

Studies on Radon Concentration in Underground Water and the Associated Health Impact Around Bauchi Metropolis, Nigeria



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ABSTRACT

Health risks of Radon in water is a global concern. Radon is the major radioactive carcinogen in water causing lung cancer among non-smokers. Radon activity concentration in underground water samples from Bauchi metropolis and their possible health risk was assessed. A total of 20 groundwater samples were analyzed using by liquid scintillation counter. The results show that the highest concentration of 25.17 Bq /L was found in sample BH1 (Hand pump borehole) and the lowest concentration of 8.35 Bq/L was in sample W9 (Hand-dug well), with a mean value 14.63 Bq /L, which is clearly above USEPA safety threshold of 11.1 Bq /L. The cumulative effective dose of ingestion and inhalation varied from 1.98 to 5.75 $\mu\text{Sv/y}$ with mean value of 3.76 $\mu\text{Sv/y}$. The total annual effective dose obtained (3.76 $\mu\text{Sv/y}$) is within the recommended safe limit of 0.1mSv/y provided by WHO (2017). The results of this study could support the efforts of authorities and regulators who are responsible for controlling and strategizing to ensure public safety against radon exposures.

Keywords:

Radon,
Annual effective dose,
Underground water,
Scintillation counter.

INTRODUCTION

The main sources of naturally occurring radioactive materials (NORMs) in our surroundings are cosmic rays from space and radioactive elements present within the Earth's crust. The key NORMs ^{238}U , ^{232}Th , and ^{40}K are distributed widely in the environment, including in soil, groundwater, bedrock, and geological formations, with their concentrations influenced by local geological conditions (Malain et al., 2012; Shuaibu et al., 2017). Radionuclides transform spontaneously into other forms, emitting ionizing radiation in the process. Some of these daughter radionuclides are stable, while others continue to decay until stability is achieved. This ongoing decay process serves as a source of radiation exposure both inside and outside the human body. Exposure to these radiations has the potential to cause damage to sensitive cellular structures in the lungs and other vital organs of living organisms (Duggal et al., 2013). Dissolved radon from secondary sources like groundwater and others from natural gas, building materials, and natural accumulation is harmful to humans when inhaled or ingested (Alter & Oswald, 1988).

Groundwater originates from geologic formations known as aquifers, and drinking water derived from these

sources may contain radon due to the presence of radium in basement rocks and surrounding mineral- or phosphate-rich soils. The radon concentrations in surface water are generally low due to air agitation and release into the atmosphere, compared with groundwater that is associated with granite, sand, and sedimentary formations (Alomari et al., 2019). Radon is an imperceptible, naturally occurring radioactive gas emitting alpha radiation. It arises from the decay of ^{226}Ra , a long-lived radionuclide with a 1600-year half-life, within the ^{238}U radioactive decay series. ^{222}Rn decays emit 5.49 MeV alpha particles, producing a series of radionuclides, primarily ^{214}Po and ^{218}Po , which contribute more than 90% of the total radiation dose associated with radon exposure (Mehra & Bala, 2014).

Generally, surface water do not contain significant level of radon with activities below 4 Bq/L however appreciable level are observed in groundwater especially when it pass through granite rocks (Ali et al., 2010). Monitoring the radiological health hazards associated with radon is crucial for protecting public health, particularly with respect to drinking water. Drinking water should be free from contaminants that may pose potential risks to users. From a radiological safety

perspective, it is essential to monitor radon levels in groundwater and assess the associated health risks from both inhalation and ingestion. This study serves as an initial investigation to provide baseline data on radon concentrations in groundwater and emphasizes the necessity for more comprehensive analyses of different environmental media in the region. This research aims to examine radon concentrations in underground water within Bauchi metropolis, serving as a radiological assessment to help enhance public health standards.

MATERIALS AND METHODS

The section explains the research approach adopted to accomplish the study's objectives. It outlines the geographical features of the study area. The procedures for sample collection, preparation, and analysis follow accepted standards. The present research mainly focuses

on the measuring ^{222}Rn concentration in water using liquid scintillation counter.

