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A Comparative Analysis of Radon-222 Concentration in Water Sources and its Potential Stomach and Lungs Doses: A Case Study of Borno State University Campus and its Environs

Waida J[1*], Rilwan U [2*]

[1] *Department of Physics, Borno State University, Maiduguri, Nigeria*
[2] *Department of Physics, Nigerian Army University, PMB 1500 Biu, Borno State, Nigeria*

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Abstract

In Borno State, groundwater serves as the predominant source of fresh water for daily consumption. However, concerns persistence about its quality due to escalating radon concentrations resulting from mining activities. This research work assesses the long time dose which result from exposure to radon through the intake of groundwater in Borno State University (BOSU) Campus and Njimtilo students' residential area, Maiduguri metropolis, Borno, utilizing a liquid scintillation counter. Thirty (30) water samples from borehole were collected, which reveals the average radon concentration of 18.1219 Bq/L in BOSU Campus and Njimtilo. The annual mean ingestion/inhalation effective doses were 6.3×10^{-2} mSv/y and 4.6×10^{-2}mSv/y, respectively. In BOSU Campus and Njimtilo, the average extra lifetime cancer risk for ingestion was 0.222×10^{-3}, and for inhalation, it was 0.16×10^{-3}. The average radon concentration in the research area exceeded the SON and USEPA standard of 11.1 Bq/L. Despite this, based on the findings of this work, the radon concentration is deemed acceptable, allowing residents to continue with the use of water in the area pending when preventive measures are implemented. Nonetheless, ongoing assessment in the area is advisable to mitigate potential cancer risks. To cover the zone entirely, further investigations should explore more sources within the area in question. Given the temporal variation in radon concentrations due to rainfall dilution, regular testing and adherence to regional guidelines are recommended to address and alleviate potential health risks.

1. Introduction.

Water play a pivotal role in our lives being it number one resources, therefore, it's quality aught to be given high priority [1-2]. Access to freshwater in many environments has become the major challenges to people living in both rural and urban areas [4].

* Corresponding author:
E-mail address: jasini@bosu.edu.ng;
rilwan.usman@naub.edu.ng

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It is very important to engage in a regular inspection of the quality of water, most importantly, in areas where geology and sources of water together formed a possible health issues to the community [5].

Almost everywhere has been dominated by radon gas. This radon gas is a radioactive gas that occurred naturally and human senses can not detect it, and therefore a detector must be used to detect it. Radon has been one of the radioactive elements that pose serious pollution to the environment, which in turn, served as a big threat to human well-being. Radon is responsible for 55% of doses received by public annually as it causes health effect in both mining and non-mining areas. It has been ranked as the second cause of lung cancer in the world. Soil and rocks located in planet's crust are the major producers of radon gas. As a gas, it diffuses from rock to the surface sources of water, and when these sources are used for domestic purposes, the radon seeps into the atmosphere. This made it vital to inspect the quality of air and water since radon can be inhaled via air, or ingested through water [6].

The need for more researches and extension of our knowledge about the radon concentration in groundwater arises because of the possible health threat that radon poses on human well-being. Groundwater has been used worldwide as drinking water because of it's availability and easy to control, prioritizing the digging of various boreholes and wells. So many chemical constituent which might pose different heath issues have contaminated groundwater as a result of anthropogenic activities [7]. Radon gas produce a kind of radiation, which when decayed in the body can break water molecules, resulting in OH (free radicals). These free radicals, as a result of their high reactions, might be very dangerous to DNA of a cell, which may in turn cause cancer. The radon gas from environment is often trapped in the body by the bronchial epithelium. Notable dosage might similarly be received by the skin as well as the extra thoracic airways while kidney and bone marrow receives low doses. Stomach also get exposed to radon gas when someone takes in radon gas via water [8, 9].

This research work therefore intend to investigate the possible health threat that might be caused by ingestion or inhalation of radon gas across Borno State University camps as well as Njimtilo students residential area, Maiduguri Metropolis, Borno State, Nigeria.

2. Materials and Method

2.1. Description of the Study Location

Borno State University, Maiduguri was created in October, 2016. It is the first state University in Borno state.

The project area is bounded by latitudes 11°50′N 13°09′E and covers an area of 105.5 km^2 (40.7 sq mi). Maiduguri town, the capital of Borno State is at the centre. The topography of the area is virtually flat lying, with visibility possible to several kilometers. It has an average elevation of 320 m (1,050 ft) above sea level as well as total and density Population 758,700 and 7,200/km^2 (19,000/sq mi) respectively (2016 projection).

The area is within the semi-arid climate region and temperature varies from 25 to 36 ℃ seasonally. The area is characterized by a long dry season (October-May) and short rainy season (November-April) and the rainfall varies from 330 to 1020 mm. The area is Generally drained by River Ngadda which has its sources from southern Borno.

The project area (Maiduguri) falls within the south-western part of the Chad Basin and is wholly underlain by Chad formation, a sequence of lacustrine and fluviatile clays and sands of pleistocene age. The top soils covering the study area within the depth range of 0-1 m consist of very loose to lose slightly clayey silts covering 49% (548 Km^2) of the area, very loose to lose slightly sandy silts covering 31% (346 Km^2) of the area, soft silty clays covering 12% (134 Km^2) of the area and firm to stiff slightly silty clays covering 8% (89 Km^2) of the area. Table 1. specifically described the geographical coordinates of the studied location, whereas the maps of the area was depicted by Fig. 1 and Fig. 2.

