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ARTICLE

Toxicity of Radon-222 in Groundwater across Keana in Nasarawa, Nigeria

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ABSTRACT

The most common supply of freshwater for drinking, irrigation, and other domestic uses is groundwater; however, because of increased radon concentrations brought on by mining activities, its quality is still a severe concern. Using a liquid scintillation detector, this study investigated the radon content, its related toxicity, and its risk to human health in the groundwater of the Keana in Nasarawa, Nigeria. Ten (10) borehole samples and five (5) well samples totaling fifteen (15) groundwater samples were taken. The results showed that the average radon concentration in water samples from Keana was 2.25 Bq/L. The mean annual effective dosage (ingestion) for adults and children in Keana was 0.016 mSv/y and 0.027 mSv/y, respectively. In Keana, the additional lifetime cancer risk per adult was 5.65×10^{-5}, and per child, it was 8.79×10^{-5}. The study's radon concentration was lower than the benchmark of 11.1 Bq/L established in 1991 by the Nigerian Standard Organization and the US Environmental Protection Agency. The results of this study indicate that the level of radon is safe; as a result, people can continue farming and other activities. To reduce the risk of cancer, however, more research could be done in the area. Further research should be done by looking at additional sources in the study area in order to cover the entire zone. Further investigation should be carried out both during the dry and wet seasons because radon concentrations in groundwater alter over time due to dilution by recharge from rainfall.

Keywords: Ingestion; Inhalation; Irrigation; Radon; Yearly effective dose; Excess lifetime cancer risk

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1. Introduction

Water is one of the most plentiful materials on earth and is a crucial component of all living things, according to a 2010 report by Darko et al. It is utilized in many facets of daily life, including domestic work, agriculture, and the production of power. Water must be free of chemical, microbiological, and radioactive contaminants as a result [1].

In the disintegration chain of Uranium-238 is the radioactive gas radon, which is colorless and odorless [2].

The above-described radon is a naturally occurring element that leads to radioactive contamination of drinking water and poses a health risk, according to reports by Farai and Sanni in 1992 [3] and Darko et al. in 2010 [4]. It has been acknowledged as a health issue since the late 1980s. When uranium or radium decays, a radioactive gas known as radon is created. It seeps into the environment or into human habitations after evaporating from the earth's crust through bedrock fractures and crevices and dissolving in ground water [1,4].

According to a 2010 assessment by Darko et al., as reported by Rilwan et al. in 2022 [4,5] the people of Nasarawa only use untreated groundwater (from wells and boreholes) and surface water sources. This is due to the limited number of pipe-borne water sources that are available and the fact that they are frequently inoperable. A naturally occurring radioactive inert gas with a half-life of 3.82 days, Radon-222 is soluble in water and belongs to the uranium decay series. The majority of the radiation from all-natural sources comes from it [5].

According to studies, the amount of Radon-222 (^{222}Rn) and its offspring that makes up the total effective dosage equivalent from natural sources is roughly 50% [5,6]. Water contains a high amount of ^{222}Rn due to the decay of Radium-226 found in rocks and soil [5,7]. Radon gas permeates rocks and soil before dissolving in water [5,8]. Drinking water from sources of groundwater typically contains more radon than surface water [5,9].

Long-term exposure to high levels of radon and its offspring can have serious health consequences for a community, including lung cancer and altered respiratory function [5,10]. Moreover, stomach and gastrointestinal tract cancer can result from very high radon levels in drinking water [5,11].

In Nasarawa, finding access to potable water sources has remained one of the major challenges. As a result, the majority of people and animals depend on untreated surface and groundwater sources for consumption. The radon level in drinking water, which in high concentration can cause a significant risk of stomach and gastrointestinal tract cancer [11], among others, needs to be investigated. The geology of Nasarawa revealed that it is highly enriched in clay, loamy, and sandy soil, and studies have shown that high activity concentrations of Radon-222 are always associated with areas rich in clay soil [11]. This is more so because our understanding of its amount of availability could be of tremendous use in resource planning [12].

Due to their strong ionization strength, alpha rays pose a greater risk than beta and gamma rays when it comes to internal exposure [13]. Because Radon-222 is very soluble, eliminating the radon can be accomplished by adjusting the water's temperature [14]. According to reports that have been published, the concentration of Radon-222 in groundwater sources can be estimated to be two- to three-times higher than that of other radioactive elements [14-18].

The radiological effects brought on by consuming dissolved radon in drinking water are described using the population's effective radiation dosage during ordinary water consumption. The average annual water consumption rates (ACR) for the general population were used to calculate the doses from drinking water intake for children and teens [19]. However, a number of 2 liters per day (730 liters per year) for adults was used here in order to be consistent with the bulk of global drinking water guidelines [20]. The International Commission on Radiological Protection (ICRP) age categories and related ACRs are listed in **Table 1**.

