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Assessment of Radon Concentration in Groundwater with Associated Human-Health Implications around Bagwai and Shanono Artisan Gold Mining Site Kano State, Northwestern Nigeria

Yakubu Hannafi[1], Koki F Salmanu[2], Musa S Abdulhamid[2], Ali Yakubu[3], Abubakar Muhammed[2] and Aliyu Rilwan[4]

[1] Department of Physics, Nigerian Army University, Biu, Borno State, Nigeria
[2] Department of Physics, Bayero University, Kano, Kano State, Nigeria
[3] Department of Physics, Federal University, Dutse, Jigawa State, Nigeria
[4] National Institute for Freshwater Fisheries Research New Bussa Niger State, Nigeria

Corresponding E-mail: hannafiyakubu2015@gmail.com

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Abstract

This study assesses the activity concentration of Radon in underground water around Bagwai and Shanono artisan gold mining Sites in Kano State, Northwestern Nigeria. A total of (39) underground water samples, including sixteen (16) from boreholes and twenty-three (23) from hand-dug wells, were randomly collected. The activity concentration of Radon was analyzed using a portable radon detector, Rad7, from DURRIDGE Company. The results show that the radon concentration in all the water samples ranges from 4.13 to 45.24 Bq/l, with an average value of 20.13 Bq/l. The calculated total annual effective dose due to both ingestion and inhalation for different age groups ranges from 42.40, 57.60 and 65.30 (μSv/y) to 457.10, 622.06 and 704.60 (μSv/y), with an average value of 203.32, 276.70 and 313.51 (μSv/y) for adults, children, and infants respectively. The total excess lifetime cancer risk for different age groups varies from 0.00149, 0.00202 and 0.0247 to 0.0160, 0.0220 and 0.0247 with mean values of 0.00703, 0.00956 and 0.0109 for adults, children, and infants. The obtained results are higher than the internationally recommended limits set by USEPA of 4 to 40Bq/l and the International Commission on Radiological Protection (ICRP) value of 0.1mS/y; thus, the water in the study area is not suitable for drinking and other domestic purposes. Hence, remedial action needs to be taken by the authorities to ensure the continuous utilization of water within the study area.

Keywords: Groundwater; Ingestion; Inhalation; Radon; Rad7 detector.

I. INTRODUCTION

Water is an essential resource for human survival, and the value of fresh drinking water cannot be overemphasized, with a substantial portion of the world's population relying on groundwater sources, such as wells and boreholes, for their very existence [1]. Groundwater contains dissolved Radon from the uranium series, which is present in soil and rocks [2]. Because water is valuable, humans will go to any extent to collect it from several sources, including rivers, streams, rain, wells and boreholes. Reference [2] observed that cancer caused by chemical carcinogens is mainly caused by drinking polluted water. Water pollution originates from fertilizers used by farmers, materials used in hospitals and industries, and the release of sewage and garbage into the environment. All these waste items typically include radioactive elements [3], with Radon being the second most common cause of death from lung cancer globally [1].

Radon (^{222}Rn), a noble radioactive gas from geogenic sources, is highly mobile due to its short half-life of 3.8 days; this short half-life makes it one of the rarest radionuclides compared to uranium and thorium (mother radionuclides) with very long half-lives (several billions of years). Despite its limited availability, it will be present in the future since it is constantly produced from its mother radionuclides (uranium). Exposure to this colourless, odourless, and tasteless chemical can pose a severe public health risk because it is responsible for the human population's radiation exposure [5]. Radon gas and its radioactive isotopes have gained special attention among all other naturally occurring radioactive materials because they provide humans with the highest total annual effective dose [6].

Groundwater is the most prevalent and commonly utilized resource. However, its quality can be affected by human activities such as metal ore mining and milling, which create a rising source of naturally occurring radioactive materials (NORMS) in the earth's crust [7]. Mining minerals contribute to the danger of exposure to naturally occurring radionuclides by exposing them to the earth's surface. The risk evolves when these radionuclides are transported into bodies of water used for drinking [8]. Previous studies reveal that gold mining occurs in Shanono and Bagwai local government areas of Kano State, Northwestern Nigeria. The populace in the proximity of Bagwai and Shanono is heavily engaged in extensive gold mining, which could potentially face a heightened risk of adverse radiological health outcomes, notably lung cancer and respiratory dysfunction [2].

