Original Research Article: Assessment of the Effective Dose Arising from Radon Exposure through Groundwater Consumption and Inhalation in Nasarawa, Nigeria

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ABSTRACT

In Nasarawa State, groundwater is the most often used source of fresh water for daily consumption, but its quality still remains a serious concern due to rising concentrations of radon resulting from activities of mining. This study assesses the effective dose arising from radon exposure through groundwater consumption and inhalation in Nasarawa, Nigeria, using the liquid scintillation detector. Ten borehole samples of groundwater were collected. The mean content of radon from water samples of Nasarawa was 19.393±0.254 Bq/l. The average ingested and inhaled dose effectiveness annually was 0.102±0.0014 mSv/y and 5.05 x10^{-5}±0.000 mSv/y, respectively. In Nasarawa, the average ingested extra lifetime cancer risk was 3.585 x10^{-4}±0.000 and for inhalation was 1.768 x 10^{-7} ±0.000. Research area's average radon concentration was higher than the standard of 11.1 Bq/l set by the SON and USEPA. Based on the findings of the present work, the radon concentration is unacceptable. Hence, inhabitants should be restricted from using the water until measures are put into place. However further analysis could be carried out in the area to prevent people from cancer risk. To cover the entire zone, additional research should be conducted covering additional sources in the study area. As concentrations of radon in water sources varies with time as a result of dilution by rainfall, more examination may be conducted in dry and raining periods.

Introduction

Managing water is a top priority issue that has a significant impact on our lives [1]. The most important natural resource is water [2]. Development requires reliable water sources to be available, which is a crucial need. Due to the lack of water, deserts are uninhabitable [3]. One of the most crucial environmental and sustainability challenges is the lack of quality and accessible freshwater [4].

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Regular groundwater quality inspections are important, particularly those places where water sources and geology together constitute a plausible risk to the community's health [5,6].

Everywhere there is radon, a naturally occurring radioactive that cannot be detected by human senses and must instead be measured using a detector. Among the radionuclides that contribute to natural background radiation, radon has been one that poses the greatest threat to human health. It accounts for around 55% of the annual dose that the general public receives. In addition, it has been proven that ^{222}Rn poses a health risk in both mining and non-mining regions. It is the second most prevalent cause of lung cancer in smokers and a significant contributor to lung cancer in non-smokers. Radon is mostly produced by rock and soils located in the planet's crust. Radon from subsurface sources can diffuse from rock into the water. Water containing radon seeps into the atmosphere when it is used for domestic reasons. The quality of the water is important for our daily activities since radon can enter the body by inhalation of radon-containing air or ingestion of radon-containing water [7,8].

The growing concern about radon (^{222}Rn) as a possible threat to the public's health has prompted calls for more research and an expansion of our understanding of radon in groundwater. Since groundwater is clean and easy to control than water from surface, it is used to supply drinkable water in many locations, necessitating the drilling of numerous wells and boreholes. Anthropogenic pollution has contaminated groundwater, and it also naturally includes several chemical components that can cause numerous health problems [9,10].

The radiation produced when radon enters the body and disintegrates there reserves power to separate molecules of water, creating radicals (free) like OH. Due to their high reactivity, free radicals can harm cells' DNA, which leads to cancer. The bronchial epithelium in the body receives the maximum radiation dosage in a radon-containing environment. However, the extrathoracic airways and the skin may also be exposed to significant doses.

Other organs, such as the bone (marrow) and kidney, may also get lower dosage. When someone takes in water with dissolved gass (radon), their stomach is exposed to it [11-13]. Since ^{222}Rn is a proven carcinogen, water with high quantities of it may pose a major hazard to people's health [14,15].