Study Area

The research area is located within Bauchi Local Government Area, situated in the southern part of Bauchi State, Nigeria, at coordinates $10^{\circ}00'\text{N}$ and $9^{\circ}30'\text{E}$. Toro covers an area of $5,918\text{ km}^2$ and is home to a dense population of 500,000. The region experiences two major seasons—dry and rainy—with an average temperature of 31.23°C . The study area is underlain by rocks of the Precambrian crystalline Basement Complex of Nigeria. The major lithologic units are: the Bauchite (Fayalite-quartz-monzonite); the biotite hornblende-granite; the porphyroblastic biotite-granites, granulites and undifferentiated migmatites and gneisses (Fig. 1) In most part of the area, these rocks are covered by the unconsolidated weathered overburden materials consisting of laterites, clays, sands and gravels.

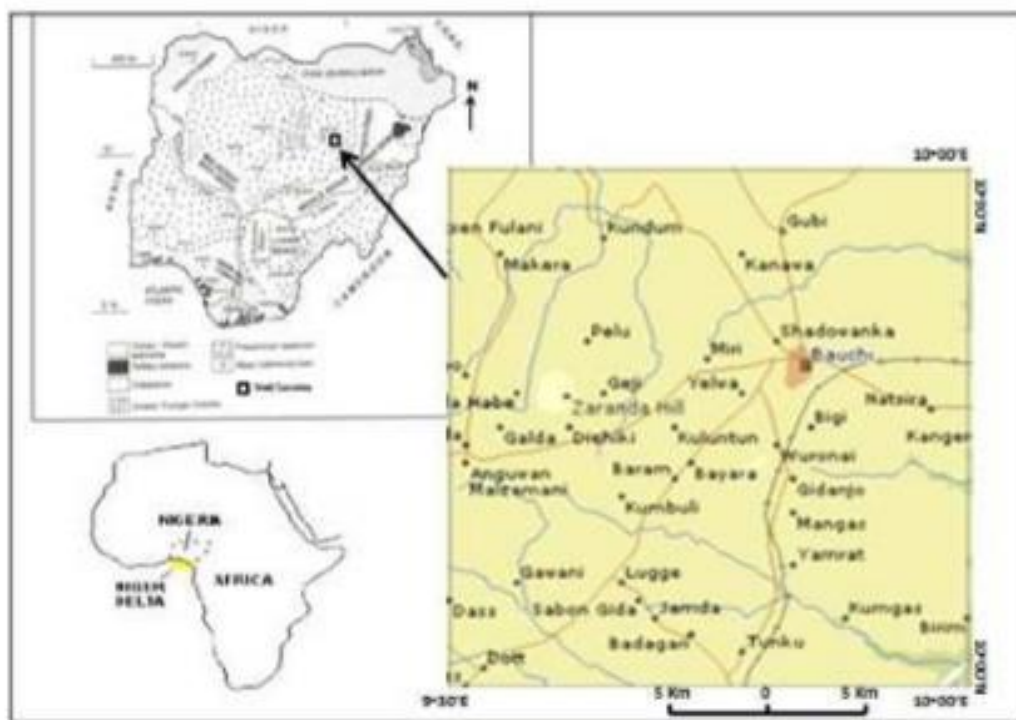


Figure 1: Map Showing Location of the Study Area (In-set: Geological map of Nigeria and Africa)

Materials

Below is the list of materials that were used in this research as described by the American Society for Testing and Materials (Abba et al., 2020). Plastic sample bottles (100 ml) were used for sample collection.

- i. Disposable hypodermic syringe (20, 10, and 2 ml capacity) with 38 mm (1in) hypodermic needle.
- ii. Surgical globe.
- iii. Water for injection and distill water.
- iv. Scintillation vial (20 ml capacity) with polyethylene inner seal cap liners.
- v. Scintillation cocktail.
- vi. Indelible ink and masking tape.
- vii. Liquid scintillation counter (Packard Tri-Carb LSA 1000TR).