Several studies have been carried out within and outside Nigeria to investigate Radon concentration in groundwater and its potential radiological human health risk to inhabitants. These studies include a survey on Radon monitoring in groundwater samples from some areas of northern Rajasthan, India, using a RAD7 detector [2]. Similarly, [5] presented a study on a new framework for groundwater resource management and radiological protection: the adoption of a Portuguese Action Plan for Drinking Water Radon and Its Effects on Human Health, while [9] investigated heavy metals and Radon concentration in soil and water samples from Wadi-B Jere Oil Exploration Sites in Maiduguri, Northeast Nigeria. Reference [1] estimated Excess Life Cancer Risk and Annual Effective Dose for boreholes and well water in Dutse, Jigawa State, Nigeria, using a liquid scintillation counter, and [10] assessed the Radon concentration and associated health implications in groundwater and soil around Riruwai mining sites, Kano State, Nigeria and its environs using Rad7 detector.

With the numerous illicit gold mines in the study area, there is a need for more studies on radon concentration at the Bagwai and Shanono artisanal gold mining sites in Kano State, Northwestern Nigeria. Sparse data on such studies exists because Radon activity concentrations are often determined without considering the excess lifetime cancer risk and annual effective dose. Therefore, measuring the radon concentrations in water is essential to monitor the public's exposure to ionizing radiation.

Thus, this study is aimed at evaluating the Radon concentrations, excess lifetime cancer risk, and annual effective dose from the consumption of borehole and well water for various age groups in the Bagwai and Shanono Local Governments, Kano State, Northwestern Nigeria, using the portable Radon detector, Rad7.

II. MATERIALS AND METHOD

A. Study Area

Bagwai and Shanono are located between latitudes 11˚93′22″ to 12˚31′38″N and longitudes 7˚81′42″ to 8˚26′26″E. They share borders with Dawakin Tofa, Tofa, and Rimin Gado local governments to the south, Gwarzo and Kabo local governments to the east, and Tsanyawa and Bichi local governments to the north, all within Kano state. To the west, they are bordered by the Musawa and Kankia local governments of Katsina state. The foundation's complex geological structure dominates the area, characterized by predominantly flat plains with isolated hills and mountains. The rocks in the area include those from the younger granite series, volcanic, and some younger dykes and flows, which suggests a diverse geological history and potentially significant mineral resources [11]. The availability of safe and reliable water sources is an essential prerequisite for sustainable development within these areas, as deserts are generally not habitable because of the absence of water [12]. Consequently, freshwater quality and availability have continued to be among the most crucial environmental and sustainability challenges of the twenty-first century [3].

