concentration of 16 Bqkg^{-1} and the highest is CZ with 32 Bqkg^{-1} . ^{238}U is generally low across all samples with MJ, G5, GN, and TC recorded as "Below Detectable Limit" (BDL) and BK had the highest concentration of 3.8 Bqkg^{-1} . ^{232}Th had its lowest concentration of 1.4 Bqkg^{-1} in BK and the highest concentration is 2.7 Bqkg^{-1} in MJ and SF.

Fig. 3 shows the distribution of ^{238}U and ^{232}Th to be uniform in all samples, indicating that the activity concentration of ^{238}U and ^{232}Th is approximately the same. More so, ^{40}K is very dominant and has activity concentration than ^{238}U and ^{232}Th .

Table 2 represents the calculated radiological risk indices. Absorbed dose (AD) for the samples was found to have the highest value of 3.96 nGyh^{-1} in CZ and lowest value of 0.74 nGyh^{-1} in G5 which are all below the UNSCEAR reference level of 59 nGy/h for global terrestrial gamma radiation.

The annual committed effective dose (CED) for long term internal exposure due to ingestion were found to be lowest at $0.20\mu\text{Svy}^{-1}$ in G5 and highest at $1.45\mu\text{Svy}^{-1}$ in CZ which are well below the 1mSvy^{-1} limit, indicating an almost negligible internal exposure risk.

The Excess Lifetime Cancer Risk (ELCR) was calculated and found to be lower in G5 with a value of $0.70\mu\text{Svy}^{-1}$ and highest at $5.09\mu\text{Svy}^{-1}$ in CZ which are below the UNSCEAR global average of 0.29mSvy^{-1} .

Radium Equivalent Activity (Ra_{eq}) which combines the contributions of ^{40}K , ^{238}U and ^{232}Th into a single index, with lowest concentration of 1.37Bqkg^{-1} in G5 and highest concentration of 8.33Bqkg^{-1} in CZ.

They are found to be below the UNSCEAR safe limit of 370Bqkg^{-1} which indicates that the

samples are far below the danger threshold and have no concerns for radiological hazards. Gamma Index which measures external gamma radiation exposure had a minimum value of 0.01Bqkg^{-1} in G5 and a maximum value of 0.06Bqkg^{-1} in CZ which is $< 1\text{Bqkg}^{-1}$ and considered safe.

4.2 Statistical Analysis

Coefficient of Variation

The coefficient of variation (CV) shows the variability in the distribution of measured activity concentrations and radiation dose rates in the samples. If CV is less than or equal to 20%, it shows minor variability. $20\% \leq \text{CV} \leq 50\%$ implies moderate variability, while $50\% \leq \text{CV} \leq 100\%$ indicates high variability (Orosun *et al.*, 2020). Therefore, the CV for ^{40}K , ^{238}U , and ^{232}Th indicates minor variability at 22.89%, 36.73%, and 19.49% respectively.

