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Radon Levels and Lifetime Cancer Risk from Ingestion and Inhalation of Well Water Samples in Akoko South West, Ondo State, Nigeria

Amanesi Abdulfatai[1*], Jimoh Asekarumeh[2], Idode Edekin Stanley[3], Oriakhi Francis igbinerediauwa[4], Osondu, Chiamaka Blessed[5] & Edekin Pleasantness Omasia[6]
[1,2,3,4,5,6]Department of General Studies, Edo State College of Nursing Sciences, Benin City, Edo State, Nigeria
[2]Department of Chemical Sciences, Adekunle Ajasin University, Akungba-Akoko, Ondo State, Nigeria
[*]Corresponding Author Email: amanesiabdulfatai@gmail.com

ABSTRACT

Due to increased population, urbanisation, and climatic change, the overexploitation and over-reliance on groundwater sources- wells and boreholes have surfaced. Groundwater is understood as harmless and safe, yet it often contains natural radioactivity. The health risks posed by the ingestion and inhalation of radon-222 from the well water in Akoko South-West Local Government Area of Ondo State, Nigeria, were assessed in this study. A liquid scintillation counter was used to analyse ten water samples from wells for radon concentration. The average radon concentration was 23.29 Bq/L, ranging between 10.30 and 41.89 Bq/L. Roughly 90% of the samples recorded concentrations greater than the United States Environmental Protection Agency's 11.1 Bq/L maximum contaminant level. The ingestion of annual effective dose was determined between 0.0018 and 0.0073mSv/y with a mean of 0.0041mSv/y while the inhalation dose ranged between 0.0260 and 0.1056mSv/y with a mean of 0.0587mSv/y. According to the assessment, 80% of estimated dose values were below the reference level specified by the World Health Organization (WHO) of 0.1 mSv/y. Cancer risk during a lifetime varies from 0.10 ×10-3 to 0.40 ×10-3 with a mean of 0.22 ×10-3. As much as about 30% of the estimated values are above the reference level of 0.29 ×10-3. In general, radon concentrations sampled in wells have exceeded the USEPA comparison level; however, the estimated radiation doses have been measured within permissible levels. Consequently, it is recommended to routinely monitor radon concentration in groundwater, which will help manage radiologic risk and safeguard public health.

Keywords:
Radon,
Well water,
Liquid Scintillation Counter,
Cancer

INTRODUCTION

On this planet, one of the most copious substances is water, and it is one of the main constituents of all living things (Dargaville & Hutmacher 2022). Drinking or potable water is the name for water that is fit for consumption. Water which not potable may be made potable by filtration, distillation, or various other means (Ahmad & Danish 2018). Safe water refers to water that is not fit for drinking but is not harmful to human health when used for activities like swimming and bathing. Water is essential for life. It is a basic need for the health of living organisms. Furthermore, it is including humans. Water that is potable in nature is already a limiting resource in many areas. Over the century, it has become more limited as numbers of population increase, urbanisation and climate change worsens. Besides, there are also more people depending on groundwater, such as borehole and well water, as their main source of supply (Jackson et al., 2001).

According to Garba et al. (2013), water quality is among the most vital parameters of environmental studies because of the potential for pollution. When pollutants, often chemical, microbiological, or radiological, enter a stream, river, lake, ocean, aquifer, or other body of water, the water quality degrades. Water pollution makes water toxic to humans or the environment. The above reasons show the importance of ensuring that water used is free from chemical, microbiological and radiological contamination (Balaram et al., 2023). Radioactive substances that enter a water supply are known as radiological water contaminants. People referred to particles as radionuclides.

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Naturally existing radiological isotopes typically found in drinking water include radium, uranium, radon, and others (Abubakar et al., 2026). According to Ali et al. (2025), the radioactive elements radon-222, radium-226, and radium-228, which commonly occur in natural waters (lakes, springs, and groundwater), pose human health risks.

When radionuclides are present in drinking water, internal exposure will happen. This occurs directly because of the decay of radionuclides when they enter our bodies (through being drunk or inhaled). It also happens indirectly when they become part of the food chain. Radon-222 is an alpha-emitting noble gas that can be found in various concentrations in soil, air, and water due to migration from rocks and soil in contact with water (USEPA, 2012). Radon concentration in air, especially dissolved radon concentration in air, and the qualitative impact of various geological formations (faults noted explicitly) on the variability of dissolved radon has received considerable attention. However, less interest has been given to radon concentration in water. The composition of geological formations is reported to influence radon concentrations in water sources situated close to these formations. However, when the water flows from the source to the consumers, natural aeration will probably lead to a reduction in radon concentrations (D'Alessandro & Vita 2003). The assessment of the radioactive level of drinking water helps to ascertain the exposure of the people to radiation due to habitual ingestion of water.

