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COMPARATIVE STUDY ON THE HEALTH EFFECT ASSOCIATED WITH RADON CONCENTRATION FOR BOREHOLE AND WELL WATER SAMPLES ACROSS DUTSE L.G.A, JIGAWA STATE, NIGERIA

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ABSTRACT

Groundwater contamination with naturally occurring radionuclides, poses significant environmental and health risks. This study assessed Radon-222 (^222Rn) concentrations in borehole water sources from Dutse Local Government Area (LGA), Jigawa State, Nigeria. Twenty borehole water samples were analyzed using a liquid scintillation counter. Radon concentrations ranged from 18.93 to 45.38 Bq/L, with a mean value of 28.59 Bq/L, exceeding the maximum contaminant levels (MCL) of 11.1 Bq/L (USEPA) and 10 Bq/L (WHO). The annual effective doses from ingestion for adults, children, and infants were 0.21, 0.31, and 0.34 mSv/y, respectively, all above the WHO permissible limit of 0.1 mSv/y. Excess lifetime cancer risks (ELCR) due to ingestion were 0.00073, 0.001096, and 0.001278 for adults, children, and infants, respectively, surpassing the recommended limit of 0.00029. These findings indicate that borehole water in Dutse LGA is not radiologically safe for consumption and requires treatment and routine monitoring.

Keywords: Annual effective dose, Borehole water, Excess lifetime cancer risk, Radon-222

INTRODUCTION

Groundwater remains the most important source of potable water in Nigeria, especially in northern regions where surface water is scarce and unreliable (Bako et al., 2023; Dankawu et al., 2022). Boreholes are increasingly relied upon due to their perceived cleanliness and year-round availability. However, groundwater can harbor naturally occurring radionuclides such as radon (^222Rn), which enters aquifers through the decay of uranium and thorium in bedrock and soils (Belete & Anteneh, 2021; Regenauer et al., 2022).

Radon is a radioactive, colorless, and odorless noble gas with a half-life of 3.82 days. It dissolves easily in water and can be ingested or released into indoor air when borehole water is used for cooking, drinking, or bathing (Grzywa-Celińska et al., 2020; Shah et al., 2024). The International Agency for Research on Cancer (IARC) and the World Health Organization (WHO) recognize radon as the second leading cause of lung cancer worldwide after tobacco smoking (WHO, 2009; Riudavets et al., 2022). While inhalation of radon progeny is the primary pathway of exposure, ingestion through contaminated drinking water also contributes to radiation doses, particularly affecting the stomach and gastrointestinal tract (Makumbi et al., 2024).

In Nigeria, studies have documented elevated radon concentrations in groundwater across various states, including Nassarawa (Bako et al., 2023), Kaduna (Syahnita, 2021), Ogun (Jidele et al., 2021), Bauchi (Abdulrasheed et al., 2024), and Jigawa (Shuaibu et al., 2024). Many reported concentrations exceed the maximum contaminant levels (MCL) of 10 Bq/L (WHO, 2003) and 11.1 Bq/L (USEPA, 1999). Yet, local-scale data are scarce for Dutse LGA, where residents depend almost entirely on boreholes.

Given the growing reliance on boreholes in Dutse and the absence of routine monitoring, this study investigates radon concentrations in borehole water, estimates annual effective doses from ingestion and inhalation for different age groups, and evaluates excess lifetime cancer risks. By focusing exclusively on borehole samples, this work provides critical insights into groundwater safety and informs public health interventions in Jigawa State, Nigeria.

MATERIALS AND METHODS

Study Area

Dutse is the capital of Jigawa State, located in northwestern Nigeria (latitude 11°42′N, longitude 9°20′E). The area covers about 1099 km² and has a population of over 365,000 people (Dankawu et al., 2024). The geology is dominated by the Chad Formation, composed of sandstones, shales, and clays, underlain by crystalline basement rocks, including granites and gneisses (Shuaibu et al., 2022). These lithologies are often associated with elevated uranium and radium content, which are sources of radon in groundwater (Freiler et al., 2016).