Table 1. Sample Identification and G.P.S Coordinates of Study Location.

Point Codes	Coordinate (North)	Coordinate (East)
A (NJ)	13.00967998970	11.85004047350
B (NJ)	13.02448590200	11.85169707910
C (NJ)	13.02458943980	11.84346582020
D (NJ)	13.01853247570	11.84237867280
E (NJ)	13.01485688210	11.84527773250
F (NJ)	13.02210453150	11.84874625040
G (NJ)	13.01599579840	11.85092054520
H (NJ)	13.03649629230	11.84548480820
I (NJ)	13.03540914490	11.84211982820
J (NJ)	13.01609933630	11.84869448150
A (BC)	12.99648432	11.84534875
B (BC)	13.00135151	11.84352743
C (BC)	13.00434564	11.84007458
D (BC)	12.99746948	11.83814361
E (BC)	13.00438698	11.84687812

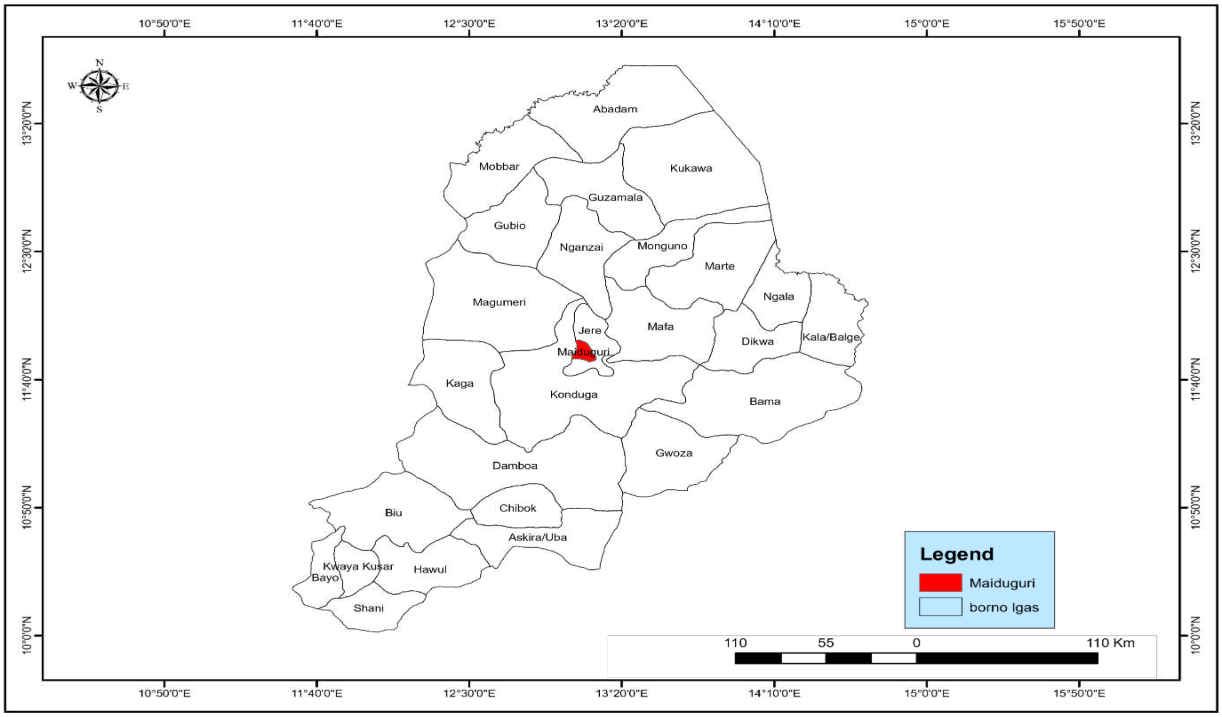

Fig. 1. Borno state map indicating Maiduguri metropolis

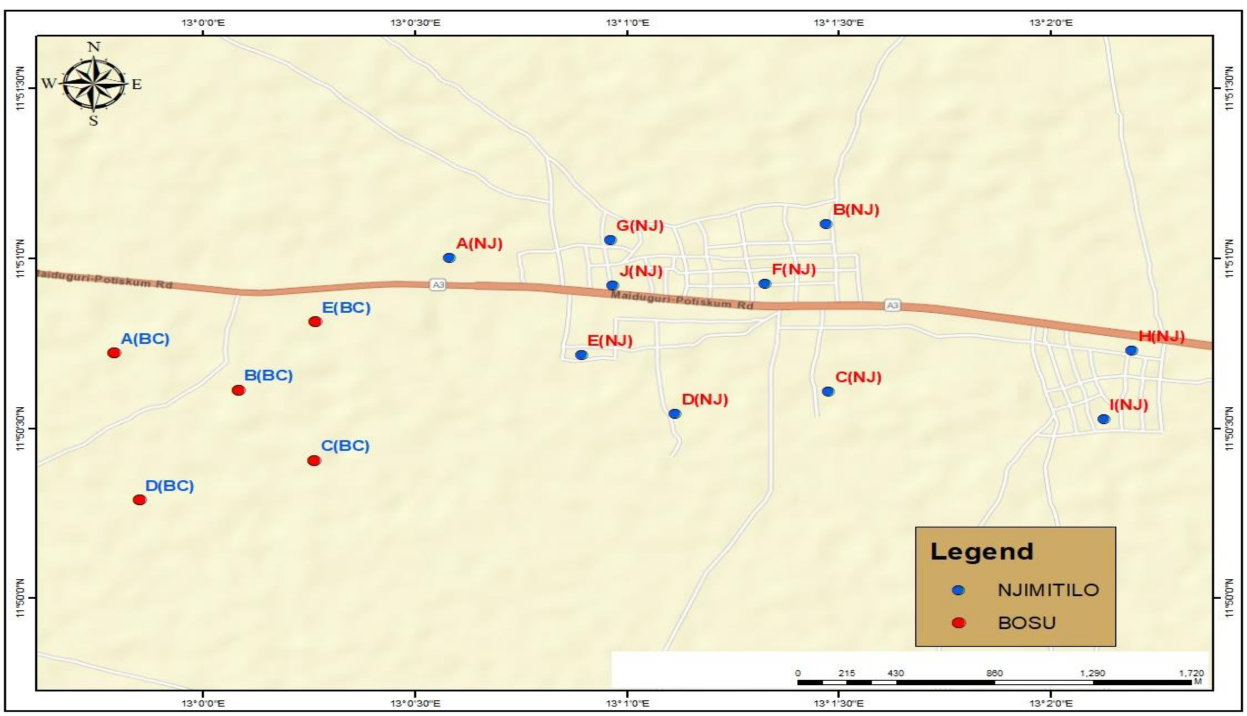

Fig. 2. Study area map indicating sampling points

2.2 Method

Thirty (30) samples (fifteen in rainy season and fifteen in dry season) were gathered from borehole water in a covered plastic containers. Out of these fifteen (15) water samples during the rainy season, ten (10) were collected from Njimtilo student residential area while five (5) were collected from BOSU main campus. The same procedure was repeated in dry season for the remaining fifteen (15) water samples in other to make a total of thirty (30) samples. The container was treated spetially with treated water in order to prevent radon from outside to contaminate the samples in the container.

20 mL of undiluted HNO_3 in a litre of water was utilized to store the water samples in order to reduce the radon absorption by the wall of the container to the nearest minimal. Each and every water sample was subsectioned into 10 mL and turned into 20 mL scintillation glass vial together with 10 mL cocktail of insta-gel scintillation, closed tightly and asked for more than 2 minutes in order to remove the radon in the water phase to the organic scintillate.

In the analysis of radon-222 concentration in water samples using a liquid scintillation counter, water samples were initially collected in containers with minimal headspace to mitigate radon loss. 10 mL of each water sample was then added to liquid scintillation vials, followed by the introduction of a scintillation cocktail designed to facilitate the release of scintillation light upon interaction with radon decay products. The samples were allowed to incubate for a predetermined duration to attain radon equilibrium. Subsequently, the emitted scintillation light was measured using a liquid scintillation counter, providing a quantitative assessment of radon-222 concentration in the water samples. Correction factors for efficiency and decay were applied to ensure accurate results, expressed in count per minutes (CPM) units. Rigorous quality control measures like background measurements, instrument checks, replicate analyses, and so on, were implemented to validate the precision and accuracy of the analysis, adhering to established protocols for reliable radon measurements in water.