Radon, which has an atomic number of 86, is a chemical element. Friedrich E. Dorn discovered it in the year 1900 in Halle, Germany. It is the fifth radioactive element to be discovered. Since he was experimenting with the element radium when he found it, he called it radium emanation. It is an inert gas that naturally occurs and is radioactive, with a half-life of 3.82 days, which was described as a member of the Uranium-238 decay series by Encyclopædia Britannica (2026). It's a colourless, odourless, tasteless, and chemically non-reactive gas that is generated as the radioactive decay product of Radium-226, a Uranium-238 decay product USEPA, 1999. Ordinary concentrations of uranium and its decay products are widely dispersed in the earth's crust, and radon-222 is thus being continuously generated. Radon-222 decays to Polonium through emission of an alpha particle. Humans are exposed to Radon in two ways. First, radon is released into the air from the home soil, where it is present in significant amounts, either through inhalation or ingestion. Second, when water is used for drinking, ingestion also takes place. Due to the decay of Radium-226 associated with the rock and soil, radon-222 activity concentration in water is present. The radon gas seeps through rock and soil and enters the water as a result. Consequently, the level of Radon present in the water is greater than it might seem (Bello et al., 2025). Usually, the concentration of radon in groundwater will be higher than in the surface water. As radon is a gas, radon that is present in water is released into the air when it comes out of the water. Activity concentrations of radon in surface water polluted with naturally occurring radioactive materials (NORM) from mining and fertilizer production are likely to be high, which has hitherto not been ascertained. Long-term exposure to radon from drinking water can cause cancer in people. Uranium-238 and Thorium-232 are the primary sources of Radon found in the environment.

MATERIALS AND METHODS

Study Area

All the sampling points are situated in Akoko South West Local Government Area. The northern senatorial district of Ondo State, southwestern Nigeria, is represented in Figure 1. Situated within the geographical coordinates of 7°20′N and 7°30′N latitudes and 5°30′E and 5°50′E longitudes is Akoko South-West Local Government Area of Nigeria. The local government area is about 226 square kilometers and was home to a total of 229,486 persons in 2006, as per the National Population Census. The majority of the population are farmers, civil servants and traders.

The Precambrian rock of southern Nigeria underlies Akoko South West L.G.A. basically. The area mainly consists of rocks of migmatite, granite, and granite-gneiss composition (Falowo et al., 2017). In parts of the local government area, the basement rocks are well exposed, especially at locations where the basement is fairly shallow, and there is pronounced erosion (Mohammed et al., 2012).

Sample collection

Water samples from 10 different locations in Akungba-Akoko, Oka-Akoko, Oba-Akoko, Iwaro Oka-Akoko, Supare-Akoko, and Etioro were collected from the selected well sources for analysis. Use of a global positioning system was used to mark the geographical location on the Earth's surface of the sampling site during sampling. Samples were gathered in 20mL plastic vials. Initially, a bailer was used to take the water sample, which was transferred to vials. Each sample collected was labelled accordingly, and the time of collection was noted and recorded.

