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Assessment of Radon Concentration in some Selected Water Sources at Kiyawa Town, Kiyawa, Jigawa State, Nigeria

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Abstract

In this study, an assessment of Radon concentration in some selected water sources from Kiyawa town, Kiyawa local Government area, Jigawa state, Nigeria was conducted. The results obtained show that the concentrations of Radon in the water samples ranged from 32.152 to 43.891 Bq/L, with mean values of 37.78 Bq/L and 35.13 Bq/L for well and borehole water respectively. These results were compared with the world average Maximum Contaminant Level (MCL) of 10 Bq/L set by the World Health Organization (WHO), and it was observed that 60% of the recorded Radon concentrations, alongside the mean values for both water types, exceeded the WHO's recommended MCL of 10 Bq/L, as well as the MCL of 11.1 Bq/L set by the United States Environmental Protection Agency (USEPA) in 1991. However, all mean values were below the recommended action level of 100 Bq/L set by the European Commission (2001/928/Euratom) for public water supplies, and WHO in 2008. Also, all the mean values of the annual effective doses exceeded the recommended level of 0.1 mSv/year set by the WHO. Consequently, it is recommended that the inhabitants of Kiyawa town boil their water, regardless of its source, before drinking to reduce Radon concentrations in the water.

Keywords: Radon-222; Water; Liquid scintillation counter; Radiation exposure; Maximum contaminant level.

I. INTRODUCTION

Water is one of the most significant resources to humans and every other life and forms the major constituent of the Earth's streams, lakes, and oceans, and the fluid of most living organisms. It covers about 71% of the earth's surface. Man uses water for various reasons such as transportation, power generation, agriculture, and other domestic activities hence its availability and quality with regards to radiological, microbiological, chemical, and any other form of contamination are delicate and vital issues [1], [2]. Unfortunately, access to potable drinking water in most developing countries such as Nigeria is a major challenge hence most people rely heavily on untreated surface and groundwater sources for consumption which may contain dissolved naturally occurring radioactive materials (NORMs) which decay to numerous isotopes including Radon.

Radon-222, a member of the uranium decay series, is a naturally occurring radioactive inert gas with a half-life of 3.82 days, which contributes to the largest proportion of total radiation from natural sources [3]. Studies have shown that Radon-222 (^{222}Rn) and its progeny contribute about 50% of the total effective dose equivalent from natural sources [4]. Radon-222 is soluble in water. The concentration of Radon in water is due to the decay of Radium-226 associated with rocks and soils which infiltrate and dissolve in water [5]. Normally, drinking water from groundwater sources has a higher concentration of Radon than surface water. The exposure of a population to high concentrations of Radon and its daughters for a long period has significant health effects including respiratory functional changes and cancer of the lungs, stomach and gastrointestinal tract [6].

The inhabitants of Kiyawa Local Government Area (LGA) of Jigawa State rely solely on untreated groundwater sources (wells and boreholes) and surface water sources for consumption and other domestic activities. This is because there are few available pipe-born water sources and in most places where such sources are available, they are not operational. It is therefore important to investigate the radiological content of ground and surface water sources in Kiyawa town to determine its suitability for consumption. Although several studies on radiological concentration in water have been conducted in Nigeria [7], [8], and [9], still most areas in Nigeria lack established data on the activity concentration of Radon-222, and Kiyawa town of Kiyawa LGA, Jigawa State is not excluded. A survey of the study area reveals that access to potable sources of water has remained one of the major challenges for most people as well as animals and a majority of the residents rely on untreated surface and groundwater sources for consumption. Thus, this study is aimed at assessing the concentration of Radon in some selected water sources at Kiyawa town, Kiyawa, Jigawa State, Nigeria. Findings from this research are expected to provide baseline data on the activity concentration of Radon-222 in Kiyawa town, Kiyawa LGA, Jigawa State, Nigeria.

II. MATERIALS AND METHOD

A. Study Area

Kiyawa is one of the twenty-seven (27) Local Government Areas within the Jigawa state, Nigeria. Geographically, Kiyawa is positioned at 11°47′05″N and 09°36′30″E, with an approximate population of 17,704 inhabitants. This locality is strategically placed along the road connecting Kano and Azare, with notable proximities to Dutse (30 km to the west), Jemma (35 km to the east), and Azare (65 km to the east) [10]. Kiyawa LGA encompasses the town of Kiyawa and comprises the area council, which includes the communities of Garko, Farke, Guruduba, Katanga, Katuka, Kiyawa, Kwanda, Maje, Tsurma, Andaza, and Abalago [11]. The region experiences two prominent climatic seasons, a harsh, oppressive rainy season characterized by cloudy weather, and a severe dry season with temperature fluctuations between 13 °C and 43 °C [12]. These made the inhabitants primarily engage in agricultural activities during the rainy season and trading in the dry season.

A. Materials

The materials used in conducting this research include plastic sample bottles (500 ml), disposable syringes (20, 10, and 2 ml), surgical globe, deionized water, scintillation vial (20 ml capacity), scintillation cocktail, indelible ink and masking tape, liquid scintillation counter (Tri-Carb LSA 1000TR).

