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Determination of Radon Concentration in Imported Tea Obtained From Maiduguri Monday Market using the Liquid Scintillation Counter Technique

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ABSTRACT

This study investigates radon-222 concentrations in imported tea samples obtained from northeastern Nigeria's Maiduguri Monday Market using Liquid Scintillation Counting (LSC) techniques. Located in the Sudano-Sahelian zone of Borno State, the study area encompasses the Maiduguri Metropolitan Council and adjacent regions, characterized by distinct seasonal variations and semi-arid conditions. Five popular imported tea brands were analyzed using a Packard Tri-Card LSA 1000TR liquid scintillation counter, with samples prepared following standardized protocols. Results revealed varying radon-222 concentrations across brands, with Lipton Tea showing the highest concentration ($0.0109\, Bq/L$), while Glen Tea and Top Tea exhibited no detectable levels. The study evaluated potential health risks through multiple parameters, including Annual Effective Dose (AED), Excess Lifetime Cancer Risk (ELCR), and Hazard Index (HI). Age-dependent analysis demonstrated heightened sensitivity among infants, particularly for Lipton Tea consumption, with an AED of $5.570 \times 10^{-4}\, mSv/year$. ELCR calculations indicated the highest lifetime cancer risk for infants consuming Lipton Tea (1.9495×10^{-3}) while remaining within acceptable limits. HI values consistently remained below 1 across all samples and age groups, suggesting minimal non-cancer health risks. The findings indicate that while radon-222 is present in some tea samples, concentrations remain well below the World Health Organization's recommended limit of $100\, Bq/m^3$ for drinking water. The study contributes valuable data to the limited research on radon contamination in consumer products within developing regions, while establishing a methodological framework for similar investigations worldwide.

Keywords:
Radon-222,
Liquid Scintillation Counting,
Tea,
Annual Effective Dose,
Cancer Risk,
Hazard Index,
Nigeria.

INTRODUCTION

Radon-222, a naturally occurring radioactive noble gas produced during the decay of uranium-238, represents a significant public health concern due to its ubiquitous presence in the environment and its established role as a carcinogen (Cecil & Green 2000). While the primary focus of radon exposure studies has traditionally centered on inhalation pathways, particularly in indoor environments, the potential risks associated with radon ingestion through food and beverages warrant careful investigation. This research addresses a critical gap in our understanding by examining radon concentrations in imported tea samples, one of the world's most widely consumed beverages (Pan *et al.*, 2009), obtained from the Maiduguri Monday Market in northeastern Nigeria.

Understanding radiation sources and their health implications is crucial for contextualizing radon exposure through tea consumption. Radiation manifests in two primary forms: non-ionizing radiation (including radio waves, microwaves, and visible light) which lacks sufficient energy to ionize atoms and molecules, and ionizing radiation (comprising alpha particles, beta particles, gamma rays, and X-rays) which carries enough energy to displace electrons from atoms, potentially causing significant cellular damage (Omer, 2021). Natural radiation exposure occurs through both terrestrial and cosmic sources. Terrestrial radiation originates from naturally occurring radioactive elements within the Earth's crust, primarily uranium, thorium, and potassium (Hamilton, 1989). These elements, through their decay processes, produce radon gas which can accumulate in various environmental media, including soil, water, and air (Grzywa-Celińska *et al.*, 2020).

The movement of radon from underground sources to the surface follows complex pathways, as illustrated in Figure 2, which demonstrates how factors such as soil density and humidity influence radon's environmental distribution (Zhang *et al.*, 2016). This process is particularly relevant when considering potential contamination pathways in agricultural products, including tea cultivation areas. Of specific concern is radon-222, which enters water supplies through the decay of radium present in rocks and soil (Skeppström & Olofsson, 2007). Groundwater sources, particularly wells and boreholes, typically exhibit higher radon concentrations due to their interaction with radium-rich geological formations (Akinnagbe *et al.*, 2018; Khandaker *et al.*, 2021; Sukanya *et al.*, 2021).

The regulation of radon in water varies internationally, with the World Health Organization recommending a guideline value of $100\,Bq/L$ (World Health Organization, 2009). The U.S. EPA proposes limits of $300\,pCi/L$ for standard cases and $4000\,pCi/L$ for situations with additional air ventilation measures (Stone, 1993; Cappello *et al.*, 2013; George, 2015; Åkerblom, 1999). These guidelines are particularly relevant when considering the potential exposure through beverage consumption, including tea.