Table 1. International Commission on Radiological Protection (ICRP) age groups and their Annual Water Consumption Rate (ACR).

Age Group	Age Range (Years)	Water Consumption (L/day)	Water Consumption (L/years)	Reference
3 Months	0 to 1	0.55	200	[12,20]
1 Year	1 to 2	0.71	260	[12,20]
5 Years	2 to 7	0.82	300	[12,20]
10 Years	7 to 12	0.96	350	[12,20]
15 years	12 to 17	1.64	600	[12,20]
Adults	Greater than 17	2.00	730	[12,20]

Measurement of radon content in water sources near the Ririwai Artisanal Tin Mine was the focus of Zakari et al.'s (2015) research [21] who did their research in Kano State, Nigeria. In their research, the amount of ^{222}Rn in three water sources near the Ririwai Artisanal Tin Mine was determined using liquid scintillation analysis. The annual effective dosage caused by the concentration of ^{222}Rn in domestic and surface water sources was also calculated. After their analysis, they concluded that the mean ^{222}Rn concentration found in this study was less than the 10 Bq/L levels that WHO and UNSCEAR recommend. Additionally, the study's annual effective dose was less than the UNSCEAR-recommended upper limit of 0.1 mSv/year. Also, Garba et al. (2013) [22] started a project called Radon Assessment of Groundwater (wells and boreholes). In their research, samples were taken from different parts of Zaria and its surroundings, including Sabongari, Tudunwada, Danmagaji, Samaru, and Bomo. In accordance with the findings of their study, the ^{222}Rn content in borehole sources is higher than that in well water sources, and both were above the USEPA-set MCL of 11.1 Bq/L. In another research, the estimation of indoor radon and its progeny in dwellings of Akoko Area, Ondo State, Southern Nigeria, was undertaken by Adeola and Isaac in 2017 [23]. Accustar alpha-track long-term passive test devices with CR-39 solid-state nuclear track detector foil were used for the test. In the Akoko region of Nigeria's Ondo state, radon levels were tested in a few residences constructed from various types of materials. The detectors were out in the elements for six months. The detectors were electrochemically etched after removal, and a computer-aided image analysis system was used to count them. The study demonstrates that radon concentrations in these places are significantly influenced by the local soil composition.

Despite the fact that Nasarawa's geology revealed that it has a high concentration of clay soil, there is no reliable information on the concentration of radon in the area from a review of the literature. As a result, this study aims to determine the potential health risk posed by radon in Nasarawa's water sources as well as the annual dose of radon consumed through drinking water. The results must be contrasted with industry standards and the results of other studies.

2. Materials and methods

2.1 Materials

The equipment and its specifications are listed in **Table 2**, and **Plate 1** shows the liquid scintillation counter that was used to gauge the radon levels in Keana's groundwater.

Table 2. Materials and their specifications.

S/N	Materials	Specifications
1	Water sample	100 mL
2	Plastic sample collection bottles	50 mL
3	Liquid Scintillation Counter (manufactured by Packard Tri-carb LSA 1000TR)	1
4	Disposable hypodemic syringe (20 mL, 10 mL and 2 mL) capacity with 38 mm hypodermic needle	8
5	distilled water	1 litre
6	Scintillation vial-20 mL with cap	Plastic
7	Surgical globe	1 pack
8	Indelible ink and masking tape	1
9	Mineral oil (insta-gel)	1

2.2 Method

Study population

The population of the study includes all of the boreholes and wells that are situated within the Keana Local Governments of Nasarawa State, which are Ewagu, Oleye, Emir Palace, Oki, Market, Aloshi, GGSS Keana, Jimini, Kachiya, Kalachi, Obne, and Madaki.

Study area

The Nasarawa South senatorial district is located in northern Nigeria's Guinea Savannah and is a part of the low plains of Benue origin. A number of weathered volcanic cones, mostly made of sandstone, surround the salt mining community of Keana. These detached synclinal areas were created by localized folding. **Table 3** displays Keana's sample codes and GPS coordinates. **Figure 1** shows a map of the research area.

Table 3. Sample codes and GPS locations of Keana.