Sample Collection

A total of 26 Water samples were collected in Dutse local government. Fourteen sample from boreholes and eleven from open well in clean plastic bottles. The containers used for the sample collection were cleaned to avoid contamination or absorption of the analyte (radon) present in the samples. Boreholes were flushed for at least four minutes prior to sampling to avoid stagnant water. Bailers assisted in gathering samples from wells that had been dug; but, in order to guarantee that new samples gathered, the stagnant water in the wells was cleansed by drawing it out and letting the well to refill. The bottle were filled to the brim to minimize radon degassing, and immediately acidified with concentrated HNO_3 to prevent radionuclide adsorption on container walls. This were done so as to achieve maximum accuracy and not to allow the composition of the sample to change.

Sample Preparation and Analysis

Samples were processed within three days of collection. A 10 mL aliquot of each sample was mixed with 10 mL of scintillation cocktail in 20 mL glass vials, tightly sealed, and equilibrated for 3–4 hours to ensure secular equilibrium between ^{222}Rn and its progeny. Radon activity concentrations were determined using a Perkin Elmer Tri-CarbLSA1000 liquid scintillation counter at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria.

Dose and Risk Estimation
Annual effective doses (AED) due to ingestion and inhalation were calculated using equations from UNSCEAR (1993, 2000), incorporating age-dependent water consumption rates (730 L/y adults, 547.5 L/y children, 182.5 L/y infants) and dose conversion factors (10^{-8}–7×10^{-8} Sv/Bq). Inhalation doses accounted for radon degassing during domestic use with equilibrium factors. Excess lifetime cancer risk (ELCR) was estimated by multiplying AED with life expectancy (70 years) and a risk factor of 0.055 Sv^{-1} for fatal cancer (USEPA, 1999; IAEA, 2018).

RESULTS AND DISCUSSION
Results
Table 1 Figure 1 and Figure 2 show the sample ID, the result obtained for ^{222}Rn Concentrations in Bq/L and annual effective dose due to inhalation and ingestion in mSv/y for different age categories (adult, child and infant) for borehole water samples. The results reveal that the 222Rn concentration varies from 16.586Bq/L as lowest value obtained from WKNY12 to 26.12095 Bq/L as the highest value obtained from WCHM10, with mean of 21.72Bq/L. The annual effective dose due to inhalation were ranged from 0.041797 mSv/y as the lowest values obtained fromWKNY12 to 0.065825 mSv/y as the highest value obtained from WCHM10 with mean of 0.0547mSv/y. However, the annual effective dose due to ingestion for adult, child and infant were ranged from (0.12108 to 0.190683), (0.181612 to 0.286024) and (0.211889 to 0.320144) mSv/y with the mean valves of (0.1585,0.2378,0.2775) mSv/L respectively.

Table 1: 222Rn Concentration (Bq/L) and Annual Effective dose due to Inhalation and Ingestion (mSvy^{-1}) for well Water Samples

S/N	SAM ID	Rn.Con	Rn(Bq/l)	AEDinh	AEDIng(A)	AEDIng(c)	AEDing(I)
1	WLMW 1	82.42	24.95295	0.062881	0.182157	0.273235	0.318774
2	WLMW 2	74.15	20.02469	0.050462	0.14618	0.21927	0.255815
3	WKCH 3	82.6	25.06021	0.063152	0.18294	0.274409	0.320144
4	WKCH 4	78.32	22.50968	0.056724	0.164321	0.246481	0.287561
5	WDR 5	74.88	20.45971	0.051558	0.149356	0.224034	0.261373
6	WDR 6	76.3	21.30592	0.053691	0.155533	0.2333	0.272183
7	WJTS 7	72.3	18.92224	0.047684	0.138132	0.207199	0.241732
8	WJTS 8	70.42	17.80191	0.044861	0.129954	0.194931	0.227419
9	WCHM 9	74.48	20.22135	0.050958	0.147616	0.221424	0.258328
10	WCHM10	84.38	26.12095	0.065825	0.190683	0.286024	0.333695
11	WKNY11	81.83	24.60136	0.061995	0.17959	0.269385	0.314282
12	WKNY12	68.38	16.58624	0.041797	0.12108	0.181619	0.211889
13	WMDB17	79.38	23.14135	0.058316	0.168932	0.253398	0.295631
14	WMDB18	81.18	24.21401	0.061019	0.176762	0.265143	0.309334
15	WSKW19	74.68	20.34053	0.051258	0.148486	0.222729	0.25985
16	WSKW20	76.17	21.22845	0.053496	0.154968	0.232452	0.271193
	Mean		21.72	0.0547	0.1585	0.2378	0.2775

