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Determination of Radon-222 Levels, Concentration Level, and Its Health Hazards in Drinking Water from Gashua and Damaturu, Yobe State, Nigeria

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Abstract: Water quality is a vital component of public health and environmental safety, as clean water is essential for drinking, food production, and sanitation. In this study, the health risk assessment of heavy metals and Radon-222 levels in portable drinking water from Gashua and Damaturu, Yobe State, Nigeria, was investigated. Forty (40) samples (twenty (20) each from Damaturu and Gashua, respectively) were collected by simple random sampling and were analyzed for radon-222 concentration level Liquid Scintillation Spectrometer. Each of the samples was coded with a number for sample identification, and the GPS location of each sample was taken. The calculated Radon-222 concentration, annual effective dose by ingestion, dose contribution to the stomach due to ingestion, annual effective dose by inhalation estimation, dose contribution to the lung due to inhalation, and excess lifetime cancer risk for Damaturu (Gashua) are 780.61655 Bq/L (753.2699 Bq/L), 0.00569855 mSv/y (0.005499 mSv/y), 0.0006816 mSv/y (0.000658 mSv/y), 34.34713 mSv/y (33.14388 mSv/y), 4.1182207 mSv/y (3.973951 mSv/y), and 1.99448E-05 (1.92E-05), respectively. The result of radon-222 concentration indicates an elevated radon concentration in water, which poses potential radiological health risks through both ingestion and inhalation exposure. However, the computed excess lifetime cancer risk (1.92E-05) falls within the acceptable risk range of 10^{-6} to 10^{-3} recommended by USEPA. Adequate portable drinking water monitoring is recommended, and safety measures should be put in place.

Keywords: Radon-222 concentration, liquid scintillation detector, radiological hazards, and well water.

1 Introduction

Radon-222 (^{222}Rn) is a radioactive noble gas that forms naturally during the decay process of uranium-238, commonly found in various geological formations [1- 5]. As an inert, invisible, and odorless gas, its presence in environmental media often goes unnoticed without analytical investigation. Although most studies on radon exposure focus on inhalation as the primary route—particularly from indoor air accumulation—emerging evidence highlights that radon dissolved in groundwater also constitutes a significant public health concern, especially in regions that depend heavily on such water sources for daily use [6-10].

In Yobe State, northeastern Nigeria, the towns of Gashua and Damaturu rely primarily on groundwater accessed through wells and boreholes. The underlying geology in this area may contain uranium-bearing rocks that release radon into aquifers, thereby elevating its concentration in drinking water. When consumed over time, this radioactive element can accumulate in internal organs, where its decay products emit alpha particles that may damage cells and increase the risk of cancers, particularly in the stomach and gastrointestinal tract [11-15].

A study by Obed et al. [5] measured radon concentrations in groundwater across parts of southwestern Nigeria and found levels exceeding the recommended safety limits set by international agencies. The authors emphasized the need for routine monitoring and public awareness regarding radiation exposure through drinking water. Similarly, Arogunjo et al. [4] assessed the radiological quality of water sources in Nigeria and identified radon-222 as a notable contributor to the overall radiation dose received by the population. Their research underlined the significance of geological formations in influencing radionuclide

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content in water and recommended further assessments across other geopolitical zones.

Given the limited data on radon contamination in the northeastern region, this study seeks to quantify the concentration of radon-222 in drinking water sources in Gashua and Damaturu. In addition, it evaluates the potential health implications based on globally accepted radiological health benchmarks. The outcomes of this research are expected to support evidence-based environmental management policies and promote public health safety in the affected communities.