The health implications of radon exposure are significant, with studies identifying it as the second leading cause of lung cancer after smoking (Lorenzo-Gonzalez *et al.*, 2019). While inhalation remains the primary exposure pathway of concern, ingestion through water and beverages presents an additional route of exposure that warrants investigation (Auvinen *et al.*, 2005). The alpha particles emitted during radon decay can cause significant damage to lung tissue when inhaled, and while ingestion has been linked to increased risk of stomach cancer, the predominant health concern remains respiratory exposure (Degu Belete & Alemu Anteneh, 2021).

The health implications of radon exposure are well-documented, with studies identifying it as the second leading cause of lung cancer after smoking (Sethi *et al.*, 2019). When radon decays, it releases radioactive particles that can be inhaled and lodge in the lungs, emitting alpha particles that cause long-term damage to lung tissue (World Health Organization, 2009). While respiratory exposure remains the primary concern, the potential health impacts of chronic low-dose exposure through ingestion pathways deserve attention, particularly in regions with elevated natural background radiation or in areas where food products may be sourced from radon-prone geological zones.

Tea consumption presents a unique avenue for investigating radon exposure through ingestion due to its global popularity and the various factors that can influence its radon content. These factors include the geological characteristics of cultivation areas, processing methods, and storage conditions. Recent studies have demonstrated varying levels of radioactivity in tea samples worldwide, highlighting the need for comprehensive monitoring and assessment of potential radiation doses to consumers. For instance, research conducted in Iraq using CR-39 nuclear track detectors revealed radon concentrations ranging from negligible levels to $34.725 \pm 13.2\,Bq/m^3$ in tea samples, emphasizing the variability in radon content across different tea products (Nasser *et al.*, 2020).

The present study employs Liquid Scintillation Counting (LSC), a highly sensitive and precise analytical technique, to quantify radon-222 concentrations in five popular imported tea brands available in the Maiduguri Monday Market. LSC offers several advantages over traditional measurement methods, including rapid analysis capabilities, high detection efficiency, and minimal sample preparation requirements (Hou & Dai 2020; Ntarisa, 2022). This methodology enables accurate determination of radon levels and subsequent assessment of potential health risks through the calculation of Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR) across different demographic groups. The study threfore aims to determine the concentration of radon-222 in selected tea samples by employing Liquid Scintillation Counting (LSC) technology. This method provides a sensitive and precise approach to quantify radon levels, ensuring accurate assessment of radioactivity in the samples.

Radioactivity and Radon

Radioactivity represents the spontaneous disintegration of unstable atomic nuclei, accompanied by the emission of particles and energy. This process follows the radioactive decay law, which describes an exponential decay pattern over time (Pathak, 2023). The mathematical representation of this decay is expressed as:

$$N_t = N_0 e^{-\lambda t} \quad (1)$$

where N_0 is the initial number of nuclei, N_t is the number of remaining nuclei after time t, and λ is the decay constant (Huestis, 2002; D'Auria & D'Auria, 2018; Pathak, 2023).

The activity of a radioactive source, measured in becquerels (Bq), represents the rate of nuclear disintegration per second (Pathak, 2023; Podgorsak & Podgoršak, 2014). Specific activity, typically expressed in Bq/kg or Bq/L, measures the activity per unit mass or volume (De Goeij & Bonardi, 2005). A crucial parameter in radioactive decay is the half-life ($t_{1/2}$), which represents the time required for half of a radioactive sample to decay, related to the decay constant through (Saha & Saha, 2010):