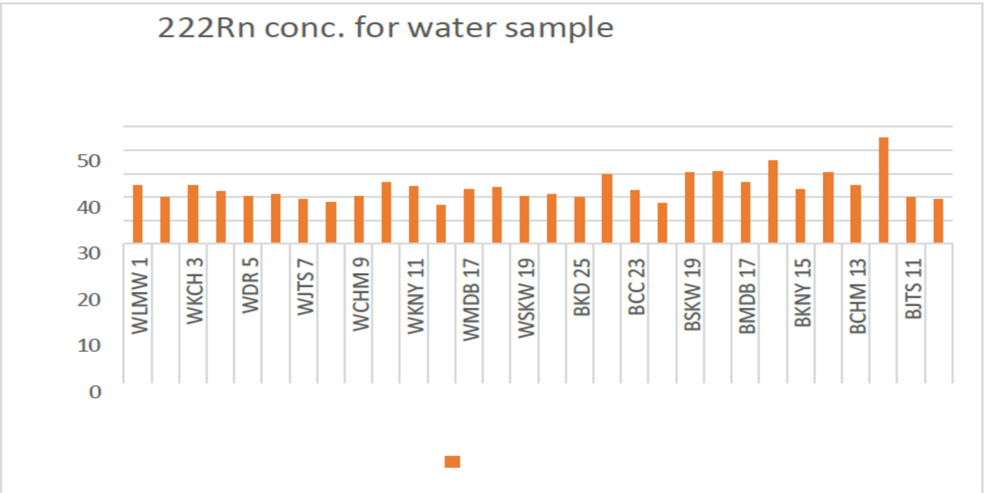

Figure 1: Result of 222Rn Concentration in Bq/L for well Water Samples

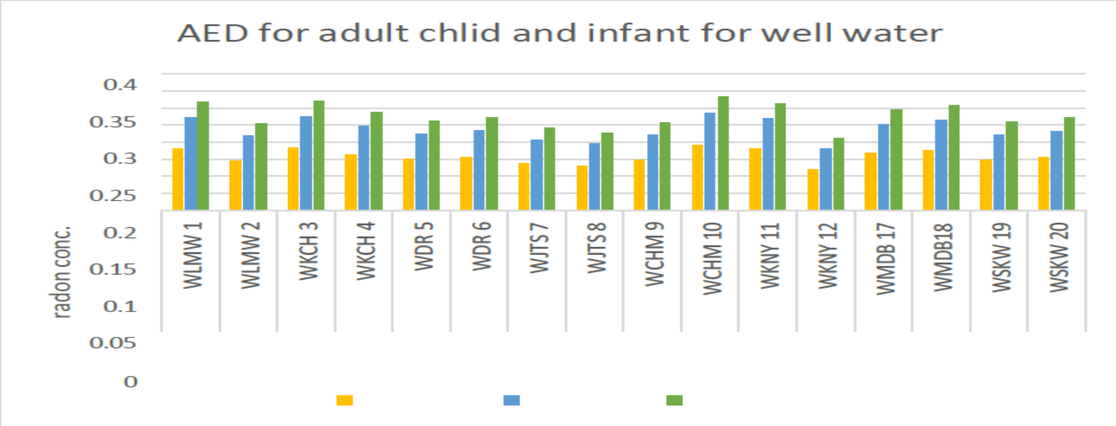

Figure 2: Result for Annual Effective dose due to Ingestion for Different age Categories (adult, child and infant) in mSv/y for well Water Samples.

Table 2, Figure 3 and Figure 4 show the sample ID, the result obtained for ^{222}Rn Concentrations in Bq/L and annual effective dose due to inhalation and ingestion in mSv/y for different age categories (adult, child and infant) for borehole water samples. The ^{222}Rn concentrations (Bq/L) of borehole water sample ranged from 17.25367 Bq/L as the lowest value obtained from BCC24 to 35.31003 Bq/L as the highest value obtained from BMDB18 with the mean of 26.80Bq/L. The annual effective dose from inhalation of borehole water sample were found in the range 0.043479 mSvy^{-1}as the lowest value obtained from BCC24 to 0.088981 mSv/y as the highest value obtained from BMDB18 with the mean of 0.0675 mSv/L. Furthermore, the annual effective dose due to ingestion for different age categories (adult, child and infant) were found to be as the ranged from (0.125952 to 0.331282), (0.188928 to 0.496923) and (0.220416 to 0.579743) mSv/L with mean of (0.1956,0.2935,0.3424) mSv/L respectively.