S/N	Sampled Water	Location	Sample Code	Latitude (°) N	Longitude (°) E
1	Borehole	Ewagu	KEB1	8.1504	8.7901
2	Borehole	Oleye	KEB2	8.1305	8.6311
3	Borehole	Emir Palace	KEB3	8.1202	8.7023
4	Borehole	Oki	KEB4	8.1513	8.8012
5	Borehole	Market	KEB5	8.1234	8.7601
6	Borehole	Aloshi	KEB6	8.1340	8.8103
7	Borehole	GGSS Keana	KEB7	8.1241	8.6201
8	Borehole	Jimini	KEB8	8.1321	8.6420
9	Borehole	Kachiya	KEB9	8.1622	8.8210
10	Borehole	Kalachi	KEB10	8.1524	8.7204
11	Well	Emir Palace	KEW1	8.1140	8.6622
12	Well	Obne	KEW2	8.1441	8.6734
13	Well	Ewagu	KEW3	8.1401	8.7904
14	Well	Oleye	KEW4	8.1503	8.8010
15	Well	Madaki	KEW5	8.1310	8.7521

KEB = Borehole Water Sample; KEW = Well Water Sample.

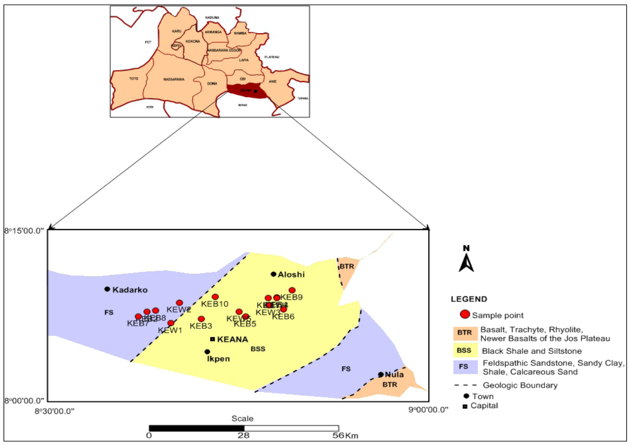

Figure 1. Map of the area showing the sample locations.

Technique used to collect samples

In plastic containers with coverings, five (5) water samples and fifteen (15) groundwater samples (from wells and boreholes) were gathered. The plastic containers were first cleaned and rinsed with distilled water to avoid radon in the samples from becoming contaminated. Water samples were held with 20 mL of concentrated HNO_3 per liter of water in order to reduce radon absorption on container walls.

The water samples were only collected after the boreholes had been operational for at least four minutes in order to ensure that new samples were obtained.

The containers were quickly sealed to prevent loss of radon during transport to the lab and were then completely filled with the water sample without any headspace. This was done to avoid CO_2 being trapped and dissolved in water, which could change the chemistry, such as pH, at each location.

The samples were sent for examination as soon as they were obtained and for no more than three days at maximum in order to minimize the effects of radioactive decay. This is done to guarantee complete accuracy without altering its composition.

Technique for preparing samples

Each sample of water was divided into 10 mL pieces, added to a 20 mL glass scintillation vial with 10 mL of an insta-gel scintillation cocktail, and shaken. The vials were tightly closed, shaken for more than two minutes, and then Radon-222 in the aqueous phase was extracted into the organic scintillate. The samples were then gathered, and for 60 minutes, they were tallied in a liquid scintillation counter employing energy discrimination for alpha particles.

Technique for analyzing samples

The samples were evaluated at Ahmadu Bello University's Centre for Energy Research and Training in Zaria, Nigeria, using a liquid scintillation counter (Tri-Carb LSA 1000TR type).

The liquid scintillation counter (LSC) was used to measure the concentration of ^{222}Rn in water. The approach was comparable to that created by the American Society for Testing and Materials (ASTM). An LSC vial containing an LSC cocktail that is incompatible with water is mixed with a water sample. When radon has reached a state of equilibrium with its short-lived decay products, shaking is utilized to shift it into the organic phase and count it. Some radionuclides are unaffected by this technique. With low-background counting equipment and a 1-hour counting period, a sensitivity of around 0.5 Bq/L could be attained [17,24].

In liquid scintillation counting devices, the main detector is an organic phosphor called Cocktail. It is uniformly disseminated after being dissolved in the proper solvent (this is commonly referred to as the cocktail). The liquid scintillation cocktail also contains a second organic phosphor that alters wavelengths. After adding the sample, this mixture creates the test source [17,24].

The solvent, primary, and secondary scintillators make up the liquid scintillation cocktail. The shelf life of the organic components utilized to make the scintillators is limited [17,24].

The liquid scintillation counter (Tri-Carb LSA 1000TR) type is shown in **Plate 1** and was used to assess the level of radon in the groundwater in Nasarawa South, Nigeria. It is located at Ahmadu Bello University in Zaria, Nigeria's Center for Energy Research and Training (CERT).

Plate 1. Showing liquid scintillation counter (Tri-Carb LSA 1000TR) model.