$$t_{1/2} = \frac{0.693}{\lambda} \quad (2)$$

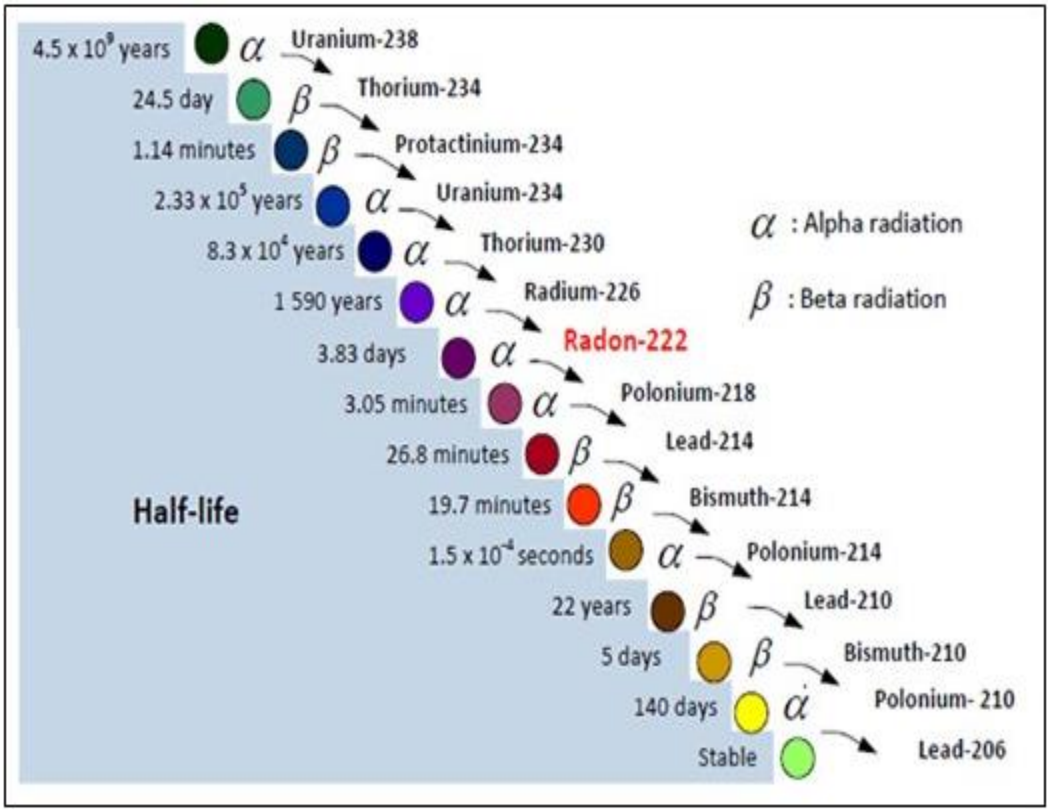

Figure 1: Uranium-238 decay chain (Canadian Nuclear Safety Commission., 2014; Bulut & Şahin, 2024)

The decay chain of Uranium-238, illustrated in Figure 1, demonstrates the complex series of radioactive transformations leading to the production of radon. Table 1 presents the fundamental physical and radioactive characteristics of radon, highlighting its unique properties as a noble gas.

Table 1: Physical and Radioactive Characteristics of Radon (Bulut, & Şahin, 2024; Gelgün *et al.*, 2009)

Property	Value
Element Symbol	Rn
Atomic Number	86
Atomic Weight	222
Number of Protons	86
Number of Electrons	86
Number of Neutrons	136
Melting Point	$-71.0\ °C\ (202.15\ K, -95.8\ °F)$
Boiling Point	$-61.8\ °C\ (211.35\ K, -79.24\ °F)$
Density	$9.73\ g/L\ (at\ 0\ °C\ and\ 1\ atm)$
Phase at Room Temperature	Gas
Color	Colorless
Radioactive Isotopes	$Rn-222$ (most stable), $Rn-220$, $Rn-219$
Half-life ($Rn-222$)	3.8 days
Decay Mode ($Rn-222$)	Alpha decay (to $Polonium-218$)
Occurrence	Found naturally in the uranium decay chain