Using a RAD7 detector, Oni *et al.* (2016) [16] researched the measurement of radon concentration in drinking water in Ado-Ekiti, Ekiti State, Nigeria. With RAD7, groundwater samples from Ado-Ekiti were collected and evaluated. Oni *et al.* discovered that none of the water samples tested for radon concentration were suitable for household use or human consumption when the result was compared to 0.1 Bq/l established by SON. In another research, Groundwater samples from chosen boreholes and wells in Idah, Nigeria, were utilized to estimate the concentration of radon (^{222}Rn) using the Liquid Scintillation Counter (LSC) in an investigation conducted by Aruwa *et al.* (2017) [17]. Aruwa *et al.* found that 80% of the samples surpassed 11.1 Bq/l. All effective dose levels in Aruwa *et al.*'s study fell below the ICRP's 3-10 mSvy^{-1} intervention level recommendation.

This study assessed the level of concentration of radon in Nasarawa town of Nasarawa state, and also evaluating the effective dose through ingestion and inhilation in both adults and children as well as their future cancer risk.

Study Area

Nasarawa is a Local Government Area within Nasarawa State, Nigeria, and it is headquartered in the town of Nasarawa, positioned at 8°32'N 7°42'E. As of 2016, the population of this region was reported as 30,949, according to Ishaya *et al.* in 2018 [18]. This local government area spans a land area of 5,704 square kilometers and had a population of 189,835 at the time of the 2006 census. The postal code for this area is 962 (for more details on specific geographic coordinates, see Table 1,

Table 1: Sampling ID and G.P.S points of Awe

Sample Points	Latitude	Longitude
N1	8^{0}40′26.084″	7^{0}48′35.844″
N2	8^{0}39′28.446″	7^{0}48′4.452″
N3	8^{0}37′28.542″	7^{0}46′59.568″
N4	8^{0}36′37.344″	7^{0}46′2.448″
N5	8^{0}35′28.962″	7^{0}45′23.364″
N6	8^{0}34′43.521″	7^{0}44′27.132″
N7	8^{0}34′11.784″	7^{0}43′29.79″
N8	8^{0}32′50.784″	7^{0}41′27.44″
N9	8^{0}32′36.744″	7^{0}40′55.77″
N10	8^{0}32′30.876″	7^{0}45′23.364″

**N = Nasarawa*

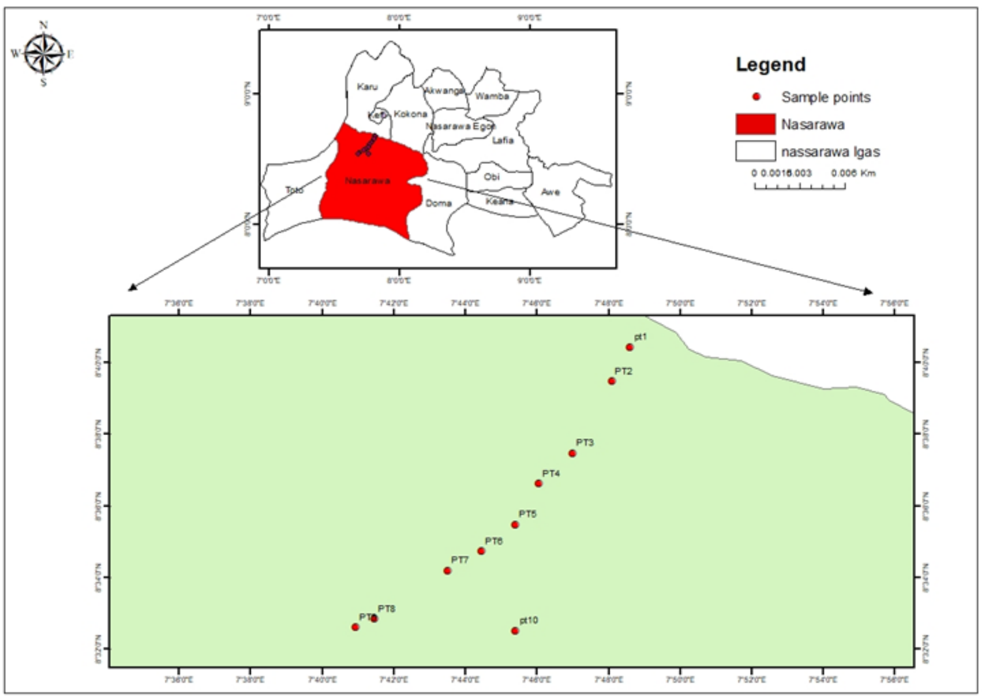

Figure 1: Study area map indicating sampling points

which provides GPS coordinates for sample codes). Furthermore, Figure 1 displays a visual representation of the research area's map.

