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Annual Effective Dose due to Ingestion and Inhalation of ^{222}Rn in Drinking Water of Daupe Village in Tafa Local Government Area of Niger State, Nigeria

*Bashir, M. and Abdullahi, S. G.

Department of Physics, Ibrahim Badamasi Babangida University, Lapai. Nigeria

*Corresponding author's email: mbashir@ibbu.edu.ng; bashirmunirat@yahoo.com

ABSTRACT

Radon is one of the sources of nuclear contamination in water and the largest contributor of the total radiation received by the general public from natural radioactive sources. In this research, the concentrations of ^{222} Rn were investigated from six (6) wells (WW) and four (4) borehole (BW) water samples collected within Daupe village, Tafa Local Government area using Liquid Scintillation Counter (LSC). The radon concentration in WW varied between 3.42 Bq/L and 8.93 Bq/L with a mean value of 5.11 Bq/L. The C_{Rn} in BW ranged from 3.35 Bq/L to 7.53 Bq/L with a mean of 5.79 Bq/L. The concentration of radon in all the samples were below the recommended safe level of 11 Bq/L proposed by United States Environmental Protection Agency (USEPA). The mean values of the annual effective doses received by stomach due to ingestion of ^{222}Rn (AED_{ing}) in WW are 0.024 mSv/yr, 0.023 mSv/yr, 0.06 mSv/yr for adults, children and infants respectively. Whereas AED_{ing} from BW were found to be 0.042 mSv/yr, 0.041 mSv/yr and 0.105 mSv/yr for adults, children and infants in sequential order. The AED_{ing} for adult and children are below the recommended safe limit of 0.1 mSv/yr set by WHO for intake of radionuclide in water. Whereas, 40% of the AED_{ing} for infant are above the recommended safe level of 0.1 mSv/yr for intake of radionuclide in water. The results also showed that the AED_{ing} for infants receive higher doses compared to that of children and adults. The annual effective dose received by lung due to inhalation of ^{222}Rn (AED_{inh}) from WW and BW are 0.013 mSv/yr and 0.015 mSv/yr respectively. The mean excess lifetime cancer risk (ELCR) for WW and BW are 0.176×10^{-3} and 0.199×10^{-3} respectively, which are below the world mean value of 0.29×10^{-3}. The probability of cancer being induced due to ingestion and inhalation of ^{222}Rn from the sampled water is insignificant. It is however recommended that the inhabitants of Daupe Village should boil their water before consumption so as to keep their exposure due to ingestion of ^{222}Rn as low as reasonably achievable (ALARA).

Keywords:
^{222}Rn,
Liquid Scintillation Counter (LSC),
Annual effective dose (AED).

INTRODUCTION

Water is a fundamental element for human existence and well-being in any location. Ensuring the quality of drinking water is of utmost importance to safeguard public health as it is used for drinking, domestic and agricultural purposes. Potential presence of radioactive isotopes in water is a significant concern in water quality assessment concentrations (Assessment, 2005). Drinking water can contain radioactive isotope such as uranium, thorium, radium, and radon from naturally occurring radioactive materials that dissolve from the soil it passes over or man-made activities such as industrial activities, mining and nuclear power plants (Joyce, et al., 2017, Voulvoulis, 2018, Thomas, 2019). Airborne radioactive materials from both naturally occurring materials and man-made can also be wash down into the ground by rain and snow (Isikwue et al., 2009, Naja and Volesky, 2017). These radioactive isotopes emit ionizing radiation in which an elevated concentration or ingestion over time can pose health risks such as cancer (Assessment, 2005, Zakariya and Kahn, 2014, Yauseyenka et al., 2020).

In recent years, there has been growing awareness about the need for comprehensive monitoring of water sources for radioactive contaminants as the quality of drinking water is directly related to the health of residents (Dinh et al., 2011, Bashir et al., 2023). Daupe Village, located in the Tafa Local Government area, is an area of particular interest due to its proximity to potential sources of radioactive isotopes, from mining activities and geological formations that may contain natural radioactive materials. Additionally, the village relies heavily on groundwater sources for drinking water, which might be more vulnerable to contamination. This research investigates the potential occurrence of ^{222}Rn and its level in the drinking water sources of Daupe Village, Tafa Local Government area of Niger state, Nigeria.

