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Radon-222 Concentration and Health Implication in Borehole Water of Ngumari Costain, Jere, Local Government, Borno State

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ABSTRACT
This study investigates the concentration of Radon-222 (^{222}Rn) in borehole water samples from Ngumari Costain in Jere Local Government Area, Borno State. Radon-222 levels were assessed using a Tri-Carb LSA-1000 liquid scintillation counter. Although Nigeria lacks specific guidelines for Radon-222 in drinking water, the U.S. Environmental Protection Agency (USEPA) advises a maximum limit of 11.1 Bq/L. The recorded concentrations ranged from 4.26 to 13.50 Bq/L, with an average of 8.83 Bq/L. Certain locations, including Layen D.J. and Layen Alau, showed slightly elevated levels above the recommended limit, while Layen Zamani recorded the lowest concentration. Despite these variations, the estimated annual effective dose from ingestion and inhalation of Radon-222 remains well within the World Health Organization (WHO) safety threshold of 0.1 mSv/year for radionuclides in drinking water. The annual effective dose for various age groups—infants, children, and adults—falls below the recommended limit, indicating that water consumption from this area is safe for human health. Additionally, calculated health risk parameters, such as Whole-Body Equivalent (WBE) and Excess Lifetime Cancer Risk (ELCR), are below international safety standards. These findings indicate that borehole water in Ngumari Costain does not pose significant health risks to the local population and is considered safe for drinking.

Keywords:
Radon,
Water,
Scintillation counter,
Annual effective dose,
UNSCEAR.

INTRODUCTION

Assessing radon-222 (^{222}Rn) concentrations in water samples is vital for understanding potential health risks associated with water consumption and household use. Elevated radon levels in water can contribute to higher indoor radon concentrations, significantly increasing the risk of lung cancer, especially in poorly ventilated homes. Therefore, monitoring ^{222}Rn levels in water sources is crucial to ensuring public health and safety. Water, a fundamental natural resource, plays a critical role in health, carrying essential minerals, dissolved salts, organic matter, and environmental pollutants Rangaswamy *et al.* (2023).

Research has shown that nearly half of the total radiation exposure from natural sources is attributed to radon-222 and its progeny (Rilwan et al. 2022; Jibrain et al. 2021). Radon (Rn), atomic number 86, is a radioactive, colourless, odourless, and tasteless noble gas. It occurs naturally as a decay product of uranium or thorium found in the Earth's crust (Oni et al. 2019). The main sources of ionizing radiation that consistently affects humans include uranium, thorium, and their decay products, with radon-222 contributing the highest proportion of human radiation exposure (Oni et al. 2019; ICRP, 2007).

Radon-222 has gained significant attention due to its harmful effects on human health, emitting alpha particles as a noble gas. It exists in various forms, such as actinium-219 (^{219}Rn), with a half-life of 3.96 seconds, thoron-220 (^{220}Rn), with a half-life of 55.6 seconds, and radon-222, which has a half-life of 3.82 days (Dahlong et al. 2023). Radionuclides in drinking water expose humans internally via two primary pathways: direct ingestion or inhalation during decay, and indirectly through the food chain (Abdulkadir et al. 2021). Radon-222 prevalence relative to other radon isotopes explains why the term "radon" commonly refers to ^{222}Rn (Bashir et al. 2023).

Radon is one of the densest gases that remains a gas under normal conditions and the only noble gas with radioactive isotopes under these conditions, posing significant health risks (Oni et al. 2019). Terrestrial radionuclides, often referred to as primordial radionuclides, primarily consist of isotopes from radioactive elements such as uranium-238 (^{238}U), thorium-232 (^{232}Th), potassium-40 (^{40}K), and uranium-235 (^{235}U), along with their decay products. These substances are present in the Earth's crust and living organisms, including food, water, and the air we breathe (Akabuogu *et al.* 2019).

On a global scale, it is estimated that soil emits 2,400 million curies (90 TBq) of radon annually, contributing to atmospheric radon levels (Yusuf & Adamu, 2014). There is no established "safe" threshold for radon exposure that guarantees no risk of lung cancer. Each nation must set a national reference level to minimize radon exposure as much as reasonably achievable (Briggs et al. 2021; Lawal et al. 2023; UNSCEAR, 2019).

