



Radiometric Analysis of Radon-222 Concentration in Water Sources Used for Domestic Purposes in Nasarawa Metropolis, Nasarawa State, Nigeria



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ABSTRACT

This study investigates the concentration of Rn-222 in domestic water sources within Nasarawa metropolis, Nasarawa State, Nigeria. With the aim of accessing the potential health concerns related to radon accumulation. A total of thirty water samples comprising ten each from wells, boreholes, and streams were collected and analyzed using a liquid scintillation counter (Tri-Carb LSA 1000). Key parameters evaluated include Rn-222 activity concentration, annual effective dose from ingestion and inhalation, dose contributions to the stomach and lungs, and the excess lifetime cancer risk. Measured Rn-222 levels ranged from 0.06 to 18.50 counts per minute (cpm), with a background radiation count of 63.83 cpm attributed to environmental and non-sample sources. Radon activity concentrations spanned from 3.14×10^0 to 1.15×10^3 Bq/L, with an average of 4.17×10^1 Bq/L which substantially exceed the World Health Organization (WHO) recommended safety threshold of 100 Bq/L for drinking water. The mean annual effective dose from ingestion (3.05×10^{-3} mSv/y) remained below the International Commission on Radiological Protection (ICRP) public exposure limit of 1 mSv/y. However, the mean dose to the stomach was 3.65×10^{-4} mSv/y, indicating minor but quantifiable internal exposure. Notably, the average annual effective dose from inhalation was 18.4 mSv/y, significantly surpassing the ICRP guideline, thus raising potential health concerns, particularly in enclosed, poorly ventilated settings where radon may accumulate. The study therefore recommends continuous monitoring of domestic water sources and improved ventilation practices to minimize radon-related health risks.

Keywords:

Rn-222,
Natural Radioactive
Sources,
Effective Dose,
Activity Concentration,
Ground water

INTRODUCTION

Water is key to human life, and its purity in terms of radioactive content is important and has received considerable attention worldwide (Adeniyi *et al.*, 2022). Groundwater is considered a vital resource that supports human existence on earth, it is more potable and not easily contaminated as surface water (Ahzegbobor, 2010) so it have been under rapidly increasing stress in large parts of the world. However, it is difficult to remediate a contaminated groundwater source. Therefore, ensuring that ground water is safe for human consumption is necessary (Alomari *et al.*, 2019).

Radiation has a number of benefits that can be found in medical, industrial and domestic applications but could be very harmful to human life when its level exceeds some permissible limits in the human body. Radiation gets to human body by ingestion (food or water), inhalation or through cutaneous contact with the skin.

Rn-222 is a radioactive noble gas that forms as portion of the uranium-238 (U-238) decay series having half-life of 3.8 days, it is both chemically inert and radioactive, enabling it to diffuse through soil, rock, and water (UNSCEAR, 2000). Because of its gaseous nature and ability to dissolve in water, radon can migrate from subsurface geological formations into groundwater sources. When water containing dissolved radon is used in homes, the gas can be released into indoor air during cooking, washing, showering and related activities, thereby becoming a significant source of internal radiation exposure through both ingestion and inhalation (WHO, 2011; Asonye *et al.*, 2007). The pathways through which radon in groundwater poses a radiological hazard to the human body when ingested are basically gastrointestinal exposure which is a threat capable of causing stomach cancer and respiratory tract exposure due to radon inhalation after its escape from water to air.

It has been established that the detrimental effect of this can cause cancer of the lungs (Agidi *et al.*, 2022).

Radon exposure is internationally acknowledged as the second foremost cause of lung cancer following smoking and the principal source of natural background radiation for the general populace. (USEPA, 2003; ICRP, 2014). The health hazards tied to radon arise mainly from its radioactive decay products, which include Po-218 and Po-214, these release alpha particles capable of damaging lung tissue upon inhalation. (Field, 2001; Asonye *et al.*, 2007). Ingestion of radon-containing water also poses potential risks to internal organs, particularly the stomach, where prolonged exposure may increase the likelihood of cancer development (Chen *et al.*, 2010; Adebo & Adetoyinbo, 2009).