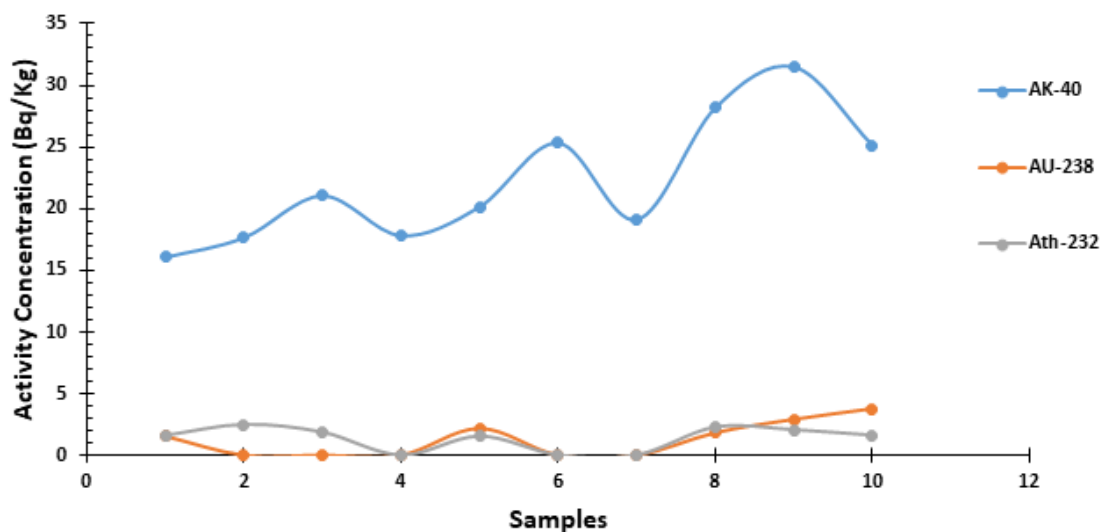
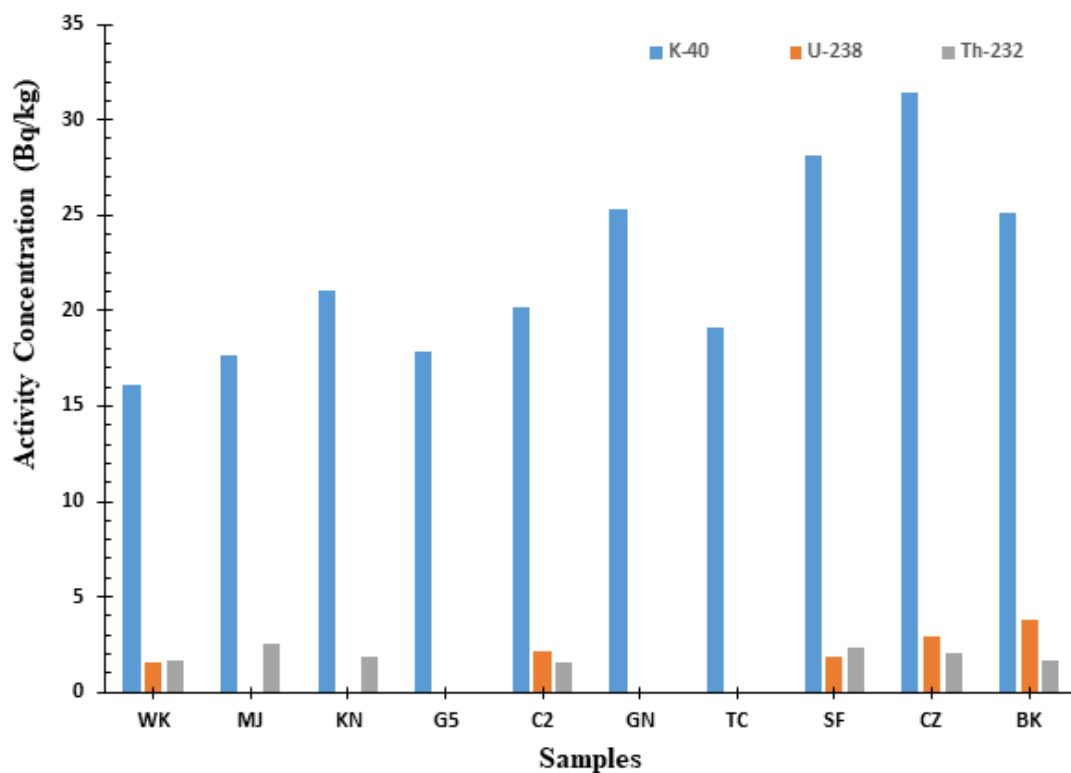
Table 1: Activity Concentration in Stimulants Samples

Sample Codes	Stimulants	^{40}K Bqkg^{-1}	^{238}U Bqkg^{-1}	^{232}Th Bqkg^{-1}
WK	Wonder Kola	16.060 ± 1.08	1.540 ± 0.14	1.620 ± 0.11
MJ	Marijuana	17.650 ± 2.01	BDL	2.530 ± 0.48
KN	Kola nut	21.050 ± 1.92	BDL	1.890 ± 0.13
G5	Ginseng	17.820 ± 2.17	BDL	BDL
C2	Cocoa Seed	20.150 ± 1.28	2.180 ± 0.42	1.560 ± 0.24
GN	Ginger	25.320 ± 2.04	BDL	BDL
TC	Turmeric	19.120 ± 1.45	BDL	BDL
SF	Snuff	28.170 ± 2.87	1.830 ± 0.31	2.310 ± 0.13
CZ	Cloves	31.470 ± 2.92	2.920 ± 0.24	2.090 ± 0.21
BK	Bitter kola	25.120 ± 2.03	3.760 ± 0.56	1.640 ± 0.17

