



# Annual Effective Dose and Excess Lifetime Cancer Risk due to Ingestion and Inhalation of Radon in Groundwater of Bosso Community Minna, North-Central Nigeria

Matthew Tikpangi Kolo<sup>a,\*</sup>, Oyeleke Olarinoye<sup>a</sup>, Simon Olonkwoh Salihu<sup>b</sup>, Hyginus Anayo Ugwuanyi<sup>a</sup>, Paul Onuche<sup>a</sup>, Opeyemi Falade<sup>a</sup>, Nwachukwu Chibueze<sup>a</sup>

<sup>a</sup>Department of Physics, Federal University of Technology, Minna, Niger State, Nigeria

<sup>b</sup>Department of Chemistry, Federal University of Technology, Minna, Niger State, Nigeria

## Abstract

Radon in potable water has become an issue of public health concern, especially when consumed or used directly from source for domestic purposes without any pre-treatment. In this study,  $^{222}\text{Rn}$  concentration in 22 water samples collected from 2 groundwater sources (open wells, 12 samples and boreholes, 10 samples) in Bosso town, North central Nigeria were measured using DurrIDGE RAD-7 radon detector with RAD-H<sub>2</sub>O accessories.  $^{222}\text{Rn}$  concentrations in open wells varied from  $2.1 \pm 0.7$  to  $27.9 \pm 2.5$  Bq L<sup>-1</sup> with a mean of  $10.2 \pm 1.5$  Bq L<sup>-1</sup>, while that in boreholes ranged from  $2.8 \pm 1.1$  to  $39.2 \pm 1.5$  Bq L<sup>-1</sup> with a mean value of  $14.3 \pm 1.7$  Bq L<sup>-1</sup>. These values are lower than the 100 Bq L<sup>-1</sup> upper limit proposed by the European Union Commission, above which any practical intervention may be necessary. Mean annual committed effective dose to adults, children and infants from ingestion of water were 74.64, 71.58 and 53.17  $\mu\text{Sv y}^{-1}$  respectively for the open wells and 104.24, 99.96 and 74.26  $\mu\text{Sv y}^{-1}$  respectively for borehole water samples. Mean whole body dose due to ingestion and inhalation of waterborne radon from open wells and boreholes are 27.56 and 38.48  $\mu\text{Sv y}^{-1}$  respectively, which are below the reference level of 0.1 mSv y<sup>-1</sup> for potable water recommended by the World Health Organization for public safety. The excess lifetime cancer risk were  $0.10 \times 10^{-3}$  for the open wells and  $0.13 \times 10^{-3}$  for the boreholes, which are lower than the world safety limit  $0.29 \times 10^{-3}$ . Water from the two groundwater sources investigated is therefore fit for consumption and other domestic usage from the point of view of radiation protection.

DOI:10.46481/jnsps.2023.896

**Keywords:**  $^{222}\text{Rn}$  concentration, groundwater, Bosso community, RAD-7 radon detector, Committed effective dose, ELCR, Nigeria

## Article History :

Received: 28 June 2022

Received in revised form: 07 January 2023

Accepted for publication: 07 January 2023

Published: 19 April 2023

© 2023 The Author(s). Published by the Nigerian Society of Physical Sciences under the terms of the Creative Commons Attribution 4.0 International license (<https://creativecommons.org/licenses/by/4.0>). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

Communicated by: M. Orosun

## 1. Introduction

The daily influx of human population coupled with rapid urbanization of Bosso community of Minna, north-central Nigeria

has put increased pressure on the existing epileptic potable water supply within the community. To effectively combat this growing challenge therefore, residents of the community have turned their attention to open wells and drilled boreholes. Groundwater has thus, become the primary source of potable water for majority of the population in the community. Groundwater, which is the World's largest reservoir of fresh water [1],

\*Corresponding author tel. no: +234 8105168992

Email address: [matthewkolo@futminna.edu.ng](mailto:matthewkolo@futminna.edu.ng) (Matthew Tikpangi Kolo)

derives its radioactivity from the underlying rocks, soil formations, dissolved radioactive and mineral substances. Dissolved radon ( $^{222}\text{Rn}$ ) in groundwater arises from the decay of naturally occurring uranium and radium ( $^{226}\text{Ra}$ ) deposits present in soil and reservoir rocks over which the water bodies move, coupled with the emanation coefficient of the reservoir rocks [2-4]. Other factors that control the distribution of  $^{222}\text{Rn}$  in groundwater includes the type of rocks, host rock mineralogy, shear zones, degree of weathering, frequency of fractures, permeability of host rock, secondary porosity, physiochemical, and nature of the geological aquifers, depths of wells and duration of water storage times [3, 5, 6].  $^{222}\text{Rn}$  often finds its way out of the earth's crust and underlying bedrocks through cracks, crevices and other openings in the foundation floor and walls, into human homes, thereby enhancing the level of human exposure. Additionally, human exposure to waterborne radon occur through daily use of groundwater for bathing, laundries, cooking and other domestic purposes [7]. Most often, human exposure occur through direct ingestion of water containing radon and inhalation of radon gas in indoor air.

Waterborne radon monitoring and mitigation has been a subject of great concern and research in many countries of the world, owing to its hazardous effects [2]. World Health Organization (WHO) [8] reported that about 1-7% of deaths from lung cancer is attributed to increased levels of waterborne radon. Various studies have also shown that direct inhalation and ingestion of waterborne radon over long period of time can lead to pathological effects such as the respiratory functional changes, and DNA damage in sensitive lung tissues leading to lung cancer (, stomach and gastrointestinal cancer [1, 2, 5, 9]. Epidemiological studies have also shown that ingestion of  $^{222}\text{Rn}$  over a considerable length of time can be responsible for stomach and gastrointestinal cancer [10]. Levels of  $^{222}\text{Rn}$  in water should therefore be measured, checked and controlled consistently in order to protect the human population from internal exposure that may arise from inhalation and ingestion of waterborne radon

Isinkaye et al [11],underscores the importance of water to human existence and an expressive indices for radiological, geological and environmental studies. Hence, its purity, accessibility and quality cannot be jeopardized especially from the point of view of human health and protection.