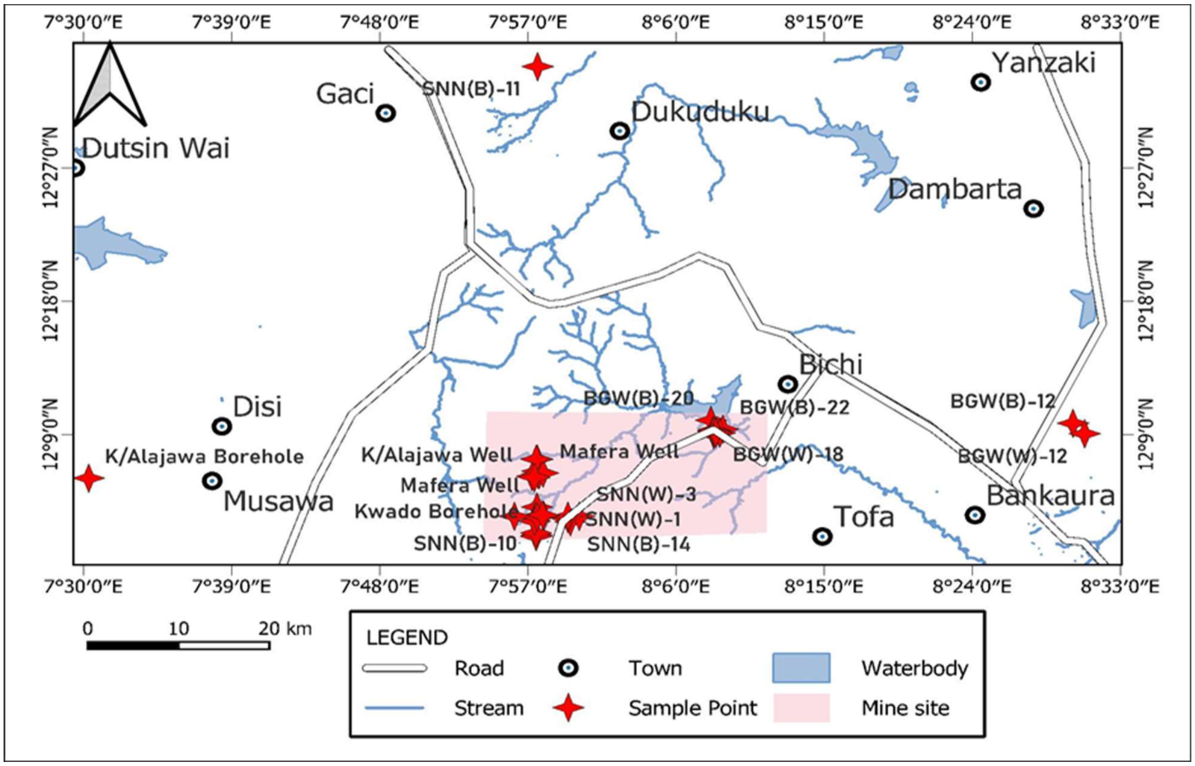

Fig. 1 Geological map of the study area.

B. Materials

The materials used for this study include a 250 ml container, water samples, capture software, GPS for coordinate mapping, and the electronic radon detector DURRIDGE RAD7 (MA 01821/3332).

C. Methods

1) Sample collection and preparation

Thirty-eight (38) groundwater samples were collected from wells and boreholes in the Bagwai and Shanono gold mining sites of Kano State, Northwestern Nigeria. The samples were carefully collected into dry, clean Faro jars, filled to the brim to avoid air pockets and sealed to prevent contamination and the escape of radon gas. All groundwater samples collected from the Bagwai and Shanono artisans' gold mining site of Kano State, Nigeria, were carefully marked and labelled with the time and location of the collection. This labelling ensures easy identification and prevents mix-ups during analysis. The well and borehole water samples were transported to the laboratory for thorough analysis.

2) Sample Analysis

Radon concentrations in water samples collected from the Bagwai and Shanono artisans' gold mining sites were measured using RAD7, an electronic radon detector connected to a RAD-H2O accessory (DURRIDGE Co., USA). Fig. 2 shows the Rad7 and RAD H2O set-up for Radon detection in water. In the set-up, the RAD7 detector was used to measure Radon in water by connecting it with a bubbling kit, which enables the degassing of Radon from a water sample into the air in a closed loop. A sample of water was taken in a Radon-tight reagent bottle with a capacity of 250 ml, connected in a closed circuit with a zinc sulfide-coated detection chamber acting as a scintillator to detect alpha activity, and a glass bulb containing calcium chloride to absorb moisture. Air was then circulated in a closed circuit for 5-10 minutes until the Radon was uniformly mixed with the air, and the resulting alpha activity was recorded, directly giving the radon concentration [4]. The Radon activity concentration in water is reduced to deficient concentrations by ensuring the air and water volumes remain constant and independent of the flow rate. The process involves continuously extracting Radon as air circulates through the water until equilibrium. This state of equilibrium is typically achieved in about 5 minutes, after which no Radon can be extracted from the water. The measurement results are displayed on the RAD-7 screen after 30 minutes, which has accuracy and sensitivity that exceed those of other existing devices [14].

Fig. 2 Rad7 and Rad-H2o Set-Up for Radon in Water Detection.

III. RADIOLOGICAL HAZARD PARAMETERS

A. Determination of Annual Effective Dose due to Ingestion (AED_{ing})

The annual effective dose (μSvy^{-1}) due to drinking water ingestion was calculated using (1).

$$AED_{ing} = K \times C_{Rn} \times C_w \times T \quad (1)$$

Where K is the conversion factor for ingesting a dose of ^{222}Rn $SvBq^{-1}$ for adults, the committed effective dose per unit intake from ingesting Radon in water (K) is $10^{-8}\ SvBq^{-1}$. It is $2 \times 10^{-8}\ SvBq^{-1}$ and $7 \times 10^{-8}\ SvBq^{-1}$ for adults, children and infants, respectively. C_w is the water consumption estimated as 2 l per day for adults, 1.5 l per day for children and 0.5 L per day for infants. C_{Rn} is the concentration of ^{222}Rn (Bq^{-1}) in each sample, and T is the period of consumption (365 days) y^{-1}.To calculate the AED_{ing}, we assumed that adults, children and infants drink directly from the source and consume an average of 2.0, 1.5, and 0.5 l of water per day, respectively [15].