MATERIALS AND METHODS

Six (6) wells water (WW) and four (4) boreholes water (BW) were collected from Daupe Village. Each sample was collected using sterile container (1litre) rinsed with respective water to prevent contamination. The samples were labelled taking note of date and time of sample collection. 10 ml of each sample was added into a vial containing 10 ml of toluene-based cocktail (scintillator) using a hypodermic syringe. The vials were tightly capped and shaken vigorously for three (3) minutes to extract ^{222}Rn in water phase into the organic scintillator. A blank sample for the background was prepared the same way as the sample using a distilled water that has been kept in a glass bottle for at least 21 days. The prepared samples were allowed to stand undisturbed for at least three (3) hours for ^{222}Rn and its alpha decay products to attain equilibrium before counting.

The prepared samples and the background (blank) were each accounted for 1200 seconds using the Liquid Scintillation Counter (Tri- Card LSA 1000) at the Center for Energy Research and Training (CERT), Ahmadu Bello University Zaria, Kaduna, Nigeria.

The activity concentration of ^{222}Rn in the background and each sample were calculated using the equation 1:

$$C_{Rn}(Bq/L) = \frac{(S-B)e^{\lambda t}}{CF \times V} \quad (1)$$

Where C_{Rn} is the concentration of ^{222}Rn in sampled water in Bq/L, S is the sample count in count per second (cps), B is the background count in cps, t is the time elapsed between sampling to counting in second (s), $\boldsymbol{\lambda}$ is decay constant (2.1 × 10^{-6} per second), CF is the calibration factor and V is the sample volume used in liters.

The corresponding annual effective doses to human stomach due to direct ingestion of ^{222}Rn (AED_{ing}) in the water samples was computed from the equation 2 (Ryan et al., 2003, Nandakumaran and Vinayachandran, 2020, Isinkaye et al., 2021):

$$AED_{ing}(mSv/yr) = C_{Rn} \times DC_{ing} \times WC \quad (2)$$

Where DC_{ing} is the dose coefficient in mSv/Bq for ingestion of water and WC the annual water consumption in L/yr. The dose coefficient DC_{ing} is 10^{-5} mSv/Bq, 2 x 10^{-5} mSv/Bq and 7 x 10^{-5} mSv/Bq for adults, children and infants respectively (UNSCEAR, 2000). The water consumption rate WC is 2 L/day (730 L/yr), 0.96 L/day (350 L/yr) and 0.71 L/day (260 L/yr) for adult, children and infant respectively (IAEA, 1996).

The annual effective dose due to inhalation of radon in water was calculated from the equation 3 (WHO, 2011, Dugal et al., 2020):

$$AED_{inh}(mSv/yr) = C_{Rn} \times DC_{inh} \times 0F \times EF \times R_{RAW} \quad (3)$$

where DC_{inh} is the dose coefficient for inhalation (9× 10^{-9} (Sv.m^3)/(Bq.h)), *OF* the average global indoor occupancy factor (7000 h/yr), *EF* the equilibrium factor between radon and its daughters for indoor environment (0.4) and R_{RAW} is the ratio of radon-in-air to radon-in-water (10^{-4}).

The annual effective dose to the whole body (AED_{tot}) is the combination of the annual effective dose to the stomach (ingestion) and lung (inhalation) calculated using equation 4.

$$AED_{tot}\ (mSv/yr) = AED_{ing} + AED_{inh} \quad (4)$$

Excess lifetime cancer risk (ELCR), which shows the extra risk of occurrence of cancer due to exposure to radon in water community was computed using the Equation 5 (Divya and Prakash, 2019, Ndubisi et al., 2021):

$$ELCR = AED_{tot} \times LD \times RF \quad (5)$$

Where LD is the lifetime duration of 70 years and RF is the risk factor taken to be 0.05 /Sv for stochastic effects (ICRP, 1991).