Approach to data analysis

The analysis for this study is divided into four (4) sections, including the determination of the concentration in Bq/L, the annual effective dose for adults and children, the excess lifetime cancer risk, and a comparison of the results with previous studies and industry standards. Tables are used to present the analysis's findings.

a. Estimation of Radon-222 concentration in Bq/L

According to Rilwan et al. (2022) and USEPA (2019) [5,25], Equation (1) was used to determine the Radon-222 concentration in Bq/L as follows:

$$Rn(BqL^{-1}) = \frac{100ml(CS - CB)}{10ml \times 1.0L(CF \times D)} \quad (1)$$

Rn is the radon level in Bq/L, and the variables are CS = sample count/second, CB = background count/second, CF = conversion factor, and D = decay constant.

b. Effective dose by ingestion per year

It is vital to translate radon concentration into a dose because of the harmful effects of radon on the human body. The radon levels for the research region were used to compute the annual effective dosage equivalent. The United Nations Scientific Committee on the Effects of Atomic Radiation recommended the following equation to calculate the annual effective dose of ^{222}Rn from drinking water [21,22,25]:

$$E = K \times G \times C \times T \times 1000 \quad (2)$$

where T is the amount of time (365 days) during which water is consumed, C is the concentration of ^{222}Rn (Bq/L), G is the amount of water consumed each day (4 L/d), E is the annual effective dose (mSv/y), D is the concentration of ^{222}Rn that results from converting Sv to mSv (7×10^{-8} Sv/Bq), and 1000 is the conversion coefficient.

c. Annual effective dose by inhalation

Adeola and Isaac (2017) and USEPA (2019) [23,25] used the following equation to get the annual effective dose of ^{222}Rn when inhaled:

$$He = C \times F \times R \times D \quad (3)$$

He equals the yearly effective dose (mSv/y), C the radon concentration (Bq/L), F the equilibrium factor (0.4), T the time of indoor occupancy (7000 h/y), and D the dose conversion factor (7×10^{-8} mSv/h/Bq/L).

d. Estimating the excess lifetime cancer risk

Garba et al. (2013) and USEPA (2019) [22,25] computed the increased lifetime cancer risk using Equation (4) as follows:

$$ELCR = AEDE \times DL \times RF \times 10^{-3} \quad (4)$$

where ELCR is for excess lifetime cancer risk, AEDE is for annual effective dose equivalent, DL is for average life expectancy (about 70 years), and RF is for risk factor (Sv^{-1}), which refers to the risk of dying from cancer according to Sievert. The ICRP adopts RF as 0.05 for public stochastic effects.

3. Results

The concentration of Radon-222 in Bq/L, the annual effective dose for adults and children, the excess lifetime cancer risk, and other outcomes from this study were all examined. These findings were compared to norms and those of other studies. **Tables 4-7** present the findings of the analysis.

Table 4 presented the analysis for concentration in Bq/L; **Tables 5 and 6** presented the analysis for annual effective doses by ingestion and inhalation for adults and children; **Table 7** presented the analysis for excess lifetime cancer risk; and **Table 8** presented a comparison of the findings with those of other researchers and industry standards.

3.1 Radon-222 concentration

Table 4 provides the results for the Rn-222 concentrations in Bq/L of water samples from Keana.

According to **Table 4**, the Rn-222 concentration in Bq/L values for both borehole and well water samples from Keana ranged from 2.0 Bq/L for the lowest concentration level for sample point KEB8 to 3.20 Bq/L for the highest con-centration level for sample point KEB3, while for well water samples they ranged from 2.06 Bq/L for the lowest concentration level for sample point KEW4 to 2.22 Bq/L for the highest concentration level for sample point KEW1 Keana's mean radon concentration was discovered to be 2.25 Bq/L.

Table 4. Rn-222 concentrations in Bq/L of water samples from Keana.

S/N	Sample ID	Radon Concentration (Bq/L)
1	KEB1	2.10
2	KEB2	2.21
3	KEB3	3.20
4	KEB4	2.41
5	KEB5	2.03
6	KEB6	2.18
7	KEB7	1.91
8	KEB8	2.00
9	KEB9	2.18
10	KEB10	2.96
11	KEW1	2.22
12	KEW2	2.12
13	KEW3	2.13
14	KEW4	2.06
15	KEW5	2.12
	Mean	**2.25**

KEB = Borehole Water Sample; KEW = Well Water Sample.

3.2 3Annual effective dose by ingestion

Equation (2) was used to compute the annual effective dosage from **Table 4**, and the results are shown in **Table 5**.

Keana's annual effective dose by ingestion was calculated from **Table 5** using the corresponding measured radon concentrations. It was found that for adults the annual effective dose by ingestion for borehole water samples varies from 0.009 mSv/y for sample point KEB7 as the lowest value to 0.023 mSv/y for sample points KEB3 as the highest value while for well water samples were 0.015 mSv/y for sample points KEW2, KEW4 and KEW5 as the lowest values to 0.016 mSv/y for sample point KEW1 and KEW3 as the highest values. Ingestion of the mean effective dosage of Radon-222 for humans from borehole and well water samples is 0.016 mSv/y.

