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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[a,*], Oyeleke Olarinoye[a], Simon Olonkwoh Salihu[b], Hyginus Anayo Ugwuanyi[a], Paul Onuche[a], Opeyemi Falade[a], Nwachukwu Chibueze[a]

[a] *Department of Physics, Federal University of Technology, Minna, Niger State, Nigeria*
[b] *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}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_2O accessories. ^{222}Rn concentrations in open wells varied from 2.1±0.7 to 27.9±2.5 Bq L^{-1} with a mean of 10.2±1.5 Bq L^{-1}, while that in boreholes ranged from 2.8±1.1 to 39.2±1.5 Bq L^{-1} with a mean value of 14.3±1.7 Bq L^{-1}. These values are lower than the 100 Bq L^{-1} 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 µSv y^{-1} respectively for the open wells and 104.24, 99.96 and 74.26 µSv 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 µSv y^{-1} respectively, which are below the reference level of 0.1 mSv y^{-1} for potable water recommended by the World Health Organization for public safety. The excess lifetime cancer risk were 0.10×10^{-3} for the open wells and 0.13×10^{-3} for the boreholes, which are lower than the world safety limit 0.29×10^{-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.

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

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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 (Matthew Tikpangi Kolo)

derives its radioactivity from the underlying rocks, soil formations, dissolved radioactive and mineral substances. Dissolved radon (^{222}Rn) in groundwater arises from the decay of naturally occurring uranium and radium (^{226}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}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}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}Rn over a considerable length of time can be responsible for stomach and gastrointestinal cancer [10]**.** Levels of ^{222}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

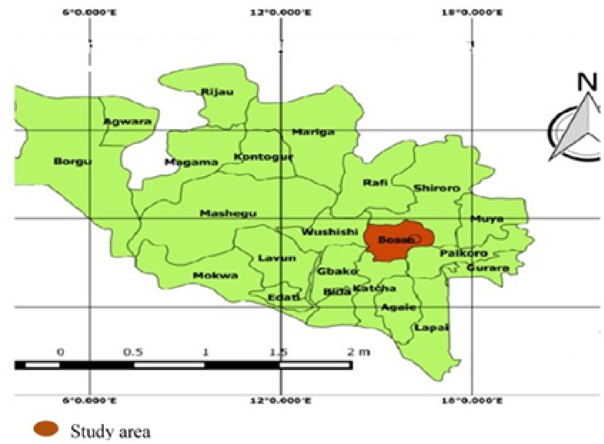

Figure 1: Map of Niger State showing the study area

Bosso community have not so far been examined or reported in literature. This study is therefore a pioneering work aimed at measuring ^{222}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^2, is geographically located within the Guinea Savanna ecological zone of Nigeria. It lies between latitudes $09^0\ 40'$ N to $09^0\ 42'$ N and longitudes $06^0\ 30'$ E to $06^0\ 36'$ 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℃.

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}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_2O 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.

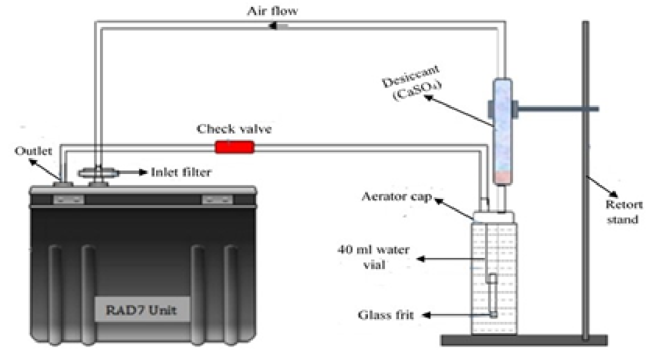

Figure 2: Schematic diagram of RAD-H_20 set for measurement of waterborne radon

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 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 Bq L^{-1}, W_{CR} is the water consumption rate per year (L yr^{-1}) and DCF is the dose conversion factor expressed in 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 χ_{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 m^3 h^{-1}), ω (0.5) is the coefficient to indoor air, v is the bulk volume of indoor air per person taken to be 20 m^3, and λ_c (0.7 h^{-1}) is the air exchange rate [22, 23].