Radon can be found in various water sources, such as springs, lakes, seas, and rivers. Loose soil near shorelines allows radioactive particles to rise to the surface, releasing substantial amounts of radon into the air, and exposing people to radiation during beach activities (Entesar et al. 2024). Radionuclides can naturally enter water as they are washed away from the soil by rain or released through human activities like mining and processing naturally occurring radioactive materials (Ana et al. 2023).

Investigating the radiological impact of radon in relation to water consumption is crucial for public health. Measuring concentrations of naturally occurring radioactive materials (NORMs) in drinking water helps protect the population (Hauwa'u et al. 2020). While radon in water presents a lower risk of cancer in internal organs, such as the stomach, compared to lung cancer from radon released into the air, the risk is still present (Jovana et al. 2018).

These regions are known for their high population density and poorly ventilated buildings. As a result, it became necessary to investigate whether the residents were exposed to elevated levels of radon-222 in their environment. Additionally, recent, though unofficial, reports of kidney disease cases in these areas prompted the need to determine if there was a connection between these health issues and increased radon exposure.

MATERIALS AND METHODS

Geology of the Study Area

Ngumari Ward, the focus of the study, is located within Jere Local Government Area (LGA) in Borno State, Nigeria. The administrative center of Jere LGA is Khaddamari town. Jere LGA spans an area of 868 square kilometers, with an average temperature of 33°C and an annual rainfall of approximately 850 mm. The area has a humidity level of around 29%. According to the 2006 census, the population of Jere was 211,204. Ngumari itself is located at approximately 12.26509° N latitude and 14.45978° E longitude, near other localities like Mafa and Konduga LGA, It sits at an elevation of about 294 meters (965 feet) above sea level.

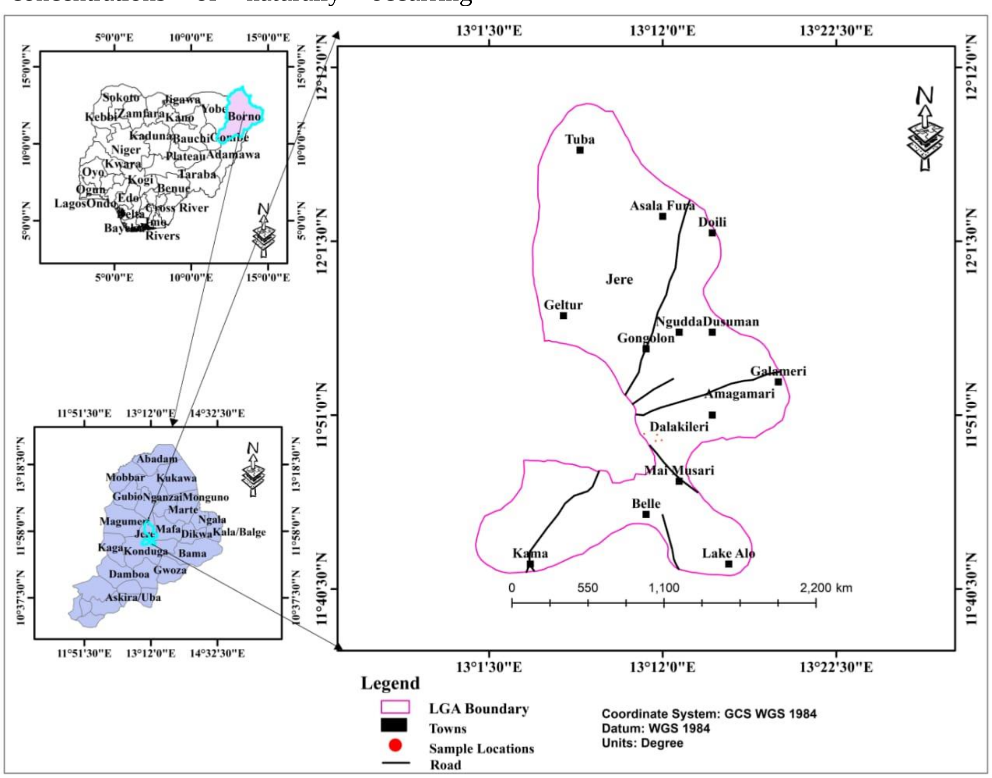

Figure 1: Map of the study area

Sample Collection

To ensure the integrity of the analysis, samples were collected in thoroughly cleaned plastic bottles, as any contamination or absorption of radon could skew the results. Before collection, borehole water was allowed to flow for at least three minutes to clear any stagnant water. The samples were analyzed as quickly as possible within three days to maintain precision since the composition could shift if left untested for too long. Accurate measurements are crucial, as delays could compromise the reliability of the data.