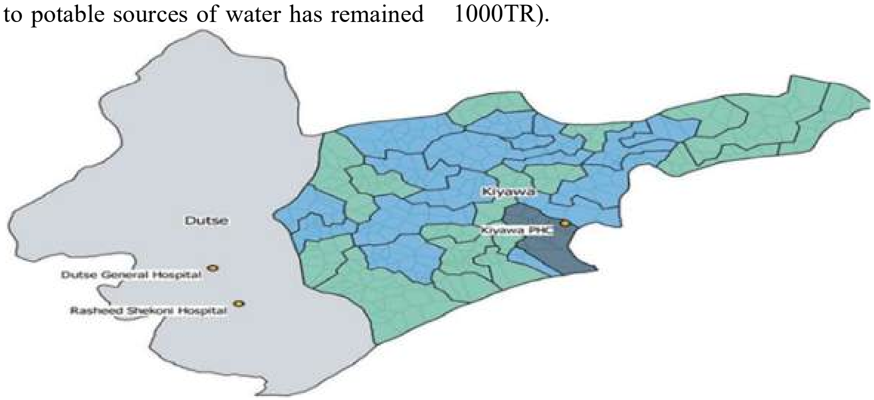

Plate 1. Map of Kiyawa Local Government Area [10].

B. Methods

1) Sample Collection

A total of ten (10) water samples were collected in 500 ml plastic bottles from boreholes and wells in the study area. The sample containers were washed with detergent and rinsed thoroughly with deionized water before filling with the water samples. The samples were subsequently labelled and meticulously filled to inhibit the entrapment and dissolution of CO_2 in the aqueous medium (which could potentially influence the chemical composition) and tightly sealed promptly to avoid the escape of Radon gas and transported to the Centre for Energy Research and Training (CERT) Zaria within short time for preparation and analysis.

2) Sample Preparation

10 ml of each sample was measured into a 20 ml scintillation vial and 10 ml of insta-gel scintillation cocktail was added. The vials were then closed and agitated for two minutes to facilitate the extraction of ^{222}Rn from the aqueous phase into the organic scintillant, followed by counting the collected samples for a period of 60 minutes using a liquid scintillation counter.

3) Sample Analysis

The sample analysis was performed after the samples stayed for about three hours after preparation to establish radioactive equilibrium between ^{222}Rn and its decay products. Before the analysis, calibration of the liquid scintillation counter was performed using the IAEA ^{226}Ra standard solution. During the calibration process, the ^{226}Ra standard samples were subjected to counting for 60 minutes and background count measurements were recorded for the same duration to assess background radiation levels. The concentration of Radon in Bq/L for the water samples was calculated using (5).

$$Rn\ (BqL^{-1}) = \frac{100 \times (\mathrm{SC}-\mathrm{BC}) \times \exp(\lambda t)}{60 \times C_F \times \mathrm{D}} \quad (1)$$

Where, $Rn\ (BqL^{-1})$ = concentration of Radon-222 (in Bq/L), SC = sample count (in cpm), BC = background count (in cpm), t = time elapsed between sampling to counting (minutes), λ = decay constant ($1.26 \times 10^{-4}\ min^{-1}$), 100 = conversion factor from ml to litre, 60 = conversion factor from minutes to seconds ($seconds$), CF = calibration factor and D = fraction of ^{222}Rn in the cocktail in a 22 ml total capacity vial for 10 ml of the sample, 10 ml of cocktail and 2 ml of air [13].

4) Estimation of Annual Effective Dose Due to Ingestion of Radon from Water

$$E = CR_{nW} \times D \times L \quad (2)$$

Where, CR_{nW} = concentration of ^{222}Radon, D = dose coefficient for adults ($10^{-8}\ Sv/Bq$), children ($2 \times 10^{-8}\ Sv/Bq$), and infants ($7 \times 10^{-8}\ Sv/Bq$), L = annual water consumption by an adult of 2 litres per day that is ($730\ l/yr$, $547.5\ l/yr$, and $182.5\ l/yr$) for adults, children, and infants respectively [14].

5) Estimation of Annual Effective Dose Due to Inhalation of Radon from Water

The annual effective dose due to inhalation of Radon from the water will be calculated using (3) as proposed by the United Nations Scientific Committee on the Effects of Atomic Radiation [14].

$$C_{inh} = C_{Rn} \times R_w \times F \times T \times DF \times 1000 \quad (3)$$

Where C_{inh} is the annual effective dose ($mSvy^{-1}$) from inhalation of Radon released from water into air, CRn is the ^{222}Rn concentration in water (Bq/l), R_w is the ratio of Radon released to air when water is used to Radon in water (10^{-4}), F is the equilibrium factor between Radon and its product (0.4), T is the average residence time of individual in the interior ($7000\ hr/y$), DF is the conversation dose factor $9\ nSv\ (Bqhm^{-3})^{-1}$, 1000 is the conversation factor of μSv to mSv.