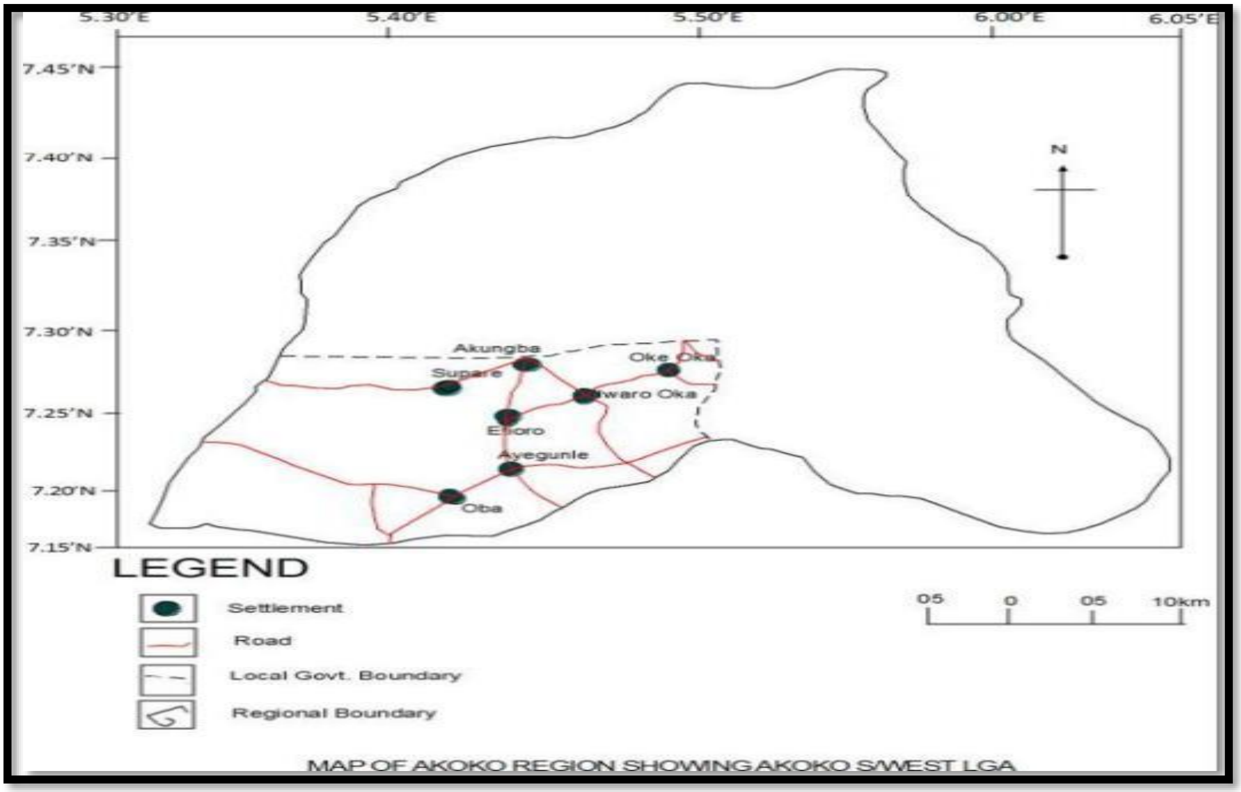

Figure 1: Map of Akoko Region showing Akoko South West L.G.A

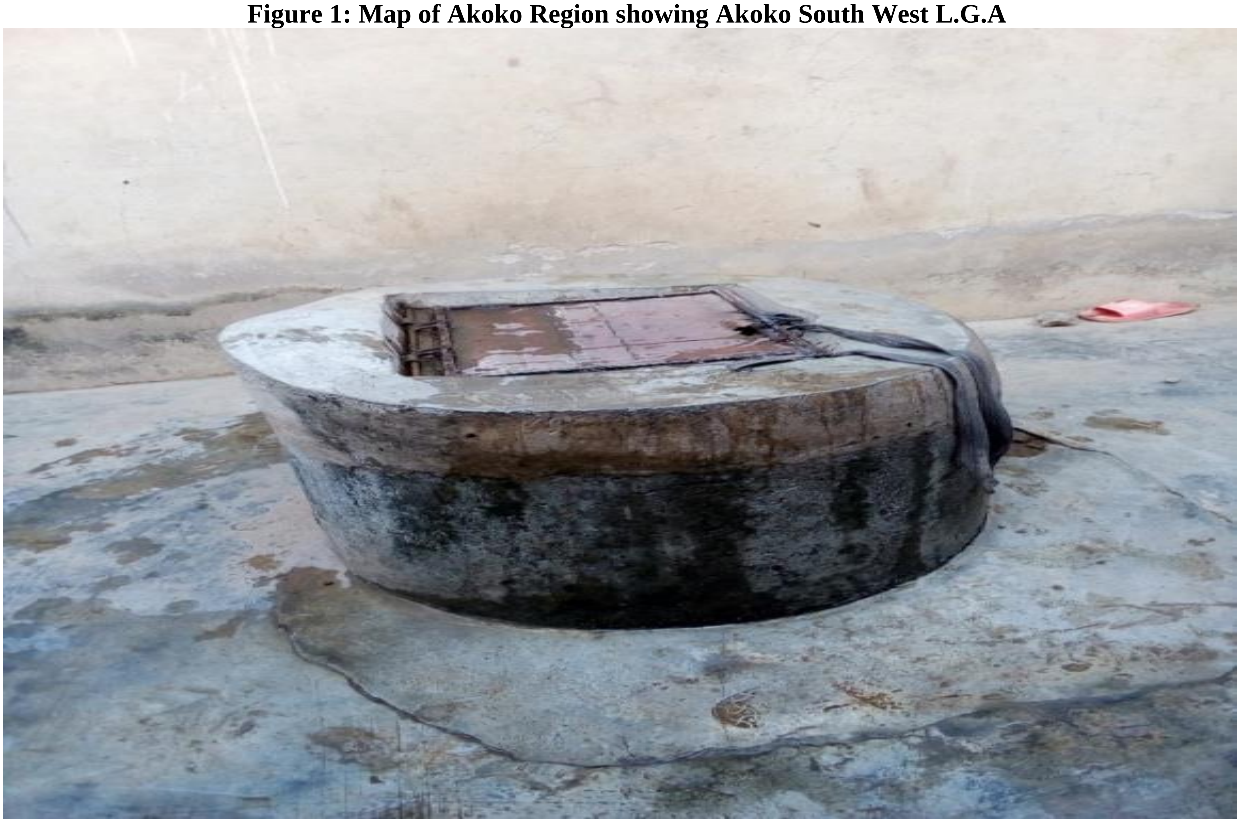

Figure 2: One of the wells from which a sample was collected.

Sample preparation

Using a hypodermic syringe, approximately 10 mL of each sample was introduced into a vial that contained 10 mL of scintillator (insta-gel-based cocktail). To extract radon-222 present in the water phase, the tightly capped vials were shaken vigorously for 3 minutes. The organic scintillator used is the one described by Palomo et al. 2011. In the same way, a blank sample for the background was prepared with distilled water stored in a glass bottle for not less than 21 days. The samples that were prepared were allowed to sit undisturbed for at least three (3) hours each in order for Radon-222 and its alpha decay products to reach equilibrium before counting.

Sample Analysis

The samples and the blank were analyzed on a Liquid Scintillation Counter (Tri-Card LSA 1000) at the Center for Energy Research and Training (CERT), Ahmadu Bello University Zaria, Kaduna State, Nigeria. Figure 3 shows the liquid scintillation analyzer (Tri-Carb LSA 1000).

Figure 3: Liquid Scintillation Analyzer (Tri-carb- LSA 1000)

The calculated activity concentration of Radon-222 from the samples and background results was done using the formula below (Abdulrasheed et al., 2024).

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