AGE	FORMATION	COMPLEX	LITHOLOGY	DESCRIPTION UNIT
PRECAMBRIAN	BASEMENT COMPLEX	PAN AFRICAN OLDER GRANITES		Alluvium
				Fayalite-Quartz-Monzonite (Bauchite)
				Biotite-Hornblende-Granite
				Quartz-Hyperstene-Diorite
				Undifferentiated Migmatite & Gnesses

Figure 2: Showing Sediments Formed from the Weathered Basement Rocks in the Study Area

Sample Collection

A total of twenty (20) borehole and well water samples were collected from different wards in the study area. 750 ml plastic pop cola bottles were used as sample containers. The sample containers will be washed and rinsed with ionized water before the collection of the water samples. The sample containers were filled to the brim to prevent CO₂ from being trapped and dissolved in water (which may likely affect the chemical content) and will be tightly closed immediately to prevent Radon gas from escaping during transportation to the laboratory. Masking tape was used to mark and label all the collected samples. GPS metre was used to measure the coordinate (latitude and longitude) of the sample collection points. All the collected samples were transported immediately to the Center for Energy Research and Training (CERT) Zaria, for preparation and analysis.

Sample Preparation

10 ml each of the samples were added into a scintillation vial containing 10 ml of the insta-gel scintillation cocktail. Having been sealed tightly, the vials were then shaken for more than two minutes to extract ²²²Rn in water phase into the organic scintillator (Balogun & Medina, 2024).

Sample Analysis

The prepared samples were analyzed using liquid scintillation counter (Tri-Carb-LSA1000) located at the Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. The samples

were analyzed after they were allowed to stay for three hours after preparation, to allow for radioactive equilibrium between ²²²Rn and its daughter progeny to be established.

Calibration of the liquid scintillation counter was made prior to the analysis using IAEA ²²⁶Ra standard solution. For the calibration, the ²²⁶Ra standard samples were counted for 60 min. For background, background count measurements were also made for same period (60 min). The ²²²Rn activity concentration was calculated using the equation

$$Rn \text{ (Bq/L)} = \frac{100 \times (Rn \times RO) \exp(\lambda t)}{60 \times 5 \times 0.964} \tag{1}$$

where Rn (Bq/L) is ²²²Rn concentration in Bq/L. Rn is the sample total count rate (count min⁻¹), RO is the background count rate (count min⁻¹), t is the elapsed time between sample collection and counting (4320 min. (3days), λ is ²²²Rn decay factor (1.26 × 10⁻⁴ min⁻¹), 100 is a conversion factor from per ml to per liter (L⁻¹), 5 is the number of emissions per count; 60 is conversion factor from min. to s. (min⁻¹ to s) and 0.964 is the fraction of ²²²Rn in the cocktail in a vial of 22 ml total capacity, assuming it contains 10 ml cocktail, 10 ml water and 2 ml air.

RESULTS AND DISCUSSION

A total of twenty (20) borehole and well water samples were collected from different wards in the study area to assess radon concentration. The measured radon concentration in the underground was compared with permissible limit of 11.1 Bq/L set by US-EPA (Althoyaib

& El-Taher, 2015). The annual effective dose for ingestion and inhalation was also computed.

Radon Concentrations in Water

Radon concentration in water was determined from 20 samples from Hand-dug well and Hand pump borehole.

The measured ^{222}Rn concentration in groundwater, fractional contribution of waterborne radon to radon in indoor and the associated health hazard within the study area are presented in Table 1.