2 Materials and Methods

Study Area

Damaturu and Gashua are key towns in Yobe State, northeastern Nigeria, both situated in a semi-arid climate with hot, dry seasons and limited rainfall. Damaturu, located at approximately 11.7461° N, 11.9608° E, serves as the state capital, while Gashua, located at 12.8734° N, 11.0406° E, lies further north near the Komadugu Yobe River. Damaturu has a population of around 44,000, whereas Gashua has about 125,000 residents.
Agriculture is central to the economy in both towns, with residents engaged in cultivating crops such as millet, sorghum, maize, and rice. Gashua, benefiting from the nearby river, supports irrigation farming, which allows for year-round crop production. In addition to farming, livestock rearing, including cattle, sheep, and goats, is common, especially among the Kanuri and Fulani ethnic groups.
Both towns face challenges, including environmental issues like desertification and climate impacts on water resources. Security issues have also disrupted economic stability, but recent improvements have enabled slow recovery efforts. The people's resilience continues to drive progress in these communities, even amid ongoing challenges.

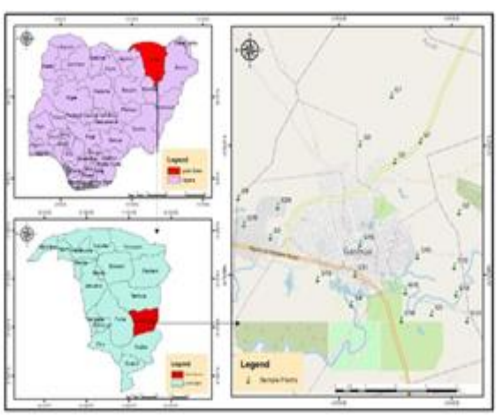

Fig. 1: Map of Study Area.

Population, Sample, and Sampling Technique

The population of the study covers drinking water sources from Gashua and Damaturu, Yobe State, Nigeria. For the purpose of obtaining representative water samples and to ensure that all water samples have equal chances of selection, a simple random sampling technique was adopted to collect forty (40) water samples from the study area.

Method of Sample Collection

The plastic containers were first washed and rinsed with distilled water to avoid radon present in the samples from being contaminated. Water samples were preserved with 20 ml of concentrated HNO_3 per liter of the water in order to minimize absorption of the dissolved radon on container walls.

The water samples were collected from the well to ensure fresh samples were obtained. At each location, the containers were filled to the brim with the water sample without any headspace to prevent CO_2 from being trapped and dissolving in water, which might affect the chemistry, e.g., pH, and then immediately closed to avoid loss of radon by degassing during transport to the laboratory.

The samples were sent for analysis immediately after collection without allowing them to stay long (three days maximum) to minimize the influence of radioactive decay. This will be done to achieve maximum accuracy and not to alter its composition. Each of the samples will be coded with a number for simple identification. The sample codes with the GPS location of each sample were taken.

Method of Sample Preparation for Radon Concentration

10 ml each of the water samples was transferred into a 20 ml glass scintillation vial, to which 10 ml of Insta-Gel scintillation cocktail was added. It was then sealed tightly. The vials were shaken for more than two minutes to extract radon-222 in the water phase into the organic scintillate, and the samples collected were counted for 60 minutes in a liquid scintillation counter using energy discrimination for alpha particles.

Method of Sample Analysis for Radon-222

The glass scintillation vial will be sealed tightly. The vials were shaken for more than two minutes to extract radon-222 in the water phase into the organic scintillate, and the samples collected were counted for 60 minutes in a liquid scintillation counter using energy discrimination for alpha particles.

The samples were analyzed using a Liquid Scintillation Counter (Tri-Carb LSA 1000TR) model located at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria-Nigeria.

Radon-222 Concentration in Bq/l Estimation Method

The activity concentration of Radon-222 was calculated from the samples and background results obtained using the formula below:

$$C_{Rn-222}(BqL^{-1}) = \frac{C - C_b}{CF\ x\ DE} . e^{\lambda t} \quad 1$$

where,
C_{Rn-222} is the Radon-222 activity concentration in water (BqL^{-1}), C is the measured count rate (cps) from the scintillation counter, C_b is the background count rate (cps), CF is the Calibration factor (0.2 cps per Bq/L), DE is the efficiency of the detector (0.08), t is the Elapsed time (in days) between sample collection and measurement, and λ is the decay constant of radon-222 (1.26×10^{-4} min^{-1}).