Table 2: Results for 222Rn Concentration in Bq/L and Annual Effective Dose due to Inhalation and Ingestion in mSvy-1 for Borehole Water Samples

S/N	SAM ID	Rn.Con	Rn(Bq/l)	AEDinh	AEDIng(A)	AEDIng(c)	AEDing(I)
1	BKD 25	73.67	19.73865	0.049741	0.144092	0.216138	0.252161
2	BKD 26	90.12	29.54153	0.074445	0.215653	0.32348	0.377393
3	BCC 23	78.8	22.79572	0.057445	0.166409	0.249613	0.291215
4	BCC 24	69.5	17.25367	0.043479	0.125952	0.188928	0.220416
5	BSKW 19	91.82	30.55459	0.076998	0.223049	0.334573	0.390335
6	BSKW 20	92.07	30.70357	0.077373	0.224136	0.336204	0.392238
7	BMDB 17	84.77	26.35336	0.06641	0.19238	0.288569	0.336664
8	BMDB 18	99.8	35.31003	0.088981	0.257763	0.386645	0.451086
9	BKNY 15	79.62	23.28437	0.058677	0.169976	0.254964	0.297458
10	BKNY 16	91.75	30.51288	0.076892	0.222744	0.334116	0.389802
11	BCHM 13	82.65	25.09001	0.063227	0.183157	0.274736	0.320525
12	BCHM 14	116.7	45.38108	0.11436	0.331282	0.496923	0.579743
13	BJTS 11	73.7	19.75653	0.049786	0.144223	0.216334	0.25239
14	BJTS 12	72.32	18.93416	0.047714	0.138219	0.207329	0.241884
	Mean		26.80	0.0675	0.1956	0.2935	0.3424

