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TECHNICAL NOTE

Level and Potential Radon (^{222}Rn) Radiation Risk in Groundwater Samples at Jimba-Oja, Northcentral Nigeria

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Abstract: Radon (^{222}Rn) concentration in groundwater was investigated using the Rad7 detector. This investigation was necessary due to the impact of a new mining company in Jimba-Oja, which may affect the surface water supply, potentially percolating into subsurface water sources. Nine (9) samples were collected from hand-pump wells and analyzed in the laboratory. The estimated radon concentration ranged from 3.08 Bq. L^{-1} to 9.18 Bq. L^{-1} with an average value of 5.00 BqL^{-1}. The average AED for groundwater ingestion by adults, children, and infants was calculated at 36.50, 54.75, and 63.88 $\mu Sv.y^{-1}$, respectively. The average AED$_{\text{total}}$ values were 162.50 $\mu Sv.y^{-1}$ for adults, 180.75 $\mu Sv.y^{-1}$ for children, and 189.88 $\mu Sv.y^{-1}$ for infants. The results indicate that the AED for infants exceeds the permissible limit of 100 $\mu Sv.y^{-1}$, while the values for children and adults remain within the recommended limit of 200 $\mu Sv.y^{-1}$. Thus, the health risk from radiological exposure is within allowable limits for children and adults but poses a potential risk for infants. Although ^{222}Rn concentrations in groundwater samples are low, are currently low, there may still be probabilistic effects on local inhabitants over time. To monitor ^{222}Rn levels, we recommend repeating these measurements in the same wells and season within the next two years to ensure consistency and detect any changes in radon levels.

Keywords: Radon (^{222}Rn) concentration, Groundwater, Jimba-Oja, Dose rate.

Introduction

^{222}Rn a naturally occurring radioactive gas originating from the disintegration of the ^{238}U series, is a natural radioactive element found within layers of the Earth [1]. ^{222}Rn has a half-life of up to 3.82 days, after which it quickly decays, producing a short-lived radioactive element polonium-218 and emitting a series of radioactive elements, as illustrated in Fig. 1 [2]. ^{222}Rn is a chemical element with the symbol Rn and an atomic number of 86. It is a colorless, odorless, and tasteless noble gas that is radioactive and soluble in water. It is a product of radium-226, which has a half-life of 1,602 years and originates from the uranium series via alpha decay. This makes it one of the main sources of radiation risk in homes, caves, water, and the environment. When radon is mixed with other atmospheric particles such as aerosols and dust and is inhaled, it can damage the lungs [3]. Alpha, beta, and gamma radiation are emitted

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during the radioactive decay chain of ^{222}Rn. This decay chain starts with the alpha decay of ^{222}Rn, producing polonium-218 with an energy of 5.49 MeV and a half-life of 3.1 minutes, which makes it useful in tracing the early history of groundwater. Other decay products, namely lead (Pb-214), bismuth (Bi-214), polonium (Po-214), lead (Pb-210), bismuth (Bi-210), polonium (Po-210), thallium (Ti-206), and lead (Pb-210) are shown in Fig. 1 along with their half-lives, energies, and emitted radiation types.