Given the potential health implications, international organisations, including the World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP), have put forth reference ranges for radon concentrations in water and indoor air. The WHO (2011) recommends a reference threshold of 100 Bq/L for radon in potable water, while the ICRP (2014) sets an annual effective dose limit of 1 mSv for public exposure from all sources of ionizing radiation, excluding medical and occupational exposure.

Nasarawa State in North Central Nigeria is geologically characterized by uranium-bearing formations, especially in areas where natural erosion and mining activities have exposed subsurface rock materials (Obaje, 2009; UNSCEAR, 2000; Sroor *et al.*, 2001). Nasarawa metropolis, relies heavily on groundwater sources such as wells, boreholes, and streams, for domestic water supply. However, studies assessing the radiological quality of these water sources, particularly with respect to radon contamination, are limited.

This study seeks to fill this knowledge gap by conducting a comprehensive radiometric analysis of radon-222 concentrations in domestic water sources within

Nasarawa metropolis. Specifically, it involves the collection and measurement of radon levels in water samples from wells, boreholes, and streams using liquid scintillation counting techniques. The study also estimates key radiological parameters, including the annual effective dose from ingestion (AED_{ing}), the dose contribution to the stomach ($D_{stomach}$), and the excess lifetime cancer risk (ELCR) associated with radon exposure.

By quantifying these parameters, this research aims to evaluate the potential radiological health risks posed to the local population, highlight the need for regular monitoring of groundwater sources, and contribute to the formulation of evidence-based public health and environmental safety policies in Nasarawa State and other regions with similar geophysical characteristics.

MATERIALS AND METHODS

The Study Area

Nasarawa Local Government Area, located in Nasarawa State, Nigeria, lies between latitude 8.5333° N and longitude 7.7167° E. It covers an expansive area and shares close proximity with the Federal Capital Territory (FCT), Abuja. The region is geologically rich, hosting a wide range of solid mineral resources such as uranium, tin, barite, limestone, coal, and tantalite. These minerals, particularly uranium, have made the area significant for both industrial development and scientific research.

The major occupation of residents in Nasarawa LGA is agriculture, with many engaged in the cultivation of crops like maize, yam, cassava, rice, and guinea corn. Livestock farming and petty trading are also common among the local population. Mining is another prominent economic activity, driven by the area's rich mineral deposits. Additionally, the LGA benefits economically from its proximity to Abuja, which facilitates trade, mobility, and access to broader markets and services.

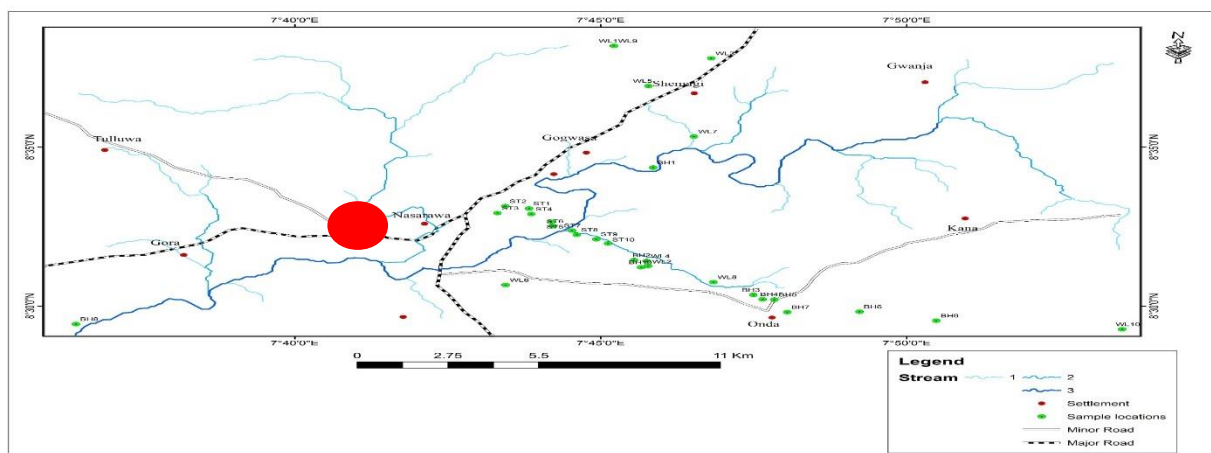


Figure 1: Map of the Study Area Showing Sample Location Coordinates.