Methodology

Ten (10) samples from borehole water were collected in plastic containers with covers. To prevent radon in the samples from being polluted, the containers were cleaned and rinsed with water (distilled).

To minimize the absoption of radon on container walls, samples of water were stored in a 20 ml of non-dilluted HNO_3 in liter of water. Each water sample was splited to ten mill (10 ml) portions and put into twenty mill (20 ml) vial of scintillation glass along ten mill (10 ml) cocktail of scintillation insta-gel, tightly closed, and then shaked for over two minutes to extract radon-222 in the phase of water to the scintillate (organic).

The analysis followed procedures outlined by ASTM (2019) [18], Garba *et al.* (2012) [19], and

Kamba *et al.* (2016) [20]. The prepared samples underwent evaluation utilizing a liquid scintillation counter (Tri-Carb-LSA1000) stationed at the Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. Calibration of the liquid scintillation counter occurred before the analysis employing the IAEA ^{226}Ra standard solution. Over the course of a 60-minute counting period, both the background and calibration solutions, as well as the sample solutions, were measured across the same spectral range. The count rates (counts.min-1) of the background and sample were recorded.

Given that ^{222}Rn and its short-lived daughters emit a cumulative total of 5 radioactive particles (3 α and 2 β) per disintegration of ^{222}Rn, their emissions were harnessed for the detection and quantification of ^{222}Rn in water due to the established secular equilibrium between ^{222}Rn and these decay daughters. This approach yields a total detection efficiency of 500%. To determine the ^{222}Rn activity concentrations in the water samples, various factors such as sample volume, total and background count rates, decay time (time elapsed between sample collection and counting), and detection efficiency were taken into account. Equation (1), as defined by ASTM (2019) [19], Garba *et al.* (2012) [20], Forte *et al.* (2016) [21], and Jacek *et al.* (2017) [22] was employed to calculate the ^{222}Rn concentration in the water samples.

This counter is gotten from Ahmadu Bello University's Centre for Energy Research and Training in Zaria, Nigeria and can be shown in Scheme 1.

Theory

The concentration (Bq/l), effectiveness dosage annually (mSv/y) to both children and adults, the extra aged risk to cancer were obtained by the use of Equations (1) to (4) and the outcome are compared with previous works and industries standards. Concentration of Radon-222 (Bq/l) was gotten from Equation (1) according to Aruwa *et al.* (2017) [19] and Jacek *et al.* (2017) [22] as follow:

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

According to Aruwa *et al.* (2017) [19] and Jacek *et al.* (2017) [22], Rn represents the ^{222}Rn concentration at the time of sample collection (Bq/l). NS stands for the total count rate of the sample (count/min.), NB indicates the background count rate (count/min.), t signifies the time that has elapsed between sample collection and counting (4320 mins), and λ denotes the decay factor of ^{222}Rn (1.26 x 10^{-4} min.$^{-1}$). The value 100 acts as a conversion factor from per 10 ml to per liter (l^{-1}). The value 60 serves as a conversion factor from minutes to seconds, The factor 5 (500%) represents the number of emissions per disintegration of ^{222}Rn (3 α and 2 β, assuming a 100% detection efficiency for each emission). The factor 0.964 signifies the fraction of ^{222}Rn in the cocktail within a vial of total capacity 22 ml, assuming the vial contains 10 ml of cocktail, 10 ml of water, and 2 ml of air.