LSC (Tri-Carb-LSA1000) obtained from the center for energy research and training (CERT) was use to carry out the analysis of the radon-222 concentration in groundwater samples via a method reported by Folger et al. (2016) [2016]. International Atomic Energy Agency (IAEA) standard solution for rad9n-222 was used to calibrate the counter before running the analysis of every sample. The background, the calibrated and the sample solutions were measured within the same spectra for 60 minutes and finally, the background and the sample count rate (count min^{-1}) were taken and recorded.

2.3 Theory

To estimate the potential risks posed by inhalation and ingestion of radon gas to public, the research used equation 1-4 to compute the radon level in Bq/L, effective dose in mSv/y due to ingestion and inhalation as well as excess lifetime cancer risk. The conversion of radon level from CPM to Bq/L was done by Equation 1 as reported by Ibikunle et al. (2018) [16].

$$Rn\left(\frac{Bq}{L}\right) = \frac{100\times(C_S - C_B)e^{-\lambda t}}{60\times5\times0.964} \quad (1)$$

Rn according to Aruwa et al. (2017), stands for radon level in Bq/L, Cs represents the sample count rate (count/min.), Cb means background count rate (count/min) t depicted the time which has ellaps along sample collection and sample counting (4320 mins), λ is the radon decay factor (1.26×10^{-4} min^{-1}). 100 represents the conversion factor from 10 mL per litre (L^{-1}) and 60 converts from minutes to seconds, 5 (500%) gives the number of emission per radon decay, 0.964 stands for radon percent in the cocktail along the overall capacity of 22 mL vial, if we consider the vial to have 10 mL of cocktail, 10 mL of water and 2 mL of air.

The ingested annual effective dose in mSv/y as reported by Ishaya et al. (2018) [17] is computed using equation (2).

$$\lambda_{ings} = C \times K \times G \quad (2)$$

With C being the radon concentration in Bq/L, G representing the daily water intake for (adults and children), estimated to be 4 L/d or 1460 L/y, K standing for the radon concentration conversion coefficient, given 3.5×10^{-5} mSv/Bq for ingestion. Equation (3) as reported by Jacek et al. (2017) [18], and Jibril et al. (2021) is used to estimate the radon inhaled annual effective dose (λ_{inh}) in mSv/y as:

$$\lambda_{inh} = C \times T \times R \times F \times P \quad (3)$$

C stands for radon level in Bq/L, F signifies the equilibrium factor, set as 0.4, T standing for the duration indoor occupancy agreed as 7000 h/y, R implying the radon concentration ratio in air to borehole set as 10^{-4} and P standing for the conversion factor reported to be 9×10^{-3} mSv/h/(Bq/m^3).