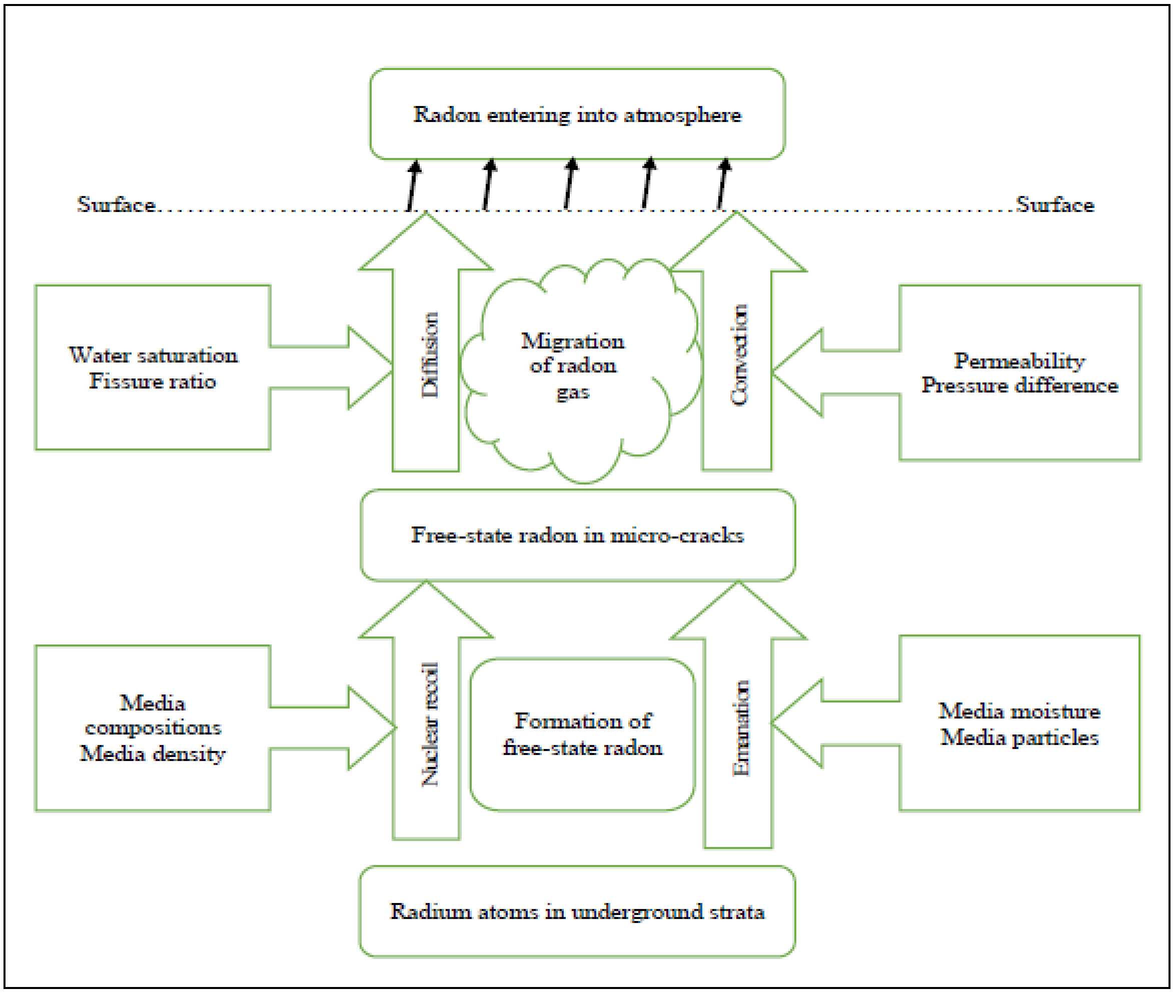

Figure 2: Surface Emission Pathways of Subterranean Radon Gas (Zhang *et al.*, 2016)

MATERIALS AND METHODS

Study area

The research was conducted in Maiduguri metropolis, situated in the Sudano-Sahelian zone of Borno State, Nigeria (Jibrin *et al.*, 2022). Maiduguri, encompassing the Maiduguri Metropolitan Council (MMC) and portions of Jere, Mafa, Konduga, and Magumeri Local Government Areas, spans 543 km^2 between latitudes $11°46'03.88"N$ and $11°55'34.66"N$, and longitudes $13°03'41.56"E$ and $13°16'01.22"E$ (Figure 4). As shown in Figure 3, the city is strategically located within Borno State, while Figure 4 provides a detailed view of the study area's urban layout and key sampling locations within the Maiduguri Metropolitan area (Abubakar et al., 2018; Google Map Data, 2024). As of 2019, the city's population was approximately 1,112,449, serving as northeastern Nigeria's primary commercial center (Kaka *et al.*, 2019).