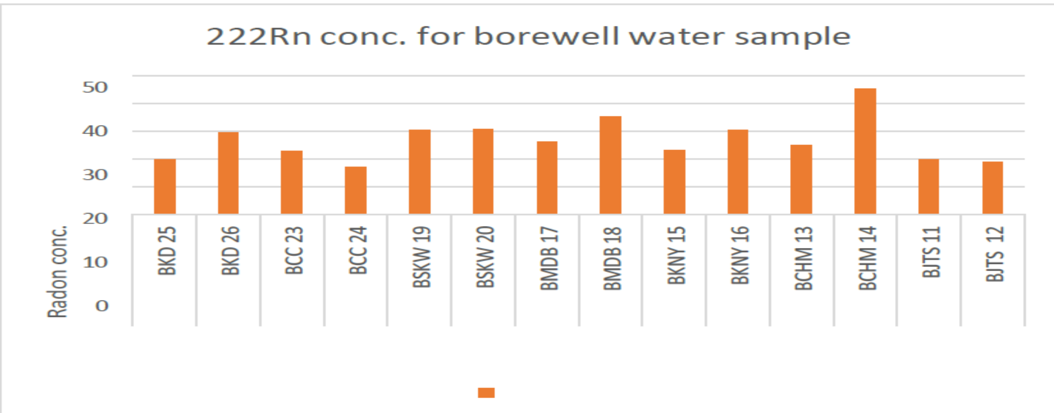

Figure 3: Result for 222Rn Concentration in Bq/L for Borehole Water Samples

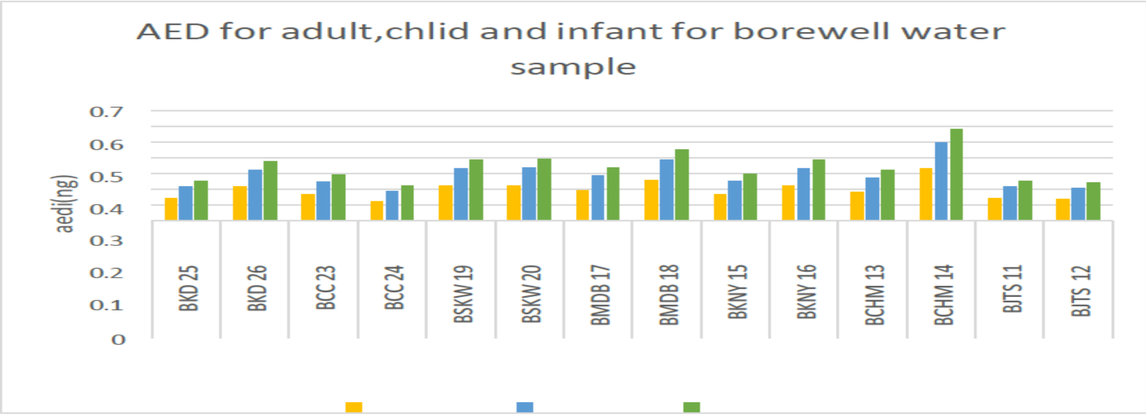

Figure 4: Result for annual Effective dose due to Inhalation and Ingestion for Adult, Child and Infant for Borehole Water Samples.

Table 3 and Figure 5 Show the sample ID, the result for excess life cancer risk due to inhalation and ingestion for different age categories (Adult, child and infant) for well water samples. The excess life cancer risk due to inhalation for well water samples were found to be in the range from 0.000146291 as the lowest value obtained from WKNY12 and 0.000230387 as the highest value obtained from WCHM10 with the mean of 0,0001916. Additionally, the table also found that the result for excess life cancer risk due to ingestion were ranged for adult, child and infant were ranged from (0.000424 obtained from WJTS12 and 0.000667 obtained from WCHM10 with the mean of 0.0005549), for child were found to be (0.000636 obtained from WKNY12 to 0.001001 obtained from WCHM10 with the mean of 0.0008324) and for infant were found to be (0.000742 obtained from WKNY12 to 0.001168 obtained from WCHM10 with th mean of 0.0009711).

Table 3: Result for Excess Life Cancer Risk due to Inhalation and Ingestion for Different age Categories (Adult, Child and Infant) for well Water Samples

S/N	SAM ID	ELCR(INH)	ELCR(ING)A	ELCR(ING)C	ELCR(ING)I
1	WLMW 1	0.000220085	0.000638	0.000956	0.001116
2	WLMW 2	0.000176618	0.000512	0.000767	0.000895
3	WKCH 3	0.000221031	0.00064	0.00096	0.001121
4	WKCH 4	0.000198535	0.000575	0.000863	0.001006
5	WDR 5	0.000180455	0.000523	0.000784	0.000915
6	WDR 6	0.000187918	0.000544	0.000817	0.000953
7	WJTS 7	0.000166894	0.000483	0.000725	0.000846
8	WJTS 8	0.000157013	0.000455	0.000682	0.000796
9	WCHM 9	0.000178352	0.000517	0.000775	0.000904
10	WCHM 10	0.000230387	0.000667	0.001001	0.001168
11	WKNY 11	0.000216984	0.000629	0.000943	0.0011
12	WKNY 12	0.000146291	0.000424	0.000636	0.000742
13	WMDB 17	0.000204107	0.000591	0.000887	0.001035
14	WMDB18	0.000213568	0.000619	0.000928	0.001083
15	WSKW 19	0.000179403	0.00052	0.00078	0.000909
16	WSKW 20	0.000187235	0.000542	0.000814	0.000949
	Mean	0.0001916	0.0005549	0.0008324	0.0009711