6) Estimation of Total Annual Effective Dose

The total annual effective dose of ^{222}Rn in water will be calculated using (4), (5) and (6):

$$TAED = E_{inh} + AE_{ing} \quad (4)$$

$$TAED = E_{inh} + CE_{\mathrm{ing}} \quad (5)$$

$$TAED = E_{inh} + IE_{ing} \quad (6)$$

Where TAED is the total annual effect in (mSv/y), E_{inh} is the annual effective dose due to inhalation of ^{222}Rn in water, AE_{ing} is the annual effective dose for adults due to ingestion of ^{222}Rn in water, CE_{ing} is the annual effective dose for a child due to ingestion of ^{222}Rn in water and IE_{ing} is the annual effective dose for infants due to ingestion of ^{222}Rn in water as in (4), (5), and (6).

7) Estimation of Excess Lifetime Cancer Risk

Excess life cancer risk (ELCR) from inhalation and ingestion for different age categories will be calculated from the annual effective dose using (7) as explained by [15].

$$ELCR = AEDE \times DL \times RF \quad (7)$$

Where ELCR is the excess life cancer risk, AEDE is the annual effective dose mSv/y, DL is the life expectancy of 70 years and RF is the fatal risk factor per Sv. International Commission on Radiological Protection (ICRP) 60 uses an RF value of 0.05 for the public in case of stochastic effects [7].

III. RESULTS AND DISCUSSION

A. Radon Concentration

The result of the analysis of Radon concentrations for the water samples collected at different locations of Kiyawa town, Kiyawa Local Government Area, Jigawa State as presented in Table I revealed that the concentrations of Radon-222 varied from 32.15166 Bq/L to 43.8918 Bq/L with a mean value of 36.46135 Bq/L. The maximum and minimum concentrations alongside their mean values were obtained from WL04 and BH02 respectively (see Table I). All the values obtained from these samples were above the maximum contaminant levels of 11.1 Bq/L set by USEPA and the world average value of 10 Bq/l set by the World Health Organization [16]. However, the mean concentration of Radon-222 was lower than the recommended guideline level of 100 Bq/L set by WHO in 2008. Fig. 1, 2 and 3 show the concentration of Radon-222 in well and borehole water respectively with their mean values.

Table I. Results of ^{222}Ra Concentrations in (Bq/L) and Annual Effective Doses due to ingestion of both adult, child and infant.

S/N	Sample ID	^{222}Rn (cpm)	^{222}Rn (Bq/L)	C_{inh} $(mSvy^{-1})$	EA_{ing}	EC_{ing}	EA_{ing}
1	WL01	97.58	33.98709	0.085647	0.248106	0.372159	0.434185
2	WL02	98.17	34.33869	0.086533	0.250672	0.376009	0.438677
3	WL03	105.00	38.40882	0.096790	0.280384	0.420577	0.490673
4	WL04	114.20	43.89128	0.110606	0.320406	0.480610	0.560711
5	WL05	104.80	38.28963	0.096490	0.279514	0.419271	0.489150
	MEAN WL	103.95	37.78310	0.095213	0.275816	0.413725	0.482679
6	BH01	97.60	33.99901	0.085678	0.248193	0.372289	0.434337
7	BH02	94.50	32.15166	0.081022	0.234707	0.352061	0.410737
8	BH03	99.50	35.13126	0.088531	0.256458	0.384687	0.448802
9	BH04	108.10	40.25617	0.101446	0.293870	0.440805	0.514273
10	BH05	97.87	34.15991	0.086083	0.249367	0.374051	0.436393
	MEAN BH	99.51	35.13960	0.088552	0.256519	0.384779	0.448908
11	MIN	94.50	32.15166	0.081022	0.234707	0.352061	0.410737
12	MAX	114.20	43.89180	0.110606	0.320204	0.480610	0.560711
13	MEAN	101.73	36.46135	0.091882	0.266167	0.465793	0.399250

Table II. Comparison of ^{222}Rn concentration with other studies

S/N	Locations	^{222}Rn conc. (Bq/L)	References
1	Kaduna, Kaduna	10.69	[17]
2	Sabon Gari, Kaduna	14.90	[18]
3	Jos, Plateau	17.00	[19]
4	Dutsen Ma	64.46	[20]
5	Dutse	83.77	[7]
6	FUD	36.80	[21]
7	Sokoto	34.00	[22]
8	Kiyawa	36.46	Current study, 2024

Table II and Fig. 4 show the comparison of ^{222}Rn concentrations in water samples from the study area with studies from other parts of Nigeria. The results obtained in this study are higher than those of Sokoto [22], Kaduna [17], Sabon Gari [18], and Jos [19], but lower than those of Dutsen Ma [20], Dutse [7], and FUD [21] respectively.