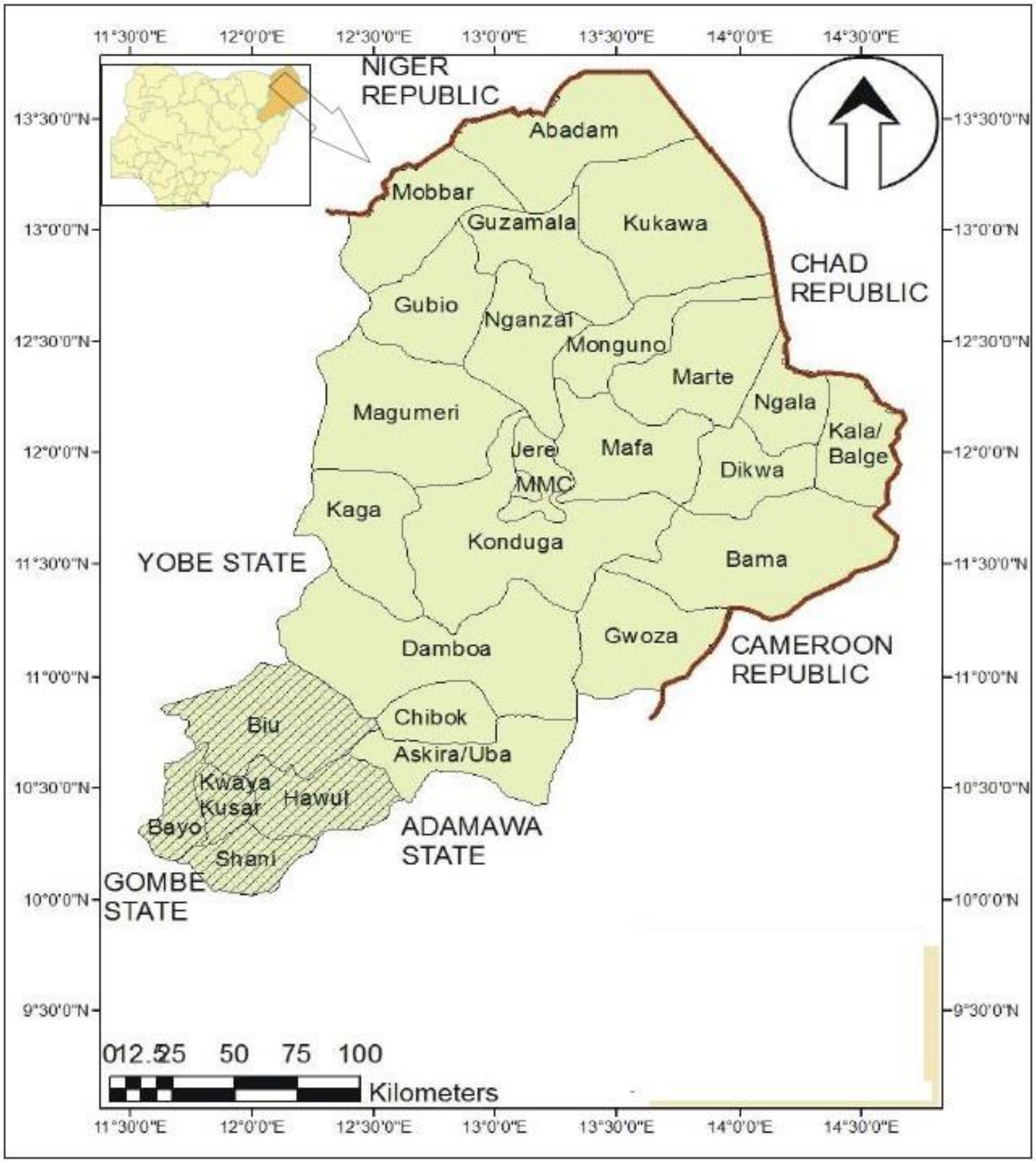

Figure 3: Map of Borno State (Bwala *et al*., 2020)

Figure 4: The Study Area (Abubakar *et al.*, 2018; Google Map Data, 2024)

The climate features a prolonged dry season (October-May) and a brief rainy season (June-September), with peak rainfall in August. Annual rainfall averages 613 mm, while temperatures range from 15°C during harmattan to 48°C in the dry season. The region's semi-arid characteristics include seasonal surface water availability and predominantly rain-fed agriculture.

Materials and experimental procedure

Sample collection

Five tea samples were collected from the Maiduguri Monday Market, representing diverse brands from different origins (Table 2). The samples were maintained in their original sealed packaging to preserve integrity until analysis.