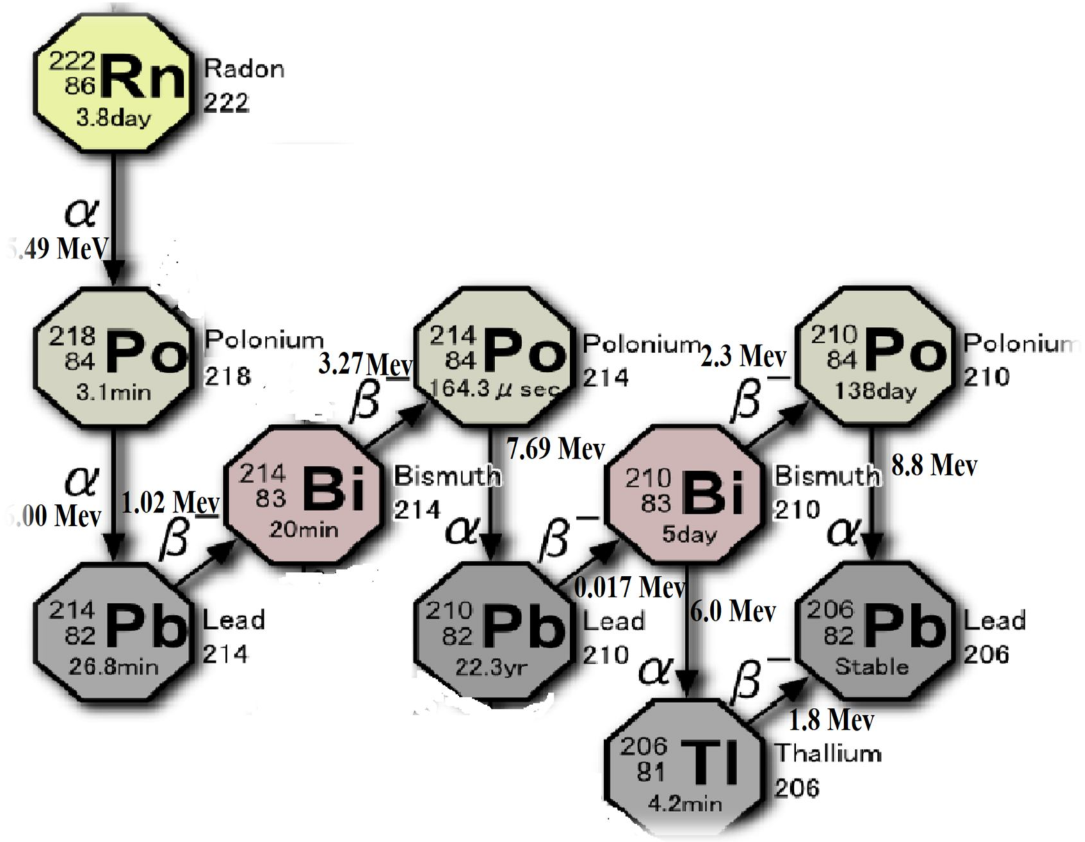

FIG. 1. The decay series from radon-222 to lead-206 (stable) [13].

Studies have reported that natural ^{222}Rn and its decay products are responsible for over fifty percent of the overall effective dose of ionizing radiation received by the global population from natural sources [2, 4]. Concentrated ^{222}Rn in groundwater can be attributed to factors such as radium/uranium levels in surrounding rocks, lithology, presence of shear zones, degree of metamorphism, and soil porosity [5]. This means that ^{222}Rn concentrations in geological environments vary depending on the activity concentration of radium in the host rocks present in the area. The concentration and associated risk of ^{222}Rn increase with higher levels of radium and uranium in groundwater [4, 5].

Water, an essential resource for living organisms, is estimated to amount to nearly a billion cubic meters on Earth [6]. Groundwater is particularly important as a primary source for domestic use, especially in Africa [4, 7]. However, this untreated water source is vulnerable to contamination from geological rocks and the decay of radioactive elements, which can lead to varying degrees of radiation hazards for residents [4]. Many researchers around the world have reported ^{222}Rn concentrations in surface and groundwater. For instance, [3] investigated ^{222}Rn concentrations in ground and surface water samples in Sankey Tank and Mallathahalli Lake, using a Durridge RAD-7 analyzer. They reported average radon activities ranging from 11.6 ± 1.7 to 381.2 ± 2.0 Bq. L^{-1} for surface water and 1.50 ± 0.83 to 18.9 ± 1.59 Bq. L^{-1} for groundwater. In another study, ^{222}Rn concentrations were measured in groundwater in the Ashanti region of Ghana using an AB-5 detector [8]. They obtained average ^{222}Rn values ranging from 0.51 to 46.16 Bq. L^{-1}. [6] determined concentrations of ^{222}Rn gas in selected bottled and sachet water from a major market of Ile-Ife, Nigeria using a RAD 7 device made by Durridge, USA. They found

^{222}Rn concentrations for bottled samples between 0.00 and 9.4493 Bq. L^{-1} (average: 2.4428 Bq L^{-1}) and for sachet samples between 0.0479 and 0.5068 Bq L^{-1} (average: 0.2492 Bq L^{-1}). These results were deemed safe for household use.