In these equations, C_{Rn} is the concentration of radon-222 in the water sample in Becquerels per litre (Bq/L). Sc is the sample count in counts per minute (CPM). Bc is the background count in counts per minute. t is the time between sample collection and counting in minutes. is the decay constant of radon-222, which equals 1.26 10-4/min. CF is the calibration factor, which has a value of 13.37/Bq. D is the fraction of radon in the scintillation cocktail. The evaluation was performed using a 22 mL vial of 10 mL water sample, 10 mL scintillation cocktail, and 2 mL air.

Annual Effective Dose Due to Ingestion

The radon found in the water may pose a health hazard to humans and may adversely affect the internal organs. The main ways people are exposed are through drinking contaminated water and breathing in radon released into homes and other indoor air. When water that has been contaminated is ingested, the stomach is exposed directly. On the other hand, inhalation affects the lungs and the respiratory tract. To evaluate this risk, Nandakumaran & Vinayachandran (2020) and Isinkaye et al. (2021) estimated the Annual Committed Effective Dose (ACED) to the stomach from ingestion of radon-contaminated water in the study area.

$$\text{ACEDing}(\text{mSv/y}) = C_{Rn} \times W_{CR} \times DCF_{ing} \times 1000 \quad (2)$$

The concentration of radon present in water (C_{Rn}) was expressed in relation to WCR, the annual water consumption for adults (730 L/y), while DCF_{ing}, the effective dose conversion factor for ingestion (3.5 nsV/Bq). Since radon is relatively insoluble in water, continual domestic use of water can lead to a continuous liberation of radon into the indoor air, thus increasing the average committed dose received via the inhalation pathway (Wu et al., 2014).