Table 2: Details of Tea Samples Collected from Maiduguri Monday Market

Code	Name of the Product	Packing	Origin
S1	Lipton	Lagos	UK
S2	Top tea	Lagos	Nigeria
S3	Ahmad tea	Ibadan	UK
S4	Glen	Lagos	Nigeria
S5	Sun Valley	Lagos	Japan

Equipment and reagents

The research utilized a comprehensive suite of analytical equipment, with the Packard Tri-Card LSA 1000TR Liquid Scintillation Counter serving as the primary analytical instrument (as illustrated in Plate 1). For sample handling and preparation, disposable hypodermic syringes in both 20 ml and 10 ml capacities were employed, along with scintillation vials featuring 20 ml capacity and polyethylene inner seal caps. The analysis required specialized scintillation cocktail as the detection medium. Additional laboratory equipment included a calibrated pH meter and standard laboratory materials necessary for sample preparation and analysis. All equipment was maintained and calibrated according to manufacturer specifications to ensure measurement accuracy and reliability throughout the study period.

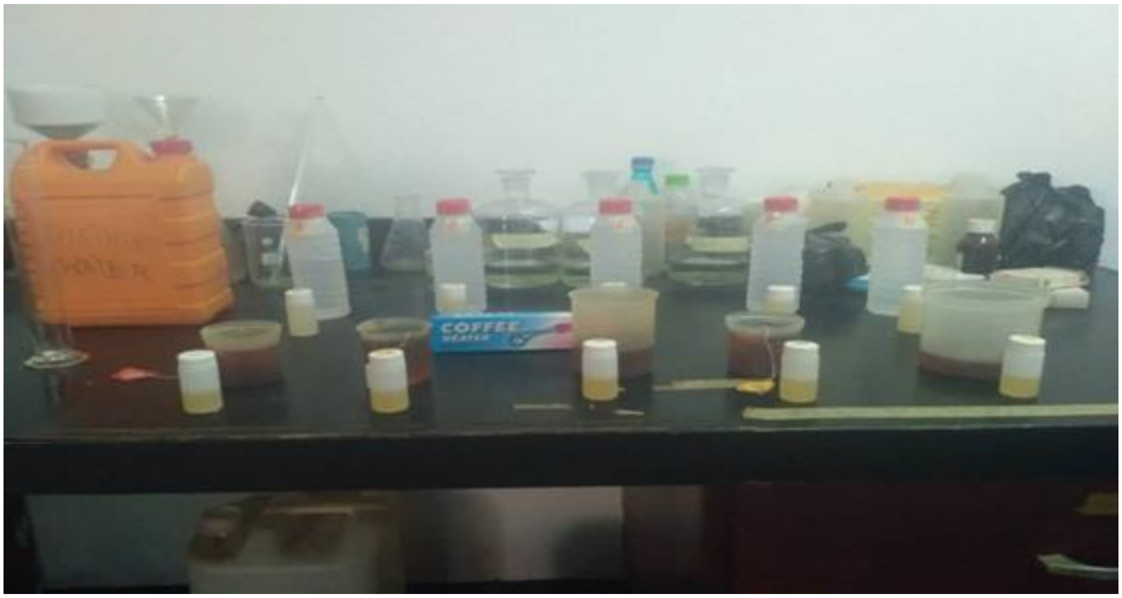

Plate 1: Counted Samples in Secondary Containment

Sample preparation and analysis

For each sample, $10\,ml$ of tea extract was carefully drawn using sterile syringes and combined with $10\,ml$ of toluene-based scintillation cocktail in vials. The mixtures were vigorously shaken for three minutes to facilitate radon-222 transfer into the organic scintillator. The samples were then placed in secondary containment during counting to ensure safe and accurate measurements, as shown in Plate 1.

Analytical calculations

The radon-222 activity concentration was calculated using the equation:

$$CRnw(Bq/L) = \frac{100 \times (SC - BC) \times exp(\lambda t)}{60 \times CF \times D} \qquad (3)$$

In Equation (3), $CRnw$ represents the concentration of radon-222 measured in Bq/L. The sample count (SC) and background count (BC) are both measured in counts per minute, providing the raw data for concentration calculations. The time elapsed between sampling and counting, denoted as t, is measured in minutes and is crucial for decay corrections. The decay constant (λ) has a value of $1.26 \times 10^{-4}\,min^{-1}$, which characterizes the radioactive decay rate of radon-222. The calibration factor (CF) ensures measurement accuracy by accounting for instrument-specific response characteristics. The parameter D represents the fraction of radon-222 present in the cocktail mixture, specifically for a $22\,ml$ total capacity vial containing $10\,ml$ of sample and $10\,ml$ of cocktail, with $2\,ml$ of air space remaining.

