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Radon Gas Risk Indices in Water on Fractured Basement of Ayetoro Housing Scheme, Oyo

Emmanuel A Oni[1], Johnson A Abilawon[1], Oluwaseun O Oloyede[1], Abraham A Aremu[1], Olukunle O Oladapo[1], Temitayo A Olajide[1], Mustapha K Lawal[1], Paul S Ayanlola[1] and Olatunde M Oni[1]

[1] Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Nigeria

Corresponding E-mail: oloyedeoluwaseun2309@gmail.com

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Abstract

Radon gas, a naturally occurring radioactive element, presents significant health risks, particularly in areas with fractured basement geology, where subsurface characteristics can elevate its concentration. As the second leading cause of lung cancer globally, after smoking, radon exposure is a critical public health concern. This study seeks to evaluate the concentration levels of radon gas, analyze its potential health risks to the residents, and provide insights into the environmental factors influencing radon accumulation in this area. Thirty (30) samples were collected for groundwater from various locations within the study area. Groundwater samples were collected from selected drinking water sources using 1.5 litre plastic bottles. Radon gas concentration was measured using a RAD7 electronic radon detector for soil and RAD7 H_2O for groundwater. The data obtained was analysed using a statistical tool to perform a one-way Analysis of Variance (ANOVA). The samples were also subjected to decay corrections to ensure the accuracy of the results. The data were analysed using descriptive and inferential statistics, with statistical significance set at $p < 0.05$. Groundwater radon concentrations ranged from 0.576Bq/L to 6.54Bq/L with a mean concentration value of 2.81 Bq/L and a standard deviation of 1.73 Bq/L. The mean annual effective dose for radon due to inhalation, ingestion and whole- body are 0.0254 mSvy^{-1}, 0.00987 mSvy^{-1} and 0.0352 mSvy^{-1} respectively. The results were all below the recommended threshold of 0.1 mSvy^{-1} set by the World Health Organization (WHO). The Excess Lifetime Cancer Risk (ELCR) value of 12.34 $\times 10^{-5}$ was obtained which corresponds to about 1.23 in 10,000 risk of developing cancer over a lifetime due to radon exposure through water. The study on radon concentration in groundwater from the Ayetoro Housing Scheme, Oyo, found an average radon level of 2.82 Bq/L, below the EPA's maximum contaminant level (MCL) of 11.1 Bq/L. This indicates that residents in the area are not at significant risk from radon exposure at the time of the study. However, it was observed that inhalation of radon from water presents a higher radiological hazard than ingestion. The study recommends regular radon monitoring in the area to ensure continued safety.

Keywords: Radon; Excess Lifetime cancer risk; Inhalation dose.

I. INTRODUCTION

Radon is a colorless, odorless, radioactive gas naturally emitted from rocks, soil, and water [1]. It can enter buildings through cracks and holes, accumulate in the air, or be introduced through well water. When water from a well is disturbed, radon is released into the air [2]. The presence of radon in groundwater primarily results from the decay of radium (^{226}Ra) in rocks and soil, rather than from radium dissolved in the water. Additionally, radon can be produced in water distribution systems with high radium levels, especially from radium absorbed into iron pipe scales [3]. Exposure to radon from water can occur through ingestion or inhalation of radon gas released from the water.

Long-term exposure to elevated radon levels can lead to severe health issues, including lung cancer [4]. The cancer risk from waterborne radon exposure, such as from showering or washing dishes, is considered higher than the risk from drinking radon-contaminated water (NRC, 1998). According to the World Health Organization [5], 1–7% of lung cancer deaths are linked to high radon levels in water, with 10–15% of indoor radon coming from radon released from tap water [6]. While drinking water with radon poses a risk for internal organ cancers, such as stomach cancer, this risk is lower than that of lung cancer from radon released into the air. In Nigeria, public awareness about radon and its health risks is limited [7]. Understanding radon concentrations is crucial for environmental sustainability, as radon in the air can affect air quality and human health [8].

Ayetoro Housing Scheme is in a geologically vulnerable area with fractured basements, where groundwater radon levels can serve as indicators of potential health risks. This study aims to fill the gap in knowledge by focusing specifically on radon levels in groundwater in the Ayetoro implement protective measures [9].