B. Determination of Annual Effective Dose due Inhalation (AED_{inh})

To calculate the AED_{inh} via inhalation, we used (2), which is given as:

$$AED_{inh} = C_{Rn} \times F \times O \times DCF \times R_w \quad (2)$$

Where AED_{inh} is the Annual effective dose via inhalation (μSvy^{-1}), C_{Rn} is the concentration of ^{222}Rn (Bq^{-1}), R_w is the ratio of Radon in the air to the Radon in water (10^{-4}); F is the equilibrium factor between Radon and its progeny (0.4), O is the average indoor occupancy time per individual (7,000 hy^{-1}). DCF is the dose conversion factor for Radon exposure ($9nSvh^{-1}(Bqm^{-3})^{-1}$) [16].

C. Determination Total Annual Effective Dose (AED_{total})

The total Annual Effective Dose (AED_{total}) derived from both ingested and inhaled dose summation due to utilization of the surface and ground waters in the mining area is calculated using (3).

$$AED_{total} = AED_{ing} + AED_{inh} \quad (3)$$

AED_{total} is the total annual effective dose(μSvy^{-1}), AED_{ing} implies the Annual effective dose from ingestion(μSvy^{-1}), and AED_{inh} implies the Annual effective dose from inhalation (μSvy^{-1})) [17].

D. Estimation of Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk (ELCR) was calculated using the AEDE values and (4).

$$ELCR\ (mSvy^{-1}) = AEDE \times ave.duration\ of\ life\ (DL) \times risk\ factor\ (RF) \quad (4)$$

AEDE is the annual effective dose equivalent, DL is the life expectancy (70 years), and RF is the fatal cancer risk factor (Sv^{-1}). For low-dose background radiation, which is thought to generate stochastic effects, ICRP 60 utilizes a fatal cancer risk factor value of 0.05 for public exposure [18].

IV. RESULTS AND DISCUSSION

Thirty-nine (39) groundwater samples were collected from Bagwai and Shanono artisans' gold mining site, Kano state, northwestern Nigeria, and analyzed for radon gas activity concentration. Sixteen(16) were samples from boreholes, while twenty-three (23) were samples from hand-dug wells, with depths ranging from 30 to 557 m in elevation. The measured results of Radon concentration are tabulated in Table I.

Table I. Results of Radon Concentrations of boreholes and well water samples in Bagwai and Shanono local Government area, Kano state, Nigeria, measured in Bq/l and total annual effective dose for different age groups (adults, children and infants) with estimated excess lifetime cancer risk for various age groups.