The study covers the Nasarawa metropolis in Nasarawa State, Nigeria, encompassing all boreholes, wells, and streams within the selected locations. A total of thirty (30) water samples were collected from these sources for analysis.

Sample Collection and Sampling Methods

To obtain representative samples and ensure equal chances of selection, a simple random sampling technique were employed to choose two areas in Nasarawa metropolis, Nasarawa state, Nigeria. This technique was employed to select thirty (30) boreholes, wells and streams from these areas for sampling.

Method of Sample Collection

Each water sample was assigned a unique identification number, and the GPS coordinates of each sampling location were recorded to ensure proper traceability. A total of thirty (30) groundwater samples including those from boreholes, wells, and streams were collected using clean plastic containers with tight-fitting lids. To avoid contamination, all containers were thoroughly cleaned and rinsed with distilled water prior to sampling. Each sample was preserved by adding 20 ml of concentrated nitric acid (HNO₃) per liter of water to reduce radon adsorption onto the container walls.

Samples from boreholes were collected after running the pump for at least four minutes to ensure that fresh water was obtained. At each site, containers were completely filled without leaving any air space, preventing the dissolution of atmospheric CO₂, which could alter water chemistry parameters such as pH. The containers were sealed immediately after collection to minimize radon loss through degassing. To maintain accuracy and reduce the impact of radioactive decay, all samples were transported to the laboratory for analysis within 24 Hours of collection.

Sample Preparation

Ten millilitres (10 ml) of each sample were introduced into a vial containing 10 ml of a toluene-based cocktail (scintillator) utilising a hypodermic syringe. The vials were tightly sealed and forcefully shaken for three (3) minutes to remove radon-222 from the water phase and into the organic scintillator. Similarly, a blank sample for the background was created using distilled water stored in a glass bottle for at least 21 days. The prepared samples were left undisturbed for at least three (3) hours per sample to allow Rn-222 and its alpha decay products to attain equilibrium before counting.

Sample Analysis Method

A Sodium Iodide (NaI) Liquid Scintillation Counter (LSC) was employed to determine the radioactive content of the samples. This technique works by detecting the flashes of light (scintillations) produced when radiation

interacts with the scintillation fluid. For the purpose of this study, the Liquid Scintillation Counter (Tri-Carb LSA 1000) was used to analyze Rn-222 in each sample at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Kaduna State, Nigeria. As Rn-222 decays, it emits alpha particles, which transfer energy to the scintillating cocktail, resulting in light pulses that are detected and recorded as digital counts.

Data Analysis Method

The data analysis was carried out in four main stages: (i) Determination of Rn-222 activity concentration in Bq/L, (ii) Calculation of annual effective doses to the stomach (ingestion) and lungs (inhalation), (iii) Estimation of the excess lifetime cancer risk (ELCR), and (iv) Comparison of the results with international standards and findings from related studies.

To determine the efficiency of the radon-222 detector, a calibration was carried out using a certified radium-226 source that emits a known quantity of radon-222. The detector's response, recorded in counts per unit time, was measured under consistent experimental conditions. The efficiency (ε) was computed using the following relation:

$$\varepsilon = \frac{\text{Net counts per second}}{\text{Activity of the standard source (Bq)}} \quad 1$$

The background count rate was subtracted from the gross counts to obtain net counts. All calibrations were performed under controlled laboratory conditions using the same geometry and measurement setup as the sample analysis.