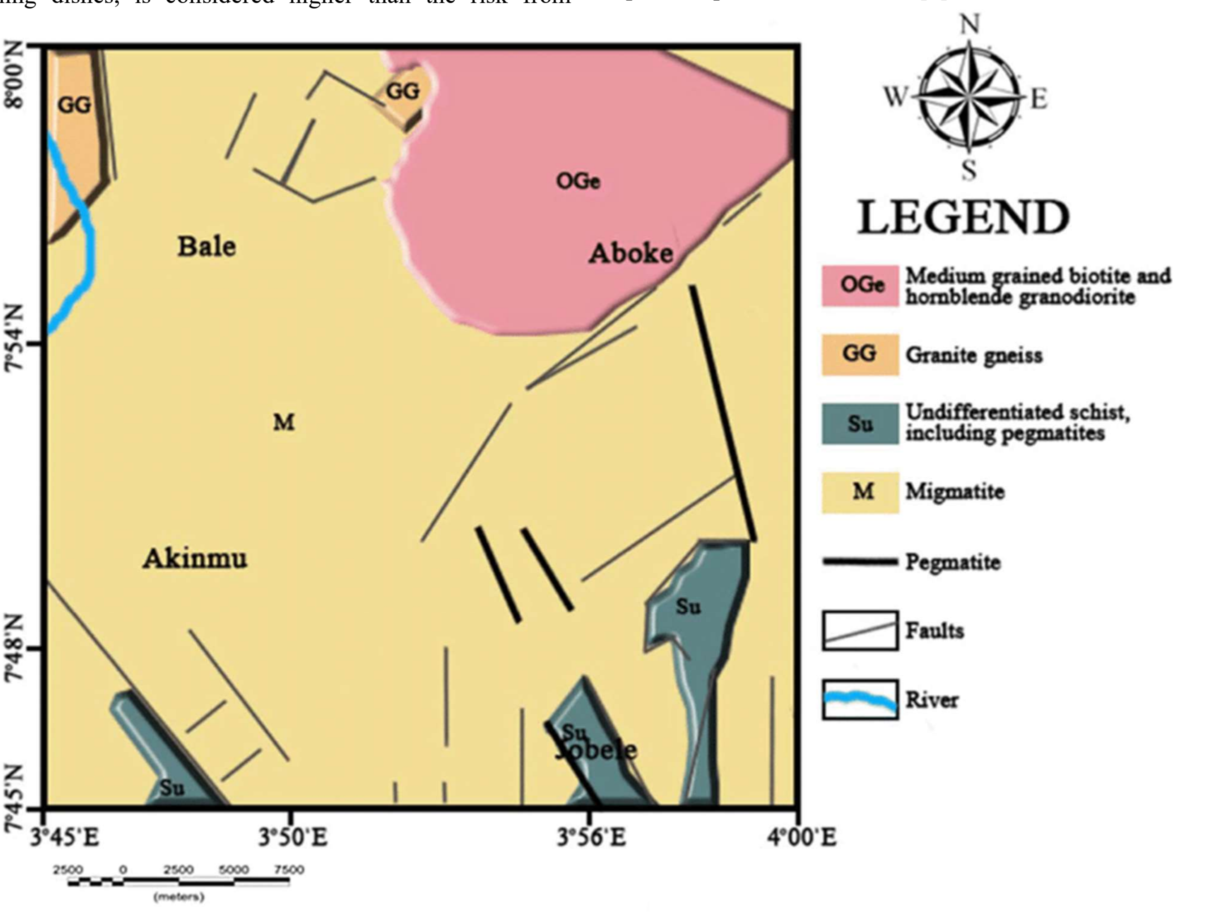

Fig. 1. Map of study location.

II. MATERIALS AND METHODS

A. Study Location

The study was conducted in the Ayetoro Housing Scheme, located in Oyo town, Oyo West Local Government Area, Oyo State, Nigeria. The study area's geographic coordinates are approximately between latitudes N 07° 50' and N 07° 52', and longitudes E 03° 53' and E 03° 54'. The area comprises a residential housing scheme with a mix of individual homes, community facilities, and open spaces as shown in Fig. 1.

The climate of Ayetoro Housing Scheme is classified as a tropical savanna, with distinct wet and dry seasons. The wet season, from April to October, is characterized by heavy rainfall, which can influence soil moisture and radon gas movement. The dry season, from November to March, experiences lower humidity and temperature fluctuations, which may also impact radon emission rates from the ground. Average annual temperatures range from 22°C to 32°C, with significant variations in humidity between the two seasons. These climatic factors play a crucial role in understanding the seasonal changes in radon concentration in groundwater.