Another study assessed the annual effective dose of ^{222}Rn in drinking water from an abandoned mining site in Oyun, Nigeria, reporting ^{222}Rn concentrations from 21.03 to 44.95 Bq L^{-1} (average: 35.86 Bq L^{-1}) [9], which exceed the United Nations Scientific Committee on the Effects of Atomic Radiation's recommended limit of 11.1 Bq L^{-1} [10]. These findings underscore the need to monitor water quality to protect public health from potential radiation hazards linked to radioactive decay [11]. Given the establishment of a new mining company in Jimba-Oja, assessing ^{222}Rn levels in the area's groundwater is especially relevant.

Area of Study

The area of study, Jimba-Oja, is located southwest of Ilorin, the state capital of Kwara State which is about 21 km from the state capital (Fig. 2). Geologically, the area lies within the Precambrian basement complex, which has been extensively described by several authors [15,16]. This part of the country consists predominantly of migmatite gneiss and the schist belt formations. The area of study is made up of about 60% rocks within the migmatite-gneiss-quartzite complex. The rocks include granite gneiss, banded gneiss, migmatite gneiss, and banded iron formations. The schist belts, which are generally localized to the southwestern part of Nigeria, contain younger meta-sediments primarily concentrated in the central part of the study area, as depicted in the geological map (Fig. 3).

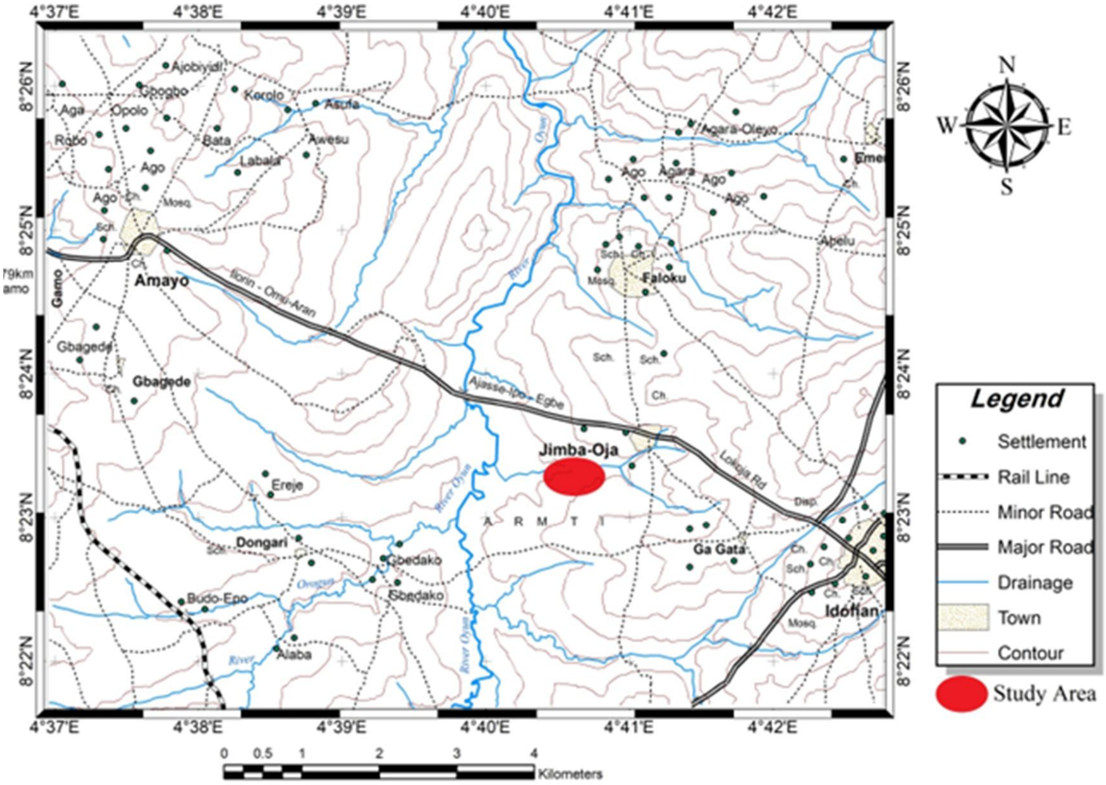

FIG. 2. Topographical map showing the area of study [17].