Table 1: Radon Concentration and Annual Effective Doses in the Samples

Sample ID	Longitude	Latitude	Rn conc. (Bq/L)	Total annual effective dose ($\mu\text{Sv/y}$)	Contribution of radon to indoor Rn (mBq/L)
Open well					
W1	10.321351°	9.87620°	13.01	3.11	4.56
W2	10.314247°	9.854342°	9.23	2.36	3.17
W3	10.336100°	9.878362°	17.91	4.15	6.08
W4	10.316291°	9.866231°	23.20	5.91	8.25
W5	10.316213°	9.871481°	14.17	3.34	5.11
W6	10.334127°	9.872890°	21.23	4.80	7.21
W7	10.31654°	9.875112°	10.13	2.72	3.32
W8	10.32624°	9.885338°	8.95	2.23	2.83
W9	10.321825°	9.82431°	8.35	1.98	2.70
W10	10.314308°	9.85428°	12.16	2.89	4.14
	Average		13.86	3.35	4.47
Borehole					
BH1	10.354203°	9.888313°	25.17	5.75	9.74
BH2	10.309808°	9.874905°	9.73	2.51	3.39
BH3	10.313623°	9.853995°	18.26	4.36	6.83
BH4	10.324805°	9.887522°	10.93	2.85	3.40
BH5	10.321825°	9.82431°	15.31	3.75	5.61
BH6	10.31654°	9.875112°	19.05	4.61	6.74
BH7	10.321763°	9.864787°	10.14	2.68	3.37
BH8	10.32085°	9.876167°	8.84	2.22	2.77
BH9	10.392156°	9.882161°	22.38	5.27	7.82
BH10	10.326241°	9.857636°	14.30	3.58	5.41
	Average		15.41	3.76	5.50

The results show that the highest concentration of 25.17 Bq/L was found in sample BH1 (Hand pump borehole) and the lowest concentration of 8.35 Bq/L was in sample W9 (Hand-dug well). A considerable variation in radon concentration was observed between the borehole and well water sources. The observed variation in radon concentration in drinking water might be affected by some factors, such as radium and uranium contents in the aquifer, half-lives of each parent radionuclide, climatic condition, transport processes, depth of aquifer and other hydrogeological conditions. Radon concentration is higher in borehole water than in well water

because boreholes tap deeper aquifers with less surface air exposure, allowing radon to accumulate in the confined, water-saturated environment. Well water, being from shallower sources exposed to the atmosphere, loses radon gas more readily through volatilization, while boreholes provide a closed system where radon, produced from naturally radioactive minerals in the surrounding rock, remains trapped (Shu'aibu et al., 2021). On the other hand, (Ajiboye et al., 2018) determined that aeration in open wells allows the dilution of radon in groundwater which results in a significant reduction of radon concentration.