The annual effective dose by ingestion for children was determined to be 0.025 mSv/y for sample points KEW2, KEW4, and KEW5, with sample point KEW11 having the highest value. For borehole water samples, the annual effective dose by ingestion ranged from 0.023 mSv/y for sample point KEB7 as the lowest value to 0.038 mSv/y for sample point KEB3. Both borehole and well water samples have a mean effective dosage via consumption of Radon-222 for children of 0.027 mSv/y.

Table 5. Annual effective dose by ingestion of water samples from Keana.

S/N	Sample ID	Annual Effective Dose by Ingestion for Adults ($mSvy^{-1}$)	Annual Effective Dose by Ingestion for Children ($mSvy^{-1}$)
1	KEB1	0.015	0.024
2	KEB2	0.016	0.026
3	KEB3	0.023	0.038
4	KEB4	0.018	0.029
5	KEB5	0.015	0.024
6	KEB6	0.016	0.026
7	KEB7	0.009	0.023
8	KEB8	0.015	0.024
9	KEB9	0.022	0.035
10	KEB10	0.016	0.026
11	KEW1	0.016	0.027
12	KEW2	0.015	0.025
13	KEW3	0.016	0.026
14	KEW4	0.015	0.025
15	KEW5	0.015	0.025
	Mean	**0.016**	**0.027**

KEB = Borehole Water Sample; KEW = Well Water Sample.

3.3 Annual effective dose by inhalation

Equation (3) was used to compute the annual effective dosage by inhalation from **Table 4**, and the results are shown in **Table 6**.

Keana's annual effective dosage from the matching measured radon concentrations was computed using data from **Table 6**. The annual effective dose by inhalation for adults was found to range from 0.048 mSv/y for sample point KEB7 to 0.075 mSv/y for sample point KEB10, while for well water samples, the annual effective dose ranged from 0.052 mSv/y for sample point KEW4 to 0.056 mSv/y for sample point KEW1 as the highest values. Both borehole and well water samples have a mean effective dosage by inhalation owing to Radon-222 of 0.055 mSv/y.

Table 6. Annual effective dose by inhalation of water samples from Keana.

S/N	Sample ID	Annual Effective Dose by Inhalation ($mSvy^{-1}$)
1	KEB1	0.053
2	KEB2	0.056
3	KEB3	0.055
4	KEB4	0.061
5	KEB5	0.051
6	KEB6	0.055
7	KEB7	0.048
8	KEB8	0.050
9	KEB9	0.055
10	KEB10	0.075
11	KEW1	0.056
12	KEW2	0.053
13	KEW3	0.054
14	KEW4	0.052
15	KEW5	0.053
	Mean	**0.055**

KEB = Borehole Water Sample; KEW = Well Water Sample.

3.4 Excess lifetime cancer risk

Equation (4) was used to compute the increased lifetime cancer risk, and the findings are shown in **Table 7**.

Keana's extra lifetime cancer risk was calculated using data from **Table 7** and the matching determined annual effective dosage. Adults' excess lifetime cancer risk from borehole water samples ranges from 3.15×10^{-5} for sample point KEB7 to 8.05×10^{-5} for sample point KEB3, while the excess lifetime cancer risk from well water samples ranges from 5.25×10^{-5} for sample points KEW2, KEW4, and KEW5 to 5.60×10^{-5} for sample points KEW1 and KE3. Both borehole and well water samples have a mean extra lifetime cancer risk for adults owing to Radon-222 of 5.65×10^{-5}.

The excess lifetime cancer risk for children in borehole water samples ranges from 8.05×10^{-5} for sample point KEB7 to 1.33×10^{-4} for sample point KEB3, while the excess lifetime cancer risk in well water samples was found to be 8.75×10^{-5} for sample points KEW2, KEW4, and KEW5 as the lowest value to 9.45×10^{-5} for sample point KEW1. Both borehole and well water samples have a mean extra lifetime cancer risk for children owing to Radon-222 of 8.57×10^{-5}.

Table 7. Excess lifetime cancer risk of water samples from Keana.

S/N	Sample ID	Excess Lifetime Cancer Risk for Adults ($\times 10^{-5}$)	Excess Lifetime Cancer Risk for Children ($\times 10^{-5}$)
1	KEB1	5.25	8.40
2	KEB2	5.60	9.10
3	KEB3	8.05	13.30
4	KEB4	6.30	1.02
5	KEB5	5.25	8.40
6	KEB6	5.60	9.10
7	KEB7	3.15	8.05
8	KEB8	5.25	8.40
9	KEB9	7.70	12.25
10	KEB10	5.60	9.10
11	KEW1	5.60	9.45
12	KEW2	5.25	8.75
13	KEW3	5.60	9.10
14	KEW4	5.25	8.75
15	KEW5	5.25	8.75
	Mean	**5.65**	**8.79**

KEB = Borehole Water Sample; KEW=Well Water Sample.