Scheme 1: Counter for scintillation of liquid

According to Aruwa *et al.* (2017) [19] and Jacek *et al.* (2017) [22], Equation (2), as proposed by the United Nations Scientific Committee on the Effects of Atomic Radiation, can be used to determine the annual effective dose of ^{222}Rn through drinking water (λ_{ings}) in mSv/y:

λ_{ings} = K x G x C (2)

Where, C is the concentration of ^{222}Rn (Bq/l), G is the daily consumed water for both adults and children (4 L/d = 1460 L/y), K is the conversion coefficient concentration of ^{222}Rn (3.5 x 10^{-9} Sv/Bq) for ingestion. According to Equation (3), as employed by Adeola *et al.* (2017) [23] and Jibril *et al.* (2021) [24], the yearly effective dosage of ^{222}Rn via inhalation (λ_{inh}) in mSv/y is given as:

λ_{inh} = C × F× T × R × P (3)

C is the radon concentration (Bq/l), F is the factor for equilibrium (0.4), T is the indoor occupancy duration (7000 h/y), and R is the ratio of radon concentration in air to borehole water (10^{-4}) and P is the Dose conversion factor (9 nSv/h/(Bq/m^3) Using Equation (4) as reported by Bako *et al.* (2023), the increased lifetime cancer risk was calculated as follows:

$\alpha = \lambda \times \mu \times \eta \times 10^{-3}$ (4)

where, α is the extra risk of cancer for lifetime. In the determination of radon concentration in groundwater from Awe local government areas in Nasarawa, Nigeria, certain parameters are crucial in assessing the associated health risks. These parameters include the annual effective dose equivalent (λ), the average duration of life (μ) (approximately 70 years), and the Risk Factor (η) (0.05 Sv^{-1}) expressed as the fatal cancer risk per Sievert.

Results and Discussion

Results

Using liquid scintillation analysis (LSA), the information regarding the Rn-222 concentrations in the CPM of the groundwater samples has been determined. Totally, ten water samples were taken at random from various locations throughout Nasarawa, Nigeria. The ten water samples (from boreholes) were tested, and the results are presented in Table 2.

To assess the potential health risks associated with radon exposure, we translated the results from Table 2 into concentrations measured in Becquerels per liter (Bq/l). These concentrations were then utilized to calculate the annual effective dose for both adults and children, estimate the excess lifetime cancer risk, and compare our findings with industry norms and the research outcomes of other investigators. Tables (3) and (4) present the comprehensive results of these analyses.

Table 2: Concentrations of Radon-222 (Bq/l) in samples of water from Nasarawa

Sample ID	Rn ± SD (CPM)	Rn ± SD (Bq/l)
N1	113.90±7.604	21.620±1.599
N2	124.37±0.870	23.822±0.183
N3	139.35±0.863	26.972±0.181
N4	94.120±0.531	17.460±0.112
N5	136.13±0.735	26.295±0.154
N6	87.580±0.019	16.085±0.004
N7	85.580±0.788	15.664±0.166
N8	99.600±0.122	18.612±0.026
N9	96.450±0.830	17.950±0.175
N10	86.850±0.833	15.931±0.175
Mean	**106.39±1.320**	**19.393±0.254**
Min	**85.580±0.788**	**15.664±0.166**
Max	**139.35±0.863**	**26.972±0.181**
SE	**6.51038**	**1.369171**

**N = Nasarawa; Rn = Radon Concentration; SE = Standard Error; and SD = Standard Deviation*

Table 3: Ingested effective dosage annually and cancer risks of water samples from Nasarawa