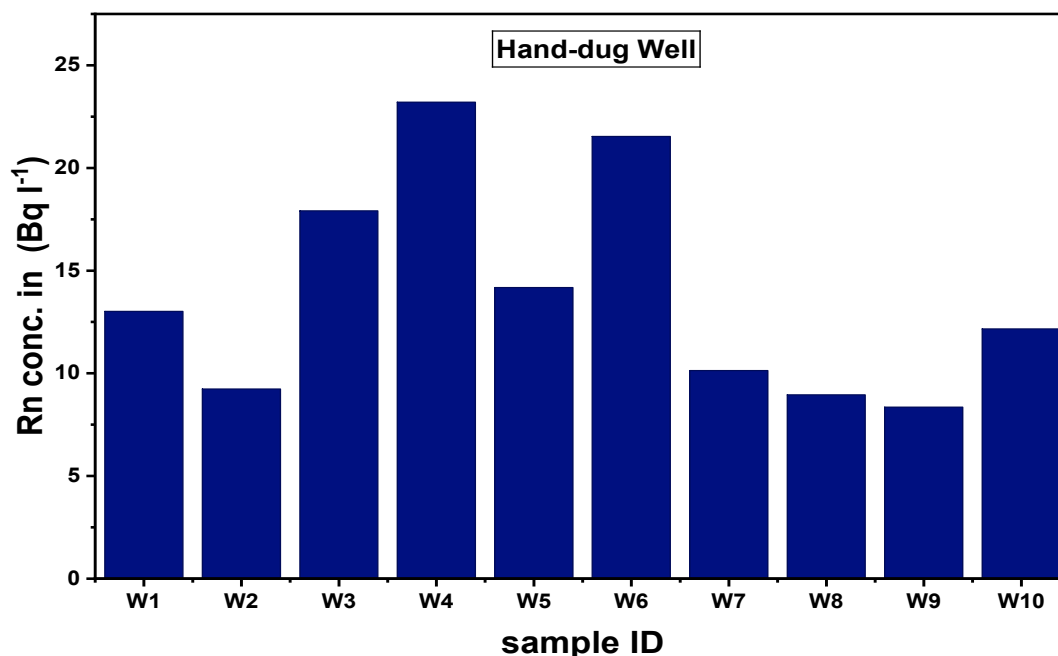


Figure 3: Activity Concentration of ²²²Rn in Hand-dug well Water Samples

Radon Concentrations in Hand-Dug Water

As shown in Table 4.1, ²²²Rn concentrations in Hand-dug well varied between 8.35 Bq/L to 25.17 Bq/L with a mean value 13.86 Bq/L, which is clearly above USEPA safety threshold of 11.1 Bq/L and about 60% of water samples from well water have ²²²Rn concentration values above the USEPA recommended limit as seen in Figure 3. ²²²Rn concentrations in Hand-dug well sources were within the

safety range of 4 – 40 Bq/L recommended by the United Nations Scientific Committee on Effects of Atomic Radiation (Shu'aibu et al., 2021). According to the recommendations of European Union commission, no remedial action should be required if the concentration of radon in drinking water is less than 100 Bq/L. The variation of ²²²Rn concentrations in Hand-dug well with sampling locations is illustrated in Figure 4.

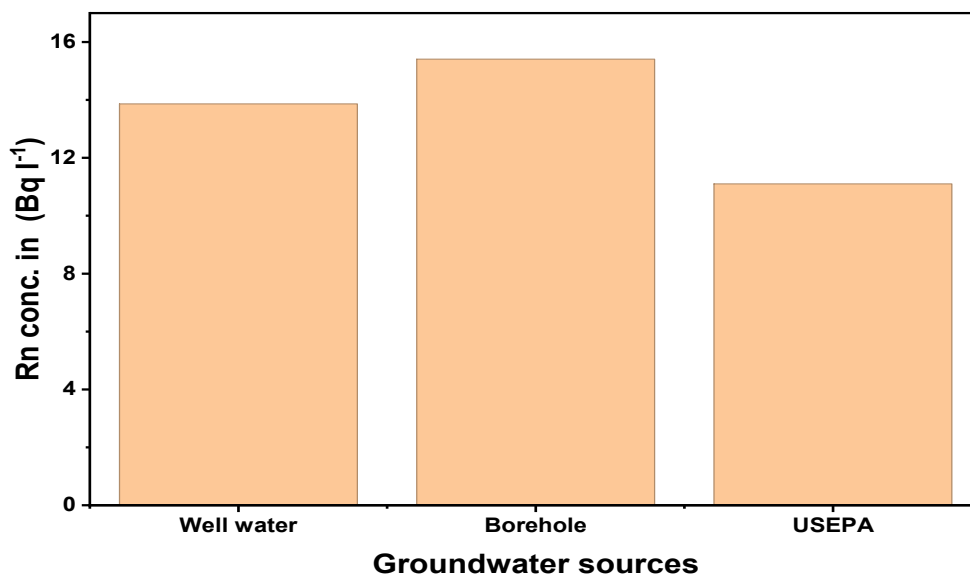


Figure 4: ²²²Rn Concentration in W and BH Sources Together with the USEPA Threshold

The sampling location W4 showed the highest value of radon among the studied well water samples. This may not be linked with the depth of the well, but due to the local geology of the area underlain by gneiss. Besides this, (Le et al., 2015) reported that low pH and low dissolved oxygen support the occurrence of elevated concentrations of radium in groundwater accompanied by soil and water temperature.