RESULTS AND DISCUSSION

The radon concentration (C_{Rn}) values in the measured well and borehole water samples are presented in Table 1. The radon concentration in wells water varied between 3.42 Bq/L and 8.93 Bq/L with a mean value of 5.11 Bq/L. The C_{Rn} in BW ranged from 3.35 Bq/L to 7.53 Bq/L with a mean of 5.79 Bq/L. The concentration of radon in all the sampled water were below the recommended safe level of 11.1 Bq/L proposed by United States Environmental Protection Agency (USEPA, 2017) and world average value of 10 Bq/L set by WHO, (2008).

Table 2 gives the mean concentration of radon in well and borehole waters within Nigeria. The mean C_{Rn} obtained from wells water in the present study is higher than that reported by Kalip et al. (2018) (1.80 Bq/L) and lower than that reported by Kolo et al. (2023) (10.2 Bq/L), Shu'abu et al. (2021) (38.3 Bq/L), Isinkaye and Ajoboye (2017) (19.5 Bq/L) and Garba et al. (2012) (7.18 Bq/L). The mean C_{Rn} from boreholes water in the present study is lower compared to Kolo et al. (2023) (14.3 Bq/L), Jibril et al (2021) (14.9 Bq/L), Isinkaye and Ajoboye (2017) (30.9 Bq/L) and Garba et al. (2012)

(7.41 Bq/L). However, the C_{Rn} from borehole water from this study is higher compared to that reported by Oni and Adagunodo (2019) (1.86 Bq/L) and Kalip et al. (2018) (0.57 Bq/L).

Table 1: Concentrations of ^{222}Rn (C_{Rn}) and their corresponding Annual Effective Doses due to ingestion of ^{222}Rn in the water samples (AED_{ing})

S/N	Type of Sample	Sample Code	C_{Rn} (Bq/L)	AED_{ing} (mSv/yr)		
				Adult	**Children**	**Infant**
1	Well water	WW1	8.93	0.065	0.063	0.163
2	Well water	WW2	3.44	0.025	0.024	0.063
3	Well water	WW3	7.80	0.057	0.055	0.142
4	Well water	WW4	3.44	0.025	0.024	0.063
5	Well water	WW5	3.65	0.027	0.026	0.066
6	Well water	WW6	3.42	0.025	0.024	0.062
		Min.	**3.42**	**0.025**	**0.024**	**0.062**
		Max.	**8.93**	**0.065**	**0.063**	**0.163**
		Mean	**5.11**	**0.037**	**0.036**	**0.093**
7	Borehole water	BW1	7.53	0.055	0.053	0.137
8	Borehole water	BW2	7.49	0.055	0.052	0.136
9	Borehole water	BW3	4.78	0.035	0.033	0.087
10	Borehole water	BW4	3.35	0.024	0.023	0.061
		Min.	**3.35**	**0.024**	**0.023**	**0.061**
		Max.	**7.53**	**0.055**	**0.053**	**0.137**
		Mean	**5.79**	**0.042**	**0.041**	**0.105**

Table 2: The mean concentration of radon (C_{Rn}) in well and borehole water within Nigeria

Location	Water sources	C_{Rn} (Bq/L)	Reference
Gadau, Bauchi State, Nigeria	Well	38.3	Shu'abu et al. (2021)
Sabon Gari, Kaduna, Nigeria	Borehole	14.9	Jibril et al. (2021)
Zaria, Nigeria	Well	7.18	Garba et al. (2012)
	Borehole	7.41	
Kaduna, Nigeria	Borehole	0.57	Kalip et al. (2018)
	Well	1.80	
Bosso, north-central Nigeria	Open well	10.2	Kolo et al. (2023)
	Borehole	14.3	
Ekiti state, Nigeria	Well	19.5	Isinkaye and Ajoboye (2017)
	Borehole	30.9	
Ogbomosho, south-west, Nigeria	Borehole	1.86	Oni and Adagunodo (2019)
Daupe, Niger State. Nigeria	Well	5.11	Present study
	Borehole	5.79	

The estimated annual effective dose to the stomach due to ingestion of ^{222}Rn (AED_{ing}) from well and borehole waters for adult, children and infant are given in Table 1. For infant, the annual effective doses due to ingestion of ^{222}Rn from the six well water samples ranged between 0.062 mSv/yr and 0.163 mSv/yr with a mean of 0.093 mSv/yr. While the AED_{ing} from the four borehole water samples ranged from 0.061 mSv/yr to 0.137 mSv/yr with a mean of 0.105 mSv/yr. As observed from Figure 1, 40 % of the AED_{ing} for infant are above the 0.1 mSv/yr recommended safe level for intake of radionuclide in water as set by WHO (2008).