Equation (4) was utilized as pointed out by Massoud et al. (2000) [19] to estimate the excess lifetime cancer risk for this study.

$$\alpha = \lambda \times \mu \times \eta \quad (4)$$

α being the excess lifetime cancer risk, λ represents the annual effective dose, μ stands for annual life duration, approximately 70 years and η estimated as 0.05 Sv^{-1} stands for the risk factor expressed as the fatal cancer risk per Sievert [20].

3. Results and Discussion

3.1. Obtained Results

We used LSC to determine the radon concentration in CPM of groundwater samples in this work. The results obtained from the analysis in CPM was converted to Bq/L (both in dried and rainy season) and presented in Table 2.

Table 2. Concentrations of Radon-222 for rainy and dry season in samples of water from BOSU and Njimtilo.

Sample ID	Rn (CPM)		Rn (Bq/L)	
	Rainy	Dry	Rainy	Dry
A (NJ)	155.92	93.68	19.361	6.2755
B (NJ)	111.25	82.43	9.9693	3.9104
C (NJ)	110.43	84.17	9.7970	4.2762
D (NJ)	102.18	128.3	8.0625	13.554
E (NJ)	92.173	110.2	5.9587	9.7486
F (NJ)	97.542	104.5	7.0874	8.5503
G (NJ)	129.60	96.45	13.827	6.8579
H (NJ)	110.37	92.13	9.7843	5.9497
I (NJ)	108.25	90.32	9.3386	5.5691
J (NJ)	101.08	78.33	7.8313	3.0484
A (BC)	94.521	71.38	6.4523	1.5873
B (BC)	96.620	75.22	6.8936	2.3946
C (BC)	115.77	96.17	10.920	6.7990
D (BC)	107.33	87.26	9.1452	4.9258
E (BC)	103.26	92.37	8.2896	6.0001
Mean	109.09	92.19	9.5145	5.9631
SD	16.043	14.43	3.3729	3.0344
CV%	14.707	15.66	35.450	50.887
Max	155.92	128.3	19.361	13.554
Min	92.173	71.38	5.9587	1.5873

The annual effective dose and excess lifetime cancer risk were respectively computed with the aid of equation (2) to (4); and presented in Table 3. and Table 4.

CPM = Count per minutes; Rn = Radon-222; Bq/L = Bequerel per litre; SD = Standard deviation; CV% = Coeffitient of variation; NJ = Njimtilo; BC = BOSU Campus.

According to Table 2., in rainy season, the concentrations of Rn-222 in BOSU Campus and Njimtilo borehole water samples ranged from 5.9587 to 19.361 Bq/L (E (NJ) to A (NJ)), with a mean of 9.5145 Bq/L and standard deviation of 3.3729 Bq/L. on the other hand, in dry season, the concentrations of Rn-222 in BOSU Campus and Njimtilo borehole water samples ranged from 1.5873 to 13.554 Bq/L (A (BC) to D (NJ)), with a mean of 5.9631 Bq/L and standard deviation of 3.0344 Bq/L. This high concentration in A (NJ) during the rainy season could be attributed to the increased groundwater infiltration, increased soil moisture content, changes in permeability of the soil, uranium leaching from the soil and rocks by rainwater, water table fluctuations influenced by rainfall, changes in groundwater levels during the rainy season, along with potential ground subsidence, while high concentration in D (NJ) during the dry season could be attributed to the reduced dilution of radon in the groundwater, lower water table, enhanced transfer of gases between the soil and the atmosphere, elevated temperatures in the soil during the dry season which may increase the mobility of radon through diffusion and then transport of radon from the soil into the groundwater, dry conditions which altered the permeability of the soil, affecting the movement of the radon gases, dry conditions which contribute to the decomposition of organic matter in the soil, and also the underlying geology of the region plays a crucial role in radon concentrations.

Based on the results presented, radon concentrations in sample A (NJ), B (NJ), C (NJ), G (NJ), H (NJ), I (NJ), J (NJ), A (BC), B (BC), C (BC), D (BC) and E (BC) are found higher in rainy season compared to dry season, which may be due to the the increased groundwater infiltration, increased soil moisture content, changes in permeability of the soil, uranium leaching from the soil and rocks by rainwater, water table fluctuations influenced by rainfall, changes in groundwater levels during the rainy season, along with potential ground subsidence. On the other hand, radon concentrations in places like D (NJ), E (NJ) and F (NJ) are found higher in dry season compared to rainy season, which may be due to the the reduced dilution of radon in the groundwater, lower water table, enhanced transfer of gases between the soil and the atmosphere, elevated temperatures in the soil during the dry season which may increase the mobility of radon through diffusion and then transport of radon from the soil into the groundwater, dry conditions which altered the permeability of the soil, affecting the movement of the radon gases, dry conditions which contribute to the decomposition of organic matter in the soil, and also the underlying geology of the region plays a crucial role in radon concentrations.

Table 3. Effective dose by ingestion and inhalation of Radon 222 for rainy and dry season in water samples from BOSU and Njimtilo.