Radon Concentrations in Hand Pump Borehole Water

The ²²²Rn concentrations in Borehole ranged from 8.84 BqL⁻¹ to 23.20 BqL⁻¹ with a mean value 15.41 BqL⁻¹ as illustrated in Table 1. The mean activity concentration of ²²²Rn in BH samples in the study area was 15.41 Bq/L which is above the USEPA action levels of 11.1 Bq L⁻¹, but it's below the WHO action level of 100 Bq/L. The variation of ²²²Rn concentrations in Hand-dug well with sampling locations is illustrated in Figure 5.

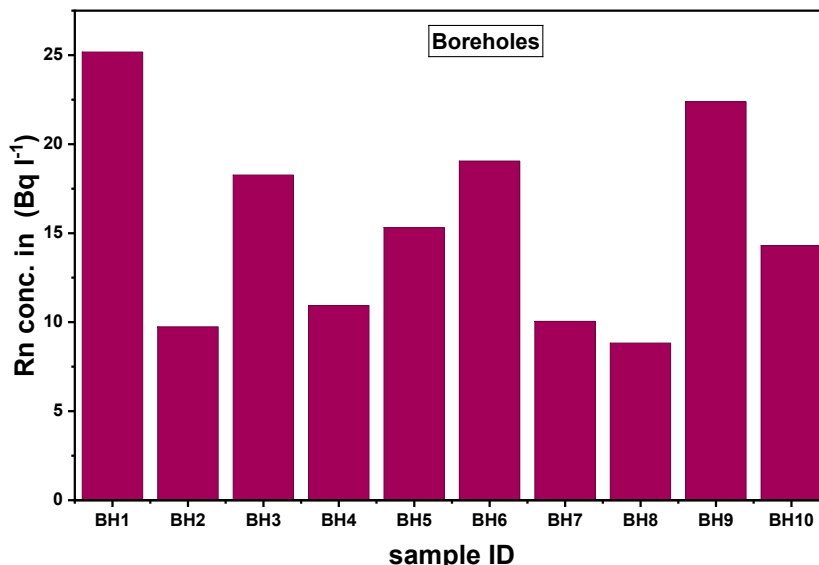


Figure 5: Activity Concentration of ²²²Rn in Hand Pump Borehole Water Samples

As shown table 1, the BH1 has the highest concentration, while the lowest concentration was observed in BH2, respectively. It is suggested that the variations in concentration are affected by factors including uranium and associated radium contents in the aquifer, the nature

of the basement rocks, the solubility and mobility of parent radionuclides in the study area, climatic conditions, transport processes, depth of aquifers, as well as various other hydrogeological conditions (Farai et al., 2023).

Table 2: Comparison of Radon Concentration in Groundwater from Bauchi with other Parts of the World

Location and Country	Radon conc. (Bq/L)	References
Vietnam	1.4	(Le et al., 2015)
Brazil	15.4	(Bonotto, 2014)
India	9.03	(Rani et al., 2013)
South-west, Nigeria	23.04	(Olise et al., 2016)
Iran	16.2	(Binesh et al., 2012)
Current study	14.63	Present study

The results of the ²²²Rn activity concentrations in water from the study area were compared with those reported in other countries worldwide (Table 2). The mean radon concentration in well water was lower than the values reported for Brazil, Iran, and southwestern Nigeria, but higher than those reported for Vietnam and India.

Annual Mean Effective Dose for Ingestion and Inhalation

The annual effective dose due to ingestion in water (E_{wig}), was computed from radon concentration determined from the experiment using equation 1.1 adopted from (UNCEAR, 2000).

$$E_{wig} \text{ (nSvy}^{-1}\text{)} = C_{Rn} \times C_w \times \text{(EDC)} \quad (2)$$

Where E_{wig} = Effective dose for ingestion

C_{Rn} = Measured radon concentration in water ($Bq l^{-1}$),

C_w = Water consumption rate ($60 l y^{-1}$)

EDC = effective dose coefficient for ingestion $3.5 nSv Bq^{-1}$.