3.5 Comparison with standard and other researchers

As shown in **Table 8** (**Figure 2**), **Table 9** (**Figure 3**) and **Table 10** (**Figure 4**), the findings from this study were compared to safety requirements, works from other researchers in Nigeria, and works from other researchers worldwide.

Table 8. Comparison of radon concentration from present study with standards.

S/N	Standard	Radon Concentration (Bq/L)	Reference
1	United Nation Scientific Committee on Effect of Atomic Radiation (UNSCEAR)	4.0-40.0	[21,26]
2	United States Environmental Protection Agency (USEPA)	11.1	[21,26]
3	European Commission for Drinking Water Purposes	100	[21,25]
4	World Average	10	[22]
5	Standard Organization of Nigeria (SON)	11.1	[21]
6	Keana	2.25	Present Study (2023)

Table 9. Comparison of radon concentration from present study with other places in Nigeria.

S/N	Location	Radon Concentration (Bq/L)	Reference
1	Kano State	2.29	[21,25]
2	Kaduna State	12.29	[22,25]
3	Ondo State	35.54	[23,25]
5	Keana	2.25	Present Study (2023)

According to **Table 8** (**Figure 2**), Keana's radon levels were within the acceptable limits recommended by the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), the European Commission for drinking purposes, the USEPA's maximum contamination level, and the global average.

According to **Table 9** (**Figure 3**), the radon concentration of groundwater samples from Keana is lower than that of Ado-Ekiti in the state of Ekiti, Gadau in the state of Bauchi, Idah in the state of Kogi, and Zaria in the state of Kaduna.

Table 10. Comparison of radon concentration of groundwater samples from present study with other parts of the world.

S/N	Location	Radon Concentration (Bq/L)	Reference
1	India	2.63	[23,25]
2	Turkey	9.28	[23,25]
3	Romania	15.40	[23,25]
4	Jordan (many locations)	2.8-116	[23,25]
5	Lebanon (many locations)	11.30	[23,25]
6	Tassili, South-east Algeria	0.67-21.25	[23,25]
7	Eastern Doon Valley, outer Himalayas	20-95	[23,25]
8	Northern Venezuela	0.1-5.76	[23,25]
9	Finland	63.0	[23,25]
10	United States of America	5.20	[23,25]
11	Keana, Nigeria	2.25	Present Study (2023)

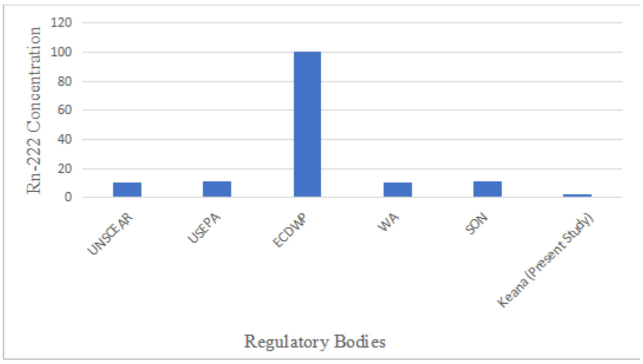

Figure 2. Comparison of radon concentration from present study with standards.

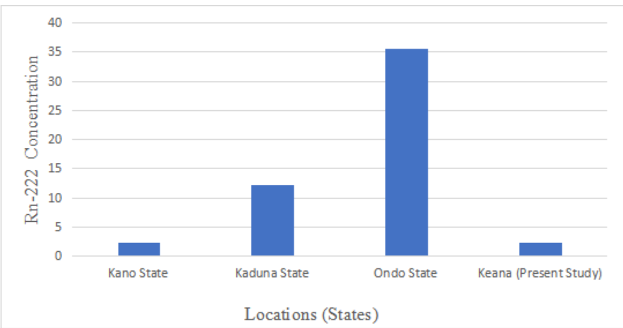

Figure 3. Comparison of radon concentration from present study with other places in Nigeria.

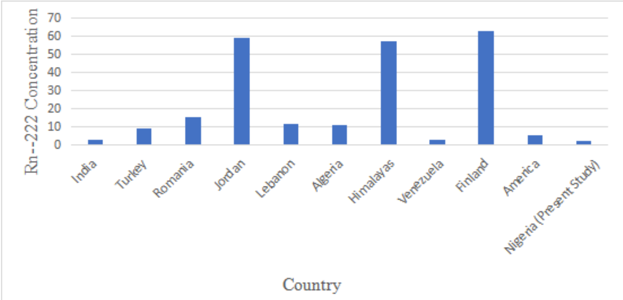

Figure 4. Comparison of radon concentration of groundwater samples from present study with other parts of the world.