Sample ID	E(ing) (mSv/y)		E(inh) (mSv/y)	
	Rainy	Dry	Rainy	Dry
A (NJ)	0.0989	0.0321	0.0488	0.0158
B (NJ)	0.0509	0.0200	0.0251	0.0099
C (NJ)	0.0501	0.0219	0.0247	0.0108
D (NJ)	0.0412	0.0693	0.0203	0.0342
E (NJ)	0.0304	0.0498	0.0150	0.0246
F (NJ)	0.0362	0.0437	0.0179	0.0215
G (NJ)	0.0707	0.0350	0.0348	0.0173
H (NJ)	0.0500	0.0304	0.0247	0.0150
I (NJ)	0.0477	0.0285	0.0235	0.0140
J (NJ)	0.0400	0.0156	0.0197	0.0077
A (BC)	0.0330	0.0081	0.0163	0.0040
B (BC)	0.0352	0.0122	0.0174	0.0060
C (BC)	0.0558	0.0347	0.0275	0.0171
D (BC)	0.0467	0.0252	0.0230	0.0124
E (BC)	0.0424	0.0307	0.0209	0.0151
Mean	0.0486	0.0305	0.0240	0.0150
SD	0.0172	0.0155	0.0085	0.0076
CV%	35.450	50.887	35.450	50.887
Max	0.0989	0.0693	0.0488	0.0342
Min	0.0304	0.0081	0.0150	0.0040

Results from Table 3 indicates that the ingestion in the rainy season has the annual effective dose ranging between 0.0304 and 0.0989 mSv/y (E(NJ) and A(NJ)), having an average of 0.0486 mSv/y with standard deviation of 0.0172 mSv/y, while that of dry season ranged between 0.0081 and 0.0693 mSv/y (E(NJ) and A(NJ)), having an average of 0.0305 mSv/y with standard deviation of 0.0155 mSv/y. These results are found lower compared to the values aggreed by WHO for drinking water of 0.1 mSv/y. This may not increase the risk of stomach cancer due to the ingestion of dissolved radon [21].

Results presented in Table 3 revealed that the effective dose as a result of inhalation in rainy season falls between 0.015 and 0.0488 mSv/y (E(NJ) and A(NJ)) having an average of 0.024 mSv/y with standard deviation of 0.0085 mSv/y, while that of dry season ranged between 0.004 and 0.0342 mSv/y (E(NJ) and A(NJ)) having an average of 0.015 mSv/y with standard deviation of 0.0076 mSv/y. These results are found lower than the results suggested by WHO for drinking water of 0.1 mSv/y. This may not increase the risk of lung cancer due to the inhalation of radon released into the air [21].

Based on the results presented for both ingestion and inhalation, the annual effective dose in sample A (NJ), B (NJ), C (NJ), G (NJ), H (NJ), I (NJ), J (NJ), A (BC), B (BC), C (BC), D (BC) and E (BC) are found higher in rainy season compared to dry season, which may be due to the corresponding high concentration of radon caused by probably increased groundwater infiltration, increased soil moisture content, changes in permeability of the soil, uranium leaching from the soil and rocks by rainwater, water table fluctuations influenced by rainfall, changes in groundwater levels during the rainy season, along with potential ground subsidence. On the other hand, annual effective dose in places like D (NJ), E (NJ) and F (NJ) are found higher in dry season compared to rainy season, which may be due to the corresponding high concentration of radon caused by probably reduced dilution of radon in the groundwater, lower water table, enhanced transfer of gases between the soil and the atmosphere, elevated temperatures in the soil during the dry season which may increase the mobility of radon through diffusion and then transport of radon from the soil into the groundwater, dry conditions which altered the permeability of the soil, affecting the movement of the radon gases, dry conditions which contribute to the decomposition of organic matter in the soil, and also the underlying geology of the region plays a crucial role in radon concentrations.

Table 4. Excess lifetime cancer risk by ingestion and inhalation of Radon-222 for rainy and dry season in water samples from BOSU and Njimtilo.

Sample ID	$C(ing) \times 10^{-3}$		$C(inh) \times 10^{-3}$	
	Rainy	Dry	Rainy	Dry
A (NJ)	0.3463	0.1122	0.1708	0.0554
B (NJ)	0.1783	0.0699	0.0879	0.0345
C (NJ)	0.1752	0.0765	0.0864	0.0377
D (NJ)	0.1442	0.2424	0.0711	0.1195
E (NJ)	0.1066	0.1744	0.0526	0.0860
F (NJ)	0.1268	0.1529	0.0625	0.0754
G (NJ)	0.2473	0.1227	0.1220	0.0605
H (NJ)	0.1750	0.1064	0.0863	0.0525
I (NJ)	0.1670	0.0996	0.0824	0.0491
J (NJ)	0.1401	0.0545	0.0691	0.0269
A (BC)	0.1154	0.0284	0.0569	0.0140
B (BC)	0.1233	0.0428	0.0608	0.0211
C (BC)	0.1953	0.1216	0.0963	0.0600
D (BC)	0.1636	0.0881	0.0807	0.0434
E (BC)	0.1483	0.1073	0.0731	0.0529
Mean	0.1702	0.1067	0.0839	0.0526
SD	0.0603	0.0543	0.0297	0.0268
CV%	35.450	50.887	35.450	50.887
Max	0.3463	0.2424	0.1708	0.1195
Min	0.1066	0.0284	0.0526	0.0140

C(ing) = Cancer risk by ingestion; C(inh) = Cancer risk by inhalation; SD = Standard deviation; CV% = Coeffitient of variation NJ = Njimtilo; BC = BOSU Campus.