The first campus of Federal University of Technology, Minna is located in Bosso community. The challenge of insufficient hostel accommodation within the campus has pushed majority of the students to rented apartments within Bosso. Bosso community is also the readily available home for local farmers who have been displaced from their respective communities due to the nefarious activities of bandits and herdsmen. As a result of the growing population, the community has resulted into drilling open wells and boreholes to meet the increasing demand for potable water supply. Locally built apartments available for rent within the community are semi en suite and poorly ventilated, resulting in high probability of population exposure to accumulated radon from groundwater used for laundry, bathing, dishwashing and other domestic activities. Moreover, radon concentration in groundwater sources in

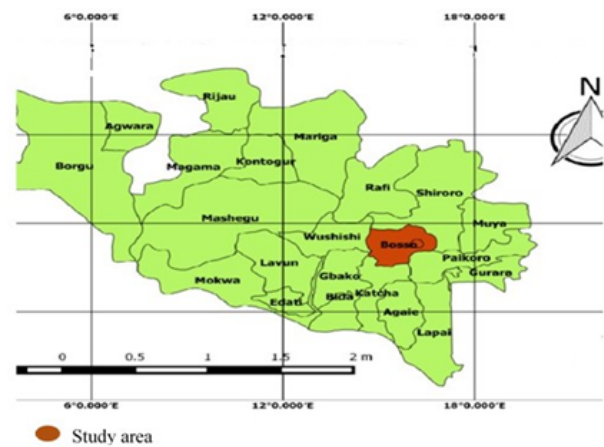


Figure 1: Map of Niger State showing the study area

Bosso community have not so far been examined or reported in literature. This study is therefore a pioneering work aimed at measuring  $^{222}\text{Rn}$  concentrations in groundwater sourced from open wells and boreholes in Bosso community and to evaluate the level of exposure to radiation dose from the daily usage of groundwater within the community. Results from this study will help in raising awareness on the likelihood of radiation incidence that may occur from daily exposure, through inhalation and ingestion, to waterborne radon within the community.

## 2. Materials and Method

### 2.1. Location and Geology of the Study Area

Bosso, a community in Niger State, north central Nigeria (Fig. 1), with average area of 1592 km<sup>2</sup>, is geographically located within the Guinea Savanna ecological zone of Nigeria. It lies between latitudes 09<sup>o</sup> 40' N to 09<sup>o</sup> 42' N and longitudes 06<sup>o</sup> 30' E to 06<sup>o</sup> 36' E. The community falls within the regional Basement Complex of Nigeria, which according to Okanlawon et al [12], is underlain by two geologic episodes viz igneous and metamorphic orogeneses. The community is underlain by undifferentiated granitic rocks which are believed to be part of the Older Granitic suites of Nigeria and various metamorphic rocks [13, 14, 15]. The metamorphic terrain is made up of gneisses, schists, quartzites and some migmatites [16]. In hand specimens, the granitic rocks constitute feldspars (mostly plagioclase), quartz, micas and some few ferromagnesian minerals like pyroxenes, amphiboles and hornblendes. The metamorphic rocks are mostly made of biotites, amphiboles, staurolites and asbestos. Structurally, most of the rocks are non-deformed to slightly deformed [17]. Secondary structures such as faults, folds, foliations and lineations are obvious on the insitu rocks. The community is marked by two distinct seasons, the raining season which lasts from the month of April to October, and the dry season which lasts from November to March/April. Annual rainfall values ranges between 900 mm to 1,000 mm, with mean temperature of around 32°C.

## 2.2. Sample Collection

12 groundwater samples from open wells and 10 groundwater samples from drilled boreholes within the community were collected and analysed for  $^{222}\text{Rn}$  concentration. Empty 75cl water bottles which were used for collection of water samples were purchased from commercial shops. The sample bottles were thoroughly washed with distilled water and with dilute 0.1M HCl after purchase. They were then allowed to dry before sample collection. Fresh water sample from open wells were collected using bailers. Clean sample bottles were gently filled with water samples by submerging them into the bailers and immediately sealed tightly with a cap underwater to avoid any formation of air bubbles. Fresh water from boreholes were collected into the samples bottles directly from the borehole tap heads after they were turned on and allowed to run freely for about five minutes. This was necessary to purge out all trapped air and to ensure that the temperature of the water is stable before collection. All samples bottles were well labelled and carefully filled to prevent agitations that could lead to the escape of radon gas.

## 2.3. Sample Analysis

All the samples were analysed at Radioanalytical Research Laboratory, Ekiti State University, Ado Ekiti, Nigeria, using RAD-7 radon analyzer (DurrIDGE Co., USA) coupled to RAD-H<sub>2</sub>O accessories. In the RAD-7 detector setup shown in Fig. 2, required portion of water sample was transferred into the 250 mL vial, from which radon gas was expelled using bubbling kit. The expelled gas was passed via air circulation into the hemisphere chamber where it decayed into its daughter nuclei, polonium (Po). A silicon solid-state detector which was maintained at high electric field, collected the Po nuclei which were finally counted by an in-built software to give an estimation of radon concentration in the water sample. Each water sample was automatically analyzed by the detector in four cycles of 5 min each, with an initial aeration time of 5 min. This was necessary for quality control purposes and to guarantee reliability of analytical methods [11, 18]. Since the counting was not immediately done at the sample collection point, radon concentration in the samples must have reduced due to radioactive decay. The results of the analysis were therefore decay-corrected back to the original concentration values at the time of sample collection, following the correction procedure outlined in DurrIDGE [19]. RAD-7 is a sophisticated, active radon detector that uses a computer-driven electronic detector with pre-programmed setups. The detector is able to give the result of analysis within 30 minutes, which makes it a comparatively faster analysis procedure.