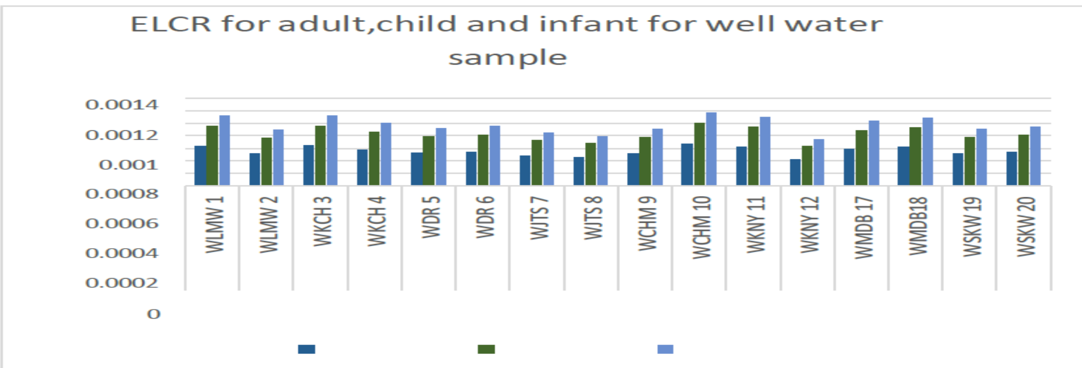

Figure 5: Result for Excess Life Cancer Risk due to Ingestion for Adult, Child and Infant for well Water Samples

Table 4 and Figure 6 Shows the sample ID, result for excess life cancer risk due to inhalation and ingestion for different age categories (Adult, child and infant) for borehole water samples.
The result for excess life cancer risk due to inhalation and ingestion for different age categories (Adult, child and infant) for borehole water samples.
The excess life cancer risk due to inhalation for borehole water samples were found to be in the range from 0.000166999 as the lowest value obtained from BJTS12 to 0.000400261 as the highest value obtained from BCHM14 with the mean value of 00002364. Moreover, the table also found that the result for excess life cancer risk due to ingestion were ranged for adult, child and infant were ranged from (0.000484 obtained from BJTS12 to 0.001159 obtained from BCHM14 with the mean of 0.0006847), for child were found to be (0.000726 obtained from BJTS12 to 0.001739 obtained from BCHM14 with the mean of 0.0010271) and for infant were found to be (0.000847 obtained from BJTS12 to 0.002029 obtained from BCHM14 with the mean of 0.0011983).

Table 4: Result for Excess life Cancer Risk due to Inhalation and Ingestion for Different age Categories (Adult, Child and Infant) for Borehole Water Samples

S/N	SAM ID	ELCR(INH)	ELCR(ING)A	ELCR(ING)C	ELCR(ING)I
1	BKD 25	0.000174095	0.000504	0.000756	0.000883
2	BKD 26	0.000260556	0.000755	0.001132	0.001321
3	BCC 23	0.000201058	0.000582	0.000874	0.001019
4	BCC 24	0.000152177	0.000441	0.000661	0.000771
5	BSKW 19	0.000269492	0.000781	0.001171	0.001366
6	BSKW 20	0.000270806	0.000784	0.001177	0.001373
7	BMDB 17	0.000232437	0.000673	0.00101	0.001178
8	BMDB 18	0.000311435	0.000902	0.001353	0.001579
9	BKNY 15	0.000205368	0.000595	0.000892	0.001041
10	BKNY 16	0.000269124	0.00078	0.001169	0.001364
11	BCHM 13	0.000221294	0.000641	0.000962	0.001122
12	BCHM 14	0.000400261	0.001159	0.001739	0.002029
13	BJTS 11	0.000174253	0.000505	0.000757	0.000883
14	BJTS 12	0.000166999	0.000484	0.000726	0.000847
	Mean	0.0002364	0.0006847	0.001027	0.0011983