Rn-222 Concentration in Bq/l Estimation Method

The activity concentration of Radon-222 was calculated from the samples and background results obtained using equation 2 below as described by (Ajiboye *et al.*, 2022):

$$C_{Rn-222}(\text{BqL}^{-1}) = \frac{C - C_b}{CF \times \varepsilon} \cdot e^{\lambda t} \quad 2$$

where, C_{Rn-222} = Rn-222 activity concentration in water (Bq/L), C = Measured count rate (cps) from the scintillation counter, C_b = Background count rate (cps), CF = Calibration factor (0.2 cps per Bq/L), ε = Efficiency of the detector (0.08), t = Elapsed time (in days) between sample collection and measurement (3.8 days), and λ = Decay constant of Rn-222 ($1.26 \times 10^{-4} \text{ min}^{-1}$)

Annual Effective Dose by Ingestion Estimation Method

The corresponding annual effective doses (mSv/y) due to ingestion of Rn-222 in water samples from the study area were also calculated using equation 3 by taking into account the dose coefficient in (Sv/Bq), the annual water consumption (L/Y) and the activity concentration of Rn-222 obtained from equation 2 using equation 3 (Dankawu *et al.*, 2021):

$$E_{Ing} = C_{RnW} \times D \times L \quad 3$$

where: CR_{nw} is the concentration of Rn-222, D is the dose coefficient ($10^{-8} Sv/Bq, 2 \times 10^{-8} Sv/Bq, 7 \times 10^{-8} Sv/Bq$) for adults, children and infants respectively. L is the annual water consumption by an adult of 2 litres per day that is $730L/Y$ (UNSCEAR, 2000).

According to United Nation Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 2000) doses due to ingestion of radon in water for similar consumption rates could be factor of 2 and 7 times higher for children and infants respectively.

Dose Contribution to the Stomach due to Ingestion

This is the product of the stomach tissue weighted factor (0.1196) with corresponding ingestion dose using Equation 4 below as described by Dankawu et al., 2021:

$$Dose\ to\ the\ Stomach\ (D_{stomach}) = E_{ing} \times 0.1196 \quad 4$$

Dose Contribution to the Lung due to Inhalation

This is the product of the lung tissue weighted factor (0.1199) and corresponding inhalation dose using Equation 5 (Dankawu et al., 2021).

$$Dose\ to\ the\ Lung\ (D_{lung}) = E_{Inh} \times 0.1199 \quad 5$$

Excess Lifetime Cancer Risk Estimation Method

The excess lifetime cancer risk was evaluated using equation 6 as described by Dankawu et al., 2021:

$$ELCR = AEDE \times DL \times RF \times 10^{-3} \quad 6$$

where ELCR is the excess lifetime cancer risk, AEDE is the annual effective dose equivalent, DL is the average duration of life (estimated to 70 years), and RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public.

RESULTS AND DISCUSSION

The study assesses the Rn-222 concentration in water samples from Nasarawa metropolis, Nasarawa State. Thirty (30) water samples (10 each for wells, boreholes and streams) were analyzed for Rn-222 concentration using a Sodium Iodide (NaI) liquid scintillation counter. The results of Rn-222 concentration in water samples collected from the study area are presented in Table 1.

Table 1: Result in count per minute of the water samples using a liquid scintillation counter