According to **Table 10** (**Figure 4**), groundwater samples from Keana have radon concentrations that are lower than those from countries like India, Romania, Jordan, the outer Himalayas, Finland, Turkey, Lebanon, and the United States, but higher than those from some regions of Algeria and some regions of Northern Venezuela.

4. Discussion

The results of this study showed that Keana's mean radon concentration was 2.25 Bq/L. This value was lower than the global average of 10 Bq/L, the Standard Organization of Nigeria's (SON) 11.1 Bq/L, the European Union Commission's 100 Bq/L, the United Nations Scientific Committee on Atomic Radiation's (UNSCEAR) 4.0-40.0 Bq/L, and the United States Environmental Protection Agency's (11.1 Bq/L) (USEPA). The results of Zakari et al. [21], who discovered a mean radon concentration of 2.29 Bq/L is within the same range, are consistent with our discovery.

This result differs from that of Garba et al. (2013) [22], who discovered that the mean radon concentration was 12.29 Bq/L. The results of Adeola and Isaac (2017) [23], who discovered that the mean radon concentration was 35.54 Bq/L, are also out of sync.

The corresponding measured radon concentrations in the borehole water samples from Keana were 0.017 mSv/y for adults and 0.028 mSv/y for children, whereas the corresponding measured radon concentrations in the well water samples were 0.015 mSv/y for adults and 0.026 mSv/y for children.

The Standard Organization of Nigeria (SON) approved the WHO's recommended reference level of 0.1 mSv/y for intake of radionuclides in water and the ICRP's recommended intervention level of 3-10 mSv/y for radionuclide intake.

The radon concentrations in the borehole water samples from Keana that corresponded to the mean annual effective dosage by inhalation were 0.056 mSv/y and 0.054 mSv/y, respectively.

All annual effective dosage by ingestion readings fell below the 1 mSv/y threshold that is advised for the general public.

For well water samples, the excess lifetime cancer risk was 5.39×10^{-5} for adults and 8.96×10^{-5} for children, whereas the excess lifetime cancer risk from the same annual effective dose of borehole water samples from Keana was 5.79×10^{-5} for adults and 8.71×10^{-5} for children.

According to the global average of 2.9×10^{-4} as reported by Ibikunle et al. in 2018, the extra lifetime cancer risk of water samples from the Keana Local Governments was found to be lower.

5. Conclusions

According to the findings, the radon levels in the groundwater samples from Keana are safe for home use and human consumption because they are below the maximum limit of 11.1 Bq/L established by the USEPA and adopted by the Standard Organization of Nigeria (SON). Since this work pioneered the determination of radon in groundwater in the study area, the data in this study might be utilized as a reference for the study location. In order to cover the entire zone, more borehole and well investigations inside the study region should be conducted. Because radon concentrations in groundwater change over time due to dilution by recharge from rainfall, research should be done both during the dry and wet seasons. Most importantly, government officials at all levels should raise awareness of the dangers of radon exposure for people. In order to establish a comprehensive reference database for radon levels in groundwater in Nasarawa State, it is also advised that future researchers expand this study to other senatorial zones of the State. Also, future researchers should determine the levels of radon in both surface water and groundwater.

Author Contributions

Idris Muhammad Mustapha, Abdullahi Abubakar Mundi and Ibrahim Maina created all the figures in the work, while Abubakar Saidu Bako, Usman Rilwan, Samson Dauda Yusuf and Ibrahim Umaru wrote the majority of the manuscript. The work was examined by all writers.

Conflict of Interest

The corresponding authors affirm that they have no known financial or interpersonal conflicts that would have appeared to have an impact on the research presented in this study.

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References

[1] Aruwa, A., Gyuk, P.M., Dogara, M.A., et al., 2017. Determination of Radon-222 concentrations and effective dose by ingestion in ground and surface water sources from Idah and Environs, Nigeria. International Journal of Research—Granthaalayah. 5(9), 15-25.

[2] Farai, I.P., Sanni, A.O., 1992. Yearly variability of ^{222}Rn in a groundwater system in Nigeria. Journal of African Earth Sciences. 15(314), 399-403.

[3] Galan, L.M., Martin, S.A., Gomez, E.V., 2004. Application of ultralow level liquid scintillation to the determination of ^{222}Rn in groundwater. Journal of Radioanalytical and Nuclear Chemistry. 261(3), 631-636.