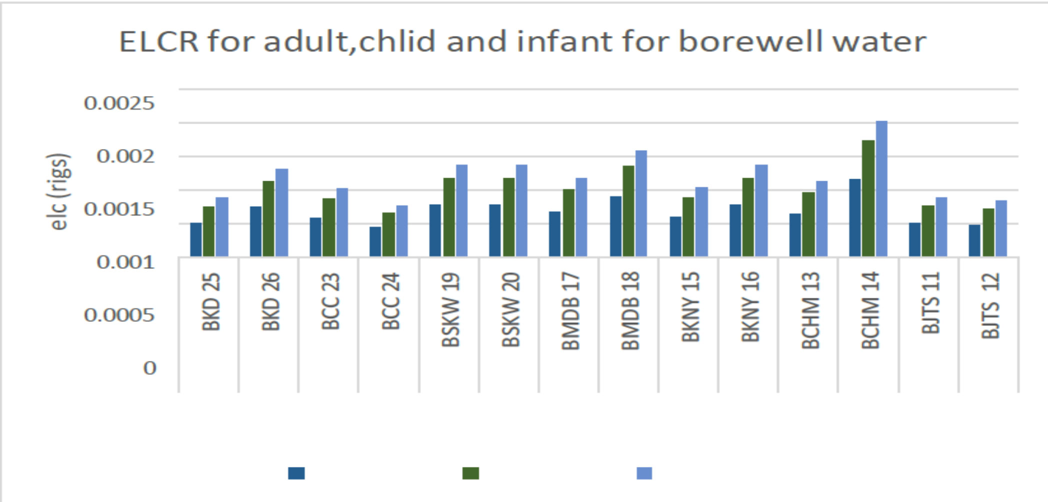

Figure 6: Result for Excess life Cancer Risk due Ingestion for Adult, Child and Infant for Borehole Water Samples

Discussion

Radon Concentration in Well Water Samples

The study revealed that the concentration of radon (^{222}Rn) in well water samples varied significantly, with values ranging from 16.586 Bq/L to 26.121 Bq/L and a mean of 21.72 Bq/L. These concentrations exceed the USEPA (11.1 Bq/L) and WHO (10 Bq/L) thresholds, indicating significant contamination, suggesting that radon levels in the studied well water samples are relatively high. However, the associated annual effective doses due to ingestion and inhalation (0.041797–0.065825 mSv/y) highlight potential health risks, especially for vulnerable groups such as children and infants, who exhibited higher dose levels (mean ingestion doses of 0.2378 mSv/y and 0.2775 mSv/y, respectively). Similar elevated values were reported in Katagum (mean 39.55 Bq/L; Abdulrasheed et al., 2024) and Kiyawa (mean 36.5 Bq/L; Shuaibu et al., 2024).

Radon Concentration in Borehole Water Samples

Borehole water samples exhibited higher radon concentrations, with values ranging from 17.254 Bq/L to 35.310 Bq/L and a mean of 26.80 Bq/L. The annual effective dose for inhalation (0.043479–0.088981 mSv/y) was also higher compared to well water, with children and infants again being the most affected due to

higher ingestion doses (mean values of 0.2935 mSv/y and 0.3424 mSv/y, respectively). Elevated radon levels in boreholes are often attributed to the geological formations of the study area, dominated by granite and sedimentary rocks, which are known sources of radon (Shuaibu et al., 2024).
Comparing well and borehole water, borehole sources consistently showed higher radon concentrations and associated health risks. This observation corroborates findings by Singh et al. (2014), who reported that deeper groundwater sources often accumulate more radon due to prolonged contact with radium-rich strata. Excess lifetime cancer risk (ELCR) calculations further underscore the differences, with borehole water showing higher ELCR values across all age groups. For example, the mean ELCR for inhalation from boreholes was 0.0002364 compared to 0.0001916 for wells, indicating a greater risk from borehole water consumption. These findings agree with previous Nigerian studies (Kolo et al., 2023; Syahnita, 2021), which identified ingestion as the dominant exposure pathway.

Implications for Public Health
Although radon levels in the studied samples fall above international thresholds, the associated health risks, particularly for infants and children are highly alarming. Chronic ingestion of radon-contaminated water increases the risk of gastrointestinal and stomach cancers, while degassed radon contributes to indoor air pollution and lung cancer risk (Moujaess et al., 2020; Riudavets et al., 2022). Moreover, the higher susceptibility of children and infants to radiation underscores the need for targeted interventions. Comparable risks were observed in Bosso, Niger State (Kolo et al., 2023) and Sabon Gari, Kaduna State (Syahnita, 2021).

RECOMMENDATIONS
To minimize radon exposure, it is essential to implement strategies such as regular water testing, especially for boreholes, and public awareness campaigns to educate communities about the risks of radon in water. Engineering solutions like aeration, granular activated carbon filtration, and boiling before use can effectively reduce radon levels in drinking water(Ajiboye et al., 2022; Becker, 2003).

CONCLUSION
This study revealed elevated ^222Rn concentrations in borehole water across Dutse LGA, with mean levels (28.59 Bq/L) more than double the permissible limits set by WHO and USEPA. The associated ingestion doses and lifetime cancer risks for all age groups exceeded recommended safety thresholds, indicating that borehole water in Dutse is not radiologically safe for direct consumption.

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