S/N	Sample Code	Geopoint		CPM
		Latitude	Longitude	
1	BH1	8.5725	7.7643	11.30
2	BH2	8.5240	7.7591	10.05
3	BH3	8.5058	7.7916	15.79
4	BH4	8.5035	7.7941	11.73
5	BH5	8.5033	7.7973	10.71
6	BH6	8.4970	7.8205	11.92
7	BH7	8.4968	7.8008	13.58
8	BH8	8.4905	7.6071	14.75
9	BH9	8.4923	7.8414	14.59
10	BH10	8.5203	7.7610	18.50
11	WL1	8.6363	7.7536	3.03
12	WL2	8.5210	7.7629	5.37
13	WL3	8.6298	7.7801	0.28
14	WL4	8.5235	7.7625	3.03
15	WL5	8.6153	7.763	5.81
16	WL6	8.5110	7.7241	3.73
17	WL7	8.5888	7.7754	1.32
18	WL8	8.5125	7.7807	2.44
19	WL9	8.6363	7.7536	4.53
20	WL10	8.4878	7.8920	4.73
21	ST1	8.5511	7.7305	4.43
22	ST2	8.5523	7.7240	0.32
23	ST3	8.5487	7.7219	5.28
24	ST4	8.5482	7.7311	4.57
25	ST5	8.5440	7.7365	0.13
26	ST6	8.5418	7.7370	1.69
27	ST7	8.5395	7.7422	0.06
28	ST8	8.5373	7.7435	1.53
29	ST9	8.5350	7.7488	0.43
30	ST10	8.5328	7.7520	3.50

Mean	6.30
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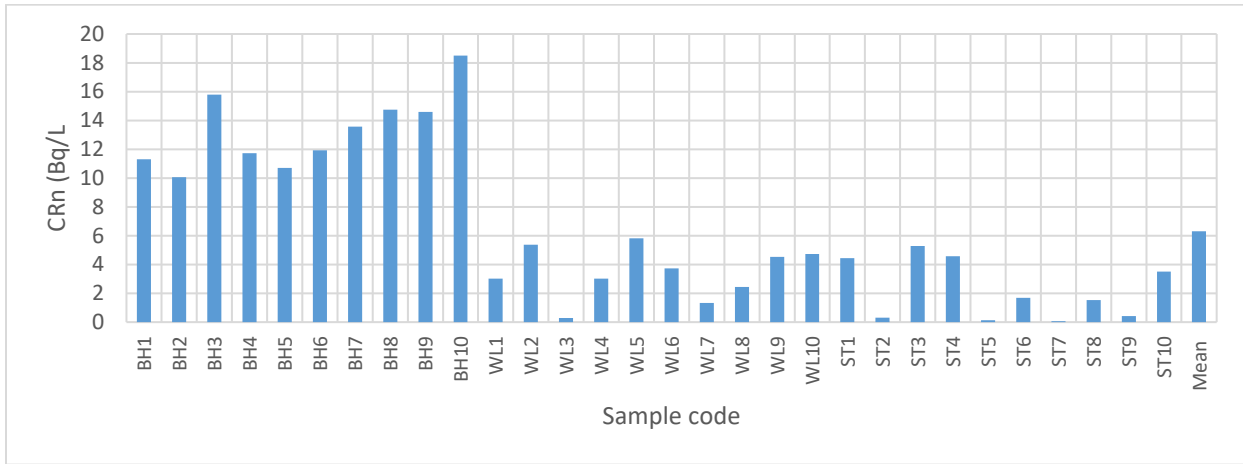


Figure 2: Comparison of count per minute of the water samples using a liquid scintillation counter. Table 1 and Figure 2 display the count per minute (cpm) results obtained from the liquid scintillation counter analysis of the water samples. The mean Rn-222 concentration levels was 6.30 cpm. This background value represents ambient radiation from the environment and the detection system itself, not originating from the actual samples. The range of sample counts indicates that while some samples show radon activity only slightly above the background level, others exhibit significantly higher activity. The mean value suggests that the radon concentration in the samples is low, possibly due to minimal radon presence or equilibrium with environmental levels.