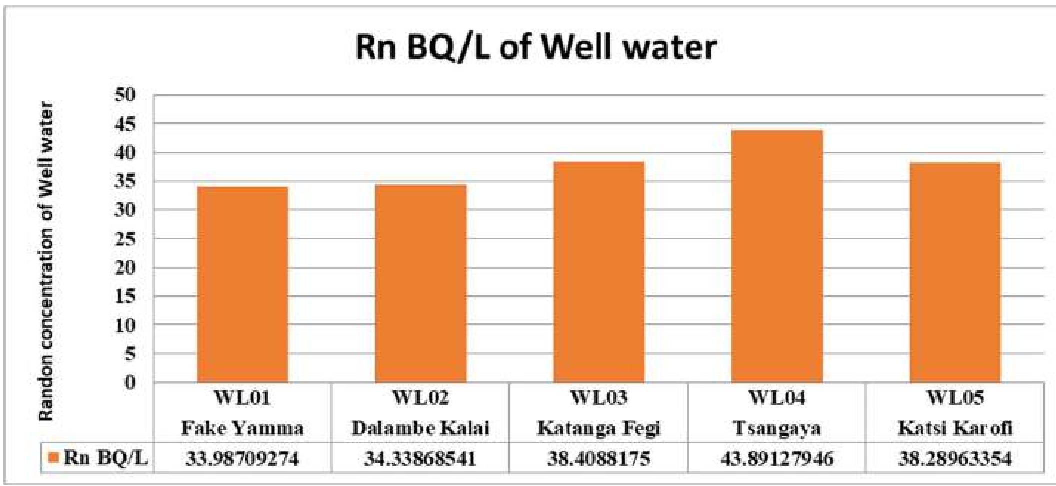

Fig. 1. Sample location of the well water with their corresponding Radon concentration.

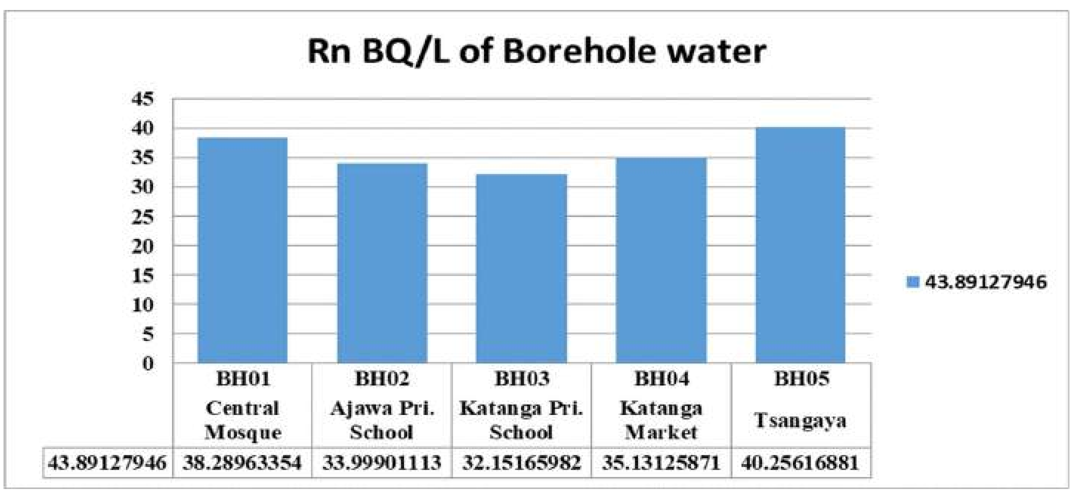

Fig. 2. Sample location of the Borehole water with their corresponding Radon concentration.

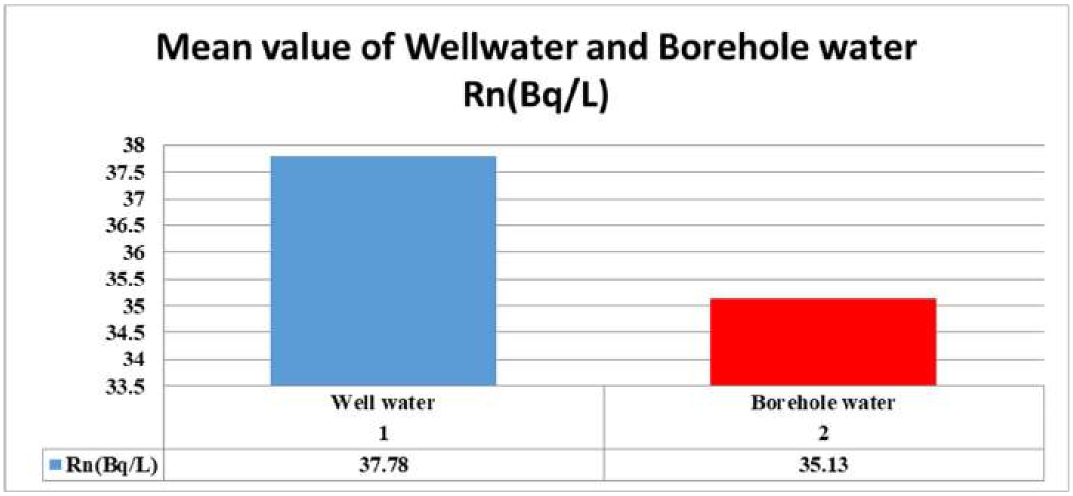

Fig. 3. Mean value of Radon-222 concentration in well and borehole water.