B. *Sample Collection*

A total of 30 groundwater samples were collected from wells and boreholes in the fractured basement area of the Ayetoro Housing Scheme. The samples were carefully gathered and sealed to prevent the escape of radon gas, with containers wrapped in cellophane to avoid contamination. Each sample was labelled, dated, timed, and then stored on ice to maintain the temperature. Radon levels in the groundwater were measured using a closed-loop method, which ensured consistent air volume and water flow. The analysis was repeated multiple times to ensure accuracy. A portable electronic radon monitor, from Durridge Company, known for its high accuracy and sensitivity, was used to measure radon levels. This device can determine radon concentrations within 30 minutes, faster than radon's half-life. The study also estimated the annual effective dose from ingestion, based on the water consumption patterns in the study area. The main goal of the research was to identify the presence of radon in the water and evaluate its potential health risks. The experimental setup for the radon measurements is shown in Fig. 2.

Fig. 2. RAD 7 setup.

C. *Estimation of Annual Effective Dose by Inhalation*

The annual effective dose by inhalation measures the radiation dose received by an individual from inhaling air containing radioactive particles or gases was estimated using (1). This is particularly important in assessing the health risks from airborne radioactive contamination, such as radon gas or dust particles containing radionuclides. The inhalation dose, E_{inh}, was calculated using the (1):

$$E_{in} = C_{Rn} \times \mathrm{R} \times \mathrm{DCF} \times \mathrm{F} \times \mathrm{T} \quad (1)$$

$C_{Rn}$is the average radon activity concentration in the water, R is the fraction of radon concentration in air to that in water (10^{-4}), DCF is the dose conversion factor ($9\, nSv\, h^{-1}(Bq/m^3)^{-1}$), F is the equilibrium factor (0.4), T is the annual indoor time ($0.8 \times 8766\, hours/year$)[10].

D. *Estimation of Annual Effective Dose by Ingestion*

The annual effective dose from ingestion refers to the radiation dose an individual receives from consuming radioactive materials, as calculated using (2). It is typically expressed in millisieverts per year (mSv/year). The calculation takes into account various factors, such as the concentration of radionuclides in food and water, the rates at which these substances are consumed, and the dose conversion factors for the specific radionuclides involved. The annual effective dose from ingestion was evaluated based on the water consumption patterns of the residents in the study area using (2).

$$E_{ing} = C_{Rn} \times D_{ing} \times D_w \times T \quad (2)$$

Where $C_{Rn}$is the average activity of radon, $D_w$is the daily water consumption (2 liters), D_{ing} is the dose conversion factor (10^{-8} Sv/Bq), and T is the number of days in a year [11].

E. Excess Lifetime Cancer Risk (ELCR)

Excess Lifetime Cancer Risk (ELCR) is a measure used to estimate the heightened likelihood of developing cancer over a person's lifetime due to exposure to carcinogenic substances, such as ionizing radiation. ELCR is commonly employed in environmental health risk assessments to evaluate the long-term cancer risks linked to radiation exposure. Specifically, the ELCR indicates the increased risk of lung cancer deaths per million individuals as a result of lifetime exposure to radon. The ELCR was calculated using (3) [13].

$$ELCR = C_{Rn} \times \mathrm{F} \times \mathrm{O} \times \mathrm{D} \times \mathrm{RF} \quad (3)$$

Where C_{Rn} = Concentration of radon ($200\, Bq/m^3$), F = Equilibrium factor (0.4), O = Occupancy factor (0.8), D = Duration of exposure (70 years) and RF = Risk factor ($5\, x\, 10 - 4\, per\, Bq/m^3$).

F. Statistical Analysis

The gathered data were analysed statistically using SPSS, with descriptive statistics such as the mean, median, and standard deviation calculated. Furthermore, Geographic Information System (GIS) software was employed for spatial analysis to map the distribution of radon levels across the study area.

III. RESULTS AND DISCUSSION

Table I displays the radon gas concentrations found in groundwater samples from different sites in the study area. These measurements are essential for assessing the potential health risks linked to radon exposure through drinking water and for understanding the distribution of radon in groundwater sources.