3.2.7.2 Annual Effective Dose by Ingestion Estimation Method

The corresponding annual effective doses (mSv/y) due to ingestion of Radon-222 in water samples from the study area were also calculated using equation 3.2 by taking into account the dose coefficient in ($\boldsymbol{Sv/Bq}$), the annual water consumption (L/Y), and the activity concentration of Radon-222 obtained from equation 3.1 using equation 2 by Rilwan et al. [16];

$$E = C_{RnW}\ x\ D\ x\ L \quad 2$$

where: $CRnw$ is the concentration of Radon-222, D is the dose coefficient (10^{-8} Sv/Bq,2×10^{-8} Sv/Bq,$7\times10^{-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 $730L/Y$ [17].
According to the United Nations Scientific Committee on the Effects of Atomic Radiation [17], doses due to ingestion of radon in water for similar consumption rates could be a factor of 2 and 7 higher for children and infants, respectively.

3.2.7.3 Dose Contribution to the Stomach due to Ingestion

It is a product of the stomach tissue weighted factor (0.1196) with the corresponding ingestion dose using Equation (3) below

$$D_{stomach} = E_{ing} \times 0.1196 \quad 3$$

3.2.7.4 Annual Effective Dose by Inhalation Estimation Method

The annual effective dose of Radon by inhalation was estimated using equation (4) as:

$$He = C \times F \times T \times D \quad 4$$

He is the annual effective dose (mSv^{-1}), C is the radon concentration (Bql^{-1}), F is the Equilibrium factor (0.5), T is the Indoor occupancy time (8000 h^{-1}), and D is the dose conversion factor (1.1×10^{-5} $mSvh^{-1}/Bql^{-1}$) [18-21].

3.2.7.5 Dose Contribution to the Lung due to Inhalation

It is the product of the lung tissue weighted factor (0.1199) and the corresponding inhalation dose using Equation (5)

$$D_{lung} = He \times 0.1199 \quad 5$$

3.2.7.6 Excess Lifetime Cancer Risk Estimation Method

The excess lifetime cancer risk was evaluated using equation (6) as:

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

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 the public [1].

3 Results and Discussion

The results of radon-222 concentration in water samples (in CPMC) from Gashua and Damaturu, Yobe State, Nigeria, are presented in Figures 2 and 3, respectively.

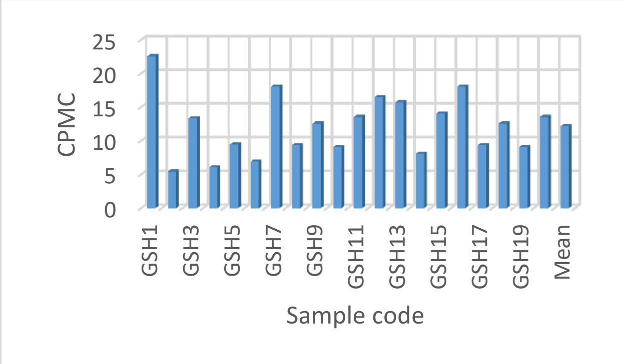

Fig.1: Radon-222 concentration in count per minute of water sample collected from Gashua, Yobe State, Nigeria.

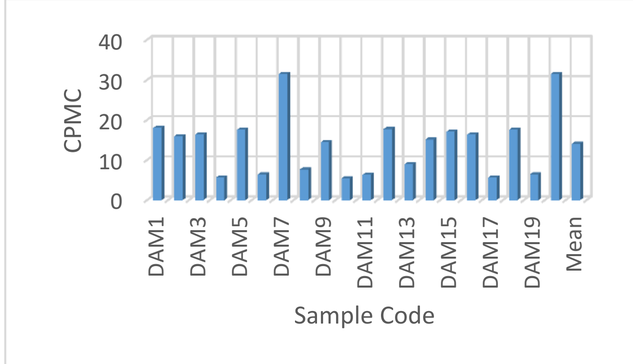

Fig.2: Rado-222 concentration in count per minute of water sample collected from Damaturu, Yobe State, Nigeria.