BDL: BELOW DETECTION LIMIT

Table 2: Statistical Summary of Radioactivity in Stimulants

	^{40}K Bqkg^{-1}	^{238}U Bqkg^{-1}	^{232}Th Bqkg^{-1}
Min	16.060	1.540	1.560
Max	31.470	3.760	2.530
Mean	22.190	2.450	1.950
SD	5.080	0.900	0.380
CV (%)	22.893	36.734	19.487

**Figure 1:** Activity Concentration in Stimulants Samples**Figure 2:** Activity Concentration in Stimulants Sample

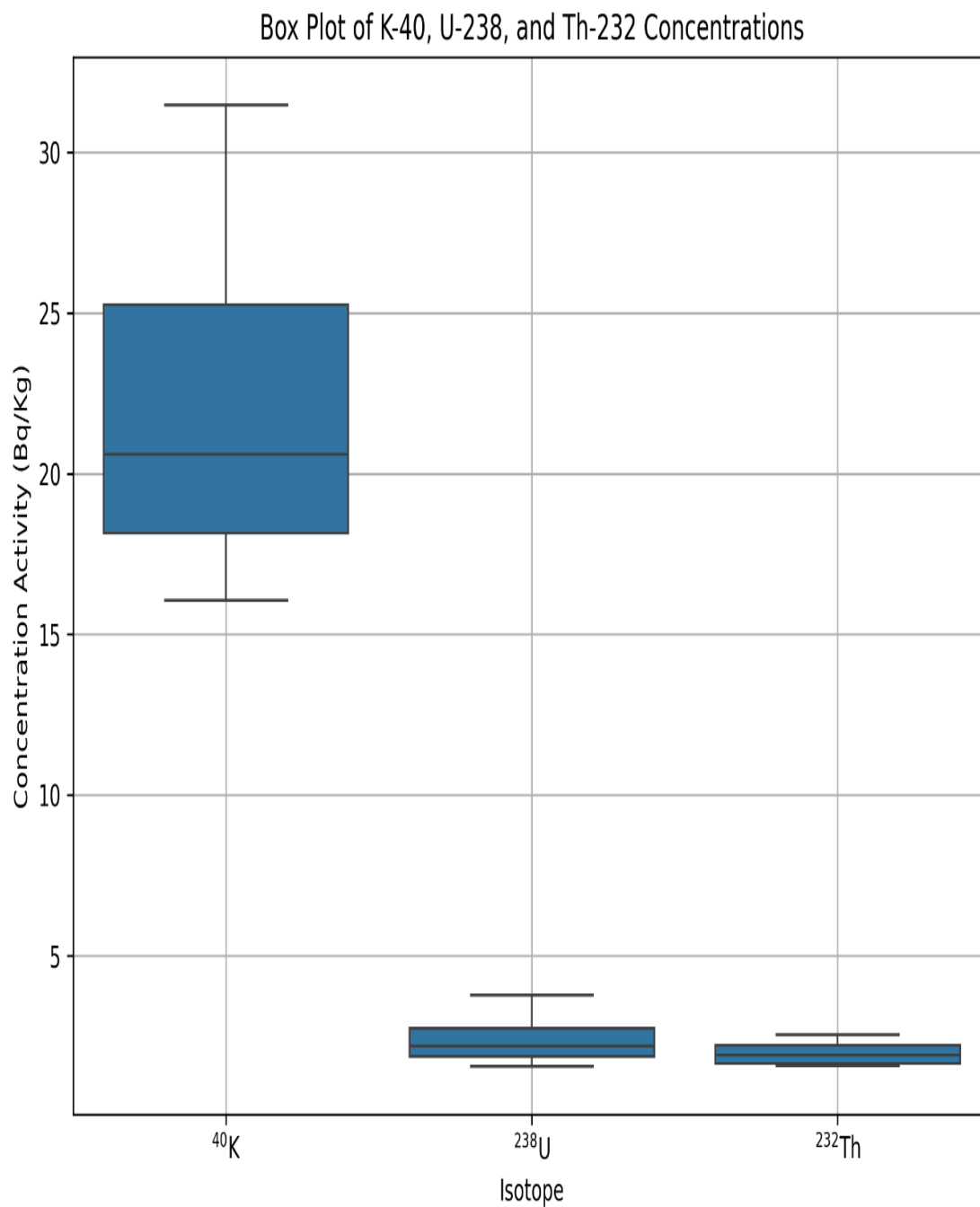


Figure 3: Box Plot of Activity Concentration in Stimulants

Table 3: Radiological Impact from Radioactivity in Stimulants

Sampl es	AD ($nGyh^{-1}$)	CED (μSvy^{-1})	ELCR (μSvy^{-1})	AGE D ($mSvy^{-1}$)	Ra eq ($Bqkg^{-1}$)	γ_I	H_{In}	H_{Out}
WK	2.387	0.975	3.411	0.017	5.093	0.037	0.018	0.014
MJ	2.307	1.244	4.355	0.016	4.977	0.037	0.013	0.013
KN	2.051	1.017	5.561	0.015	4.324	0.033	0.012	0.012
G5	0.743	0.199	0.696	0.006	1.372	0.12	0.004	0.004

C2	2.816	1.047	3.666	0.020	5.962	0.044	0.022	0.016
GN	1.056	0.283	0.989	0.008	1.950	0.017	0.005	0.005
TC	0.797	0.213	0.747	0.006	1.472	0.013	0.004	0.004
SF	3.455	1.419	4.966	0.024	7.302	0.054	0.025	0.020
CZ	3.969	1.453	5.085	0.028	8.332	0.061	0.030	0.023
BK	3.803	1.264	4.424	0.026	8.039	0.058	0.032	0.022

Table 4: Statistical Summary of Radiological Indices in Stimulants

	AD ($nGyh^{-1}$)	CED (μSvy^{-1})	ELCR (μSvy^{-1})	AGED ($mSvy^{-1}$)	Ra eq ($Bqkg^{-1}$)	γ_I	H_{In}	H_{Out}
Min	0.743	0.199	0.696	0.006	1.372	0.012	0.004	0.004
Max	3.959	1.453	5.085	0.028	8.332	0.061	0.032	0.023
Mean	2.338	0.911	3.190	0.016	4.882	0.037	0.016	0.013
SD	1.197	0.496	1.734	0.008	2.621	0.018	0.011	0.007
CV (%)	51.198	54.447	54.357	50.000	53.687	48.649	68.750	53.846