## 2.4. Annual Effective Dose Estimation

Exposure to waterborne radon by human and animal population occur on daily basis as a result of water consumption and other various domestic use, which results in the annual committed effective dose (ACED) incurred. ACED to different ICRP

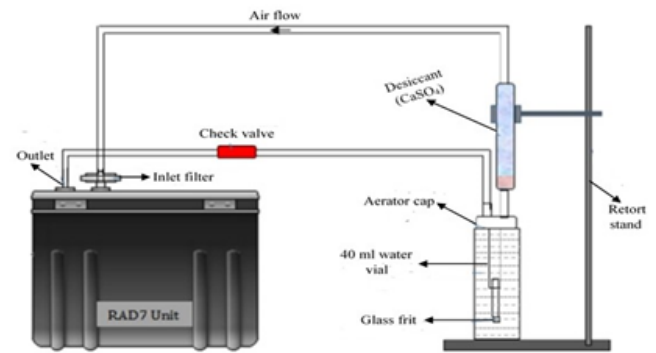


Figure 2: Schematic diagram of RAD-H<sub>2</sub>O set for measurement of waterborne radon

age groups due to ingestion of waterborne radon was computed from the equation

$$ACED = C_{Rn} \times W_{CR} \times DCF \quad (1)$$

where  $C_{Rn}$  is the radon concentration in groundwater measured in  $\text{Bq L}^{-1}$ ,  $W_{CR}$  is the water consumption rate per year ( $\text{L yr}^{-1}$ ) and DCF is the dose conversion factor expressed in  $\text{Sv Bq}^{-1}$ .  $W_{CR}$  and DCF values adopted in this study are given in Table 1.

The contribution of radon in the different sources of water to indoor radon was determined using equation [21]:

$$\chi_{Rn} = C_{Rn} \times w \times \frac{\omega}{v \times \lambda_c} \quad (2)$$

where  $\chi_{Rn}$  is the fractional contribution of waterborne radon to radon in indoor air,  $C_{Rn}$  is the radon concentration in water,  $w$  is the water consumption rate per person ( $0.01 \text{ m}^3 \text{ h}^{-1}$ ),  $\omega$  (0.5) is the coefficient to indoor air,  $v$  is the bulk volume of indoor air per person taken to be  $20 \text{ m}^3$ , and  $\lambda_c$  ( $0.7 \text{ h}^{-1}$ ) is the air exchange rate [22, 23].

## 3. Results and Discussion

### 3.1. Radon Concentration

The measured  $^{222}\text{Rn}$  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 2

As shown in Table 2,  $^{222}\text{Rn}$  concentrations in LW varied between  $2.1 \pm 0.7$  to  $27.9 \pm 2.5 \text{ Bq l}^{-1}$  with a mean value of  $10.2 \pm 1.5 \text{ Bq l}^{-1}$ . Similarly,  $^{222}\text{Rn}$  concentrations in BH ranged from  $2.8 \pm 1.1$  to  $39.2 \pm 1.5 \text{ Bq l}^{-1}$  with a mean value of  $14.3 \pm 1.7 \text{ Bq l}^{-1}$ . According to Kalip, Haque and Gaiya [24], and Suresh et al [25], observed differences in radon concentrations in LW and BH may be due to the depth of water sources, hydrogeological state of the source location and the prevailing climatic conditions. Although 33% of water samples from both LW and BH have  $^{222}\text{Rn}$  concentration values above the USEPA safety threshold of  $11.1 \text{ Bq l}^{-1}$  as seen in Figure 3,  $^{222}\text{Rn}$  concentration in two groundwater sources were within the safety range

Table 1:  $W_{CR}$  and DCF for respective ICRP age groups [20]

Age group	Age range(yrs)	Water consumption		
		(L/day)	$W_{CR}$ (L/yr)	DCF (Sv/Bq)
3 months	0 - 1	0.55	200	
1 yr (infants)	1 - 2	0.71	260	$2 \times 10^{-8}$
3 yrs	2 - 7	0.82	300	
10 yrs (children)	7 - 12	0.96	350	$2 \times 10^{-8}$
15 yrs	12 - 17	1.64	600	
Adults	> 17	2.00	730	$1 \times 10^{-8}$

Table 2:  $^{222}\text{Rn}$  concentration in groundwater, fractional contribution of waterborne radon to radon in indoor and the associated health hazard within the study area