For children, the AED_{ing} from the sampled wells water varied from 0.024 mSv/yr to 0.063 mSv/yr with a mean of 0.036 mSv/yr. Whereas, the AED_{ing} from the sampled boreholes water ranged between 0.023 mSv/yr and 0.053 mSv/yr with a mean of 0.041 mSv/yr. Figure 1 shows that the AED_{ing} for children from consumption of both well and borehole waters are below the recommended safe limit of 0.1 mSv/yr set by WHO (2008).

For adult, the annual effective dose received by stomach due to ingestion of ^{222}Rn from wells water ranged from 0.025 mSv/yr to 0.065 mSv/yr with a mean of 0.037 mSv/yr. Whereas the AED_{ing} from boreholes water ranged between 0.024 mSv/yr and 0.055 mSv/yr with a mean of 0.042 mSv/yr. Figure 1 showed that the AED_{ing} for infants receive higher doses compared to that of children and adults.

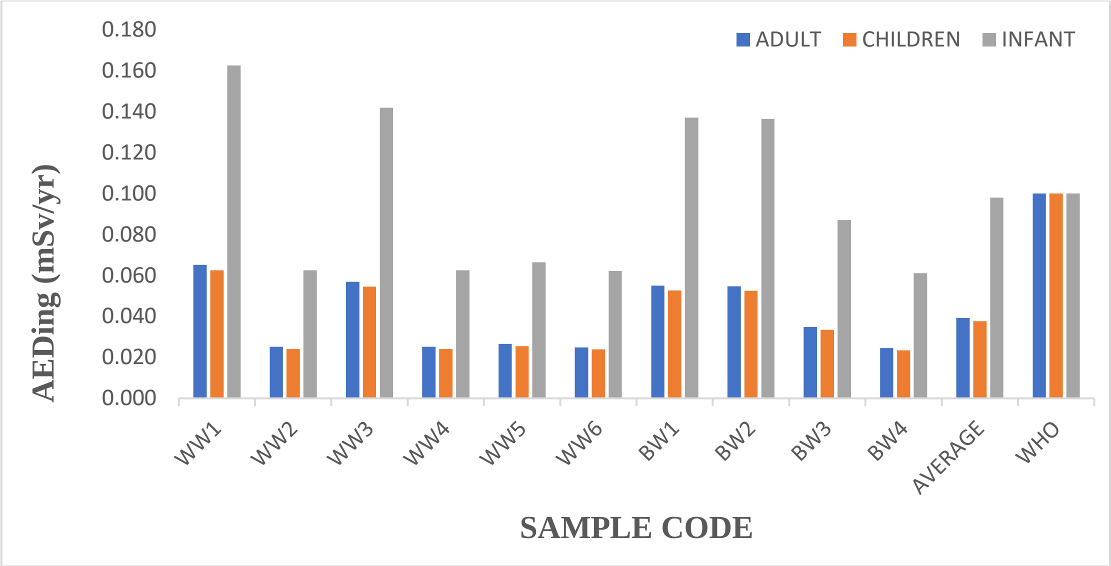

Figure 1: The annual effective dose due to ingestion of ^{222}Rn (AEDing) from wells and boreholes water for adult, children and infant, and the recommended safe limit