Sample Preparation

To experiment, 10 ml of each sample was added to a scintillation vial containing 10 ml of Insta-gel scintillation cocktail. The vials were tightly sealed and shaken vigorously for over two minutes to transfer the radon-222 from the water into the organic scintillator. A blank sample, used to measure the background radiation, was prepared in the same way with distilled water that had been stored in a glass bottle for at least 21 days. The prepared samples were then left undisturbed for a minimum of three hours, allowing radon-222 and its alpha decay products to reach equilibrium before proceeding with the counting.

Sample Analysis

The analysis followed the procedures outlined by (Garba et al. 2012; Garba et al. 2013; Jibrain et al. 2021). The prepared samples were examined using a liquid scintillation counter (Tri-Carb LSA-1000) at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. Before analysis, the liquid scintillation counter was calibrated with an IAEA ^{226}Ra standard solution. Background, calibration, and sample solutions were measured across the same spectral range and for an equal counting period of 60 minutes. The count rates for both background and samples (in counts per minute) were recorded. Radon-222 (^{222}Rn) and its short-lived decay products release a total of five radioactive particles (3 α and 2 β) per disintegration. Since secular equilibrium was achieved between radon-222 (^{222}Rn) and its decay daughters, all five emissions were used to detect and quantify radon-222 (^{222}Rn) in the water samples, resulting in a detection efficiency of 500%. Radon-222 (^{222}Rn) activity concentrations were calculated by considering the sample volume, total and background count rates, decay time (the interval between sample collection and analysis), and detection efficiency. This allowed for determining radon-222 (^{222}Rn) concentration in the water samples (Jibrain et al. 2021).

Table 1: Comparison of radon concentration in Tap water from Ngumari Costain with other parts of the world

S/N	Study Location	Radon Concern Bq/L	Reference
1	Garhwal Himalaya, India	183.9	Krishna et al. 2023
2	Karnataka, Indian	22.62	Suresh et al. 2020
3	Pir Panjal Hungary	60.61	Salik et al. 2020
4	Rusaifah in Central Jordan	151.9	Sura. A and Mohammad. A, 2019
5	Peshawar, Pakistan	8.8	Khattak et al. 2011
6	Ghana	0.093	Opoku-Ntim *et al.* 2019
7	Ogbomoso, Nigeria	1.86	Oni et al. 2019
8	Sarbon Gari Kaduna. Nigerai	11.1	Jibrain et al. 2021
9	Kano, Nigeria	2.37	Umma et al. 2020
10	Northwest, Nigeria	12.00	Abdu et al. 2020
11	Sokoto, Nigeria	10.60	Abdullahi et al. 2021

Annual Effective Dose (Ingestion)

The annual effective dose due to the ingestion of radon from water is calculated according to equation 1. (Irene et al. 2019; Jibrain et al. 2021; Suresh et al. 2020; Rangaswamy et al. 2023; Yashaswini et al. 2020).

$$H_{ing}\left(\frac{mSv}{yr}\right) = C_{Rn} \times D_{ig} \times L \qquad (1)$$

where H_{ing} is the annual effective dose for ingestion in $\left(\frac{mSv}{yr}\right)$, C_{Rn} is the concentration of radon in water samples analyzed in Bq/L, D_{ig} is the conversion factor in $1 \times 10^{-8}\left(\frac{Sv}{Bq}\right)$, L is the annual water consumption by an adult of 2L (730 liters per year) was estimated as the conversion factor of radon ingestion in infant children and adults respectively.