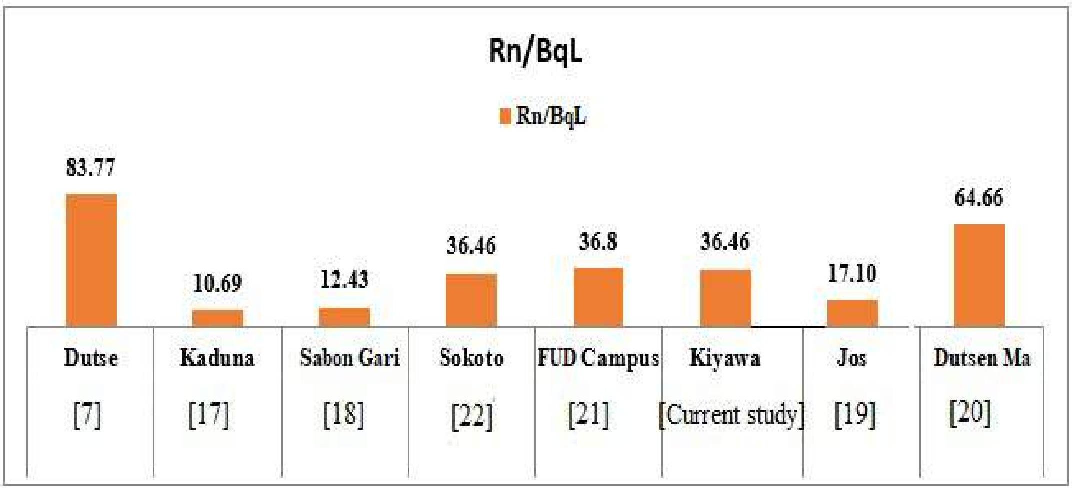

Fig. 4. Comparison between ^{222}Rn concentrations from this study with studies from other parts of Nigeria.

B. Annual Effective Doses

The corresponding annual effective doses due to intake of Radon-222 from well water samples collected at Kiyawa town, Kiyawa local government area, Jigawa State were found to range from 0.3337 to 0.4310 mSv/y, 0.4578 to 0.5912 mSv/y and 0.5198 to 0.6713 mSv/y as shown in Table III with corresponding mean values of 0.3710, 0.5089 and 0.5778mSv/y for adults, children and infants respectively. The estimated annual effective doses of Radon-222 from borehole water samples were found to range from (0.3157 to 0.3953) mSv/y, (0.4330 to 0.5422) mSv/y and (0.5200 to 0.6157) mSv/y with corresponding mean values of 0.3450, 0.4733, and 0.5374 mSv/y for adults, children and infants respectively as shown in Fig. 5, 6 and 7 respectively. 66.67% of the estimated annual effective doses were found to be above the recommended reference level of 0.1 mSv/y for intake of radionuclides in water set by WHO [23].

Table III. TAED for adults, children, and infants.

S/N	Sample ID	TAED (mSv/y)	TCED (mSv/y)	TIED (mSv/y)
1	WL01	0.333753	0.457806	0.519833
2	WL02	0.337206	0.462542	0.525211
3	WL03	0.377175	0.517367	0.587463
4	WL04	0.431012	0.591216	0.671317
5	WL05	0.376004	0.515761	0.585641
	MEAN WL	0.371030	0.508938	0.577893
6	BH01	0.333871	0.457967	0.520015
7	BH02	0.315729	0.433083	0.491761
8	BH03	0.344989	0.473218	0.537333
9	BH04	0.395316	0.542251	0.615718
10	BH05	0.335451	0.460134	0.522476
	MEAN BH	0.345071	0.473331	0.537461
11	MIN	0.315729	0.433083	0.491176
12	MAX	0.431012	0.591216	0.671317
13	MEAN	0.358050	0.491134	0.557676