S/N	Sample ID	Latitude	Longitude	Rn (Bq/l)	AEDEing (A)	AEDEing (C)	AEDEing (INF)	AEDEinh	AEDEtot (A)	AEDEtot (C)	AEDEtot (I)	ELTCR (A)	ELTCR (C)	ELTCR (I)
1	KD01 (W)	12°2´12.3"	7°57'32.8"	14.72	107.46	161.18	188.05	41.216	148.67	202.4	229.26	0.0005	0.0007	0.0008
2	KD02 (W)	12°2´09.0"	7°57'30.4"	8.34	60.882	91.323	106.54	23.352	84.234	114.68	129.9	0.0003	0.0004	0.0005
3	KD03 (B)	12°2´22.6"	7°57'30.6"	15.91	116.14	174.21	203.25	44.548	160.69	218.76	247.8	0.0006	0.0008	0.0009
4	U/S01 (W)	12°6´21.5"	7°57'37.3"	12.2	89.06	133.59	155.86	34.16	123.22	167.75	190.02	0.0004	0.0006	0.0007
5	U/S02 (W)	12°6´22.9"	7°57'42.2"	16.86	123.08	184.62	215.39	47.208	170.29	231.83	262.59	0.0006	0.0008	0.0009
6	U/S03 (B)	12°6´20.1"	7°57'42.0"	6.78	49.494	74.241	86.615	18.984	68.478	93.225	105.6	0.0002	0.0003	0.0004
7	MAF01 (W)	12°6´33.5"	7°57'35.8"	14.27	104.17	156.26	182.3	39.956	144.13	196.21	222.26	0.0005	0.0007	0.0008
8	MAF02 (W)	12°6´25.3"	7°57'56.4"	26.1	190.53	285.8	333.43	73.08	263.61	358.88	406.51	0.0009	0.0013	0.0014
9	MAF03 (B)	12°4´08.0"	7°57'34.2"	15.9	116.07	174.11	203.12	44.52	160.59	218.63	247.64	0.0006	0.0008	0.0009
10	K/BA01 (W)	12°7´22.5"	7°57'32.7"	31.36	228.93	343.39	400.62	87.808	316.74	431.2	488.43	0.0011	0.0015	0.0017
11	K/BA02 (W)	12°7´21.5"	7°57'35.4"	26.46	193.16	289.74	338.03	74.088	267.25	363.83	412.11	0.0009	0.0013	0.0014
12	K/BA03 (B)	12°7´21.7"	7°57'31.2"	28	204.4	306.6	357.7	78.4	282.8	385	436.1	0.001	0.0013	0.0015
13	K/AL01 (W)	12°6´11.9"	7°57'15.4"	16.8	122.64	183.96	214.62	47.04	169.68	231	261.66	0.0006	0.0008	0.0009
14	K/AL02 (W)	12°6´07.7"	7°57'24.7"	42	306.6	459.9	536.55	117.6	424.2	577.5	654.15	0.0015	0.002	0.0023
15	K/AL03 (B)	12°6´04.8"	7°57'19.8"	7.31	53.363	80.045	93.385	20.468	73.831	100.51	113.85	0.0003	0.0004	0.0004
16	BGW(B)-12	12°9´47.2"	8°30'8.11"	6.4	46.72	70.08	81.76	17.92	64.64	88	99.68	0.0002	0.0003	0.0003
17	BGW(B)-19	12°9´1.23"	8°30'18.6"	6.25	45.625	68.438	79.844	17.5	63.125	85.938	97.344	0.0002	0.0003	0.0003
18	BGW(B)-20	12°9´59.23"	8°8'8.11"	30.14	220.02	330.03	385.04	84.392	304.41	414.43	469.43	0.0011	0.0015	0.0016
19	BGW(B)-22	12°9´23.26"	8°8'52.01"	13.33	97.309	145.96	170.29	37.324	134.63	183.29	207.61	0.0005	0.0006	0.0007
20	BGW(B)-23	12°9´8.58"	8°8'26.58"	31.19	227.69	341.53	398.45	87.332	315.02	428.86	485.78	0.0011	0.0015	0.0017
21	BGW(B)-13	12°9´20.53"	8°8'17.36"	18.18	132.71	199.07	232.25	50.904	183.62	249.98	283.15	0.0006	0.0009	0.001
22	BGW(W)-12	12°9´4.72"	8°30'50.8"	18.7	136.51	204.77	238.89	52.36	188.87	257.13	291.25	0.0007	0.0009	0.001
23	BGW(W)-15	12°9´14.16"	8°8'16.34"	45.1	329.23	493.85	576.15	126.28	455.51	620.13	702.43	0.0016	0.0022	0.0025
24	BGW(W)-16	12°9´15.92"	8°8'20.23"	31.95	233.24	349.85	408.16	89.46	322.7	439.31	497.62	0.0011	0.0015	0.0017
25	BGW(W)-17	12°9´80.23"	8°8'40.16"	4.46	32.558	48.837	56.977	12.488	45.046	61.325	69.465	0.0002	0.0002	0.0002
26	BGW(W)-18	12°9´12.32"	8°8'26.52"	17.1	124.83	187.25	218.45	47.88	172.71	235.13	266.33	0.0006	0.0008	0.0009
27	BGW(W)-21	12°9´9.34"	8°8'26.28"	13	94.9	142.35	166.08	36.4	131.3	178.75	202.48	0.0005	0.0006	0.0007
28	SNN(B)-8	12°3´26.1"	7°57'26.23"	45	328.5	492.75	574.88	126	454.5	618.75	700.88	0.0016	0.0022	0.0025
29	SNN(B)-9	12°3´29.2"	7°57'28.10"	14.06	102.64	153.96	179.62	39.368	142.01	193.33	218.98	0.0005	0.0007	0.0008
30	SNN(B)-10	12°3´10.3"	7°57'25.1"	4.19	30.587	45.881	53.527	11.732	42.319	57.613	65.259	0.0001	0.0002	0.0002
31	SNN(B)-11	12°3´52.1"	7°57'36.2"	12.11	88.403	132.6	154.71	33.908	122.31	166.51	188.61	0.0004	0.0006	0.0007
32	SNN(B)-14	12°3´8.44"	7°59'35.8"	5.51	40.223	60.335	70.39	15.428	55.651	75.763	85.818	0.0002	0.0003	0.0003
33	SNN(W)-1	12°3´19.9"	7°59'26.8"	36.7	267.91	401.87	468.84	102.76	370.67	504.63	571.6	0.0013	0.0018	0.002
34	SNN(W)-3	12°3´30.3"	7°59'68.4"	16.59	121.11	181.66	211.94	46.452	167.56	228.11	258.39	0.0006	0.0008	0.0009
35	SNN(W)-4	12°3´30.9"	7°59'26.8"	13.77	100.52	150.78	175.91	38.556	139.08	189.34	214.47	0.0005	0.0007	0.0008
36	SNN(W)-5	12°3´27.1"	7°57'34.8"	32.56	237.69	356.53	415.95	91.168	328.86	447.7	507.12	0.0012	0.0016	0.0018
37	SNN(W)-6	12°3´32.8"	7°57'99.1"	45.24	330.25	495.38	577.94	126.67	456.92	622.05	704.61	0.0016	0.0022	0.0025
38	SNN(W)-7	12°3´35.8"	7°57'84.2"	16.44	120.01	180.02	210.02	46.032	166.04	226.05	256.05	0.0006	0.0008	0.0009
39	SNN(W) 2	12°6´35.8"	8°3´1515.8"	24.05	175.57	263.35	307.24	67.34	242.91	330.69	374.58	0.0009	0.0012	0.0013
	Min. Value			4.19	30.587	45.881	53.527	11.732	42.319	57.613	65.259	0.0001	0.0002	0.0002
	Max. Value			45.24	330.25	495.38	577.94	126.67	456.92	622.05	704.61	0.0016	0.0022	0.0025
	Ave. Value			20.129	146.94	220.41	257.15	56.361	203.3	276.77	313.51	0.0007	0.001	0.0011