Table 2: Calculated values of the radiological hazards parameters

S/n	Sample Code	C Rn-222 (Bq/L)	AED _{ing} (mSv/y)	D _{Stomach} (mSv/y)	D _{Lung} (mSv/y)	ELCR
1	BW1	7.08×10^2	5.17×10^{-3}	6.18×10^{-4}	3.74×10^4	1.81×10^{-2}
2	BW2	6.37×10^2	4.65×10^{-3}	5.56×10^{-4}	3.36×10^4	1.63×10^{-2}
3	BW3	9.90×10^2	7.23×10^{-3}	8.65×10^{-4}	5.22×10^4	2.53×10^{-2}
4	BW4	7.30×10^2	5.32×10^{-3}	6.37×10^{-4}	3.85×10^4	1.87×10^{-2}
5	BW5	6.72×10^2	4.90×10^{-3}	5.86×10^{-4}	3.54×10^4	1.72×10^{-2}
6	BW6	7.54×10^2	5.51×10^{-3}	6.59×10^{-4}	3.98×10^4	1.93×10^{-2}
7	BW7	8.52×10^2	6.22×10^{-3}	7.44×10^{-4}	4.49×10^4	2.18×10^{-2}
8	BW8	9.25×10^2	6.75×10^{-3}	8.08×10^{-4}	4.88×10^4	2.36×10^{-2}
9	BW9	9.15×10^2	6.68×10^{-3}	7.99×10^{-4}	4.83×10^4	2.34×10^{-2}
10	BW10	1.15×10^3	8.43×10^{-3}	1.01×10^{-3}	6.09×10^4	2.95×10^{-2}
11	WW1	1.92×10^2	1.40×10^{-3}	1.68×10^{-4}	1.01×10^4	4.90×10^{-3}
12	WW2	3.37×10^2	2.46×10^{-3}	2.94×10^{-4}	1.78×10^4	8.60×10^{-3}
13	WW3	2.33×10^2	1.69×10^{-3}	2.03×10^{-4}	1.23×10^4	5.94×10^{-3}
14	WW4	1.53×10^2	1.12×10^{-3}	1.34×10^{-4}	8.07×10^3	3.91×10^{-3}
15	WW5	3.71×10^2	2.71×10^{-3}	3.24×10^{-4}	1.96×10^4	9.49×10^{-3}
16	WW6	2.28×10^2	1.67×10^{-3}	1.99×10^{-4}	1.20×10^4	5.83×10^{-3}
17	WW7	6.72×10^2	6.10×10^{-4}	7.34×10^{-5}	$4.43E+03$	2.15×10^{-3}
18	WW8	8.40×10^1	1.12×10^{-3}	1.34×10^{-4}	8.11×10^3	3.93×10^{-3}

19	WW9	1.54×10^2	2.03×10^{-3}	2.43×10^{-4}	1.47×10^4	7.11×10^{-3}
20	WW10	2.78×10^2	2.16×10^{-3}	2.58×10^{-4}	1.56×10^4	7.56×10^{-3}
21	SW1	2.96×10^2	1.98×10^{-3}	2.38×10^{-4}	1.44×10^4	6.95×10^{-3}
22	SW2	2.72×10^2	1.50×10^{-3}	1.75×10^{-5}	1.06×10^3	5.13×10^{-4}
23	SW3	2.01×10^2	2.43×10^{-3}	2.90×10^{-4}	1.75×10^4	8.49×10^{-3}
24	SW4	3.32×10^2	2.14×10^{-3}	2.56×10^{-4}	1.55×10^4	7.50×10^{-3}
25	SW5	2.93×10^2	5.49×10^{-3}	6.57×10^{-6}	3.97×10^4	1.92×10^{-4}
26	SW6	7.53×10^0	8.24×10^{-3}	9.86×10^{-5}	5.96×10^3	2.88×10^{-3}
27	SW7	1.13×10^2	2.29×10^{-3}	2.74×10^{-6}	1.65×10^2	8.01×10^{-5}
28	SW8	3.14×10^0	7.00×10^{-3}	8.38×10^{-5}	5.06×10^3	2.45×10^{-3}
29	SW9	9.60×10^1	1.97×10^{-3}	2.35×10^{-5}	1.42×10^3	6.89×10^{-4}
30	SW10	2.70×10^1	5.17×10^{-3}	6.18×10^{-4}	3.74×10^4	1.81×10^{-2}
	Mean	4.17×10^1	3.05×10^{-3}	3.65×10^{-4}	2.20×10^4	1.07×10^{-2}
	Min	3.14×10^0	2.29×10^{-5}	2.74×10^{-6}	1.65×10^2	8.01×10^{-5}
	Max	1.15×10^3	8.43×10^{-3}	1.01×10^{-3}	6.09×10^4	2.95×10^{-2}