Sample ID	λing ± SD (mSv/y)	λinh x10-5 ± SD (mSv/y)	αing x10-4 ± SD	αinh x10-7 ± SD
N1	0.110±0.0082	5.45±0.00	3.867±0.00	1.907±0.00
N2	0.122±0.0009	6.00±0.00	4.261±0.00	2.101±0.00
N3	0.138±0.0009	6.80±0.00	4.824±0.00	2.379±0.00
N4	0.089±0.0006	4.40±0.00	3.123±0.00	1.540±0.00
N5	0.134±0.0008	6.63±0.00	4.703±0.00	2.319±0.00
N6	0.082±0.0000	4.05±0.00	2.877±0.00	1.419±0.00
N7	0.080±0.0008	3.95±0.00	2.802±0.00	1.382±0.00
N8	0.095±0.0001	4.69±0.00	3.329±0.00	1.642±0.00
N9	0.092±0.0009	4.52±0.00	3.210±0.00	1.583±0.00
N10	0.081±0.0009	4.01±0.00	2.849±0.00	1.405±0.00
Mean	0.102±0.0014	5.05±0.000	3.585±0.00	1.768±0.00
Min	0.080±0.0008	3.95±0.00	2.802±0.00	1.382±0.00
Max	0.138±0.0009	6.80±0.00	4.824±0.00	2.379±0.00
SE	0.007013	0.345543	0.244885	0.12072844

**N = Nasarawa; λ_{ing} = Annual Effective Dose by Ingestion; λ_{inh} = Annual Effective Dose by Inhalation; α_{ing} = Excess Lifetime Cancer Risk due Ingestion; α_{inh} = Excess Lifetime Cancer Risk due Inhalation; and SE = Standard Error*

According to Table 2, the concentrations of Rn-222 in Nasarawa borehole water samples ranged from 15.664±0.166 to 26.972±0.181 Bq/l (N7 to N3), with a mean of 19.393**±**0.254 Bq/l and standard error of 1.369171 Bq/l.

Effective Dose per Year of Ingestion

The computation of annual effective dosage was carried out using Equation 2, taking into account the data provided in Table 2. The obtained results have been presented in Table 3.

The determination of the annual effective dose by ingestion was performed for the Nasarawa area using the relevant data from Table 3 and the corresponding measured radon concentrations. The results indicate that, in the case of ingestion, the annual effective dose by ingestion from borehole water samples ranged from 0.080±0.0008 to 0.138±0.0009 mSv/y (N7 to N3), with a mean value of 0.102±0.0014 mSv/y and standard error of 0.007013 mSv/y.

The annual effective dose by inhalation for the Nasarawa area was estimated based on the measured radon concentrations, as also presented in Table 3. The analysis revealed that for borehole water samples, the annual effective dose by inhalation ranged from 3.95 $x10^{-5}$±0.00 to 6.80 $x10^{-5}$±0.000 mSv/y (N7 to N3) with a mean value of 5.05 $x10^{-5}$±0.000 mSv/y and standard error of 0.345543 $x10^{-5}$ mSv/y. Based on Table 3, excess lifetime cancer risks due to ingestion for borehole water were found to range from 2.802 $x10^{-4}$±0.000 to 4.824 $x10^{-4}$±0.000 (N7 to N3) with a mean of 3.585 $x10^{-4}$±0.000 and standard error of 0.244885 $x10^{-4}$. Lastly, according to Table 3, excess lifetime cancer risks du to inhalation for borehole water were found to range from 1.382 $x10^{-7}$±0.000 to 2.379 $x10^{-7}$±0.000 (N7 to N3) with a mean of 1.768 $x10^{-7}$±0.000 and standard error of 0.12072844 $x10^{-7}$.

Comparison to Other Researchers and the Standard

The findings of this investigation were contrasted with safety requirements and other studies (Tables 4 to 6)

Table 4: Comparison of concentration of radon of groundwater samples for the current work with regulatory bodies

Regulatory Bodies	Concentration of Radon (Bq/l)	Sources
United Nation Scientific Committee on the Effect of Atomic Radiation (UNSCEAR)	22	[25]
United States Environmental Protection Agency (USEPA)	11.1	[26]
European Commission for Drinking Water Purposes (ECDWP)	100	[27]
World Average (WA)	10	[28]
Standard Organisation of Nigeria (SON)	11.1	[29]
Nasarawa	19.393	Present Study