Fig. 3 shows a plot of the Radon activity concentration of borehole and well water samples in Bq/l against the Sample ID of the study area, with values ranging from 4.19 to 45.24 Bq/l with a mean value of 20.13 Bq/l which is above the recommendation limits of 11.1 Bq/L as set by the United States Environmental Protection Agency [5], world average value of 10 Bq/l and 11.1 Bq/l set by the Standard Organization of Nigeria [19], [20]. These results revealed that 15% of all the water samples collected are below the United States Environmental Protection Agency limit, 76% are above the safe limit recommended by USEPA, and 9% are above the $4 - 40$ Bq/l safe limit of radon concentration in drinking water samples as recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation [8]. Based on these findings, 91% of the water collected within the study area is unsafe for drinking and other domestic use. Thus, the consumption of water obtained within the study area threatens the health of both humans and animals alike by exposing sensitive cells in their digestive system and other organs once it is taken into the bloodstream. Also, radon in drinking water may have other harmful impacts on human health beyond causing lung cancer.

A comparison of the Radon concentration in the study area with other studies carried out in some states within Nigeria, Kwara [15], Dutse, Jigawa [3], Katsina [21], Borno [9] and Lagos [22] is depicted in Fig. 4. The radon concentration in water samples in [9] is in close agreement with the present study. However, the radon concentration in [15], [3], and [21] are higher, while the concentration of Radon in [22] is lower than the reported values in the present study.

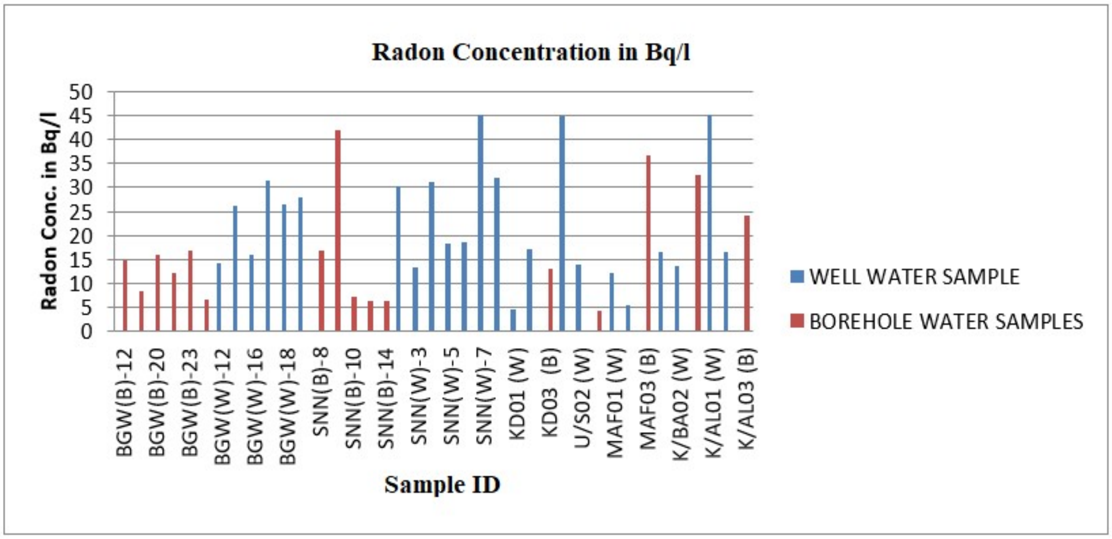

Fig. 3 Estimated Radon activity concentration of borehole and well water in Bq/l against the Sample ID of the study area.