The average effective dose incurred through inhalation can be enhanced due to consistent liberation of radon gas from continuous domestic utilization of water into the indoor air due to its insolubility in water (Wu et al., 2014, Nandakumaran and Vinayachandran, 2020). The annual effective dose received by lung due to inhalation of ^{222}Rn (AED_{inh}) from well and borehole waters ranged from 0.009 mSv/yr to 0.023 mSv/yr, and 0.008 mSv/yr to 0.019 mSv/yr respectively (see Table 3). The annual effective dose to the whole-body (AED_{tot}) and the excess lifetime cancer risk (ELCR) values are presented in Table 3. The annual effective dose to the whole-body ranged between 0.034 mSv/yr and 0.088 mSv/yr with a mean of 0.050 mSv/yr for consumption of well water. While the AED_{tot} ranged from 0.033 mSv/yr to 0.074 mSv/yr with a mean of 0.057 mSv/yr for borehole water consumption. The mean ELCR for WW and BW are 0.176×10^{-3} and 0.199×10^{-3}in sequential order. The mean ELCR from this work is below the world mean value of 0.29×10^{-3}, which means the likelihood of inducing extra cancer in the inhabitant consuming the sampled water is low.

Table 3: The annual effective doses due to ingestion (AEDing) and inhalation (AEDinh) of sampled water for adult, the annual effective dose to the whole body and the excess lifetime cancer risk (ELCR)

Sample code	AED_{ing} (mSv/yr)	AED_{inh} (mSv/yr)	AED_{tot} (mSv/yr)	ELCR $\times 10^{-3}$
WW1	0.065	0.023	0.088	0.307
WW2	0.025	0.009	0.034	0.118
WW3	0.057	0.020	0.077	0.268
WW4	0.025	0.009	0.034	0.118
WW5	0.027	0.009	0.036	0.125
WW6	0.025	0.009	0.034	0.117
Min	**0.025**	**0.009**	**0.034**	**0.117**
Max	**0.065**	**0.023**	**0.088**	**0.307**
Mean	**0.037**	**0.013**	**0.050**	**0.176**
BW1	0.055	0.019	0.074	0.259
BW2	0.055	0.019	0.074	0.258
BW3	0.035	0.012	0.047	0.164
BW4	0.024	0.008	0.033	0.115
Min	**0.024**	**0.008**	**0.033**	**0.115**
Max	**0.055**	**0.019**	**0.074**	**0.259**
Mean	**5.79**	**0.015**	**0.057**	**0.199**

CONCLUSION

A total of ten (10) water samples which include six (6) wells and four (4) boreholes water samples collected were measured for radon concentration using liquid scintillation counter. The mean concentration of radon (C_{Rn}) value in wells (WW) and boreholes (BW) water are 5.11 Bq/L and 5.79 Bq/L, respectively. The radon concentration values in all the sampled water were below the recommended safe level of 11.1 Bq/L proposed by United States Environmental Protection Agency (USEPA) and world average value of 10 Bq/L set by World Health Organization (WHO). The mean values of the annual effective doses received by stomach due to ingestion of ^{222}Rn (AED_{ing}) in WW are 0.024 mSv/yr, 0.023 mSv/yr, 0.06 mSv/yr for adults, children and infants respectively. Whereas AED_{ing} due to the intake of ^{222}Rn from BW were found to be 0.042 mSv/yr, 0.041 mSv/yr and 0.105 mSv/yr for adults, children and infants in sequential order. The AED_{ing} for adult and children are below the recommended safe limit of 0.1 mSv/yr set by WHO for intake of radionuclide in water. Whereas, 40% of the AED_{ing} for infant are above the recommended safe level of 0.1 mSv/yr for intake of radionuclide in water. The results also showed that the AED_{ing} for infants receive higher doses compared to that of children and adults. The annual effective dose received by lung due to inhalation of ^{222}Rn (AED_{inh}) from WW and BW are 0.013 mSv/yr and 0.015 mSv/yr respectively. The mean excess lifetime cancer risk (ELCR) for WW and BW are 0.176×10^{-3} and 0.199×10^{-3}, which is below the world mean value of 0.29×10^{-3}. The probability of extra cancer being induced due to ingestion and inhalation of the water is insignificant. However, inhabitants of such area are advised to boil the water if they must use it for consumption so as to degas radon thereby keeping the concentration of ^{222}Rn in the water as low as reasonably achievable.

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