Annual Effective Dose Due to Inhalation

The following equation (ICRP, 1993; United Nations Scientific Committee on the Effects of Atomic Radiation

[UNSCEAR], 2000; Duggal et al., 2020; Dankawu et al., 2021) was used to compute the Annual Committed Effective Dose (ACED) from inhalation of waterborne radon.

$$ACED_{inh}(mSV/y) = \frac{C_{Rn} \times R_{AW} \times EF \times OF \times DCF_{inh}}{1000} \quad (3)$$

C_{Rn} refers to radon concentration in water. RAW is the radon-in-air-to-radon-in-water ratio (10-4). EF is the equilibrium factor between radon and its progeny for the indoor environment (0.4). OF is the average global indoor occupancy 7000 h/y), and DCFinh is the dose conversion factor for exposure to radon in air (9 nSvBq-1h-1m3) (Adamoh, 2021; Dankawu et al., 2021).

Whole Body Dose (WBD) is the total annual effective dose in (mSv/y) (Adamoh, 2021).

$$\mathrm{WBD} = \mathrm{ACED_{inh}} + \mathrm{ACED_{ing}} \quad (4)$$

Evaluation of Excess Lifetime Cancer Risk

To assess the cancer incidence risk, a quantitative study has been developed to determine the carcinogenic effects on humans from prolonged exposure to radon-contaminated water. In order to determine the risk due to water-borne radon in the studied population, Excess Lifetime Cancer Risk (ELCR) was calculated using the equation (Divya & Prakash, 2019; Ndubisi et al., 2021).

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

Where WBD is the whole-body dose in μSvy^{-1}, RF is the risk factor taken to be 0.05 Sv^{-1} for stochastic effects, and DL is the lifetime duration of 70 years (ICRP, 1991).

RESULTS AND DISCUSSION

Table 1 displays the values of Radon Concentration (Bq/m3), estimated annual effective dose from ingestion ($ACED_{ing}$) in mSv/y, estimated annual effective dose from inhalation ($ACED_{inh}$) in mSv/y, and external exposure (WBD) in mSv/y in addition to the ELCR risk (in mSv/y) for the 10 sampling locations.

Radon concentrations (RN) in samples of Oka and Aku were measured up to a maximum value of 41.89 Bq/L and a minimum value of 10.30 Bq/L, respectively. The average radon level of the sampling sites is 23.292Bq/L.

The ingestion annual effective dose ($ACED_{ing}$) estimate ranged from 0.0018 to 0.0073 mSv/y, with the highest value of 0.0073 mSv/y at Oka 2 and the lowest at Aku 2 (0.0018 mSv/y). The mean ingestion dose was 0.0041 mSv/y. Similarly, the inhalation annual effective dose ($ACED_{inh}$) was found to be between 0.0260 and 0.1056 mSv/y, with the highest value being for Oka 2 and the lowest for Aku 2, with a mean of 0.0587 mSv/y.

The range of Whole-Body Dose (WBD) was between 0.028 – 0.119 mSv/y, with a maximum at Oka 2 and a minimum at Aku 2. Mean WBD was found to be 0.0628 mSv/y. Inhalation contributed more than ingestion to the estimated annual effective dose in all sampling locations. The ELCR values were 0.10×10^{-3} to 0.40×10^{-3}, with the highest cancer risk estimated at Oka 2 (0.40×10^{-3}) and the lowest cancer risk estimated at Aku 2 (0.10×10^{-3}). Average ELCR was found to be 0.22×10^{-3}. This means that the estimated lifetime excess cancer risk for the sampling locations varied according to a pattern that was broadly similar to the radon concentration and dose estimates.

Overall, the maximum value for radon concentration, ingestion dose, inhalation dose, whole-body dose, and ELCR was recorded at Oka 2, whereas the lowest value was recorded at Aku 2. Consequently, according to the findings, the concentrations of radon in all locations indicate inhalation as the most likely pathway for exposure.