3. Results and Discussion

3.1. Radon Concentration

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 2

As shown in Table 2, ^{222}Rn concentrations in LW varied between 2.1±0.7 to 27.9±2.5 Bq l^{-1} with a mean value of 10.2±1.5 Bq l^{-1}. Similarly, ^{222}Rn concentrations in BH ranged from 2.8±1.1 to 39.2±1.5 Bq l^{-1} with a mean value of 14.3±1.7 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}Rn concentration values above the USEPA safety threshold of 11.1 Bq l^{-1} as seen in Figure 3, ^{222}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	2×10^{-8}
3 yrs	2 - 7	0.82	300	
10 yrs (children)	7 - 12	0.96	350	2×10^{-8}
15 yrs	12 - 17	1.64	600	
Adults	> 17	2.00	730	1×10^{-8}

Table 2: ^{222}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}Rn(Bq l^{-1})	χ_{Rn} (mBq l^{-1})	ACED (μSv y^{-1}) to ICRP age groups Adults	Children	Infants
Open wells					
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
Boreholes					
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
Min	2.8±1.1	1.00	20.44	19.60	14.56
Max	39.2±1.5	13.99	286.16	274.40	203.84
Mean	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 water 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}Rn concentration in the two groundwater sources (LW and BH) of the studied community. ACED due to ingestion of water from LW source by

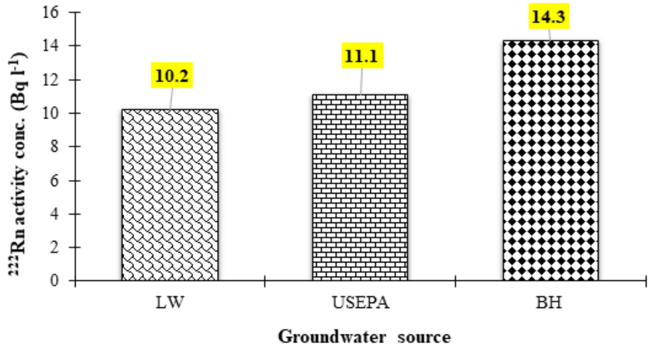

Figure 3: ^{222}Rn concentration in LW and BH sources together with the USEPA threshold

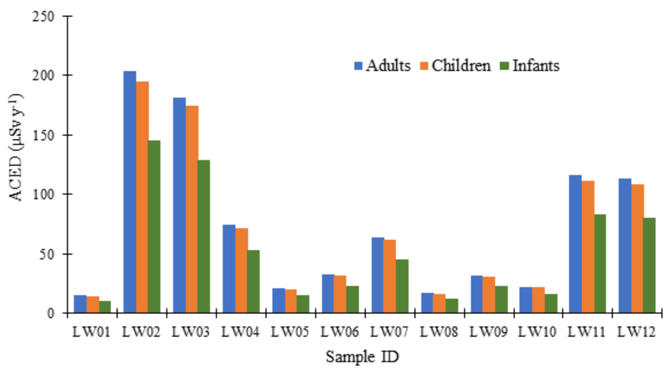

Figure 4: ACED received by different ICRP age groups due to waterborne radon from LW groundwater sources

adult population ranged from 15.33 to 203.67 µSv y^{-1} with an average value of 74.64 µSv y^{-1}, from 14.70 to 195.30 µSv y^{-1} with a mean value of 71.58 µSv y^{-1} for the children, while infants recorded ACED values between 10.92 to 145.08 µSv y^{-1}, with a mean value of 53.17 µSv 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 µSv 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 mSv y^{-1} and 0.274 mSv y^{-1} respectively. These values are below the 1mSv 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