Sample ID	$^{222}\text{Rn}(\text{Bq l}^{-1})$	$\chi_{Rn}$ (mBq l $^{-1}$ )	ACED ( $\mu\text{Sv y}^{-1}$ ) to ICRP age groups		
			Adults	Children	Infants
<b>Open wells</b>					
LW 01	2.1±0.7	0.75	15.33	14.70	10.92
LW 02	27.9±2.5	9.96	203.67	195.30	145.08
LW 03	24.9±2.5	8.89	181.77	174.30	129.48
LW 04	10.2±1.6	3.64	74.46	71.40	53.04
LW 05	2.9±0.8	1.04	21.17	20.30	15.08
LW 06	4.5±1.1	1.61	32.85	31.50	23.40
LW 07	8.8±1.4	3.14	64.24	61.60	45.76
LW 08	2.4±0.8	0.86	17.52	16.80	12.48
LW 09	4.4±1.1	1.57	32.12	30.80	22.88
LW 10	3.1±2.0	1.11	22.63	21.70	16.12
LW 11	16.0±2.8	5.71	116.80	112.00	83.20
LW 12	15.5±0.8	5.53	113.15	108.50	80.60
Min	2.1±0.7	0.75	15.33	14.70	10.92
Max	27.9±2.5	9.96	203.67	195.30	145.08
Mean	10.2±1.5	3.65	74.64	71.58	53.17
<b>Boreholes</b>					
BH 01	28.7±3.1	10.25	209.51	200.90	149.24
BH 02	10.1±1.5	3.61	73.73	70.70	52.52
BH 03	22.2±1.0	7.93	162.06	155.40	115.44
BH 04	2.8±1.1	1.00	20.44	19.60	14.56
BH 05	39.2±1.5	13.99	286.16	274.40	203.84
BH 06	9.9±2.0	3.53	72.27	69.30	51.48
BH 07	12.3±4.5	4.39	89.79	86.10	63.96
BH 08	10.5±0.2	3.75	76.65	73.50	54.60
BH 09	3.7±0.8	1.32	27.01	25.90	19.24
BH 10	3.4±1.3	1.21	24.82	23.80	17.68
<b>Min</b>	2.8±1.1	1.00	20.44	19.60	14.56
<b>Max</b>	39.2±1.5	13.99	286.16	274.40	203.84
<b>Mean</b>	14.3±1.7	5.10	104.24	99.96	74.26

of 4 – 40 Bq l $^{-1}$  recommended by the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR). 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 $^{-1}$  [26, 27]. Results of this study does not therefore suggest any immediate implimentation of whichever practical radon programme in Bosso community. The contribution of waterborne radon to radon in indoor air varies from 0.75 to 9.96 mBq l $^{-1}$  for LW wa-

ter sources and from 1.00 to 13.99 mBq l $^{-1}$  for the BH water. These values are lower than the estimated mean indoor radon level of 1.3 pCi/l (48.1 mBq l $^{-1}$ ), thereby indicating the paltry contribution of waterborne radon within the community to total radon in indoor air.

Table 2 also shows the computed annual effective dose (ACED) to the adults, children and infants due to  $^{222}\text{Rn}$  concentration in the two groundwater sources (LW and BH) of the studied community. ACED due to ingestion of water from LW source by

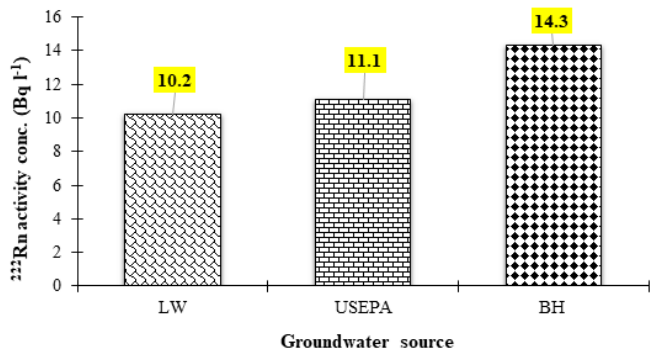


Figure 3: <sup>222</sup>Rn concentration in LW and BH sources together with the USEPA threshold

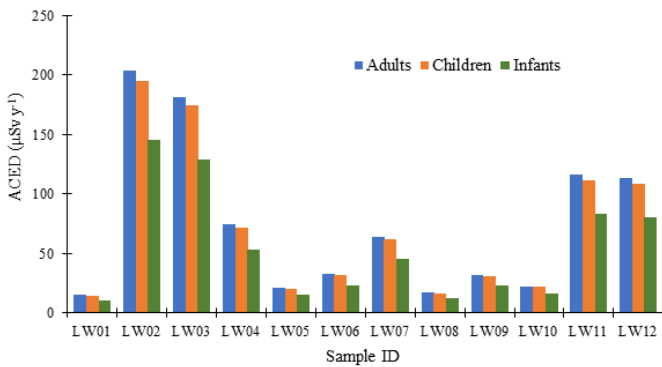


Figure 4: ACED received by different ICRP age groups due to waterborne radon from LW groundwater sources

adult population ranged from 15.33 to 203.67  $\mu\text{Sv y}^{-1}$  with an average value of 74.64  $\mu\text{Sv y}^{-1}$ , from 14.70 to 195.30  $\mu\text{Sv y}^{-1}$  with a mean value of 71.58  $\mu\text{Sv y}^{-1}$  for the children, while infants recorded ACED values between 10.92 to 145.08  $\mu\text{Sv y}^{-1}$ , with a mean value of 53.17  $\mu\text{Sv y}^{-1}$ .

Similarly, average ACED due to ingestion of water from BH source by adult, children and infants population of the studied community are 104.24, 99.96 and 74.26  $\mu\text{Sv y}^{-1}$  respectively. The results shows that ACED increases with mean radon concentration, rate of water consumption and age; thus, infants suffer least radon exposure compared to the children and adults. This agrees with the results obtained for similar studies by Kalip et al [24] and Ravikumar and Somashekar [10]. Furthermore, the highest ACED due to groundwater consumption from LW and BH sources among the ICRP age groups is 0.204  $\text{mSv y}^{-1}$  and 0.274  $\text{mSv y}^{-1}$  respectively. These values are below the 1 $\text{mSv y}^{-1}$  safety threshold recommended by UNSCEAR and WHO. The infants, children and adult population of Bosso community are therefore not under any immediate health threat from waterborne radon. Variations of ACED received by different ICRP age groups due to ingestion of waterborne radon from LW and BH groundwater sources in the studied community are shown in Figures 4 and 5.