The determination of the excess lifetime cancer risk by ingestion was performed for the BOSU Campus and Njimtilo students residential area and the data are presented in Table 4. The results indicate that, in the case of ingestion during the rainy season, the excess lifetime cancer risk from borehole water samples ranged from0.1066×10^{-3} to 0.3463×10^{-3} (E(NJ) to A(NJ)), with a mean value of $0.1702 \times 10^{-3}$and standard deviation of 0.0603×10^{-3}, while in the case of ingestion during the dry season, the excess lifetime cancer risk from borehole water samples ranged from 0.0284×10^{-3} to 0.2424×10^{-3} (E(NJ) to A(NJ)), with a mean value of $0.1067 \times 10^{-3}$and standard deviation of 0.0543×10^{-3}. These values are found lower than the values recommended by WHO for drinking water of 0.29×10^{-3} except for A(NJ) in rainy season which was found higher. The higher value observed in A(NJ) might instigate the risk of getting stomach cancer in the long run, while other points with lower values may not increase the risk of stomach cancer due to the ingestion of dissolved radon [22].

The excess lifetime cancer risk by inhalation for the BOSU Campus and Njimtilo students residential area was estimated based on the measured radon concentrations, as also presented in Table 4. The analysis revealed that for borehole water samples, the excess lifetime cancer risk by inhalation during the rainy season ranged from0.0526×10^{-3} to 0.1707×10^{-3} (E(NJ) to A(NJ)) with a mean value of 0.0837×10^{-3} and standard error of 0.0297×10^{-3}, while the excess lifetime cancer risk by inhalation during the dry season ranged from 0.014×10^{-3} to 0.1195×10^{-3} (E(NJ) to A(NJ)) with a mean value of 0.0526×10^{-3} and standard error of 0.0268×10^{-3}. These values are found lower than the values recommended by WHO for drinking water of 0.29×10^{-3}. This may not increase the risk of lung cancer due to the inhalation of radon released into the air [23].

Based on the results presented for both ingestion and inhalation, the values for the excess lifetime cancer risk in sample A (NJ), B (NJ), C (NJ), G (NJ), H (NJ), I (NJ), J (NJ), A (BC), B (BC), C (BC), D (BC) and E (BC) are found higher in rainy season compared to dry season, which may be due to the corresponding high annual effective dose caused by high concentration probably attributed to increased groundwater infiltration, increased soil moisture content, changes in permeability of the soil, uranium leaching from the soil and rocks by rainwater, water table fluctuations influenced by rainfall, changes in groundwater levels during the rainy season, along with potential ground subsidence. On the other hand, excess lifetime cancer risk value in places like D (NJ), E (NJ) and F (NJ) are found higher in dry season compared to rainy season, which may be due to the corresponding high annual effective dose coursed by high concentration of radon, which may be probably related to reduced dilution of radon in the groundwater, lower water table, enhanced transfer of gases between the soil and the atmosphere, elevated temperatures in the soil during the dry season which may increase the mobility of radon through diffusion and then transport of radon from the soil into the groundwater, dry conditions which altered the permeability of the soil, affecting the movement of the radon gases, dry conditions which contribute to the decomposition of organic matter in the soil, and also the underlying geology of the region plays a crucial role in radon concentrations [24-30].

Table 5. Summary of the concentration and risks parameters for ingestion and inhalation of Radon-222 in rainy and dry seasons

Seasons	Rn (Bq/L)	E(ing) (mSv/y)	E(inh) (mSv/y)	C(ing)	C(inh)
Rainy	9.5145± 3.3729	0.0486± 0.0172	0.0240± 0.0085	0.1702± 0.0603	0.0839± 0.0297
Dry	5.9631± 3.0344	0.0305± 0.0155	0.0150± 0.0076	0.1067± 0.0543	0.0526± 0.0268
Mean	7.7388± 3.2037	0.0396± 0.0164	0.0195± 0.0081	0.1385± 0.0573	0.0683± 0.0283

The data presented in Table 2. to Table 4. respectively for radon-222 concentration in Bq/L, effective dose by ingestion and inhalation in mSv/y and excess lifetime cancer risks for ingestion and inhalation are summarized and presented in Table 5.

Based on the table, it could be observed that, the radon-222 concentration with mean value recorded as 7.7388±3.2037 Bq/L has high value of 9.5145±3.3729 Bq/L in rainy season compared with dry season which has recorded value of 5.9631±3.0344 Bq/L.

The effective dose by ingestion of radon-222 with mean value recorded as 0.0396±0.0164 mSv/y has high value of 0.0486±0.0172 mSv/y in rainy season compared with dry season which has recorded value of 0.0305±0.0155 mSv/y. in a similar manner, the effective dose by inhalation of radon-222 with mean value recorded as 0.0195±0.0081 mSv/y has high value of 0.0240±0.0085 mSv/y in rainy season compared with dry season which has recorded value of 0.0150±0.0076 mSv/y.

The excess lifetime cancer risk by ingestion of radon-222 with mean value recorded as 0.1385±0.0573 mSv/y has high value of 0.1702±0.0603 mSv/y in rainy season compared with dry season which has recorded value of 0.1067±0.0543 mSv/y. in a similar manner, the excess lifetime cancer risk by inhalation of radon-222 with mean value recorded as 0.0683±0.0283 mSv/y has high value of 0.0839±0.0297 mSv/y in rainy season compared with dry season which has recorded value of 0.0526±0.0268 mSv/y.

3. 2. Results Comparison

The results from this work as presented in Table 5 was compared with the results reported by World Health Organization (WHO).