Table 1: Radon Concentration, Annual Effective Dose from Ingestion and Inhalation, Whole-Body Dose, and Excess Lifetime Cancer Risk (ELCR) across the Sampling Locations

SAMP LOC	RN Con(BqL^{-1})	LAT	LONG	$ACED_{ing}$ (mSv/y)	$ACED_{inh}$ (mSv/y)	WBD (mSv/y)	ELCR(10^{-3})
Aku 1	12.61	7°28'29.	5°44'13.	0.0022	0.0318	0.030	0.12
Aku 2	10.30	7°28'34.	5°44'29.	0.0018	0.0260	0.028	0.10
Etioro	14.95	7°26'22.	5°43'24.	0.0026	0.0377	0.043	0.14
Iwaro 1	15.30	7°26'57.	5°44'56.	0.0027	0.0386	0.042	0.14
Iwaro 2	15.59	7°26'58.	5°44'54.	0.0027	0.0393	0.040	0.15
Oba 1	21.80	7°22'12.	5°43'38.	0.0038	0.0549	0.058	0.21
Oba 2	38.79	7°22'45.	5°43'34.	0.0068	0.0978	0.105	0.37
Oka 1	33.71	7°27'18.	5°48'50.	0.0059	0.0849	0.098	0.32
Oka 2	41.89	7°27'24.	5°48'7.5	0.0073	0.1056	0.119	0.40
Sup	27.98	7°26'46.	5°41'25.	0.0049	0.0705	0.074	0.26
MEAN	**23.292**			**0.0041**	**0.0587**	**0.0628**	**0.22**

The measured radon concentration levels of the ten sampling areas are presented in Table 1 and Figure 4. The spatial distribution indicates pronounced variability among the different sampling locations. The values obtained from different locations varied from a minimum of 10.30 Bq/L recorded at Akungba 2 to a maximum value of 41.89 Bq/L at Oka 2, with mean concentration of 23.292Bq/L for the entire study area.

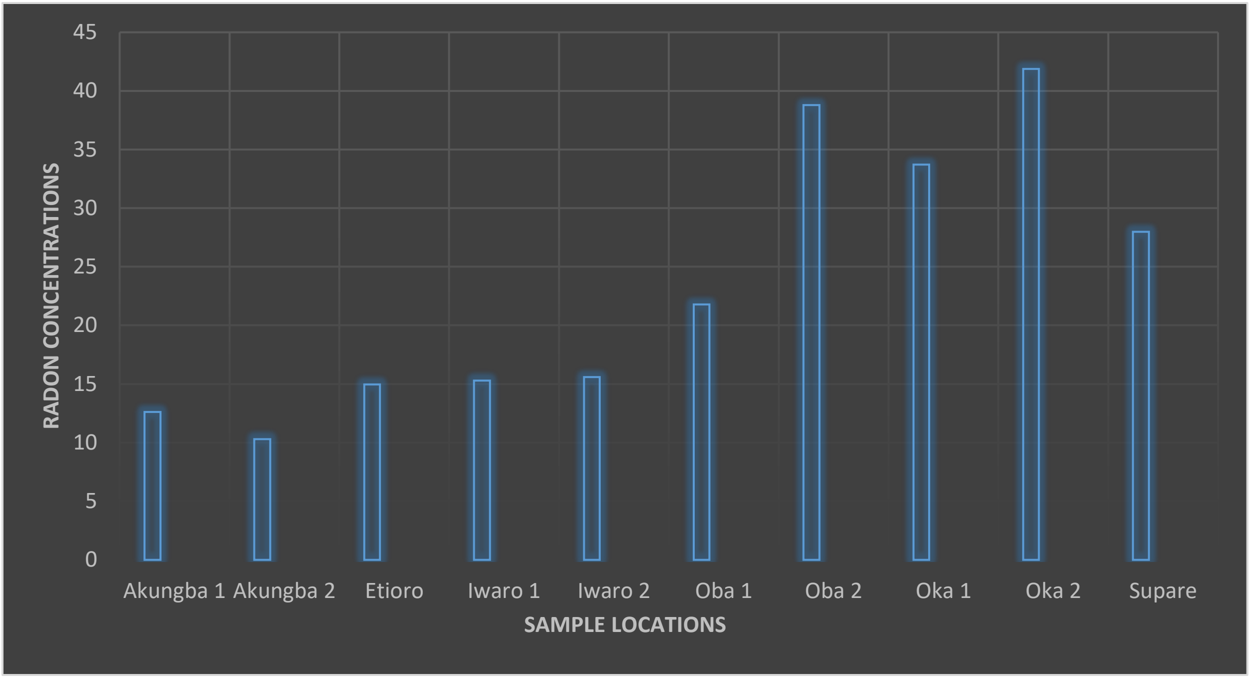

Figure 4: Chart of radon concentration in the well water samples.