Table 3 shows the comparison of the results of this investigation with those of similar studies from different parts of

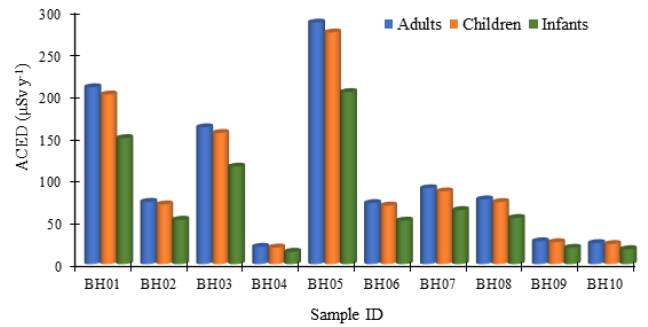


Figure 5: ACED received by different ICRP age groups due to waterborne radon from BH groundwater sources

Nigeria. Mean radon concentration for open wells within the community (10.2  $\text{Bq l}^{-1}$ ) is higher than that reported by Kalip et al [24] for Kaduna (1.8  $\text{Bq l}^{-1}$ ). Additionally, average value obtained for the boreholes within the community (14.3  $\text{Bq l}^{-1}$ ) is about 54% lower than the one reported by Isinkaye and Aji-boye [28] for Ekiti State. This may be due to variations in local geology of the respective sampling areas and depth of sampling. Judging from the Table generally, the range of radon concentration values obtained for the two groundwater sources in Bosso community is comparable to those reported in literature from other parts of Nigeria.

### 3.2. Evaluation of Excess Lifetime Cancer Risk and Annual Effective Dose Due to Inhalation and Ingestion

Radiation dose to the internal organs of human population from waterborne radon has been identified as a highly potent human health threat. Human exposure to waterborne radon is principally through direct ingestion of radon-contaminated water and inhalation of radon-saturated indoor air. Direct ingestion results in radiation dose delivery to the human stomach while inhalation pathway delivers dose to the lungs and respiratory track. Annual committed effective dose (ACED) to human stomach from direct ingestion of radon-contaminated water in the studied community was calculated from the equation [11, 35]:

$$ACED_{ing} (\text{mSv y}^{-1}) = C_{Rn} \times W_{CR} \times DCF_{ing} \quad (3)$$

where  $C_{Rn}$  is the concentration of radon in water,  $W_{CR}$  the annual water consumption for adults (730  $\text{L y}^{-1}$ ) and  $DCF_{ing}$  is the effective dose conversion factor for ingestion (3.5  $\text{nSv Bq}^{-1}$ ).

Since radon is comparatively insoluble in water, continuous domestic utilization of water can result in consistent liberation of radon gas into the indoor air, thereby enhancing the average committed dose incurred via inhalation pathway [9, 35]. ACED due to inhalation of waterborne radon was computed from the equation [8, 36]:

$$ACED_{inh} (\text{mSv y}^{-1}) = C_{Rn} \times R_{AW} \times EF \times OF \times DCF_{inh} \quad (4)$$

where  $C_{Rn}$  is the concentration of radon in water,  $R_{AW}$  is the ratio of radon-in-air to radon-in-water ( $10^{-4}$ ), EF is the equilibrium factor between radon and its progeny for indoor environment (0.4), OF is the average global indoor occupancy factor

Table 3: Comparison of radon concentrations in groundwater obtained in this study with other locations within Nigeria

Location	Source of water	$^{222}\text{Rn}$ Conc (Bq l $^{-1}$ )	References
Ekiti State, Nigeria	borehole	30.9	Isinkaye and Ajoboye [28]
	well	19.5	
Ogbomosho, SW Nigeria	borehole	0.60 - 2.64 (1.86)	Oni et al. [29]
Ekiti State University, Nigeria	Hand pumped boreholes	7.0 - 41.5 (23.3)	Isinkaye et al. [11]
	hand dug wells	0.6 - 36.2 (13.33)	
	Motorized boreholes	0.6 - 27.4 (7.4)	
Gadau, Bauchi State, Nigeria	well	4.92 - 82.89 (38.3)	Shu'abu et al. [30]
Ibadan, Nigeria	well	2.18 - 76.75	Ademola and Oyeleke [31]
Kaduna, Nigeria	well	0.85 - 2.57 (1.8)	Kalip et al. [24]
	borehole	0.35 - 085 (0.57)	
Ogun State, Nigeria	borehole	1.23 - 12.68	Fatoki and Ademola [32]
Zaria, Nigeria	borehole	7.41	Garba et al. [33]
	well	7.18	
Sabon Gari, Kaduna, Nigeria	borehole	14.9	Jibril et al. [34]
Bosso, north-central Nigeria	borehole	14.3	Present study
	Open well	10.2	

Mean values are in parenthesis.

(7000 h y $^{-1}$ ) and  $DCF_{inh}$  is the dose conversion factor for exposure to radon in air (9 nSv Bq $^{-1}$  h $^{-1}$  m $^3$ ).