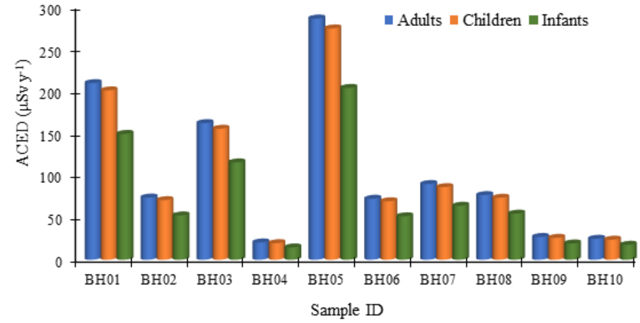

Figure 5: ACED received by different ICRP age groups due to waterborne radon from BH groundwater sources

Nigeria. Mean radon concentration for open wells within the community (10.2 Bq l^{-1}) is higher than that reported by Kalip et al [24] for Kaduna (1.8 Bq l^{-1}). Additionally, average value obtained for the boreholes within the community (14.3 Bq l^{-1}) is about 54% lower than the one reported by Isinkaye and Ajiboye [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]:

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

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

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

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}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 µSv y^{-1}, with a mean value of 1.79 µSv y^{-1}, while the ACED range to the lungs via inhalation is 5.29 to 70.31 µSv y^{-1} with an average value of 25.77 µSv y^{-1}. Similarly, the range of ACED from BH sources delivered to the stomach via the ingestion pathway is 0.49 to 6.86 µSv y^{-1} with a mean of 2.50 µSv y^{-1} and to the lungs via inhalation route is 7.06 to 98.78 µSv y^{-1} with an average value of 35.99 µSv 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 5.66×10^{-3} to 0.075 mSv y^{-1} for LW groundwater sources and from 7.55×10^{-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 µSv 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 0.10×10^{-3} and 0.13×10^{-3} respectively, which are below the world mean value of 0.29×10^{-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}Rn) concentration using Durridge RAD-7 radon detector. The results showed that, although ^{222}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}Rn (Bq/l)	ACED (µSv/y) to internal organs Ingestion (Stomach)	Inhalation (lungs)	Whole body	ELCR (10^{-3})
Open wells					
LW 01	2.1±0.7	0.37	5.29	5.66	0.02
LW 02	27.9±2.5	4.88	70.31	75.19	0.26
LW 03	24.9±2.5	4.36	62.75	67.11	0.23
LW 04	10.2±1.6	1.79	25.70	27.49	0.10
LW 05	2.9±0.8	0.51	7.31	7.82	0.03
LW 06	4.5±1.1	0.79	11.34	12.13	0.04
LW 07	8.8±1.4	1.54	22.18	23.72	0.08
LW 08	2.4±0.8	0.42	6.05	6.47	0.02
LW 09	4.4±1.1	0.77	11.09	11.86	0.04
LW 10	3.1±2.0	0.54	7.81	8.35	0.03
LW 11	16.0±2.8	2.80	40.32	43.12	0.15
LW 12	15.5±0.8	2.71	39.06	41.77	0.15
Min	2.1±0.7	0.37	5.29	5.66	0.02
Max	27.9±2.5	4.88	70.31	75.19	0.26
Mean	10.2±1.5	1.79	25.77	27.56	0.10
Boreholes					
BH 01	28.7±3.1	5.02	72.32	77.35	0.27
BH 02	10.1±1.5	1.77	25.45	27.22	0.10
BH 03	22.2±1.0	3.89	55.94	59.83	0.21
BH 04	2.8±1.1	0.49	7.06	7.55	0.03
BH 05	39.2±1.5	6.86	98.78	105.64	0.37
BH 06	9.9±2.0	1.73	24.95	26.68	0.09
BH 07	12.3±4.5	2.15	31.00	33.15	0.12
BH 08	10.5±0.2	1.84	26.46	28.30	0.10
BH 09	3.7±0.8	0.65	9.32	9.97	0.03
BH 10	3.4±1.3	0.60	8.57	9.16	0.03
Min	2.8±1.1	0.49	7.06	7.55	0.03
Max	39.2±1.5	6.86	98.78	105.64	0.37
Mean	14.3±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.

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