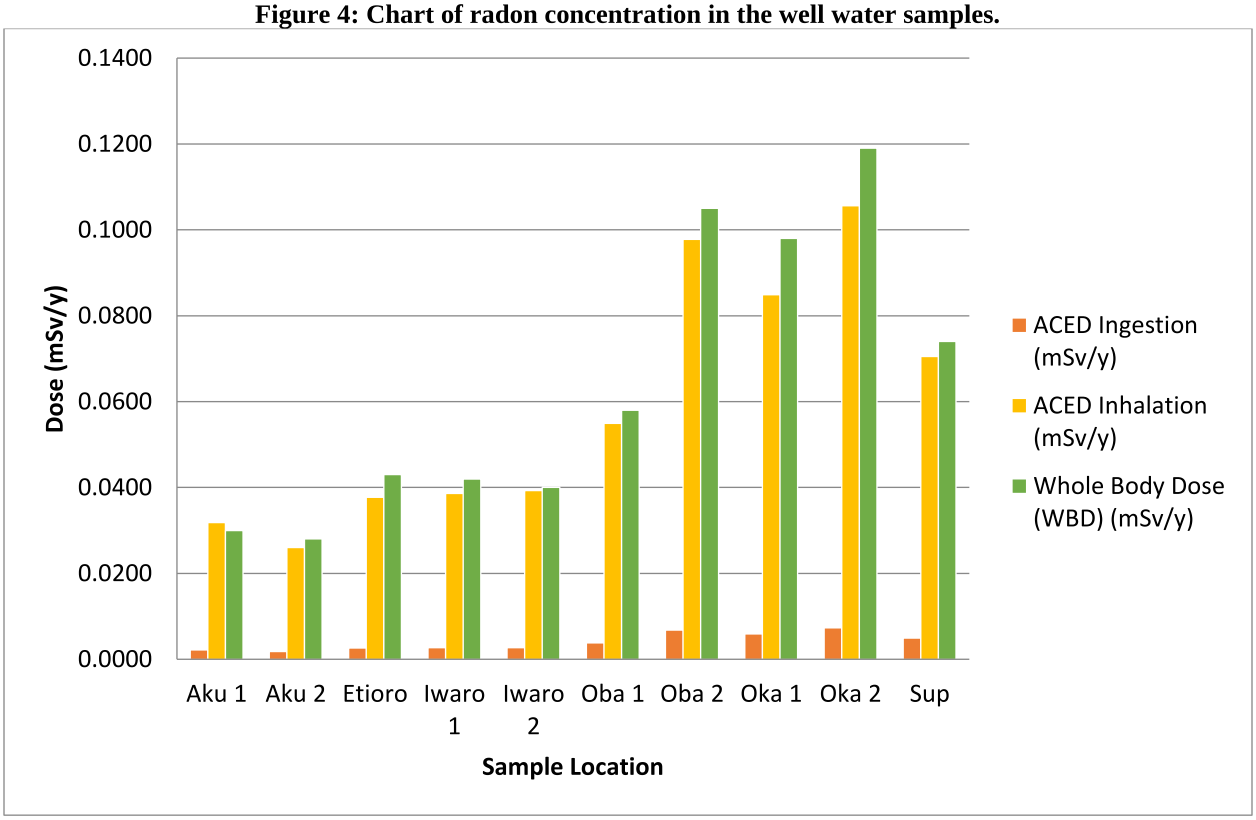

Figure 5: Chart of Annual Effective Dose from Ingestion, Inhalation and Whole-Body Dose from well water samples.