Likewise, for inhalation (E_{win}) was determined from equation 1.2

$$E_{win} = C_{Rn} \times R_{a,w} \times R \times O \times (DCF) \quad (3)$$

E_{win} = effective dose for inhalation

C_{Rn} = measured radon concentration in water

$R_{a,w}$ = Ratio of radon concentration in air to radon in tap water (10^{-4})

F = equilibrium factor between radon and its progeny

O = is the global average indoor occupancy factor ($7000 h y^{-1}$)

DCF = Dose conversion factor ($9 nSv h^{-1} (Bq m^{-3})^{-1}$) (Ibrahim et al., 2023).

The cumulative effective dose of ingestion and inhalation varied from 1.98 to 5.75 $\mu Sv y^{-1}$ with mean value of 3.76 $\mu Sv y^{-1}$ as shown in Table 1. The total annual effective dose obtained (3.76 $\mu Sv y^{-1}$) is within the recommended safe limit of 0.1 mSv y^{-1} provided by WHO (2004).

The Contribution of Radon in the Water to Indoor Radon

The contribution of radon in the different sources of water to indoor radon was determined using equation 1. (Zalewski et al., 2001)

$$C_{inRn} = C_{Rn} \times W \times \frac{e}{V \times \lambda_c} \quad (4)$$

Where C_{inRn} is the radon from water to indoor air radon contribution, C_{Rn} is the radon in water concentration, W is the water consumption per hour per person ($0.01 m^3 h^{-1}$), e (0.5) is the coefficient to indoor air, V ($20 m^3$) is the bulk volume of indoor air per person, λ_c ($0.7 h^{-1}$) is the air exchange rate.

The variation of Radon contribution from water to indoor air was from 2.70 to 9.74 mBq l^{-1} with an average of 5.50 mBq/L. The highest contribution (9.74 mBq/L) from water to indoor air was from Borehole water while the lowest contribution (2.70 mBq/L) was from well water. The mean Radon contribution from water to indoor air is lower than the WHO recommended limits of 100 Bq/ m^3 . The mean Radon contribution from water to indoor air from this study is comparably higher reported in Malaysia by (Nuhu et al., 2020).

CONCLUSION

The radon concentration in water samples and the associated radiological health impacts on inhabitants of the study area were evaluated. The findings of this research contributed to existing knowledge and successfully met the study objectives as outlined below: The results show that the highest concentration of 25.17 Bq l^{-1} was found in sample BH1 (Hand pump borehole)

and the lowest concentration of 8.35 Bq l^{-1} was in sample W9 (Hand-dug well). A considerable variation in radon concentration was observed between the borehole and well water sources. The observed variation in radon concentration in drinking water might be affected by some factors, such as radium and uranium contents in the aquifer, half-lives of each parent radionuclide, climatic condition, transport processes, depth of aquifer and other hydrogeological conditions.

Approximately 60% of the analyzed samples exhibited radon concentrations exceeding the USEPA reference limit. The study indicated that radon distribution in groundwater of the area was affected by the local geology of the well. The mean annual effective dose of 3.76 $\mu Sv y^{-1}$ from the consumption of groundwater in the studied area was found to be lower than the safe limit 0.1 mSv y^{-1} suggested by World Health Organization (2004) and European Commission (2005).

The variation of Radon contribution from water to indoor air was from 2.70 to 9.74 mBq/L with an average of 5.50 mBq/L. The highest contribution (9.74 mBq/L) from water to indoor air was from Borehole water while the lowest contribution (2.70 mBq/L) was from well water. The mean Radon contribution from water to indoor air is lower than the WHO recommended limits of 100 Bq/ m^3 .

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