Figures 1 and 2 present the raw results of Rado-222 concentration in count per minute of water samples collected from Gashua and Damaturu, respectively. The raw result of Radon-222 concentration in counts per minute (cpm) represents the detected radioactivity from a sample, as measured by a radiation detector such as a scintillation counter, Geiger-Müller tube, or an alpha spectrometer. The cpm value indicates the number of radiation events (alpha decays) detected per minute and depends on factors like detector efficiency, background radiation, and measurement conditions.

The calculated hazard parameter due to radon-222 concentration level in water, and the background results obtained were determined. The annual effective dose by ingestion, dose contribution to the stomach due to ingestion, annual effective dose by inhalation estimation, dose contribution to the lung due to inhalation, and excess lifetime cancer risk, were estimated. Table 1 and 2 present the result of the calculated hazard parameters of radon-222 concentration in water sample collected from Damaturu, and Gashua, respectively.

Table 1: Calculated hazard parameters of radon-222 concentration in water sample collected from Damaturu, Yobe State.

Sample Code	**C_{Rn-222} (Bq/L)**	**E_{Ing} (mSv/y)**	**$D_{Stomach}$ (mSv/y)**	**E_{inh} (mSv/y)**	**D_{Lung} (mSv/y)**	**ELCR**
DAM1	1128.949	0.008241	0.000986	49.67378	5.955886	2.88447E-05
DAM2	999.2644	0.007295	0.000872	43.96763	5.271719	2.55312E-05
DAM3	1412.753	0.010313	0.001233	62.16114	7.45312	3.60958E-05
DAM4	340.8149	0.002488	0.000298	14.99586	1.798003	8.70782E-06
DAM5	1023.698	0.007473	0.000894	45.0427	5.40062	2.61555E-05
DAM6	836.3749	0.006106	0.00073	36.8005	4.412379	2.13694E-05
DAM7	380.9108	0.002781	0.000333	16.76008	2.009533	9.73227E-06
DAM8	592.0407	0.004322	0.000517	26.04979	3.12337	1.51266E-05
DAM9	432.9101	0.00316	0.000378	19.04805	2.283861	1.10609E-05
DAM10	1130.829	0.008255	0.000987	49.75647	5.965801	2.88927E-05
DAM11	586.4022	0.004281	0.000512	25.8017	3.093623	1.49826E-05

DAM12	786.8815	0.005744	0.000687	34.62279	4.151272	2.01048E-05
DAM13	568.8602	0.004153	0.000497	25.02985	3.001079	1.45344E-05
DAM14	848.9048	0.006197	0.000741	37.35181	4.478482	2.16895E-05
DAM15	1033.722	0.007546	0.000903	45.48376	5.453503	2.64116E-05
DAM16	984.2284	0.007185	0.000859	43.30605	5.192395	2.5147E-05
DAM17	507.4634	0.003704	0.000443	22.32839	2.677174	1.29657E-05
DAM18	882.1092	0.006439	0.00077	38.81281	4.653656	2.25379E-05
DAM19	354.5979	0.002589	0.00031	15.60231	1.870717	9.05998E-06
DAM20	780.6166	0.005699	0.000682	34.34713	4.118221	1.99448E-05
Mean	**780.61655**	**0.00569855**	**0.0006816**	**34.34713**	**4.1182207**	**1.99448E-05**

Table 2: Calculated hazard parameters of radon-222 concentration in water sample collected from Gashua, Yobe State.