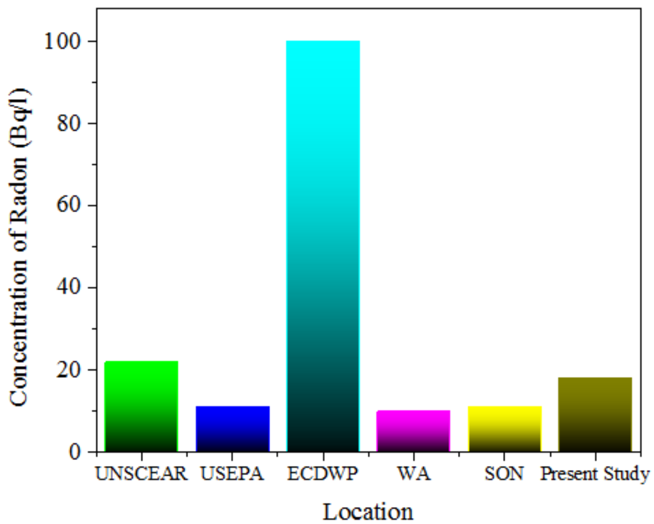

Figure 2: Comparison of concentration of radon of groundwater samples for the current work with regulatory bodies

According to Table 4 and Figure 2, the radon concentration values in this investigation were found to be a bit higher than the safe limits prescribed by authoritative bodies such as the, United State Environmental Protection Agency (USEPA), global average (WA), and Standard Organization of Nigeria. Even though found lower than that prescribed by European Commission for Drinking Water Purposes (ECDWP) and United Nation Scientific Committee on the Effect of Atomic Radiation (UNSCEAR).

Table 5: Comparison of concentration of radon of groundwater samples for the current work with other places in Nigeria

Location	Radon Concentration (Bq/l)	Reference
Ekiti State	13.59	[30]
Kogi State	13.77	[31]
Kaduna State	11.80	[32]
Ondo State	35.54	[33]
Present Study	19.393	Present Study

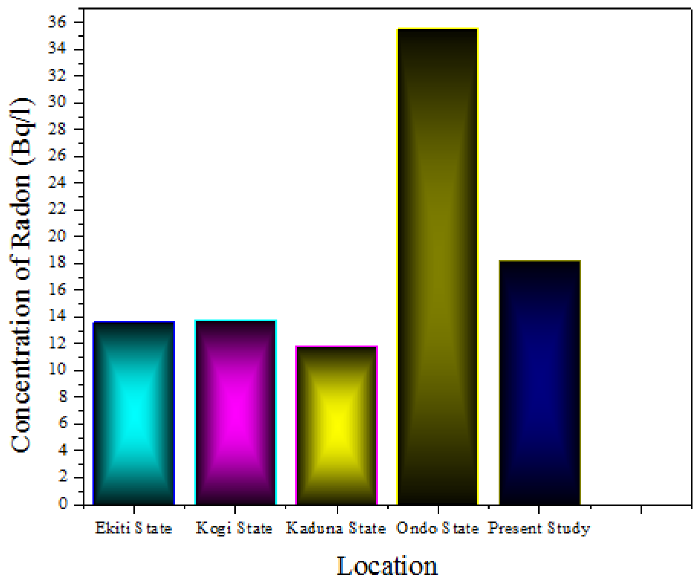

Figure 3: The comparison of radon concentration of the present study and other parts of Nigeria

From Table 5 and Figure 3, it can be shown that the radon levels in the groundwater samples from the current study are higher than those from Ado-Ekiti in Ekiti State, Zaria in Kaduna State, Idah in Kogi State but lower than that of Ondo State.