[4] Darko, E.O., Adukpo, O.K., Fletcher, J.J., 2010. Preliminary studies on ^{222}Rn concentration in groundwater from selected areas of the Accra metropolis in Ghana. Journal of Radioanalytical and Nuclear Chemistry. 283(1), 507-512.

[5] Rilwan, U., Yahaya, I., Musa, M., et al., 2022. Investigation of Radon-222 in water from Loko Town in Nasarawa, Nasarawa State, Nigeria. Journal of Oncology and Cancer Screening. 4(2), 1-7.

[6] Hussein, A.S., 2014. Radon measurements in water samples from western desert of Egypt using nuclear track detectors and estimation of corresponding doses. Radiation Protection and Environment. 37(3), 165-174.

[7] United Nations, 2003 Water for People Water for Life—The United Nations World Water Development Report Executive Summary [Internet]. Available from: https://sustainabledevelopment.un.org/content/documents/WWDR_english_129556e.pdf

[8] International Commission on Radiation Protection, 2005. Annals of ICRP. 60(1), 411-440.

[9] Kumar, A., Kaur, M., Sharma, S., et al., 2016. Radiation dose due to radon and heavy metal analysis in drinking water samples of Jammu district, Jammu & Kashmir, India. Radiation Protection Dosimetry. 71(2), 217-222.

[10] Taskin, H., Karavus, M., Ay, P., et al., 2009. Radionuclide concentrations in soil and life time cancer risk due to gamma radioactivity in Kirklareli, Turkey. Journal of Environmental Radioactivity. 35(1), 53.

[11] Mustapha, A.O., Patel, J.P., Rathore, I.V.S., 2002. Preliminary report on Radon concentration in drinking water and indoor air in Kenya. Environmental Geochemistry and Health. 24(1), 387-396.

[12] WHO, 2011. The guidelines for drinking-water quality, 4th edition. WHO: Geneva.

[13] Hamanaka, S., Shizuma, K., Wen, X.Q., et al., 1998. Radon concentration measurement in water by means of α liquid-scintillation spectrometry with a PERALS spectrometer. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 410(2), 314-318.

[14] Kam, E., Bozkurt, A., 2007. Environmental radioactivity measurements in Kastamonu region of northern Turkey. Applied Radiation and Isotope. 65, 440-444.

[15] Akawwi, E., 2014. Radon-222 concentrations in the groundwater along Eastern Jordan Rift. Journal of Applied Sciences. 14, 309-316.

[16] Ali, N., Khan, E., Akhter, P., et al., 2010. Estimation of mean annual effective dose through radon concentration in the water and indoor air of Islamabad and Murree. Radiation Protection Dosimetry. 141, 183-191.

[17] Forte, M., Rusconi, R., Cazzaniga, M., et al., 2017. The measurement of radioactivity in Italian drinking waters. Microchemical Journal. 85(1), 98-102.

[18] Rangel, J.D., Del-Río, H.L., García, F.M., et al., 2002. Radioactivity in bottled waters sold in Mexico. Applied Radiation and Isotope. 56, 931-936.

[19] Ravikumar, P., Somashekar, R.K., 2014. Determination of the radiation dose due to radon ingestion and inhalation. International Journal of Environmental Science and Technology. 11(1), 489-508.

[20] Cevik, U., Damla, N., Karahan, G., et al., 2006. Natural radioactivity in tap waters of eastern black sea region of Turkey. Radiation Protection Dosimetry. 118(1), 88-92.

[21] Zakari, Y.I., Nasiru, R., Ahmed, Y.A., et al., 2015. Measurement of Radon concentration in water sources around Ririwai Artisanal Tin Mine Kano State, Nigeria. Journal of Natural Sciences Research. 5(24), 49-55.

[22] Garba, N.N., Rabi'u, N., Dewu, B.B.M., et al.,

2013. Radon assessment in ground water sources from Zaria and environs, Nigeria. International Journal of Physical Sciences. 8(42), 1983-1987.

[23] Adeola, M.A., Isaac, R.A., 2017. Estimation of indoor Radon and its progeny in dwellings of Akoko Region, Ondo State, Southwestern Nigeria. Journal of Scientific Research & Reports. 14(3), 1-7.

[24] Jacek, P., Anna, P., Andrzej, Z., et al., 1997. Commissioning of a Quant ulus 1220™ liquid scintillation beta spectrometer for measuring ^{14}C and ^{3}H at natural abundance levels. Radiocarbon. 40(1), 201-209.

[25] United State Environmental Protection Agency, 2019. National primary drinking water regulations on Radon-222. Federal Register. 64(211), 59245-59294.

[26] UNSCEAR, 2017. 2017 Report to General Assembly, Annex A [Internet]. Available from: https://www.unscear.org/docs/publications/2017/UNSCEAR_2017_Report.pdf