Table 5: Radioactivity analysis in similar studies

Location		^{40}K $Bqkg^{-1}$	^{238}U $Bqkg^{-1}$	^{232}Th $Bqkg^{-1}$	Sources
Vizag, India	Min	3.00	1.50	0.10	Patra et al., 2014
	Max	110.80	10.60	2.00	
	Mean	43.78	5.30	0.80	
Rio de Janeiro, Brazil	Min	21			Garcez et al., 2018
	Max	1288			
	Mean	467.35			
South-West, Nigeria	Min	301.46	1.73	1.22	Kolapo et al., 2018
	Max	658.36	5.41	8.49	
	Mean	493.19	2.99	3.57	
Poços de Caldas, Brazil	Min	21.75			Silva et al., 2021
	Max	606.2			
	Mean	254.81			
South-South, Nigeria	Min	16.06	1.54	1.56	This work
	Max	31.47	3.76	2.53	
	Mean	22.19	2.45	1.95	
		420	33	45	World Average (UNSCEAR, 2000)

Pearson Moment Correlation Coefficient Analysis

The Pearson correlation coefficient was employed to show the relationships and strength between various variables. Table 6 displays the

degree of correlation between the specific activity of each radionuclide and their corresponding radiological indices. Figure 4 shows the heat-map which is a pictorial representation of Table 6.

Table 6: Pearson Correlation Coefficient for Radionuclide Activity and Radiological Indices

	^{40}K	^{238}U	^{232}Th	AD	CED	ELCR	AGED	Ra_{eq}	γ_I	H_{in}	H_{out}
^{40}K	1.00										
^{238}U	0.48	1.00									
^{232}Th	0.22	0.13	1.00								
AD	0.60	0.77	-0.01	1.00							
CED	0.44	0.41	0.61	0.94	1.00						
ELCR	0.44	0.41	0.61	0.94	1.00	1.00					
AGED	0.61	0.75	-0.00	1.00	0.94	0.94	1.00				
Ra_{eq}	0.58	0.77	-0.00	1.00	0.95	0.95	1.00	1.00			
γ_I	0.60	0.74	0.03	1.00	0.95	0.95	1.00	1.00	1.00		
H_{in}	0.58	0.91	-0.22	0.99	0.88	0.88	0.99	0.99	0.98	1.00	
H_{out}	0.58	0.77	-0.00	1.00	0.95	0.95	1.00	1.00	1.00	0.98	1.00