Sample Code	C_{Rn-222} (Bq/L)	E_{Ing} (mSv/y)	$D_{Stomach}$ (mSv/y)	E_{inh} (mSv/y)	D_{Lung} (mSv/y)	ELCR
GSH1	403.4647393	0.002945293	0.000352257	17.75244853	2.128518579	1.03085E-05
GSH2	1973.468834	0.014406322	0.001722996	86.83262868	10.41123218	5.04221E-05
GSH3	479.8975005	0.003503252	0.000418989	21.11549002	2.531747254	1.22614E-05
GSH4	903.4101772	0.006594894	0.000788749	39.7500478	4.766030731	2.30821E-05
GSH5	342.0679312	0.002497096	0.000298653	15.05098897	1.804613578	8.73984E-06
GSH6	395.3202648	0.002885838	0.000345146	17.39409165	2.085551589	1.01004E-05
GSH7	1109.528033	0.008099555	0.000968707	48.81923346	5.853426092	2.83484E-05
GSH8	559.4627519	0.004084078	0.000488456	24.61636108	2.951501694	1.42943E-05
GSH9	946.0120441	0.006905888	0.000825944	41.62452994	4.99078114	2.41706E-05
GSH10	1068.179162	0.007797708	0.000932606	46.99988314	5.635285989	2.7292E-05
GSH11	711.0752782	0.00519085	0.000620826	31.28731224	3.751348738	1.8168E-05
GSH12	380.9108098	0.002780649	0.000332566	16.76007563	2.009533068	9.73227E-06
GSH13	466.7410416	0.00340721	0.000407502	20.53660583	2.462339039	1.19252E-05
GSH14	432.9101473	0.003160244	0.000377965	19.04804648	2.283860773	1.10609E-05
GSH15	1068.179162	0.007797708	0.000932606	46.99988314	5.635285989	2.7292E-05
GSH16	586.4021677	0.004280736	0.000511976	25.80169538	3.093623276	1.49826E-05
GSH17	598.9321286	0.004372205	0.000522916	26.35301366	3.159726338	1.53027E-05
GSH18	568.8602225	0.00415268	0.00049666	25.02984979	3.00107899	1.45344E-05
GSH19	974.204456	0.007111693	0.000850558	42.86499606	5.139513028	2.48909E-05
GSH20	1096.371574	0.008003512	0.00095722	48.24034927	5.784017877	2.80123E-05
Mean	753.2699	0.005499	0.000658	33.14388	3.973951	1.92E-05

The annual effective dose due to ingestion of Damaturu (Gashua) is 0.00569855 mSv/y (0.005499 mSv/y), which is below the International Commission on Radiological Protection (ICRP) reference dose limit of 0.1 mSv/y for drinking water [27-29]. This indicates that the ingestion route does not contribute significantly to radiation exposure. Similarly, the stomach dose contribution (0.0006816 mSv/y) is minimal, suggesting that ingestion of radon-contaminated water is not the primary concern.

The estimated annual effective dose by inhalation of Damaturu (Gashua) is 34.34713 mSv/y (33.14388 mSv/y) is alarmingly high compared to the ICRP recommended public exposure limit of 1 mSv/y [13]. This level is of significant concern because inhalation is the primary route of radon exposure, leading to an increased risk of lung cancer. The lung dose contribution (4.1182207 mSv/y) further supports the potential radiological impact on respiratory health.

The computed excess lifetime cancer risk of Damaturu (Gashua) is 1.99448E-05 (1.92E-05) is within the acceptable range of 10^{-6} to 10^{-3} recommended by USEPA [22]. However, considering the high inhalation dose, there is a need for risk mitigation strategies to reduce radon exposure.

4 Conclusion

The study provides results of radon-222 contamination in some selected well water sources from Gashua and Damaturu, Yobe State, Nigeria. Radon-222 concentrations in groundwater were found to be significantly high, surpassing international safety guidelines. The major risk is through inhalation, leading to a high annual effective dose and increased lung cancer risk. The estimated excess lifetime cancer risk (ELCR) due to radon exposure is above acceptable limits, suggesting an increased probability of developing lung cancer over a lifetime for individuals who consume and use the contaminated water regularly. Therefore, proper mitigation strategies should be carried out so that communities in Gashua and Damaturu may not face increasing health burdens related to chronic heavy metal toxicity and radiation exposure.

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