For infants ($0 - 1$ year) $1.1 \times 10^{-8}\left(\frac{\text{mSv}}{Bq}\right)$

For children $(1 - 17$ years) $7.6 \times 10^{-9}\left(\frac{\text{mSv}}{\text{Bq}}\right)$

For adults: $6.9 \times 10^{-9}\left(\frac{mSv}{Bq}\right)$ (UNSEAR, 2000; Mathew et al. 2021; ICRP, 2014)

Annual Effective Dose (Inhalation) equation

The annual effective dose due to radon inhalation in water is given by equation (2) (Jibrain et al. 2021; Bashir and Abdullahi, 2024).

$$H_{inh}\left(\frac{mSv}{yr}\right) = C_{Rn} \times R_{aw} \times F \times GO \times DCF \quad (2)$$

Where R_{aw} is the radon ratio of air to water 10^{-4}, F is the equilibrium factor between the radon and its daughters 0.4, GO, Global average indoor occupancy factor of 7000 $h\ y^{-1}$, DCF, the required dose conversion factor for radon 9×10^{-9} ($Sv\ Bq^{-1}\ h^{-1}\ m^{3}$).

the total annual effective dose due to whole-body exposure (WBE) is the combination of annual effective due to ingestion inhalation is given by equation (3)

$$WBE\left(\frac{mSv}{yr}\right) = H_{ing} + H_{inh} \quad (3)$$

Excess lifetime cancer risk showing the probability of developing cancer due to radon exposure above the background cancer risk over a person's lifetime is given in equation (4)

$$ELCR = WBE \times LTD \times RF \quad (4)$$

(Bashir and Abdullahi, 2024) Where LTD is the lifetime duration which is estimated to be 70 years and the RF, rest factor is 0.05 */Sv* for stochastic effect

RESULTS AND DISCUSSION

The concentration of Radon-222 (^{222}Rn) in selected borehole water samples from the study area was measured using a liquid scintillation counter (Tri-Carb LSA-1000) and summarized in Table 1. Currently, there are no regulations for Radon-222 levels in drinking water in Nigeria, though the United States Environmental Protection Agency recommends a limit of 11.1 *Bq/L* (USEPA, 2017).

The Radon-222 concentrations in the borehole water samples ranged from 13.50 to 4.26 *Bq/L*, with an average concentration of 8.83 *Bq/L*. Notably, the levels in Layen D.J. and Layen Alau slightly exceeded the permissible limit of 11.1 *Bq/L*, while Layen Zamani recorded the lowest concentration at 4.2 *Bq/L*. The variations in concentrations from locations such as Layen Alau, Layen D.J., Layen London Chiki, Kalere, and Layen Gwaza were higher than those reported by previous studies, including Onie et al. (2019), Khatak et al. (2019), Opoku et al. (2019), and Umma et al. (2020), indicating that the study area's water remains safe for drinking and poses no significant threat to the local population.

The estimated annual effective dose due to ingestion of Radon-222 for infants, children, and adults is presented in Table 1. The dose from the ten water samples ranges from 3.43E-05 to 1.08E-04 *mSv/ yr*, with a mean value of 7.09E-05 *mSv/ yr*. For children, the dose ranges from 2.15E-05 to 7.49E-05 *mSv/ yr*, with an average of 4.90E-05 *mSv/ yr*. For adults, the annual effective dose ranges from 2.15E-05 to 6.80E-05 *mSv/ yr*, with a mean and average dose of 4.45E-05 *mSv/ yr*.

Table 2: Activity concentration, Annual Effective Dose, ingestion, inhalation, annual effective dose in infant, children, adult whole body exposure, and excess lifetime cancer risk

Location	Radon concentration in Bq/L	^{222}Rn annual effective dose in Sv/Bq						
		H_{ing}	H_{inh}	H_{inf}	H_{child}	H_{adult}	WBE	ELCR
Kalere	11.66466791	8.52E-05	2.9E-07	9.37E-05	6.47E-05	5.88E-05	8.54E-05	2.99E-04
layen D J	12.29971713	8.98E-05	3.1E-07	9.88E-05	6.82E-05	6.20E-05	9.01E-05	3.15E-04
Layen Gwazari	10.70162622	7.81E-05	2.7E-07	8.51E-05	5.94E-05	5.39E-05	7.84E-05	2.74E-04
Layen London chiki	11.46926815	8.37E-05	2.8E-07	9.21E-05	6.36E-05	5.78E-05	8.40E-05	2.94E-04
Layen Alau	13.50351923	9.86E-05	3.8E-07	1.08E-04	7.49E-05	6.80E-05	9.89E-05	3.46E-04
Site pocket	7.11813417	5.2E-05	1.7E-07	5.72E-05	3.95E-05	3.59E-05	5.21E-05	1.86E-04
Layen Masallache	6.179517458	4.51E-05	1.5E-07	4.96E-05	3.43E-05	3.11E-05	4.53E-05	1.58E-04
Layen Masallache Sallake	5.879439253	4.29E-05	1.4E-07	4.76E-05	3.26E-05	2.96E-05	4.31E-05	1.51E-04
Layen Church	5.226943621	3.82E-05	1.3E-07	4.20E-05	2.90E-05	2.63E-05	3.83E-05	1.34E-04
Layen Zamani	4.26739122	3.12E-05	1.1E-07	3.43E-05	2.39E-05	2.15E-05	3.13E-05	1.09E-04
Min	**4.26739122**	**3.12E-05**	**1.08E-07**	**3.43E-05**	**2.37E-05**	**2.15E-05**	**3.13E-05**	**1.09E-04**
Max	**13.50351923**	**9.86E-05**	**3.40E-07**	**1.08E-04**	**7.49E-05**	**6.80E-05**	**9.89E-05**	**3.46E-04**
Aver	**8.831022436 3**	**6.45E-05**	**2.23E-07**	**7.09E-05**	**4.90E-05**	**4.45E-05**	**6.46E-05**	**2.26E-04**