Computed values for committed annual effective dose (ACED) received by internal organs (stomach and lungs) due to ingestion and inhalation of waterborne radon in Bosso community and presented in Table 4. Also presented in Table 4 is the calculated excess lifetime cancer risk (ELCR) due to waterborne radon in the studied community. ACED delivered to the stomach as a result of ingestion of waterborne radon from LW sources varied from 0.37 to 4.88  $\mu\text{Sv y}^{-1}$ , with a mean value of 1.79  $\mu\text{Sv y}^{-1}$ , while the ACED range to the lungs via inhalation is 5.29 to 70.31  $\mu\text{Sv y}^{-1}$  with an average value of 25.77  $\mu\text{Sv y}^{-1}$ . Similarly, the range of ACED from BH sources delivered to the stomach via the ingestion pathway is 0.49 to 6.86  $\mu\text{Sv y}^{-1}$  with a mean of 2.50  $\mu\text{Sv y}^{-1}$  and to the lungs via inhalation route is 7.06 to 98.78  $\mu\text{Sv y}^{-1}$  with an average value of 35.99  $\mu\text{Sv y}^{-1}$ .

With reference to the US National Academy of Sciences report of 1999, UNSCEAR [37] computed mean dose from radon in drinking water to be 0.002 mSv y $^{-1}$  and 0.025 mSv y $^{-1}$  for ingestion and inhalation pathways respectively. The results further show that the highest percentage of whole body dose comes through the inhalation pathway, hence, the lung cells and respiratory track in general are more prone to cancer incidences compared to the walls of the stomach. The total annual effective doses due to ingestion and inhalation (whole body dose) incurred from waterborne radon in Bosso community ranged from  $5.66 \times 10^{-3}$  to 0.075 mSv y $^{-1}$  for LW groundwater sources and from  $7.55 \times 10^{-3}$  to 0.106 mSv y $^{-1}$  for BH groundwater sources, with mean values of 0.0276 and 0.0385 mSv y $^{-1}$  in sequence. These values are below the threshold value of 0.1 mSv y $^{-1}$  recommended by UNSCEAR and WHO for public safety.

The probability of cancer incidence was evaluated in order to assess any possible potential carcinogenic effects to human population for a specific lifetime of exposure to waterborne

radon. Excess lifetime cancer risk (ELCR), which shows the extra risk of occurrence of cancer due to exposure to waterborne radon in the studied community was computed using the equation [38, 39]:

$$ELCR = WBD \times RF \times DL \quad (5)$$

where WBD is the whole body dose in  $\mu\text{Sv y}^{-1}$ , RF is the risk factor taken to be 0.05 Sv $^{-1}$  for stochastic effects [40] and DL is the lifetime duration of 70 years.

Computed ELCR values which gives an indication of extra risk of cancer incidence due to exposure to waterborne radon among the studied community are presented in Table 4. Average ELCR values for LW and BH groundwater sources in Bosso community are  $0.10 \times 10^{-3}$  and  $0.13 \times 10^{-3}$  respectively, which are below the world mean value of  $0.29 \times 10^{-3}$ . The likelihood of any cancer incidence among the population of the studied community is therefore insignificant. Hence water from the two groundwater sources investigated is fit for consumption and for other domestic usage from the point of view of radiation protection.

#### 4. Conclusion

Water samples from two major groundwater sources (open wells and boreholes) in Bosso community were collected and analysed for their radon ( $^{222}\text{Rn}$ ) concentration using DurrIDGE RAD-7 radon detector. The results showed that, although  $^{222}\text{Rn}$  concentration values in about 33% of water samples from the two groundwater sources were above the USEPA safety threshold, all values were within the safety range of 4 – 40 Bq l $^{-1}$  recommended by the United Nations Scientific Committee on Effects of Atomic Radiation. The results also indicated that about 94% of whole body dose comes through the inhalation pathway, which shows that inhalation of radon escaping from water is a considerable

Table 4: Radon concentration, ACED to internal organs and ELCR in LW and BH water samples

Sample ID	$^{222}\text{Rn}$ (Bq/l)	ACED ( $\mu\text{Sv/y}$ ) to internal organs			ELCR ( $10^{-3}$ )
		Ingestion (Stomach)	Inhalation (lungs)	Whole body	
<b>Open wells</b>					
LW 01	2.1 $\pm$ 0.7	0.37	5.29	5.66	0.02
LW 02	27.9 $\pm$ 2.5	4.88	70.31	75.19	0.26
LW 03	24.9 $\pm$ 2.5	4.36	62.75	67.11	0.23
LW 04	10.2 $\pm$ 1.6	1.79	25.70	27.49	0.10
LW 05	2.9 $\pm$ 0.8	0.51	7.31	7.82	0.03
LW 06	4.5 $\pm$ 1.1	0.79	11.34	12.13	0.04
LW 07	8.8 $\pm$ 1.4	1.54	22.18	23.72	0.08
LW 08	2.4 $\pm$ 0.8	0.42	6.05	6.47	0.02
LW 09	4.4 $\pm$ 1.1	0.77	11.09	11.86	0.04
LW 10	3.1 $\pm$ 2.0	0.54	7.81	8.35	0.03
LW 11	16.0 $\pm$ 2.8	2.80	40.32	43.12	0.15
LW 12	15.5 $\pm$ 0.8	2.71	39.06	41.77	0.15
<b>Min</b>	2.1 $\pm$ 0.7	0.37	5.29	5.66	0.02
<b>Max</b>	27.9 $\pm$ 2.5	4.88	70.31	75.19	0.26
<b>Mean</b>	10.2 $\pm$ 1.5	1.79	25.77	27.56	0.10
<b>Boreholes</b>					
BH 01	28.7 $\pm$ 3.1	5.02	72.32	77.35	0.27
BH 02	10.1 $\pm$ 1.5	1.77	25.45	27.22	0.10
BH 03	22.2 $\pm$ 1.0	3.89	55.94	59.83	0.21
BH 04	2.8 $\pm$ 1.1	0.49	7.06	7.55	0.03
BH 05	39.2 $\pm$ 1.5	6.86	98.78	105.64	0.37
BH 06	9.9 $\pm$ 2.0	1.73	24.95	26.68	0.09
BH 07	12.3 $\pm$ 4.5	2.15	31.00	33.15	0.12
BH 08	10.5 $\pm$ 0.2	1.84	26.46	28.30	0.10
BH 09	3.7 $\pm$ 0.8	0.65	9.32	9.97	0.03
BH 10	3.4 $\pm$ 1.3	0.60	8.57	9.16	0.03
<b>Min</b>	2.8 $\pm$ 1.1	0.49	7.06	7.55	0.03
<b>Max</b>	39.2 $\pm$ 1.5	6.86	98.78	105.64	0.37
<b>Mean</b>	14.3 $\pm$ 1.7	2.50	35.99	38.48	0.13

