

Assessment of Radon - 222 Activity Concentration and Associated Effective Doses in Groundwater Sources in BIU, Borno State, Nigeria

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ABSTRACT

This research titled “Assessment of Radon - 222 Activity Concentration and Associated Effective doses in Groundwater Sources in Biu, Borno State, Nigeria” Were carried out in Biu due it geological nature that contains sedimentary rock basement and the good number of population attracted from near by villages due to insurgence. This studies investigates the concentration of Radon-222 Activity in groundwater sources used for domestic purposes. Fifteen (15) water samples were collected from wells and boreholes across selected locations within Biu Metropolis . The percentage of borehole to well water sample collected is at the ratio of (70 to 30) %. The samples were analyzed using a Liquid Scintillation Counter (Tri-Carb-LSA1000) at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. It was observed in table 2., Well water recorded a higher concentration of 22.45 Bq/L than borehole water 13.59 Bq/L The highest value (22.5 Bq/L) occurred in Yawi, while the lowest (10 Bq/L) was found in Tasha Dan Fulani. The overall average concentration is found to be 14.77 Bq/L, which exceeds the USEPA (11.1 Bq/L) and WHO (10 Bq/L) permissible limits of the international safety limits. The overall Annual effective dose due to inhalation of Radon in the water sources is found to be less than the permissible limit of 100 μ Svy-1 set by WHO. Also, the overall AED due to ingestion of Radon is found to be higher than the WHO permissible limit of 100 μ Svy-1 for adults and less than the permissible limit of 200 μ Svy-1 for children. The findings indicate a stochastic health risk in near future and it is recommended that continuous monitoring, public sensitization, and sample aeration techniques be adopted to reduce radon exposure from groundwater sources.

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INTRODUCTION

Water is the major constituent of the Earth's streams, lakes, oceans and the fluid of most living organisms. It covers about 71% of the Earth surface. It is vital for all known forms of life especially humans. Humans uses water for various reasons such as transportation, power generation, agriculture and other domestic activities. Hence, its availability and quality with regards to radiological, microbiological, chemical and any other form of contamination is a delicate and vital issue (Garba *et al.*, 2008) . Unfortunately, access to clean and potable drinking water in most developing countries such as Nigeria is a major challenge, hence leading most people to rely heavily on untreated surface and ground water sources for consumption (Garba *et al.*, 2008). Radon (^{222}Rn) is an odorless, colorless and tasteless naturally occurring radioactive inert gas that is soluble in water, having a half-life of 3.82 days. It is a member of the Uranium decay series that contributes the largest proportion of the total radiation from natural sources (Somlai, 2007). Radon gas can easily penetrate through soil and rocks and dissolves in water, with a higher concentration in drinking water from groundwater sources than those from surface water (Xinwei, 2006). The exposure of a population to high concentration of Radon and its daughters elements for a long period has significant health effects ranging from respiratory functional changes, cancer of the lungs, stomach and gastrointestinal tract cancer, etc. . In the last decade, Radon concentration in water sources has become one of the major problems of radiation protection (Xinwei, 2006; Shilpa *et al.*, 2017). Reports have shown that high activity concentration of ^{222}Rn is associated with areas rich in granite (David *et al.*, 1989). Also, studies reveal that

the entire Biu Local Areas is underlain by a basement complex of igneous and metamorphic rocks, and since rocks and soil contain radium that decays to form radon, both underground water and surface water should contain the dissolved gas (Garba *et al.*, 2012). Radon level monitoring in water sources is essential, this is to ensure public health and safety. Water, is a fundamental natural resource that plays critical role in carrying essential minerals in the body as reported by Jauro *et al.* 2024. It is shown that, nearly 50% of a research regarding radiation exposure from natural sources is contributed by radon-222 and its progeny (Rilwan *et al.* 2022; Jibrain *et al.* 2021). Radiation exposure in drinking water usually takes place in two ways in human such as direct ingestion or inhalation during decay, and indirectly through the food chain (Abdulkadir *et al.* 2021) As reported by Jauro *et al.*, 2024, Ngumari Costain in Jere Local Government Area, Borno State. Northeastern Nigeria . Radon-222 levels were assessed using a Tri-Carb LSA-1000 liquid scintillation counter. The Radon concentrations ranged from 4.26 to 13.50 Bq/L, with an average of 8.83 Bq/L which is below the limit of 11.1 Bq/L as given by (USEPA) . The level of radon in water sources should be investigated. In Biu Local Government Area of Borno State whose majority of population consisting of both humans and animals lack access to portable sources of water, the presence of radon in groundwater and agricultural produce is of concern due to its potential health risks, and in areas with high concentrations of uranium in soil and water, radon levels tend to be higher. It is vital to measure and analyze the level of Radon-222 in drinking water as long-term exposure to radon can lead to