A. Radiological Risk Indices

Table II presents the measurement of radiological risk indices, which are essential for assessing the potential health risks associated with exposure to radiation in the study area. These indices provide a comprehensive evaluation of the radiological safety of the Ayetoro Housing Scheme, and its environs, helping to understand the impact of natural radiation on public health. It also reports a comprehensive overview of the annual effective doses of ^{222}Rn in water across the sample location. The summary encompasses the inhalation and ingestion routes of exposure, as well as the Excess Lifetime Cancer Risk (ECLR). According to the recommendations from reputable sources such as the World Health Organization (WHO) and the European Union (EU), the suggested annual permissible limit for radiation dose resulting from the consumption of drinking water stands at 0.1 mSv y^{-1} [12].

The mean annual effective doses of ^{222}Rn due to inhalation and ingestion were calculated for each sample and summarized. Results revealed that the mean annual exposure for inhalation, ingestion and combined ingestion and inhalation (whole-body) is 0.0254 mSv/y, 0.00987 mSv/y and 0.0352 mSv/y respectively. The results revealed that annual effective doses from all locations were found within the 0.1 mSv y^{-1} recommended threshold by the World Health Organization (WHO) [13]. The higher mean annual effective doses could cause various kinds of cancer in humans. If the radiation dose in water intended for drinking is equal to or below 0.1 mSv y−1, it is considered safe and does not require further action. If the dose from drinking water exceeds the annual safe limit of 0.1 mSv y^{-1}, corrective measures are necessary to reduce the risk. Comparing the results obtained in the present work with a recent study conducted in the Mulazai area of Peshawar city, in Pakistan, the average radiation exposure for individuals from water sources used for drinking purposes was found to be 0.0025, 0.0307, and 0.0333 mSv y^{-1} through ingestion, inhalation, and combined ingestion and inhalation (whole-body) is said to be in the range of safe limit [14 - 15]. Therefore, it can be concluded that the presence of ^{222}Rn in the water of the study area does not pose any potential health risk.

Table I. Radon gas concentration in groundwater.

Sampling ID	Latitude (°)	Longitude (°)	Concentration (Bq/L)
S1	N 0751 53	E 03 53 32	2.37
S2	N 07 51 56	E 03 53 47	2.32
S3	N 07 51 59	E 03 53 50	1.22
S4	N 07 51 9	E 03 53 53	1.54
S5	N 07 51 30	E 03 53 56	1.99
S6	N 07 51 51	E 03 53 59	1.74
S7	N 07 51 46	E 03 53 59	1.51
S8	N 07 51 44	E 03 53 58	1.15
S9	N 07 51 39	E 03 54 01	1.31
S10	N 07 51 38	E 03 53 59	1.22
S11	N 07 51 11	E 03 53 53	1.37
S12	N 07 5130	E 03 53 46	1.05
S13	N 07 51 25	E 03 53 48	0.90
S14	N 07 51 19	E 03 53 50	0.57
S15	N 07 51 16	E 03 53 59	1.90
S16	N 07 51 13	E 03 54 06	0.71
S17	N 07 51 25	E 03 54 00	2.44
S18	N 07 51 10	E 03 54 11	2.63
S19	N 07 51 00	E 03 54 03	4.33
S20	N 07 50 15	E 03 53 57	5.57
S21	N 07 50 22	E 03 53 56	4.51
S22	N 07 50 28	E 03 53 58	4.25
S23	N 07 50 35	E 03 54 00	3.95
S24	N 07 50 40	E 03 54 01	3.66
S25	N 07 5045	E 03 54 04	3.76
S26	N 07 50 25	E 03 54 19	3.95
S27	N 07 50 10	E 03 54 15	5.01
S28	N 07 50 50	E 03 54 20	6.46
S29	N 07 50 30	E 03 54 30	4.64
S30	N 07 50 00	E 03 54 40	6.54