The calculated concentrations of Rn-222 in Bq/L of the water samples from the study area are presented in Table 2. The mean concentration of Rn-222 across all samples is 416.6651 Bq/L, meaning that. The values range widely, from 3.1356 Bq/L to 1154.5460 Bq/L, indicating significant variation in radon levels among the sampled sources, this variation of Rn-222 concentration in different water source is similar to observations made by (Shilpa et al., 2017, Rajesh et al., 2014). The mean concentration notably exceeds the World Health Organization recommended accepted level for radon in drinking water which is 100 Bq/L, suggesting a potential health concern (WHO, 2000).

The AEDing estimation for Rn-222 concentration in water quantifies the radiation dose received by an individual during a year of consuming radon-contaminated water. The mean AED_{ing} is 3.05×10^{-3} mSv/y which is significantly lower than the recommended reference dose limit for radiation exposure from all sources, which is 1 mSv/year for the general public according to the ICRP guidelines. The range of AED_{ing} spans from 2.29×10^{-5} mSv/y (0.0000229 mSv/y) to 8.43×10^{-3} mSv/y (0.00843 mSv/y). As a result, the average dose from radon consumption in this water sample is far lower than the threshold of concern.

The Dose Contribution to the Stomach (D_{stomach}) from consumption of Rn-222 in water is the localised radiation dose that the stomach lining receives when radon-contaminated water is consumed. When radon in water is ingested, some of it is absorbed into the bloodstream, while the remainder may decay in the stomach, creating alpha particles that can directly irradiate the stomach wall. The mean dosage of 3.65×10^{-4} mSv/y reveals that, on average, the stomach receives a small but measurable dose of radiation from radon consumption. This dose is

low compared to the general public exposure limit of 1 mSv/year set by the ICRP. Hence, the mean dose contribution to the stomach is well within safety limits.

The Excess Lifetime Cancer Risk (ELCR) caused by Rn-222 concentration in a water sample is a useful tool for determining the potential long-term risk of cancer from radon exposure in water. Rn-222 is a radioactive gas which upon ingestion or inhalation (from water vapor), can contribute to internal radiation dose. The mean value of ELCR is 1.07×10^{-2} and range from 8.01×10^{-5} to 2.95×10^{-2} . The ELCR for the lower bound (8.01×10^{-5}) will give a much smaller risk, while the upper bound (2.95×10^{-2}) will produce a higher risk. This range can show the variation in potential cancer risk due to water source or environmental factors. The UNSCEAR recommends an ELCR of 0.29×10^{-3} .

Continuous consumption or usage of water with elevated radon levels can lead to health hazards, primarily through ingestion or inhalation of radon gas released during everyday activities such as cooking, bathing, or washing. Over time, such exposure increases the risk of developing serious health conditions, particularly lung cancer, highlighting the importance of monitoring and managing radon levels in domestic water supplies.

CONCLUSION

This study reveals that domestic water sources in Nasarawa Metropolis contain elevated levels of Rn-222, with average concentrations of 416.6651 Bq/L significantly exceeding the world Health Organization (WHO) recommended limit of 100 Bq/L. While the annual effective dose from ingestion been 3.05×10^{-3} mSv/y remains within ICRP safety limits, the inhalation dose of far exceeds the 1 mSv/y threshold according to the ICRP guidelines, indicating a potential radiological

health risk, especially in poorly ventilated indoor environments. The mean ELCR value of 1.07×10^{-2} far exceeds the 0.29×10^{-3} as recommended by the UNSCEAR. The findings emphasize the urgent need for public awareness, routine monitoring, and implementation of mitigation measures such as improved ventilation and water treatment to reduce radon exposure. Further studies are recommended to assess seasonal variations and expand the geographical coverage for a more comprehensive risk assessment.

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