influence on the radiological hazard of the population. Average whole body dose due to ingestion and inhalation of waterborne radon from open wells and boreholes in the study area were below the reference level of 0.1 mSv  $y^{-1}$  for potable water recommended by the World Health Organization for public safety. There is therefore no indication of any likelihood of cancer incidence as a result of waterborne radon within the studied community that may demand urgent intervention from radiological point of view.

### Acknowledgements

The assistance, comfortable environment and research equipment provided by the head and the entire staff of Radioanalytical Research Laboratory, Department of Physics, Ekiti State University, Ado Ekiti, Nigeria, are highly acknowledged.

### References

- [1] G. Krishan, M. Rao, C. Kumar & P. Semwal, "Radon concentration in groundwater of east coast of West Bengal, India", *JRNC* **303** (2015) 2221.
- [2] V. Duggal, R. Mehra & A. Rani, "Determination of  $^{222}\text{Rn}$  level in ground-water using a RAD7 detector in the Bathinda district of Punjab, India", *Radiat. Prot. Dosimet.* **156** (2013) 239.
- [3] S. Khaled, A. Khaled, R. Shaban & A. A. Baset, "Measurement of  $^{222}\text{Rn}$  concentration levels in drinking water samples from Qena city (Egypt) and evaluation of the annual effective doses", *International Journal of Radiation Research* **18** (2020) 227.
- [4] T. A. Przylibski, E. DOMIN, J. Gorecka & A. Kowalska, " $^{222}\text{Rn}$  concentration in groundwaters circulating in granitoid massifs of Poland", *Water* **12** (2020) 748.
- [5] H. Nuhu, S. Hashim, M. S. M. Sanusi & M. A. Saleh, "Radon activity concentration measurements in water sources from Perak state Malaysia", *Journal of Radiation Research and Applied Sciences* **13** (2020) 665.
- [6] S. Sukanya, S. Joseph & J. Noble, "Evaluation of radiation dose from radon ingestion and inhalation in groundwater of a small tropical river basin, Kerala, India", *Isotopes Environ. Health Stud.* **57** (2021) 204.
- [7] K. Badhan, R. Mehra & R. Sonkawade, "Measurement of radon concentration in ground water using RAD7 and assessment of average annual dose in the environs of NITJ, Punjab, India", *IJPAP* **48** (2010) 508.
- [8] WHO, "Guidelines for Drinking-water Quality", Fourth edition, World Health Organisation Geneva, Switzerland (2011).
- [9] Y. Y. Wu, Y. Z. Ma, H. X. Cui, J. X. Liu, Y. R. Sun, B. Shang & X. Su, "Radon concentrations in drinking water in Beijing City, China and contribution to radiation dose", *Int. J. Environ. Res. Public Health* **11** (2014) 11121.
- [10] P. Ravikumar & R. Somashekar, "Determination of the radiation dose due