Table 6: Comparison of radon concentration of groundwater samples from Nasarawa South with other parts of the world

Location	Radon Concentration (Bq/l)	Reference
India	2.63	[34]
Turkey	9.28	[35]
Romania	15.40	[36]
Lebanon (many locations)	11.30	[37]
United States of America	5.20	[38]
Present Study	19.393	Present Study

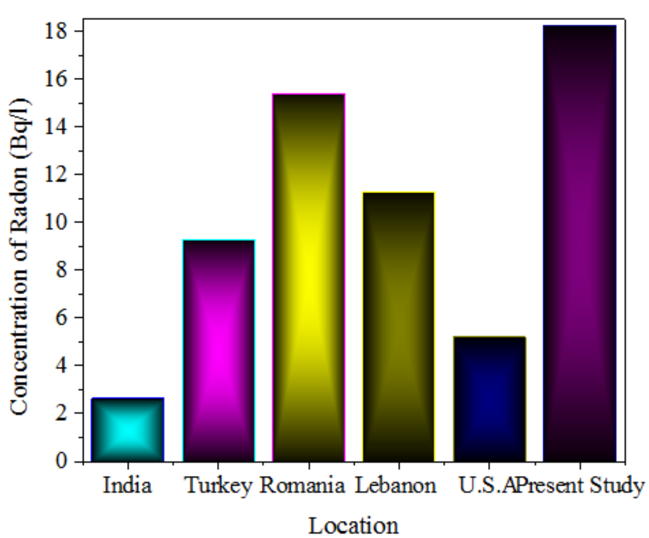

Figure 4: The comparison of radon concentration of the present study and other parts of the world.

Based on the findings presented in Table 6 and Figure 4, the radon concentrations observed in the groundwater samples from this study were comparatively lower than those reported in countries such as Algeria and specific areas in Northern Venezuela, Romania, Jordan, the outer Himalayas, Finland, Turkey, Lebanon, and United States and india.

Discussion

According to the work's findings, Nasarawa had a mean radon content of 19.393±0.254 Bq/l. This value rose above the benchmarks of 11.1 Bq/l set by the Standard Organization of Nigeria (SON) and the United States Environmental Protection Agency, the value was also above the world average limit of 10 Bq/l. The value fell below 100 Bq/l prescribed by the European Union Commission for Drinking Water Purposes and 22 Bq/l set by the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), The matching measured radon concentrations from Nasarawa resulted in a mean annual effective exposure by consumption and breathing (Table 3) of 0.102±0.0014 mSv/y and $5.05x10^{-5}$±0.000 mSv/y, respectively.

The Standard Organization of Nigeria (SON) has endorsed the World Health Organization's (WHO) recommended reference level of 0.1 mSv/y for the intake of radionuclides in water. In the case of present study conducted in Nasarawa, the corresponding observed radon concentrations yielded a mean annual effective by ingestion was found greater than than the above mentioned standards while that of inhalation dose lower than the above mentioned standards. In the case of ingestion, the borehole water in the area is adviced not safe for the public, while in the case of inhalation, the borehole water in the area is adviced as safe for the general public. The extra risk of cancer over lifetime from borehole and well water samples by ingestion and inhalation in Nasarawa was 3.585×10^{-4}±0.000 and 1.768×10^{-7} ±0.000. Water samples from Nasarawa in Nasarawa Local Governments had excess lifetime cancer risk values for ingestion that were slightly higher than the global average of 2.9×10^{-4} while that of inhalation were far lower than the global average of 2.9×10^{-4} [32].

Conclusion

According to the findings, the groundwater samples used in the current investigation had radon concentrations beyond the maximum limit of 11.1 Bq/l reported by US-EPA and agreed by SON, making them non-suitable for utilization at home by human. This spike in radon concentration of the study area may be attributed to the illegal mining activities going on across the bushes round the area. If major restriction could be placed on the local miners, the magnitude of radionuclide excavation from beneath the soil to the top surface of the soil may be reduced to the bearest minimal, which may in turn go a long way in reducing the quantity of radon gas coming from those excavated radionuclides to people's environment. Thus, the future cancer risk can be minimize. As a result, the information from this study could be applied to the study area because it was the first to determine the presence of radon in the groundwater there in the area. To fully cover the zone, further research involving additional boreholes and wells in the study area should be conducted. As radon concentrations in ground-water varries with time as a result of dilution from rainwater, more examination may be carried out in the dry and rainy seasons.

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