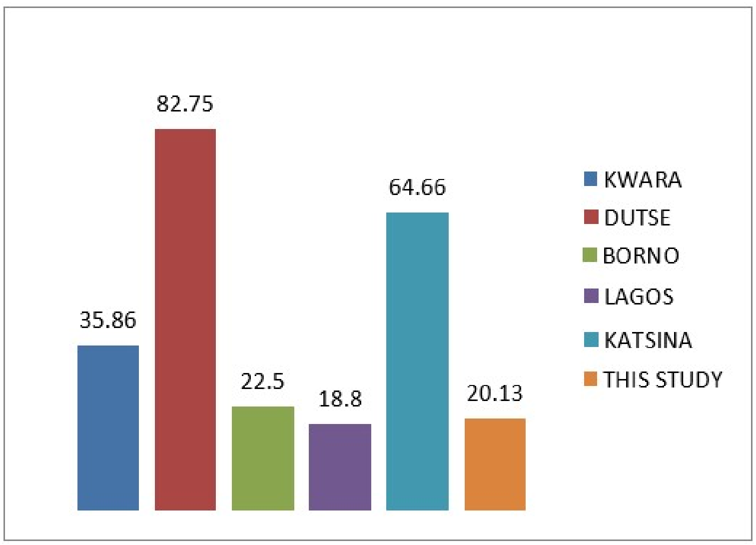

Fig. 4 Comparison of Estimated Radon concentration of the study area with other states.

Fig. 5 depicts the estimated total annual effective dose for different age groups (Adults, Children and Infants) for all the locations within the study area. The mean total annual effective dose due to ingestion for various age groups is given by 42.40, 57.60 and 65.30 ($\mu Sv/y$) to 457.10, 622.06 and 704.60 ($\mu Sv/y$), with an average value of 203.32, 276.70 and 313.51 ($\mu Sv/y$) for adults, children, and infants. The total annual effective dose for adults and children of the studied water samples is above the safe limit (100 μSr 0.1 mSv/y) recommended by WHO (2003) and the EU Council (1998), while the annual effective dose due to inhalation is within the safe limit of 0.1 mSv/y recommended by WHO (2004) and the European Council (EU) (1998) [2]. Several factors, including the methods of measurement, depth of water resources, the geological structure of the area, and hydrological processes, could influence the results obtained. The data reveal significant radiological health concerns across all age groups, as the recorded values exceed the WHO's permitted limits of 100 $\mu Sv/y$ for adults. Since newborns receive higher radiation doses than both adults and children, these results reveal a severe health risk. This is alarming because, compared to adults and children, infants' developing vital organs make them more susceptible to radiation [10].

Fig. 6 illustrates the estimated excess lifetime cancer from inhalation for boreholes and well water samples against sample ID.

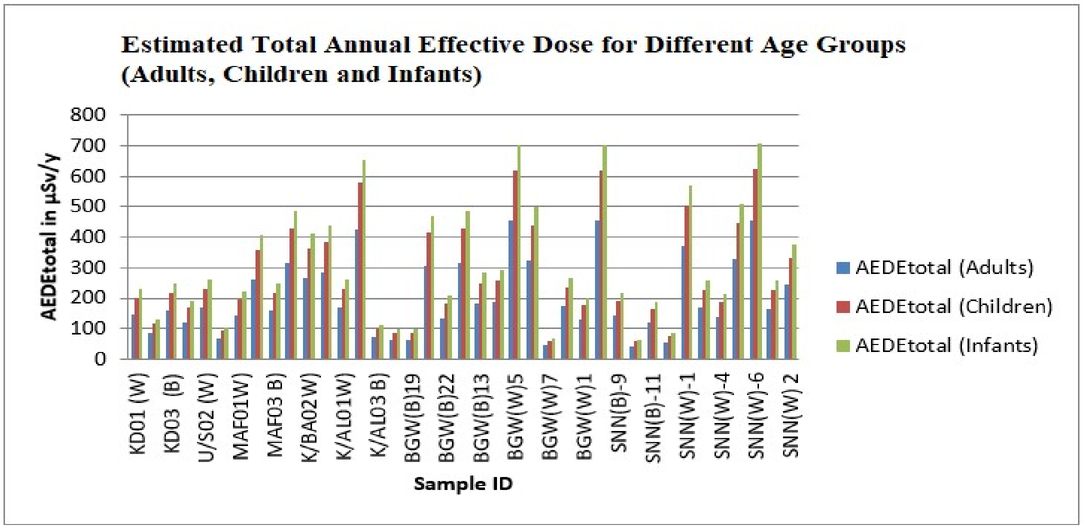

Fig. 5 Estimated total annual effective dose for different age groups (Adults, Children, and Infants) for all the locations in the study area.