lung cancer, kidney problems, and other serious health conditions (Kendel et al, 2002).

This research is limited to Biu metropolis where 80 to 90 percent of the population settled due to insurgence few kilometer away is not safe. Biu metropolis has few abandon well and higher numbers of drilled borehole as a source of drinking water and its environs has a basement that contains sedimentary rocks which radon gas can easily penetrate and dissolve in water. Hence is the need for the research.

MATERIALS AND METHODS

Geology of the Study Area

Biu is the second largest local government in Borno state, northeastern part of Nigeria with land area of 3,165 to 3423 Square Kilometer, average annual temperature of 32°C, humidity ranging between 10% and 29% during the day. According to census 2006 Biu has a population of 175,760 and is situated at a latitude of 10.61°N and longitude of 12.19° E with average elevation of 2300 feet (700 meters).

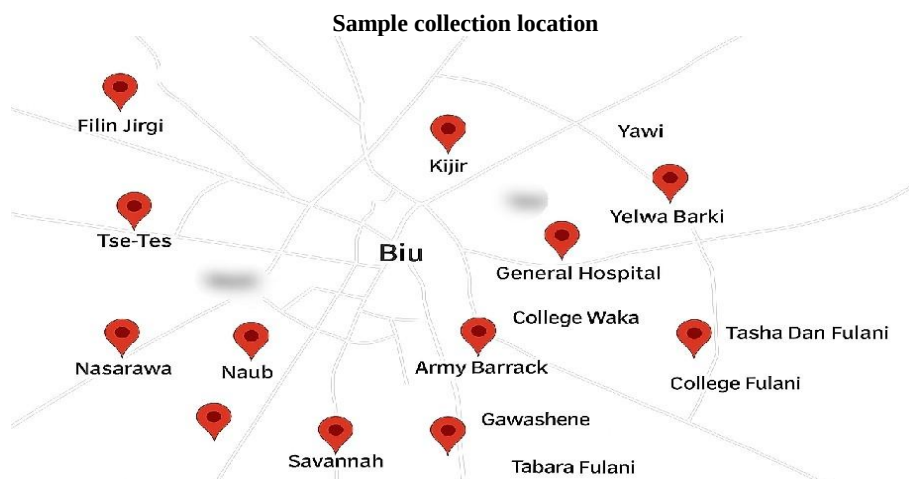


Figure 1: A Map showing the Description of Study Area in Biu Local Government, Borno State Nigeria

The water samples are collected from fifteen areas as captured in the map namely: Filin jirgi, Kijir, Yawi, Tse Tse, Nasarawa, Collage Waka, General Hospital, NAUB, Army Barrack, Tabra fulani, Gawashene, Yelwa Barki, Tashan Dan Fulani, Mbulamel and Savannah

Sampling Techniques

In the sampling Techniques, fifteen (15) water samples from both well and borehole were collected in a cleaned plastic bottles to prevent any contamination or absorption of radon to alter the results. Before collection, borehole water been the predominant was allowed to flow for at least three minutes to clear any stagnant water also sample from well. 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. Accuracy in measurements are important, as delays could compromise the credibility of the data.

Stratified random sampling which divided the area into different strata based on the type of water source. From each stratum, water sources will be randomly selected, ensuring that each type of water source is adequately represented in the sample pool.