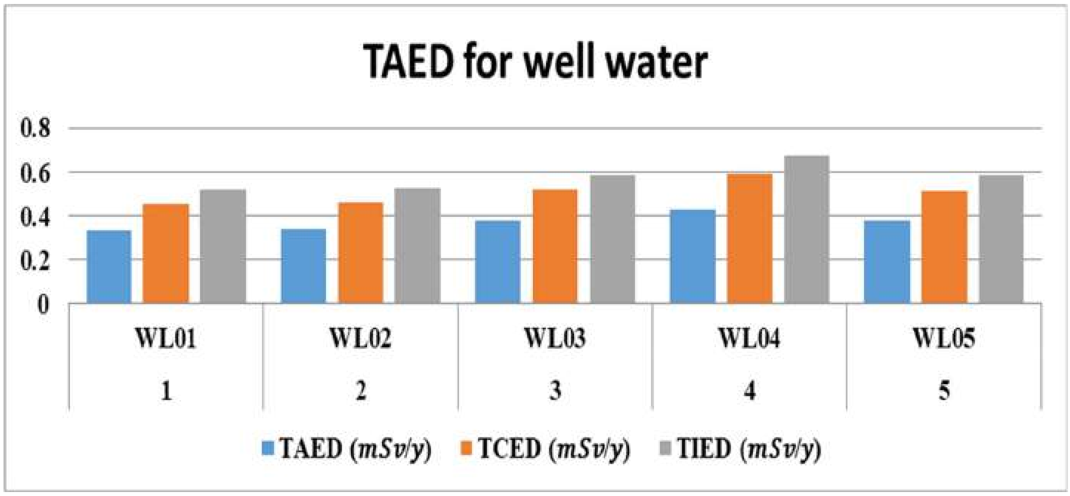

Fig. 5. TAED (for adults, children, and infants) for well water.

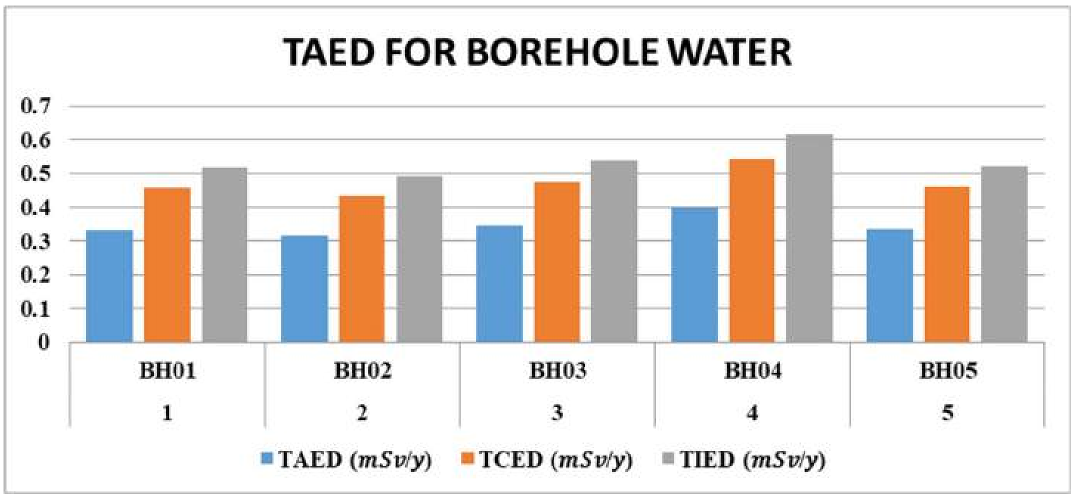

Fig. 6. TAED (for adults, children, and infants) for borehole water.

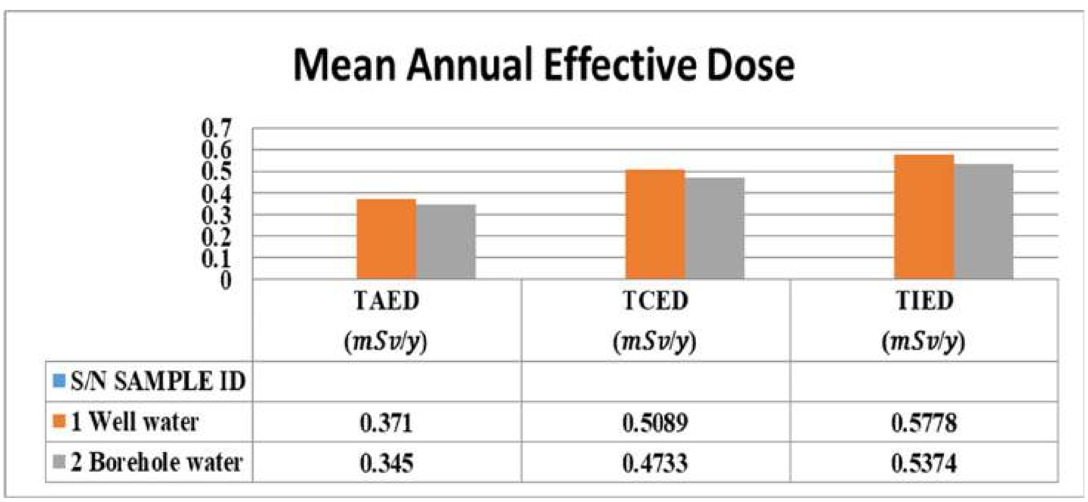

Fig. 7. Mean AED (for adults, children, and infants) for the well and borehole water.

C. *Excess life cancer risk due to ingestion and inhalation*

Table IV illustrates the ELCR due to inhalation (ELCRI) and ingestion ($ELCRI_{ing}$) for adults, children, and infants. The minimum and maximum excess life cancer risk from annual effective dose due to inhalation for water samples obtained from BH02 and WL04 ranged from 0.000284 to 0.0003871 respectively with a mean value of 0.000322, while the value for ingestion ranged from $0.000821 - 0.001121$, $0.001232 - 0.001682$, and $0.001438 - 0.001962$ for adults, children, and infants respectively, with mean values of 0.000932, 0.001397, and 0.00163 for adults, children, and infants respectively (see Fig. 8, 9, 10, and 11).