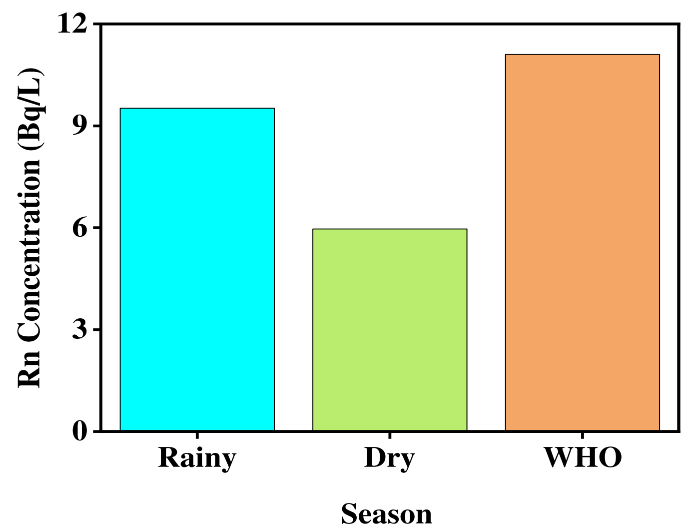

Fig. 3. Average Radon Concentration for Rainy, Dry Season and WHO.

Fig. 3. showed that the radon level in rainy season was found higher than that in dry season. Both dry and rainy seasons in this work were recorded to be lower than the World Health Organization limit of 11.1 Bq/L.

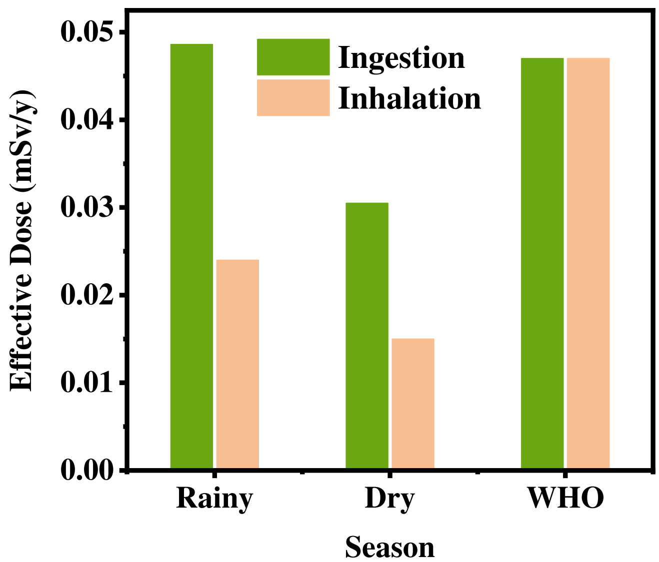

Fig. 4. Average Effective Dose for Rainy, Dry Season and WHO.

From the Fig. 4., it is obvious that the effective dose for both ingestion and inhalation in rainy season was recorded to be higher than that in dry season. Both dry and rainy seasons (with exception of ingestion in rainy season which was observed to be above the World Health Organization limit of 0.047 Bq/L) were recorded to be lower than the World Health Organization limit of 0.047 Bq/L.

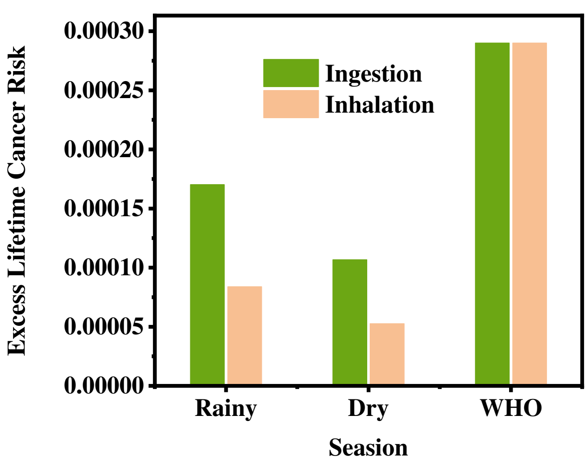

Fig. 5. Average Excess Lifetime Cancer Risk for Rainy, Dry Season and WHO.

From the Fig. 5., it is evident that the excess lifetime cancer risk for both ingestion and inhalation in rainy season was recorded to be higher than that in dry season. Both dry and rainy seasons were recorded to be lower than the World Health Organization limit of 0.29×10^{-3}Bq/L.

Table 6. Comparison of this study with regulatory Bodies.

Location	Radon Concentration (Bq/L)	Reference
Ekiti State	13.59	[32]
Kogi State	13.77	[32]
Kaduna State	11.80	[32]
Ondo State	35.54	[33]
BOSU and Njimtilo	7.74	Present Study

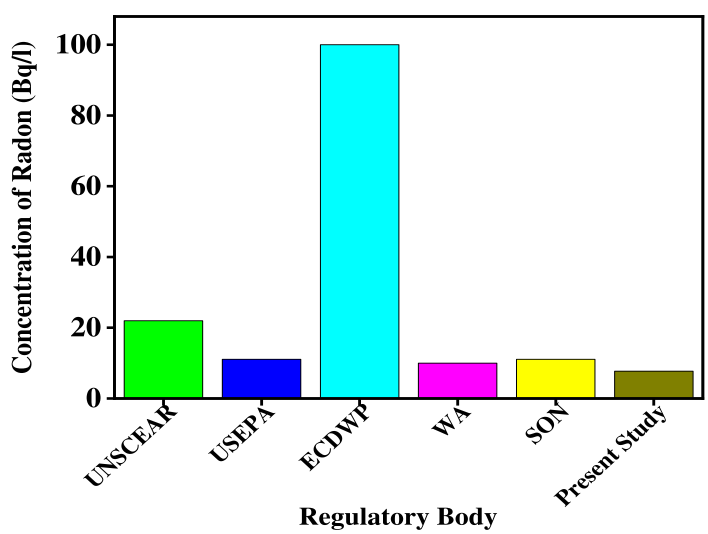

Fig. 6. Comparison of this study with regulatory Bodies.
Table 6 and Fig. 6 revealed that the radon in this work is lower than the safe limits reported by regulatory bodies like USEPA, WA, SON, ECDWP and UNSCEAR.