Annual effective dose (E) was calculated using:

$$E = C_{RnW} \times D \times L \qquad (4)$$

In Equation (4), D represents the age-specific dose coefficients, which vary by age group: $10^{-8}\,Sv/Bq$ for adults, $2 \times 10^{-8}\,Sv/Bq$ for children, and $7 \times 10^{-8}\,Sv/Bq$ for infants. The variable L denotes the annual liquid consumption, standardized at $730\,L/year$ for adults, which serves as a baseline for exposure calculations. Additional calculations included Excess Lifetime Cancer Risk (ELCR), Hazard Index (HI), and radon exhalation rates.

RESULTS AND DISCUSSION

Radon-222 activity concentration

Analysis of the tea samples revealed varying concentrations of radon-222 across different brands. The highest concentration was observed in Lipton Tea at $0.0109\,Bq/L$, while Glen Tea and Top Tea showed no detectable levels. Ahmed Tea and Sun Valley demonstrated intermediate concentrations of $0.0054\,Bq/L$ and $0.0027\,Bq/L$, respectively.

When comparing our findings with similar studies, notable differences in both methodology and results emerge. A relevant study conducted in Misan markets, Iraq, by Abdul Hussein *et al.* (2019) employed LR-115 detectors to measure radon concentrations in tea samples, reporting significantly higher concentrations ranging from 40.0 to $220.0\,Bq/m^3$, with a mean value of $158.64\,Bq/m^3$. This substantial difference from our measurements using Liquid Scintillation Counting can be attributed to several factors, including variations in detection methodologies, geographic and geological differences between Iraq and Nigeria influencing background radiation levels, different sourcing and processing methods, and varying storage conditions between production and testing.

Despite these methodological and geographical differences, both studies reached similar conclusions regarding public health implications. Abdul Hussein $et\ al.$ (2019) found that their measured concentrations remained below the International Commission on Radiological Protection's recommended action levels of $200-600\ Bq/m^3$, concluding that the samples posed no significant health risks. Similarly, our findings indicate that even the highest measured concentrations fall well below the World Health Organization's recommended limit of 100 Bq/m^3 for drinking water.

Table 3: Radon-222 Activity Concentration in Imported Tea Samples from Maiduguri Monday Market

Tea Sample	Sample Count (CPM)	Background Count (CPM)	Activity Concentration (Bq/L)
Ahmed Tea	3.30	3.28	0.0054
Sun Valley	8.93	8.92	0.0027
Glen Tea	1.75	1.75	0.0000
Lipton Tea	2.62	2.58	0.0109
Top Tea	3.22	3.22	0.0000

Annual Effective Dose (AED)

The calculated AED values demonstrated clear age-dependent variation in radiation exposure. Infants showed the highest potential exposure, particularly from Lipton Tea ($5.570\times10^{-4}\ mSv/year$), while adults exhibited the lowest dose exposure. Importantly, all values remained well below the International Commission on Radiological Protection's recommended limit of 1 $mSv/year$, indicating minimal radiation risk from tea consumption across all age groups.

Table 4: Annual Effective Dose (AED) Values for Radon-222 Ingestion in Tea Samples Across Different Age Groups

Tea Sample	Adults ($mSv/year$)	Children ($mSv/year$)	Infants ($mSv/year$)
Ahmed Tea	3.942×10^{-5}	7.884×10^{-5}	2.759×10^{-4}
Sun Valley	1.971×10^{-5}	3.942×10^{-5}	1.380×10^{-4}
Glen Tea	0.0000	0.0000	0.0000
Lipton Tea	7.957×10^{-5}	1.591×10^{-4}	5.570×10^{-4}
Top Tea	0.0000	0.0000	0.0000

Excess Lifetime Cancer Risk (ELCR)

Analysis of ELCR calculations (Table 5) revealed that Lipton Tea presented the highest lifetime cancer risk, particularly for infants (1.9495×10^{-3}), though still within acceptable limits. Glen Tea and Top Tea showed no significant cancer risk (ELCR = 0.0000) across all age groups. These findings suggest that while some brands contain detectable levels of radon-222, the associated cancer risks remain minimal under normal consumption patterns.