Table IV. ELCR due to inhalation (ELCRI) and ingestion ($ELCRI_{ing}$) for adults, children, and infants

S/N	SAMPLE ID	$ELCR_I$	$ELCRA_{ing}$	$ELCRC_{ing}$	$ELCRI_{ing}$
1	WL01	0.000300	0.000868	0.001303	0.001521
2	WL02	0.000303	0.000877	0.001316	0.001535
3	WL03	0.000339	0.000981	0.001472	0.001717
4	WL04	0.000387	0.001121	0.001682	0.001962
5	WL05	0.000338	0.000978	0.001467	0.001712
	MEAN WL	0.000333	0.000965	0.001448	0.001689
6	BH01	0.000300	0.000869	0.001303	0.001522
7	BH02	0.000284	0.000821	0.001232	0.001438
8	BH03	0.000310	0.000898	0.001346	0.001571
9	BH04	0.000355	0.001029	0.001543	0.001800
10	BH05	0.000301	0.000873	0.001309	0.001527
	MEAN BH	0.000310	0.000898	0.001347	0.001572
11	MIN	0.000284	0.000821	0.001232	0.001438
12	MAX	0.000387	0.001121	0.001682	0.001962
13	MEAN	0.000322	0.000932	0.001397	0.001630

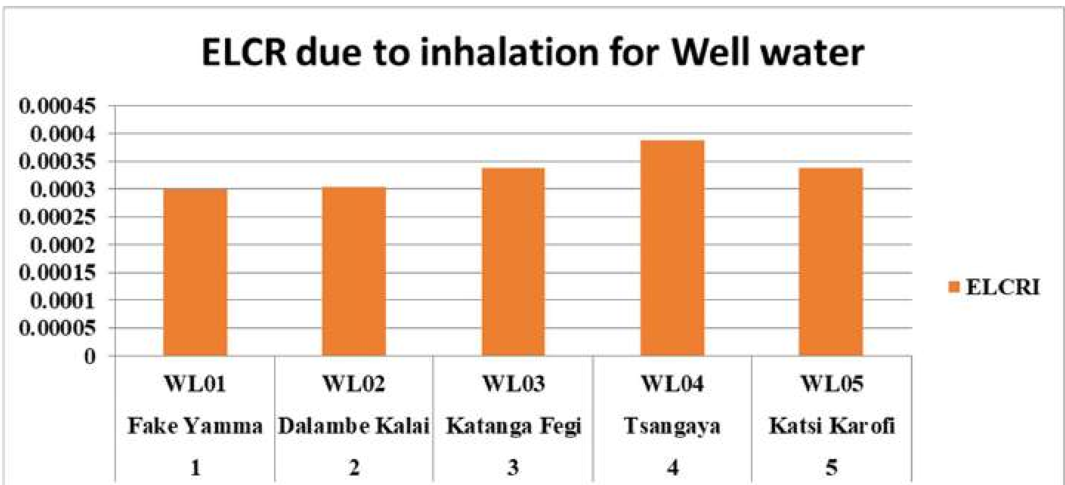

Fig. 8. Bar chart of ELCR due to inhalation of well water.

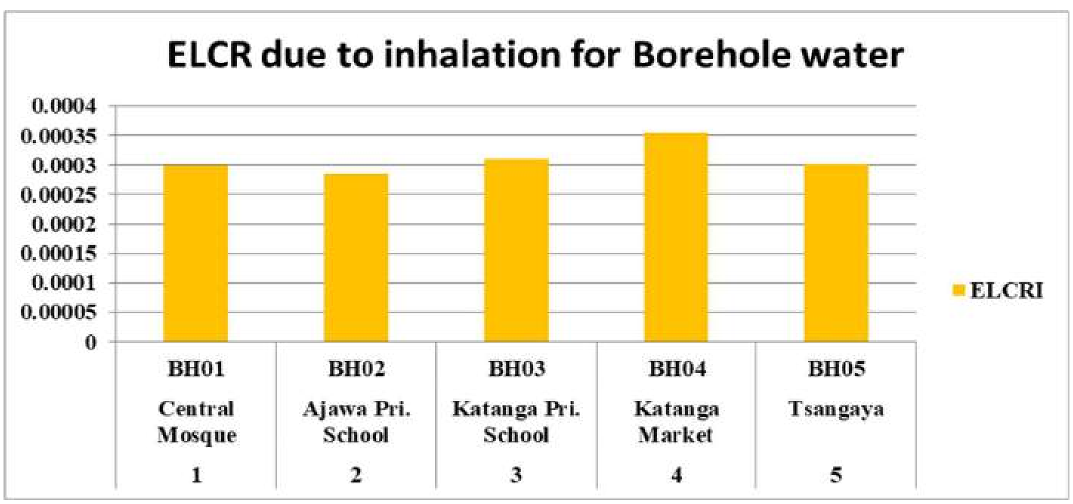

Fig. 9. Bar chart of ELCR due to inhalation of borehole water.