Sample Collection Procedures

In the analysis, 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. In this regard GPS device is used to ascertain and to record the exact location of each sample. This ensures that the data can be accurately referenced for environmental analysis and geographical correlation also time of sample collection were record to account for any variations in radon levels that could occur over time

Sample Analysis

The analysis sequence the procedures outlined by (Garba et al. 2012; Garba et al. 2013; Jibrain et al. 2021). The prepared samples were examined at Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. using a liquid scintillation counter (Tri-Carb LSA-1000) in the 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

Table1: Comparison of Radon Concentration in Biu and other Part of the World

S/N	Study Area	Radon Conc. Bq/L	Reference
1	Ghana	0.093	Opoku-Ntim et al., 2019
2	Rusaifa Central Jordan	151.9	Sura A and Mohammad A., 2019
3	Karkataka, India	22.62	Suresh et al., 2020
4	Garhwal Himalaya, India	183.9	Krishna, 2023
5	Sokoto Nigeria	10.60	Abdullahi et al., 2020
6	Kano Nigeria	2.37	Umma et al., 2020
7	Pir Panjal Hungary	60.61	Salik et al., 2020
8	Sabon Gari Kaduna Nigeria	11.1	Jubrain et al., 2021

Theory of Calibration Factor

$$CF = \frac{SC-BC}{C-V} \quad (1)$$

Where SC = Standard ²²⁶Ra Count (count/min), BC = Background Count rate (count/min), C = Standard ²²⁶Ra concentration (Bq/L)

V = Volume of Standard ²²⁶Ra used (L)

Computation of Radon Concentration

$$Rn(BqL^{-1}) = \frac{100(SC-BC)e^{\lambda t}}{60 \times DF \times CF} \quad (2)$$

Where Rn = Radon concentration, SC= sample count per second BC = Background count per second, 100 = conversion factor from per 10 mL to per λ = decay factor ($1.26 \times 10^{-4} \text{ min}^{-1}$)

t = time elapsed between sample collection and counting (4320min = 3days)

CF = Calibration Factor (0.964, which represents the Fraction of Radon in a vial of 22 ml capacity)

DF = Decay Factor Number of emissions per disintegration of Radon (Given as 5)

The annual effective doses due to ²²²Rn ingestion and inhalation were calculated using equations (3) and (4)

$$Eing = CFing \times Rn \times TW \quad (3)$$

$$Einh = Rn \times Rw \times F \times tR \times CFinh \quad (4)$$

Where ,Eing= Annual Effective dose due to Radon Ingestion

CFing = Ingestion dose Conversion factor

for adults, children, and infants were taken as

$10^{-8} \text{ SvBq}^{-1}$, $2 \times 10^{-8} \text{ SvBq}^{-1}$ and $7 \times 10^{-8} \text{ SvBq}^{-1}$ respectively

(Duggal et al., 2013; Bem et al., 2014).

Annual Water Consumption (Tw)

According to ICRP, water consumed by adults, children, and infants were 2, 1.5 and 0.5 liters per day. These are 730, 547.5, and 182.5litres per yr.

Einh= Annual Effective dose due to Radon Inhalation Rw = Ratio of Radon released in air when water is used to Radon in water (10-4)

F = Equilibrium factor between Radon and its daughters (0.4)

tR = Average Residence time of individual in the interior (7000h/year) CFinh= Dose conversion factor due to inhalation ($9nSvBqhm^{-3}$)

RESULTS AND DISCUSSION**Table 2: Mean 222 Rn Concentration and Annual Effective dose in well and Borehole Water**