Table 5: Excess Lifetime Cancer Risk (ELCR) Values for Radon-222 Ingestion in Tea Samples Across Different Age Groups

Tea Sample	Adults (ELCR)	Children (ELCR)	Infants (ELCR)
Ahmed Tea	1.3797×10^{-4}	2.7594×10^{-4}	9.658×10^{-4}
Sun Valley	6.8985×10^{-5}	1.3797×10^{-4}	4.829×10^{-4}
Glen Tea	0	0	0
Lipton Tea	2.7850×10^{-4}	5.5700×10^{-4}	1.9495×10^{-3}
Top Tea	0	0	0

Hazard Index (HI)

The calculated HI values (Table 6) for all samples remained significantly below 1, indicating minimal non-cancer health risks. Lipton Tea showed the highest HI for infants (5.570×10^{-4}), while Glen Tea and Top Tea presented no hazard ($HI = 0.0000$).

Table 6: Hazard Index (HI) Values for Radon-222 Ingestion Across Different Tea Samples and Age Groups

Tea Sample	Adults (HI)	Children (HI)	Infants (HI)
Ahmed Tea	3.942×10^{-5}	7.884×10^{-5}	2.759×10^{-4}
Sun Valley	1.971×10^{-5}	3.942×10^{-5}	1.380×10^{-4}
Glen Tea	0.0000	0.0000	0.0000
Lipton Tea	7.957×10^{-5}	1.591×10^{-4}	5.570×10^{-4}
Top Tea	0.0000	0.0000	0.0000

The findings indicate that while radon-222 is present in some tea samples, the concentrations remain well below international safety thresholds. The World Health Organization's recommended limit of 100 Bq/m^3 for drinking water provides a relevant comparison point, suggesting that the measured concentrations pose minimal immediate health risks through normal consumption patterns.

CONCLUSION

This research investigated the presence and concentration of Radon-222 in imported tea samples from the Maiduguri Monday Market, northeastern Nigeria, utilizing Liquid Scintillation Counting (LSC) techniques. The study aimed to assess potential radiological risks associated with tea consumption across different demographic groups, contributing to the limited body of research on radon contamination in consumer products within developing regions. The investigation centered on five widely consumed tea brands, analyzing their Radon-222 concentrations and evaluating associated health risks through multiple parameters including Annual Effective Dose (AED), Excess Lifetime Cancer Risk (ELCR), and Hazard Index (HI). The results, as presented in Tables 3-6, revealed significant variations in radon concentrations across different brands, with Lipton Tea showing the highest concentration at 0.0109 Bq/L, while Glen Tea and Top Tea exhibited no detectable levels. Analysis of the Annual Effective Dose, detailed in Table 4, demonstrated age-dependent variation in potential radiation exposure. Most notably, infants showed heightened sensitivity to radiation exposure, particularly when consuming Lipton Tea, with an AED of 5.570×10^{-4} mSv/year. However, these values remained well below the International Commission on Radiological Protection's recommended limit of 1 mSv/year, suggesting minimal immediate health risks through normal consumption patterns. The ELCR calculations, as shown in Table 5, indicated that lifetime cancer risks were highest for Lipton Tea, particularly among infants (1.9495×10^{-3}), though still within acceptable limits defined by international standards. The Hazard Index values (Table 6) consistently remained below 1 across all samples and age groups, indicating minimal non-cancer health risks associated with radon ingestion through tea consumption. Based on the comprehensive analysis conducted in this study, several significant conclusions emerge regarding the safety and public health implications of radon levels in imported tea products: The measured Radon-222 concentrations in all analyzed tea samples fall well below international safety thresholds, as evidenced by the data presented in Table 3. This finding suggests that current tea importation and distribution practices in the Maiduguri region maintain adequate safety standards regarding radioactive contamination. The variation in radon levels among different brands, as illustrated through our analyses, indicates that processing methods, storage conditions, and geographical origin may significantly influence radon content in the final product. The age-dependent risk assessment, detailed through Tables 4-6, confirms that radiation exposure sensitivity varies significantly with age. Infants demonstrated the highest potential risk, particularly when consuming certain brands like Lipton Tea. However, even these elevated risk levels remained within acceptable international safety parameters, suggesting that current market offerings pose minimal radiological health risks to consumers of any age group. The study's findings align with previous research while adding valuable data specific to the Nigerian context. The results contribute to filling a critical knowledge gap regarding radon contamination in consumer products within developing regions, particularly in areas with potential geological predisposition to elevated background radiation levels.

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