Figure 2 shows the centration of radon in water samples, indicating that Layen Alau has the highest values, which is above the limit set by USEPA. From the chart in Figure 2, the variation in concentration from Layen Alau to Layen Zamani shows a decline in value to 4.2673 *Bq/ L*, confirming that the water in the study area is safe for drinking.

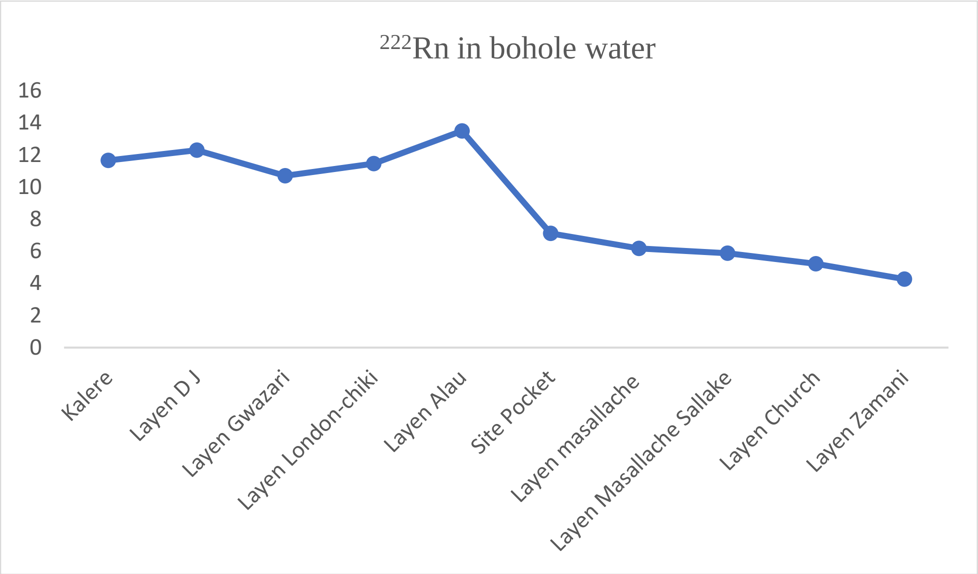

Figure 2: Showing concentration of radon ^{222}Rn in ten water samples

From Fig 3: The annual effective dose resulting from the ingestion and inhalation of Radon-222 in water samples from the ten locations in the study area falls well within the low limit, not exceeding 0.1 *mSv/ yr*. This value complies with the permissible threshold set by the World Health Organization (WHO) for all radionuclides, as established by WHO, (2008).