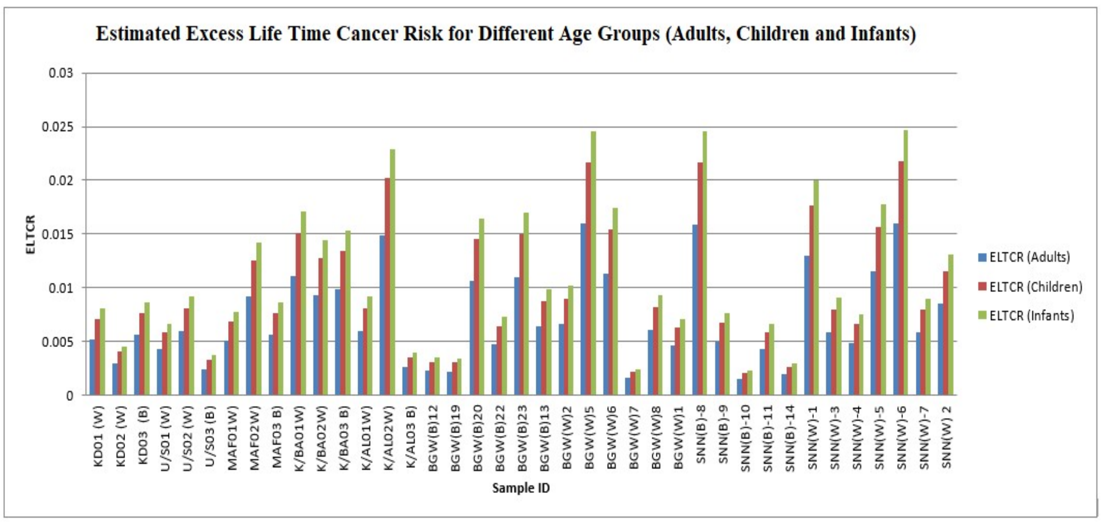

Fig. 6 Estimated Excess lifetime cancer due to inhalation for boreholes and well water samples against sample ID.

The total excess lifetime cancer risk for different age groups was found to vary from $0.00149, 0.00202$ and 0.0247 to $0.0160, 0.0220$ and 0.0247, respectively, with mean values of 0.00703, 0.00956 and 0.0109 for adults, children, and infants respectively (See Table I). All the average values obtained for excess lifetime cancer risk due to ingestion and inhalation are above the world average of $0.002.9 \times 10^{-4}$ reported by the United Nations Scientific Committee on the Effects of Atomic Radiation [11].

V. CONCLUSION

Radon concentrations were measured with a calibrated RAD7-Active Electronic Portable Detector, and the total annual effective doses for adults, children, and infants and total excess lifetime cancer risk were computed. An assessment of Radon levels in groundwater at Bagwai and Shanono artisan mining sites within Kano State, Northwestern Nigeria, revealed significant radiological risks associated with water from boreholes and hand-dug wells. The results indicated that Radon concentration surpassed international safety limits, posing a radiological threat to people residing within these areas. Nigeria currently lacks specific regulations for Radon in drinking water. Hence, there is a need to establish a national maximum contaminant limit for Radon and other radionuclides. A thorough investigation of Radon levels in drinking water sources across all geopolitical zones in Nigeria is crucial to identifying high-risk areas and protecting citizens from the dangers of Radon exposure. The study also underscores the importance of reassessing the public water system and educating the public about Radon, its health risks, and methods to reduce its concentration in water. Both inhalation and ingestion of Radon are associated with higher risks of stomach and lung cancers, highlighting the necessity of public health initiatives. Additionally, the study recommends conducting epidemiological research to examine the incidence of lung and stomach cancers in regions with more elevated Radon concentrations, providing essential data for health policies and risk management. Finally, this research underscores the urgent need for national regulations on Radon in drinking water, comprehensive monitoring across Nigeria, public education on Radon risks, and further epidemiological studies to safeguard public health.

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