Sample ID	Sources	Location	Latitude (°)	Longitude (°)	Rn (Bq/L)	Mean deviation	Mean ± Uncertainty	Annual Effective dose (μSv/Bq)			
								Inhalation (All Ages)	Ingestion (Adult)	Ingestion (Children)	Ingestion (Infant)
BSA1	Borehole	FilinJirgi	10.580725	12.2082667	13.90	0.223	0.1289	35.03	101.47	152.21	177.57
BSA2	Borehole	Kigir	10.566662	12.218255	14.70	0.00034	0.00019	37.00	107.00	160.60	187.40
WSA3	Well	Yawi	10.625562	12.1790067	22.50	4.2680	2.4671	56.80	151.00	246.80	287.80
BSA4	Borehole	Tse-Tes	10.606145	12.20471	14.90	0.0012	0.00069	37.55	108.77	163.16	190.33
BSA5	Borehole	Nasarawa	10.617492	12.1727183	13.10	0.1992	0.1151	33.01	95.63	143.45	167.35
BSA6	Borehole	Collage waka	10.639688	12.1954483	16.00	0.1081	0.0624	40.40	117.00	175.60	204.80
BSA7	Borehole	General Hospital	10.604132	12.2023867	12.70	0.3060	0.1768	32.00	92.71	139.07	162.24
BSA8	Borehole	Naub	10.612397	12.1569250	10.80	1.1257	0.6506	27.30	79.00	118.50	138.30
BSA9	Borehole	Army Barrack	10.599127	12.1905067	13.20	0.1760	0.1017	33.26	96.36	144.54	168.63
BSA10	Borehole	Tabra Fulani	10.616995	12.1997510	12.40	0.4012	0.231	31.25	90.52	135.78	158.41
BSA11	Borehole	Garwashene	10.612177	12.1982450	16.30	0.1672	0.0966	41.08	118.99	178.49	208.23
WSA12	Well	YelwaBarki	10.596428	12.215545	22.40	4.1538	2.4036	56.45	163.52	245.28	286.16
BSA13	Borehole	Tasha Dan Fulani	10.613362	12.1953633	10.00	1.6252	0.9394	25.20	90.50	109.60	127.80
BSA14	Borehole	Mbulamei	10.623328	12.1887183	13.70	0.0817	0.0473	34.40	99.70	149.50	174.30
BSA15	Borehole	Savannah	10.624138	12.1862883	15.00	0.0037	0.0021	37.80	108.04	162.06	189.07
				Mean	14.77	0.9053	0.498	37.24	108.01	161.64	188.56

Data Analysis

The data were analyzed using computer software which employed Statistical Package for the Social Sciences (SPSS): For more advanced statistical analysis, including ANOVA (Analysis of Variance), correlation analysis, and significance testing.

Radon Concentration in Water Samples

Radon Concentration and the Resulting Annual Effective Dose Table 2 shows the coordinates, radon concentration (BqL⁻¹) and the annual effective dose (μSv⁻¹) of the studied area (Selected Areas of Biu Local government). There are

Fifteen (15) sampling locations comprising of two (2) wells, Thirteen (13) boreholes water sample. The overall mean radon concentration of the waters samples is found to be 14.77 BqL⁻¹, with boreholes having a mean concentration of 13.59BqL⁻¹ and wells 22.45 BqL⁻¹ respectively. WSA3 Yawi with well water sample type recorded the highest radon concentration of 22.5 BqL⁻¹, while BSA Tasha Dan fulani with borehole water sample type recorded the least value of 10BqL-1. All the Fifteen (15) sample types had radon concentration above the maximum permissible limit of 11.1 BqL⁻¹ (USEPA, 2003) and the world average value of 10 Bq/L (UNSCEAR, 1993 and WHO, 2004).