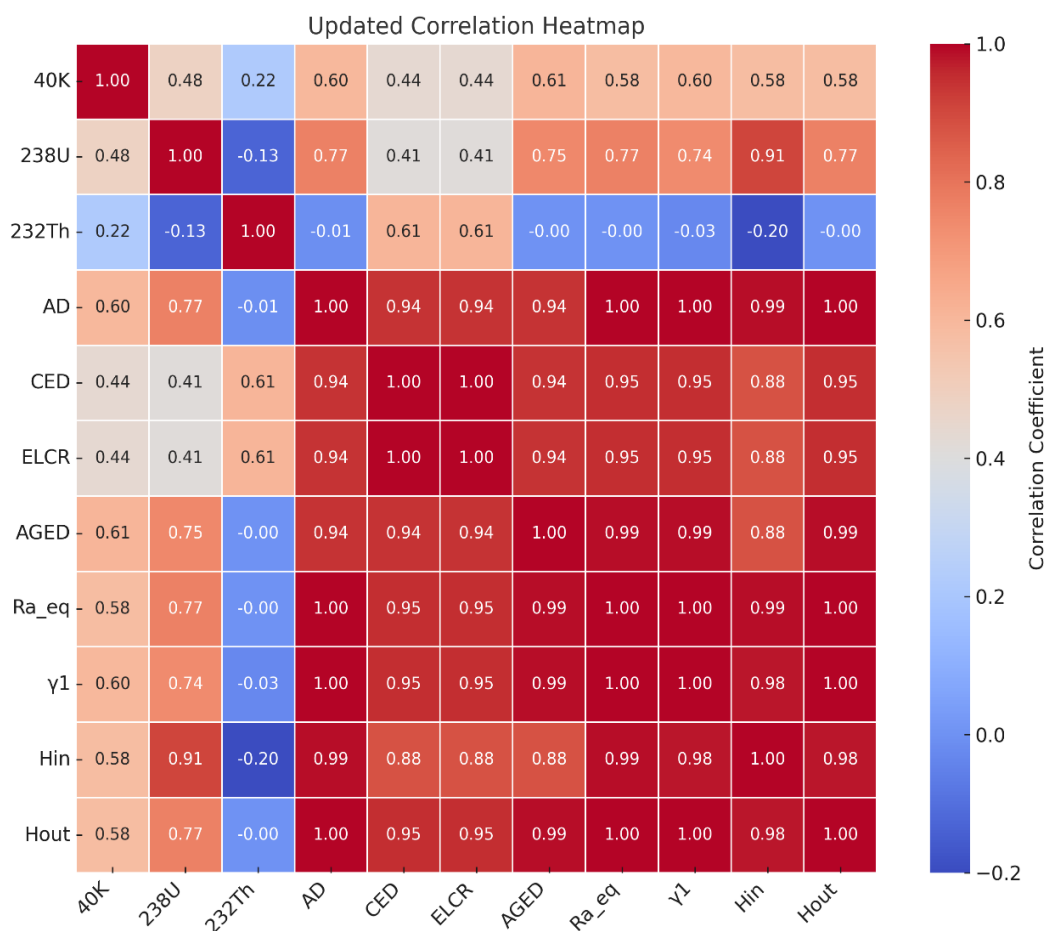


Figure 4: Heat-map for Radionuclide Activity and Radiological Indices

5.0 Conclusion

This research has established that the selected stimulants consumed in Akwa Ibom State contain naturally occurring radionuclides ^{238}U , ^{232}Th , and ^{40}K —but at levels well below internationally recommended safety limits. Radiological risk indices such as absorbed dose, CED, AGED, ELCR, radium equivalent activity, gamma index, and hazard indices were all found to be within acceptable bounds, suggesting no significant internal or external radiation hazard to consumers. Cloves (CZ) and bitter kola (BK) exhibited relatively higher radiological parameters, though still within safe margins, while ginseng (G5) and ginger (GN) showed minimal activity levels. The correlation analysis confirmed a strong interdependence between radionuclide concentrations and radiological health indices. The findings support the radiological safety of these stimulants and provide a valuable reference point for future assessments. Continuous monitoring is, however, recommended to detect any potential changes in radionuclide levels due to environmental or anthropogenic influences.

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