Table II. Radon concentration and annual effective doses in the samples

Sample ID	Concentration (Bq/L)	E_{ing} (mSv/y)	E_{inh} (mSv/y)	E_{tot} (mSv/y)	ELCR (x 10^{-5})
S1	2.37	0.00830	0.02133	0.02963	10.4
S2	2.32	0.00812	0.02088	0.02900	10.2
S3	1.22	0.00427	0.01098	0.01525	5.34
S4	1.54	0.00539	0.01386	0.01925	6.74
S5	1.99	0.00697	0.01791	0.02487	8.71
S6	1.74	0.00609	0.01566	0.02175	7.61
S7	1.51	0.00529	0.01359	0.01888	6.61
S8	1.15	0.00403	0.01035	0.01437	5.03
S9	1.31	0.00459	0.01179	0.01638	5.73
S10	1.22	0.00427	0.01098	0.01525	5.34
S11	1.37	0.00480	0.01233	0.01713	5.99
S12	1.05	0.00368	0.00945	0.01313	4.59
S13	0.897	0.00314	0.00807	0.01121	3.92
S14	0.574	0.00201	0.00517	0.00717	2.51
S15	1.897	0.00664	0.01707	0.02371	8.30
S16	0.705	0.00247	0.00634	0.00881	3.08
S17	2.44	0.00854	0.02196	0.03050	10.7
S18	2.63	0.00921	0.02367	0.03287	11.5
S19	4.33	0.01516	0.03897	0.05413	18.9
S20	5.57	0.01950	0.05013	0.06963	24.4
S21	4.51	0.01579	0.04059	0.05637	19.7
S22	4.25	0.01488	0.03825	0.05313	18.6
S23	3.95	0.01383	0.03555	0.04938	17.3
S24	3.655	0.01279	0.03289	0.04569	16.0
S25	3.762	0.01317	0.03386	0.04703	16.5
S26	3.95	0.01383	0.03555	0.04938	17.3
S27	5.01	0.01754	0.04509	0.06263	21.9
S28	6.46	0.02261	0.05814	0.08075	28.3
S29	4.64	0.01624	0.04176	0.05800	20.3
S30	6.54	0.02289	0.05886	0.08175	28.6

Excess lifetime cancer risk refers to the likelihood of developing cancer that surpasses the typical risk level of 240 due to prolonged exposure to carcinogenic substances. The Excess Lifetime Cancer Risk (ELCR) value of 12.34×10^{-5} obtained in this study represents the estimated probability of developing cancer over a lifetime due to radon exposure. According to the EPA recommendation, an acceptable risk for radon in drinking water corresponds to an ELCR range of 1 in 10,000 to 1 in 1,000,000 (i.e., 10^{-4} to 10^{-6}). Hence, an ELCR of 12.34 x 10^{-5} corresponds to about 1.23 in 10,000 risk of developing cancer over a lifetime due to radon exposure through water.

Although this value is slightly higher than the EPA's lower bound for acceptable risk, it is still considered a low probability, especially in comparison to higher risks found in areas with higher radon concentrations. The estimated ELCR in this study was higher than the reported ELCR in Vietnam [16] but lower than the ELCR associated with exposure in Iran [17].

Table III shows the descriptive statistics of radon concentration in water (Bq/L) across the study area. It summarizes key statistical measures, including the mean, median, and standard deviation, providing an overview of the variation and central tendency of radon levels in water samples, and also presents the Minimum and Maximum concentrations of the dataset of 0.574 Bq/L and 6.540 Bq/L respectively, with the mean radon concentration of 2.81 Bq/L and Standard deviation of 1.726 Bq/L.

Table III. Descriptive Statistics of Radon Concentration in Water (Bq/L)

Statistics	Concentration (Bq/L)	Uncertainty Value (Bq/L)
Count	30	30
Mean	2.818	0.053
Standard Deviation	1.726	0.013
Minimum	0.574	0.029
25^{th} Percentile (Q1)	1.325	0.042
Median (Q2)	2.345	0.056
75^{th} Percentile (Q3)	4.175	0.065
Maximum	6.540	0.075

The analysis revealed that all the samples collected from various sample locations are within the MCL of 11.1 Bq/L recommended by USEPA, 2009. A comparison of all the results with the European Union (EU, 2001) recommended level, revealed that all the samples analyzed have radon concentrations below the recommended limit. Although all the samples were below the recommended value, however, some areas had high radon concentrations than in other locations, these sample locations are, S19, S20, S21, S22, S27, S28, S29 and S30. These high values could be due to the fracture level in these locations or the geological nature of the bedrock which increases the uranium concentration in the local geology.

IV. CONCLUSION

The radon concentration of groundwater samples collected from Ayetoro Housing Scheme, Oyo, has been determined. The mean radon concentration of groundwater was found to be 2.82 Bq/L (2818Bq/m^3), which is below the 11.1Bq/L MCL proposed by EPA in controlling radon contamination in public water supplies, by implication the inhabitant of Ayetoro Housing Scheme was considered as a safe zone from radon gas environmental hazard as at the period this research was carried out.

Also, the annual effective dose due to inhalation and ingestion of water- borne radon was estimated and found that the radon inhaled from water has higher radiological hazard than the radon ingested from water. Hence, it is recommended that regular radon gas monitoring should be carried out in the study areas.

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