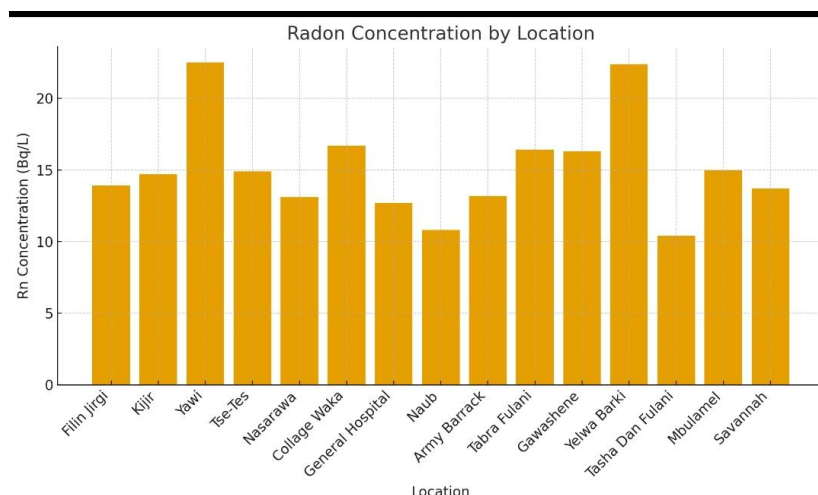


Figure2: Radon Concentration by Sample Location

Figure 2 show how Radon (Rn) vary across the 15 location. Highest concentration occur in yawi and yalwabarki, while Tasha dan Fulani has the lowest. The graph shows a clear pattern where well samples exhibit higher radon concentration compared to boreholes. This may be attributed

to longer contact time between well water and uranium-bearing geological formations such as granite and gneiss, which are abundant in Biu LGA. The elevated levels in well water indicate a stronger influence of subsurface geology and lower ventilation rates in confined aquifers.

Annual Effective Dose Due to Inhalation and Ingestion

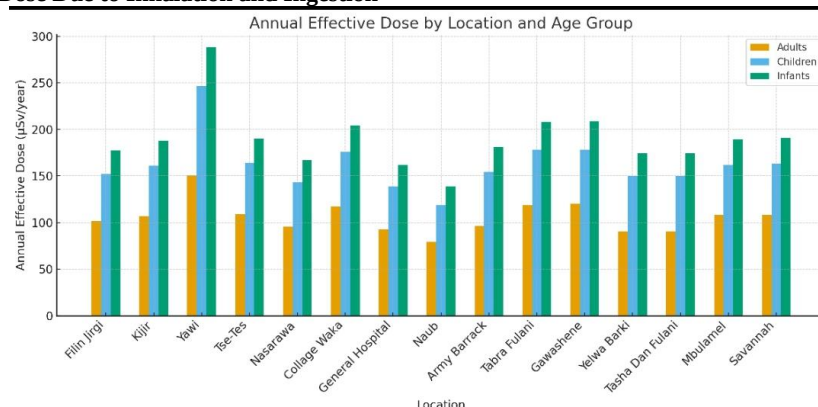


Figure 3: Clustered Bar Graph-annual Effective doses

Figure 3 shows the variation of the annual effective dose by age group and location. The graph indicates that the infant group consistently receives the highest effective dose, followed by children and adults. This is due to the smaller body mass and higher water consumption rate per unit body weight among infants. The annual effective dose (AED) in ($\mu\text{Sv}\cdot\text{y}^{-1}$) for inhalation and ingestion of Radon from the water sources was estimated using equation (3) and (4) respectively. The overall AED due to inhalation (all age) of Radon is calculated to be $37.24 \mu\text{Sv}\cdot\text{y}^{-1}$ with well and borehole water type having an average of 56.63 and $34.25 \mu\text{Sv}\cdot\text{y}^{-1}$ respectively. This value is less than the permissible limit of $100 \mu\text{Sv}\cdot\text{y}^{-1}$ set by world health organization (WHO, 2004). Also, the overall AED due to ingestion of Radon in the water sources is calculated to be 157.26 , 246.04 , and $286.98 \mu\text{Sv}\cdot\text{y}^{-1}$ respectively for both Adult, children and Infant. For consumption of well water only, the average AED is 56.63 , 166.2 and $193.9 \mu\text{Sv}\cdot\text{y}^{-1}$ respectively for adults, children and infants. As for the consumption of borehole water only, the average AED for adults, children and infants were 100.44 ,