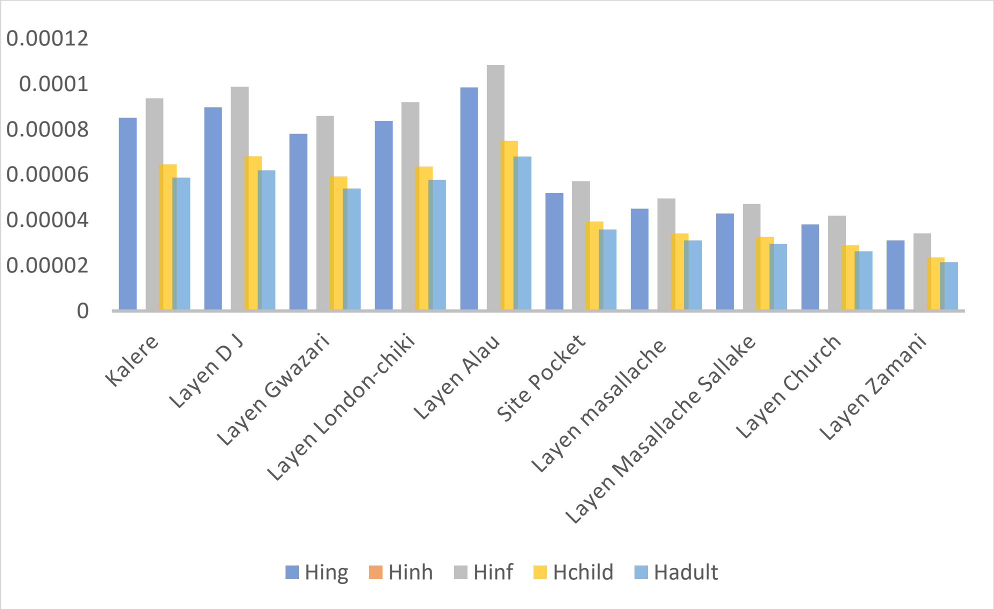

Figure 3: Shows the annual effective dose due to ingestion, and inhalation of ^{222}Rn in boreholes for infants, children, and adults

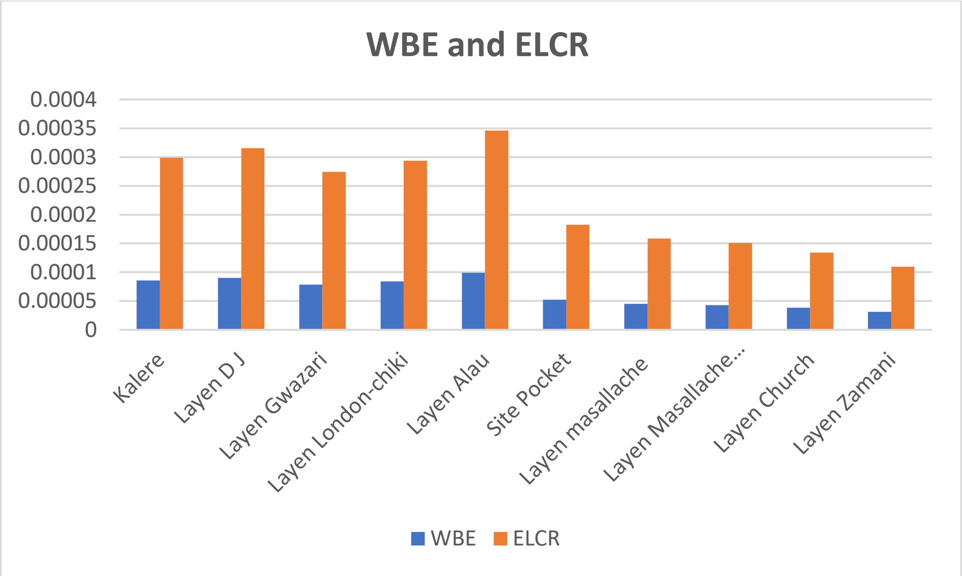

Figure 4: WBE and ELCR

Fig 4: showing the whole body exposures and excess lifetime cancer risk. The mean values of WBE and ELCR and max values range from 3.13E-05, 1.09E-04, and 9.89E -05, 3.46E-04 with average values of 6.46E-05 and 2.26E-04 respectively. the values given were all lower than the world limit of 0.2×10^{-2} therefore the water consumption from the study area is safe for drinking.

CONCLUSION

In conclusion, the measured concentrations of Radon-222 in borehole water samples from the study area largely fall within safe limits, with only slight exceedances in a few locations. While the concentrations in some areas, like Layen D.J. and Layen Alau, surpass the USEPA's recommended limit of 11.1 *Bq/L*, the overall levels remain within a range that poses no significant health risk to the population. The estimated annual effective doses from Radon-222 ingestion and inhalation are well below the threshold set by the World Health Organization (0.1 *mSv/ yr*), further affirming that water from the studied locations is safe for consumption. Moreover, the calculated health risk parameters, such as the WBE and ELCR, remain lower than international safety limits. Therefore, the findings indicate that the borehole water in the study area does not pose a health hazard and is safe for drinking.

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