- to radon ingestion and inhalation”, *Int. J. Environ. Sci. Technol.* (Tehran) **11** (2014) 49.
- [11] M. O. Isinkaye, F. Matthew-Ojelabi, C. O. Adegun, P. O. Fasanmi, F. A. Adeleye & O. G. Olowomofe, “Annual effective dose from  $^{222}\text{Rn}$  in groundwater of a Nigeria University campus area”, *Applied Water Science* **11** (2021) 1.
- [12] M. Okanlawon, A. Idris-Nda, A. Amadi, N. Waziri, T. Ako, U. Onoduku, “The Geology and Petrographic Characterization of Rocks in parts of Tegna Sheet 142SE and Alawa Sheet 143SW North-Central Nigeria”, *Minna Journal of Geosciences* **1** (2017) 64.
- [13] O. Momoh, A. Amadi, I. Abdulfatai, Y. Omananyi, U. Onoduku & M. Onah, “Exploration of Groundwater within the Mariam Babangida Girls Science Secondary School Minna, North-central Nigeria using Schlumberger Vertical Electrical Sounding Techniques”, *Journal of Science, Technology, Mathematics and Education* **8** (2012) 21.
- [14] T. A. Ako, U. S. Onoduku, H. D. Salihu, S. J. Ejepu, I. A. Abdulfatai, “Petrographic and Structural Analysis of Exposed Rocks of Bishini Sheet (Block 2), North Central Nigeria”, *Canadian Center of Science and Education. Earth Science Research* **2** (2013) 143.
- [15] S. Ali, T. Ako, U. Onoduku, B. Omang & J. Ejepu, “Petrographic and Phisico-Mechanical Characteristics of Quartzite from the Wolframite Mine in Zumba, Northcentral Nigeria: Implication for their Use as Construction Materials”, *Minna Journal of Geosciences* **2** (2018).
- [16] T. Ako, U. Onoduku, S. Oke, B. Essien, F. Idris, A. Umar & A. Ahmed, “Environmental effects of sand and gravel mining on land and soil in Luku, Minna, Niger State, North Central Nigeria”, *Universal Journal of Geosciences* **2** (2014) 42.
- [17] S. Oke, O. Okeke, A. Amadi & U. Onoduku, “Geotechnical Properties of the Subsoil for Designing Shallow Foundation in some selected parts of Chanchaga area, Minna, Nigeria”, *Journal of Environmental Science* **1** (2009) 45.
- [18] Y. Ajiboye, M. Isinkaye & M. Khandekar, “Spatial distribution mapping and radiological hazard assessment of groundwater and soil gas radon in Ekiti State, Southwest Nigeria”, *Environmental earth sciences* **77** (2018) 1.
- [19] Durrige, “Radon instrumentation: Big bottle Rad H2O user manual”, DUIRRIDGE Company Inc Billerica, USA (2013).
- [20] IAEA, International Atomic Energy Agency, “International basic safety standards for protection against ionizing radiation and for the safety of radiation sources”, *Vienna Safety Series* 115 (1996).
- [21] M. Zalewski, M. Karpińska, Z. Mnich, J. Kapala & P. Zalewski, “Study of  $^{222}\text{Rn}$  concentrations in drinking water in the north-eastern hydroregions of Poland”, *J. Environ. Radioact.* **53** (2001) 167.
- [22] UNSCEAR, “Sources and Effects of Ionizing Radiation. Report to General Assembly with Scientific Annexes”, United Nations, New York (1993).
- [23] L. Xinwei, W. Lingqing, J. Xiaodan, Y. Leipeng & D. Gelian, “Specific activity and hazards of Archeozoic-Cambrian rock samples collected from the Weibei area of Shaanxi, China”, *Radiat. Prot. Dosimet.* **118** (2006) 352.
- [24] A. Kalip, M. Haque & S. Gaiya, “Estimation of annual effective dose due to ingestion and inhalation of radon in groundwater from Kaduna, Nigeria”, *Phys Sci Int J.* **19** (2018) 1.
- [25] S. Suresh, D. Rangaswamy, E. Srinivasa & J. Sannappa, “Measurement of radon concentration in drinking water and natural radioactivity in soil and their radiological hazards”, *Journal of radiation research and applied sciences* **13** (2020) 12.
- [26] EU, “European Union Commission Recommendation 20 December, 2001 on the protection of the public against exposure to radon in drinking water” (2001a).
- [27] EU, “European Union Commission Recommendation on the protection of the public against exposure to radon in drinking water supplies”, *Office J Eur Community L* **344** (2001b) 85.
- [28] M. Isinkaye & Y. Ajiboye, “Assessment of annual effective dose due to radon concentrations in deep and shallow wells within Ekiti State, Nigeria”, *Radioprotection* **52** (2017) 167.
- [29] E. A. Oni & T. A. Adagunodo, “Assessment of radon concentration in groundwater within Ogbomoso, SW Nigeria, *Journal of Physics*”, Conference Series, IOP Publishing (2019) 012098.
- [30] H. K. Shuaibu, M. U. Khandaker, A. Baballe, S. Tata & M. A. Adamu, “Determination of radon concentration in groundwater of Gadau, Bauchi State, Nigeria and estimation of effective dose”, *RaPC* **178** (2021) 108934.
- [31] J. A. Ademola & O. A. Oyeleke, “Radon-222 in groundwater and effective dose due to ingestion and inhalation in the city of Ibadan, Nigeria”, *J. Radiol. Prot.* **37** (2017) 189.
- [32] O. O. Fatoki & J. A. Ademola, “Occurrence and Dose From Intake of Radon In Drinking Groundwater In Ogun State, Nigeria”, *Radiat. Prot. Dosimet.* **192** (2020) 421.
- [33] N. N. Garba, R. U. Nasru & B. B. M. Dewu, “Preliminary Studies on  $^{222}\text{Rn}$  Concentration in Ground Water from Zaria, Nigeria”, *Journal of Physical Science* **23** (2012) 57.
- [34] M. Jibril, N. Garba, R. Nasiru & N. Ibrahim, “Assessment of radon concentrations in water sources from Sabon Gari local government area, Kaduna State, Nigeria”, *Fudma Journal of Sciences* **5** (2021) 254.
- [35] P. Nandakumaran & N. Vinayachandran, “A preliminary appraisal of radon concentration in groundwater from the high background radiation area (HBRA) of Coastal Kerala”, *J. Geol. Soc. India* **95** (2020) 491.
- [36] V. Duggal, S. Sharma & R. Mehra, “Risk assessment of radon in drinking water in Khetri Copper Belt of Rajasthan, India”, *Chemosphere* **239** (2020) 124782.
- [37] UNSCEAR, “Sources and Effects of Ionizing Radiation. Report to General Assembly, with Scientific Annexes”, United Nations, New York (2000).
- [38] P. Divya & V. Prakash, “Investigation on radon concentration in drinking water to assess the whole body dose and excess lifetime cancer risk along coastal Kerala, India”, *JRNC* **322** (2019) 37.
- [39] O. A. Ndubisi, M. A. Briggs-Kamara, F. B. Sigalo & T. A. Iyeneomie, “Analysis of Indoor Radon Level and its Health Risks Parameters in Three Selected Towns in Port Harcourt, Rivers State, Nigeria”, *Journal of the Nigerian Society of Physical Sciences* **3** (2021) 181.
- [40] ICRP, ICRP Publication 60, “1990 Recommendations of the International Commission on Radiological Protection”, Elsevier Health Sciences (1991).