148.66 , and $173.42 \mu\text{Sv}\cdot\text{y}^{-1}$ respectively. These values are higher than the WHO permissible limit of $100 \mu\text{Sv}\cdot\text{y}^{-1}$ for adults and less than the permissible limit of $200 \mu\text{Sv}\cdot\text{y}^{-1}$ for children. Generally, it is observed that the radon level was higher in the well water samples as compared to the boreholes water samples. This can be attributed to the fact that radon readily dissolve in water under pressure, leading to radon accumulation in ground water (Cho et al., 2004). Another reason may be due to human activities such as farming and other natural phenomena such as weathering and volcanic actions (Oni et al., 2016). Also, the average AED of $37.24 \mu\text{Sv}\cdot\text{y}^{-1}$ obtained due to inhalation implies that the inhabitant of Selected Area of Biu local government are safe from any radiological health related effect that could result from the inhalation of radon gas. As for ingestion, the results show that both Children and Infant are safe from any radiological health risk, but for Adults, consuming any of the water sources (Well, Borehole and Surface) over a prolong period of time is not completely safe and may result in radiological health hazard

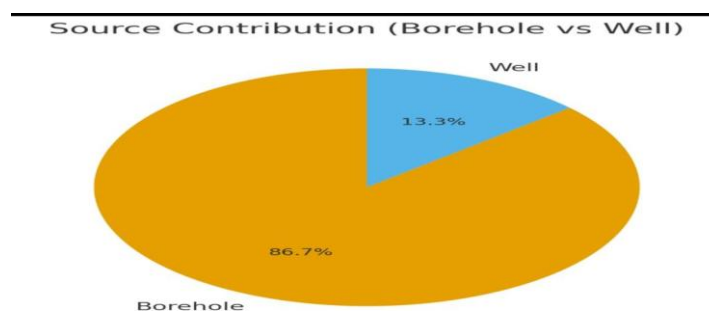


Figure 3: Source Contribution of Borehole and Well Water

A comparative analysis in the above figure, shows that boreholes account for 86.7% of total water samples, While Well Water constitutes 13.3%. Despite there smaller number, well samples contributed a higher means of radon concentration (22.50 Bq/L) compared to borehole (16.30 Bq/L). This confirms that wells are the dominant sources of radon exposure in the study area. Possible reasons for the higher radon concentration in well water include:

- (a) Poor aeration and limited radon escape from deep wells
- (b) Greater rock–water contact in well aquifers. (c) High uranium content in local granite bedrock (d) Absence of radon degassing during water drawing.

Health Implications

Radon exposure primarily affects the respiratory and gastrointestinal systems. Although the ingestion and inhalation doses from this study fall within safe radiological limits, cumulative exposure from other environmental sources (e.g., soil gas and indoor air) could increase the total annual effective dose. Infants and children remain more vulnerable due to physiological factors, necessitating periodic monitoring and public awareness campaigns.

CONCLUSION

From the analysis, it was observed that the radon concentration in both Well and Borehole water is higher than the permissible level of 11.1 Bq/L set by USEPA. The overall Annual effective dose due to inhalation of Radon in the water sources is found to be less than the permissible limit of $100\mu\text{Sv}\cdot\text{y}^{-1}$ set by WHO. Also, the overall AED due to ingestion of Radon is found to be higher than the WHO permissible limit of $100\mu\text{Sv}\cdot\text{y}^{-1}$ for adults and less than the permissible limit of $200\mu\text{Sv}\cdot\text{y}^{-1}$ for children. Therefore, the inhabitant of Selected Area of Biu local government are safe from any radiological health related effect that may result from the inhalation of radon gas. As for ingestion, the results show that both Children and Infant are safe from any radiological health risk, but for Adults, consuming any of the water sources (Well and Borehole) for a long period of time is not completely safe and may result in radiological health hazard.

RECOMMENDATION

- i. Continuous assessment of radon levels in groundwater should be carried out, especially in wells, to detect seasonal or geological variations.
- ii. Residents should be educated on the potential health risks associated with radon and encouraged to ventilate homes effectively, particularly bathrooms and kitchens.
- iii. Installing simple water aeration or degassing systems for wells can help reduce radon concentration before consumption.
- iv. In

high-radon areas (e.g., Yawi and YelwaBarki), residents should consider mixing well water with borehole or treated water to minimize exposure.

v. Policy and Regulation: Government agencies (e.g., NESREA, NNRA) should establish guidelines and permissible limits for radon in drinking water at national and local levels

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