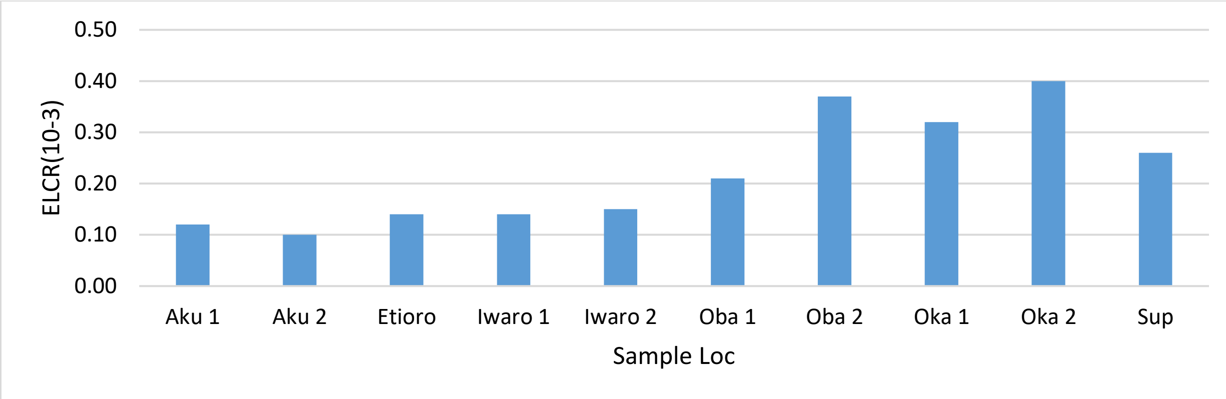

Figure 6: Chart of Excess Lifetime Cancer Risk (ELCR) from well water samples.

The well-water samples showed a radon-222 concentration that ranged from 10.30 Bq/L to 41.89 Bq/L. The mean concentration was 23.29 Bq/L. The Oka-Akoko location recorded the highest concentration, while Akungba-Akoko recorded the lowest. The differences in the spatial patterns may be due to local geology, groundwater residence time, well characteristics, and the uranium–radium content of the underlying formations. Most samples (90%) exceeded the USEPA reference value of 11.1 Bq/L, but none exceeded 148 Bq/L. The mean concentration was lower than the values reported by Joseph et al. (2018) in Dutsin-Ma, Katsina State. It falls within the range reported for groundwater by Sule et al. (2026), however. Variations in geological and hydrogeological circumstances in the study area could have caused these variations.

The yearly effective dose to which one would be exposed due to the consumption of radon varies from 0.0018 to 0.0073 mSv/y, with the mean value of 0.0041 mSv/y. According to WHO (2004), all values were below the reference level of 0.1 mSv/y; therefore, radiological dose received through direct consumption is low. I've seen similar things in the literature, as noted by Oniya et al. (2021), who say that doses from ingesting radon depend on activity concentration, as well as consumption of water and exposure characteristics.

The yearly effective dose committed inhalation perhaps ranges from 0.0260 0.1056 mSv/y with a mean of 0.0587 mSv/y. According to the estimates, inhalation contributed more to the estimated exposure than ingestion. This is consistent with the potential for dissolved radon in water to be transferred to indoor air through household activities. In line with Kolo et al. (2023), inhalation is another pathway of exposure to waterborne radon.

The annual large-scale body organ dose exposure ranged from 0.028 to 0.119 mSv/y, with an average of 0.0628 mSv/y, while the excess lifetime cancer risk (ELCR) ranged from 0.10×10^{-3} to 0.40×10^{-3}, with an average of 0.22×10^{-3}. Higher dose and ELCR values were recorded at sites with higher radon concentrations. Oka-Akoko site, which recorded the highest radon level, demonstrates this correlation. Although the mean ELCR was low, some sites exceeded the comparison value of 0.29×10^{-3} adopted in this study. According to James et al. (2022) and Nunes et al. (2023), a connection exists between radon concentration, radiation dose, and estimated cancer risk.

The results showed that radon-222 is present in well water in Akoko South-West. However, the results varied widely. Although ingestion risk was low, the inhalation route was the most important exposure pathway. It is therefore suggested that radon in groundwater is periodically monitored in areas with relatively high concentrations for the assessment and management of long-term radiological risks.

CONCLUSION

The study showed the occurrence of radon-222 in all the well-water samples collected from different locations in Akoko South-West Local Government Area, Ondo State, with 90% of the samples above the USEPA reference value of 11.1 Bq/L. The differences in the underlying geology and soil characteristics of the area may explain the spatial variation in radon concentration observed.

The estimated effective dose from inhalation on a yearly basis is larger than that from ingestion and accounts for about 93.5% of the total. Inhalation of radon released from water is the major exposure pathway. Indoor radon attributable to domestic water use needs more attention. Approximately 70% of the samples indicated that the estimated excess lifetime cancer risk is below the reference level of $0.29 \times 10{-}3$, which shows that the estimated radiological risk is low in most locations. However, a few locations need attention.

It is thus recommended to continually monitor radon in groundwater and investigate the geological and hydrogeological factors affecting its distribution to give more comprehensive information for the radiological risk assessment and health protection in the study area.

Competing interest

I declare that no competing interests exist

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