The results from the current work were compared with safety regulations as well as studies from other authors (Table 6. to Table 8). Charts were also plotted for better comparison and are presented in Fig. 6 to Fig. 8.

Table 7. Comparison of this study with other works in Nigeria.

Regulatory Bodies	Concentration of Radon (Bq/L)	Sources
UNSCEAR	22	[31]
USEPA	11.1	[31]
ECDWP	100	[31]
WA	10	[31]
SON	11.1	[31]
BOSU and Njimtilo	7.74	Present Study

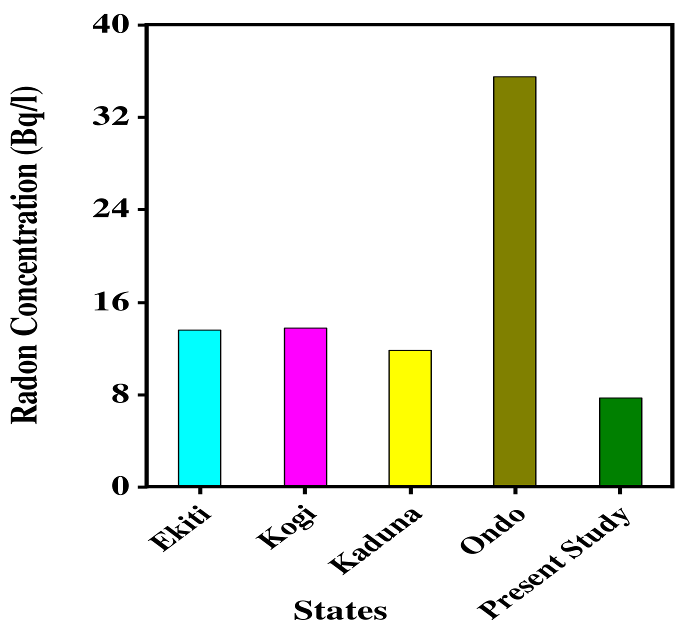

Fig. 7. Comparison of this study with other parts of Nigeria.

Table 7. and Fig. 7. showed that the values from this work are lower than those from Zaria in Kaduna state, Ado-Ekiti in Ekiti State, Idah in Kogi State and Ondo State.

Table 8. Comparison of this study with other parts of the World.

Location	Radon Concentration (Bq/L)	Reference
India	2.63	[34]
Turkey	9.28	[34]
Romania	15.40	[34]
Lebanon (many locations)	11.30	[35]
United States of America	5.20	[36]
BOSU and Njimtilo	7.74	Present Study

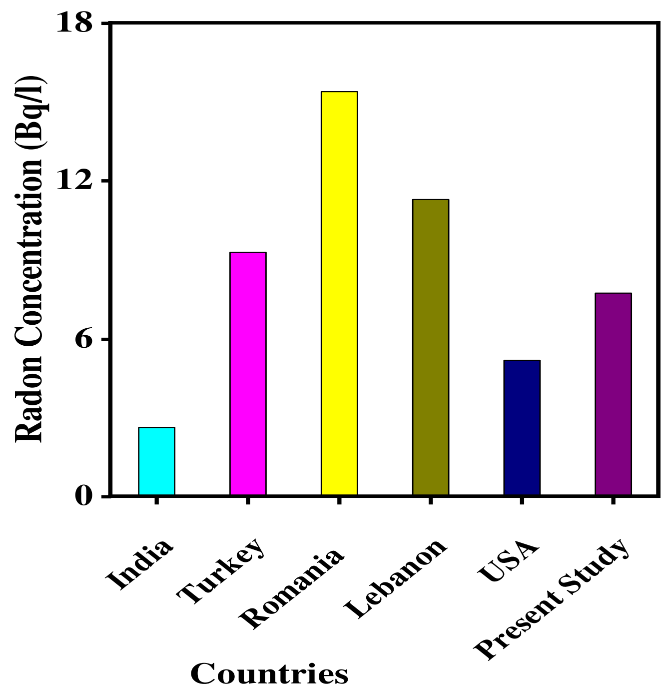

Fig. 8. Comparison of this study with other parts of the World.

Based on the findings presented in Table 8 and Figure 8, the radon concentrations observed in the groundwater samples from this study were comparatively lower than those reported in countries such as Turkey, Romania and Lebanon but higher than India and United State of America (USA).

4. Conclusion

This work investigated the level of radon in groundwater samples across Borno State University campus and environ. The work reported radon concentration higher than MPL of 11.1 Bq/L reported by US-EPA and SON. Based on this findings, the water in the investigated area is not good for use. The high concentration of radon in this work might be associated with the local and the anthropogehic activities in the area. It will complement the safety of the public, if government will place serious restrictions on the anthropogenic activities in the area which may greatly reduce the amount of radon gas coming from those activities to the public environment. Doing this will equally reduce the possibility of future cancer risk that may result from radon exposure.

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