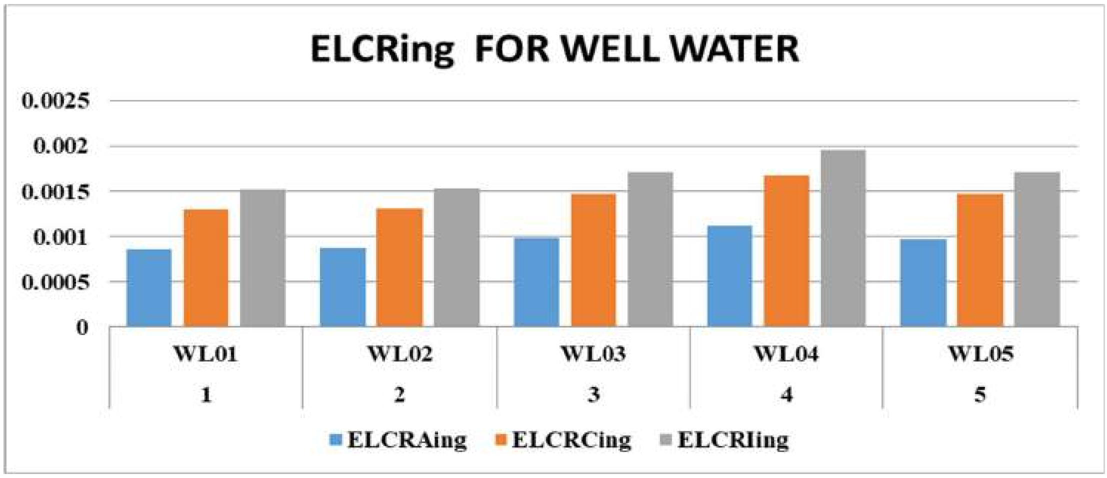

Fig. 10. Bar chart of ELCR (for adults, children, and infants) due to ingestion for well water samples.

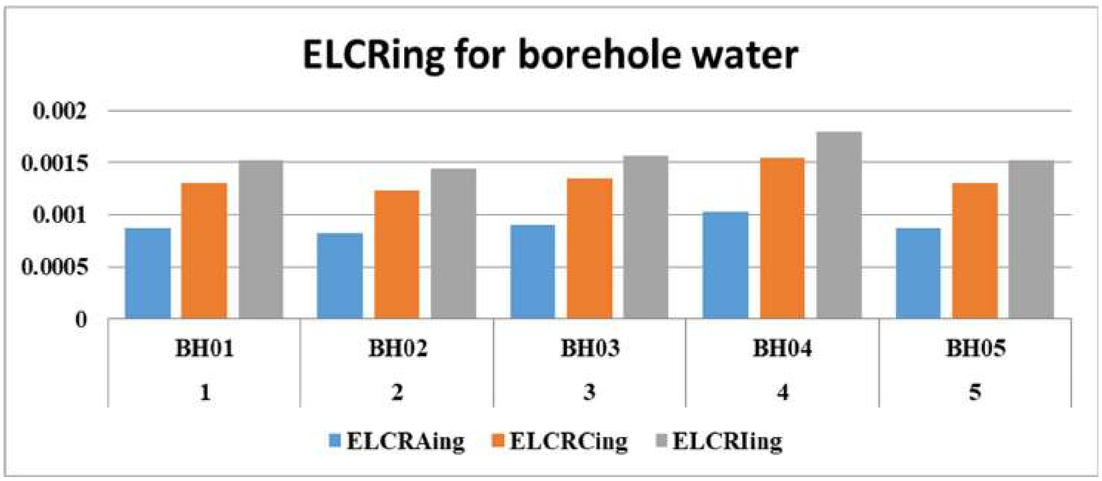

Fig. 11. Bar chart of ELCR due to ingestion (for adults, children, and infants) for borehole water samples.

IV. CONCLUSION

The concentration of Radon-222 and the corresponding radiological hazard indices for well and borehole water samples in Kiyawa town of Kiyawa LGA, Jigawa State, Nigeria, were analyzed via liquid scintillation. The radiological hazard indices evaluated include annual effective dose and excess life cancer risk from ingestion and inhalation for infants, children and adults. The results obtained indicate the presence of high concentration of Radon-222 exceeding the WHO's recommended MCL of 10 Bq/L, as well as the MCL of 11.1 Bq/L set by the USEPA. The higher values of Radon-222 concentrations in water could be linked to the geology of the area and could pose a threat to the health of the inhabitants of the study area particularly those living in Tsangaya and Katanga markets. Therefore, the inhabitants of such areas are advised to boil the water before consumption to degas Radon thereby keeping the concentration of Radon-222 in the water as low as possible. We recommend further studies on the activity concentrations of Radon-222 in water sources including surface water in Kiyawa town and its environs. Equally, epidemiological studies of the general population need to be conducted to determine the incidences of lung and stomach cancer.

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