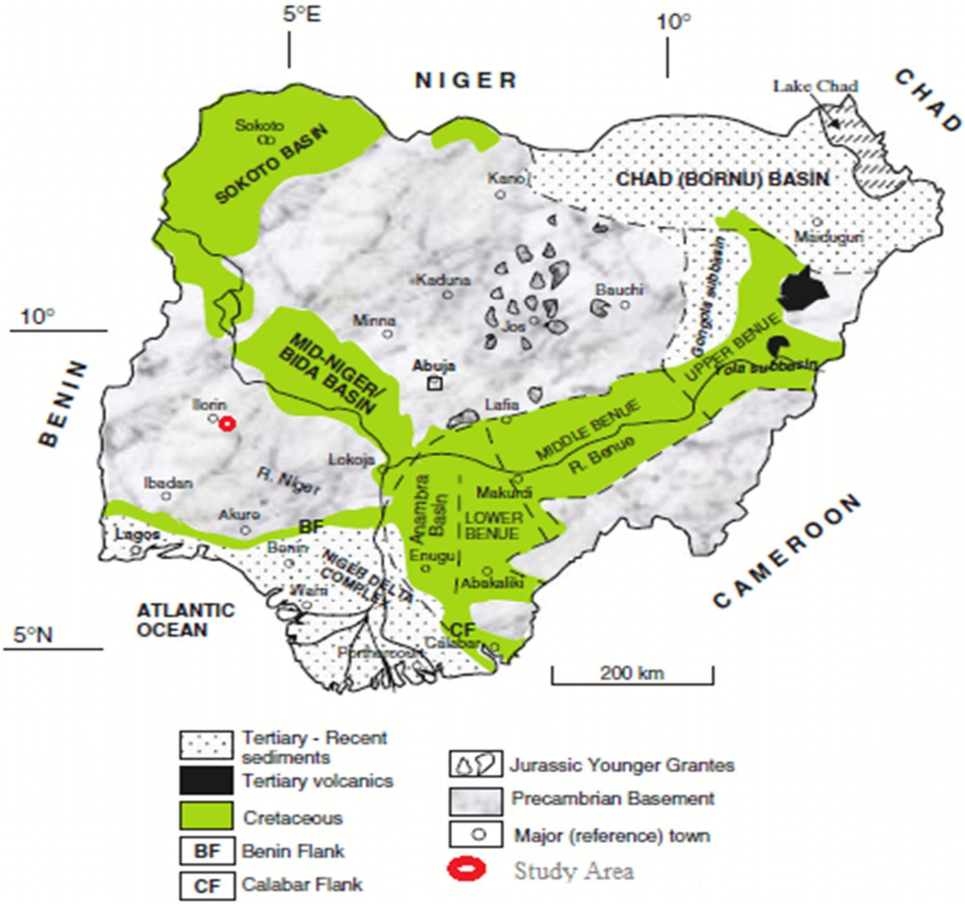

FIG. 3. Nigeria geological map showing the area of study [18].

Methodology

Nine groundwater samples were randomly collected from sites near KAM Wire Company, where the water sources serve domestic purposes for the local inhabitants. Samples were taken as early as possible from their sources to prevent agitation by the inhabitants. Each sample was drawn from hand pump wells after allowing the water to run from the pump for 10 to 15 minutes before collection to prevent radon mixing [4, 9]. The water was collected below the surface and filled to the brim of a 250 mL plastic bottle. Bubbles were removed, and each bottle was sealed tightly with a detector water kit to prevent radon loss due to degassing [9].

In the lab, a Rad-7 detector, manufactured by Durridge Company, Inc., was used to measure radon (^{222}Rn) concentrations [19]. The RAD7 operates as an aerated, closed-loop system comprising: (a) the RAD7 monitor, (b) a desiccant tube supported by a retort stand, and (c) a watertight aerator (Fig. 4). Based on alpha particle disintegration, the detector uses a solid-state sensor to identify alpha particles with varying energy levels [3, 19]. This solid-state detector converts alpha particle energy into electrical signals, enabling the identification of disintegration products from ^{222}Rn to ^{218}Po and ^{214}Po, each emitting particles at unique energy levels (Fig. 1). Radon concentration was measured using a radon-in-air monitor (RAD7) coupled with a specially fabricated closed-loop aeration system that released radon gas from the water, maintaining constant air and water volumes independent of flow rate. This closed-loop system ensures that air and water volumes remain consistent, regardless of flow fluctuations. After 15 to 20 minutes, radon concentration levels in the groundwater samples were accurately assessed through energy-specific windows, which filter out interference and maintain low background counts for precise radon measurement [12].

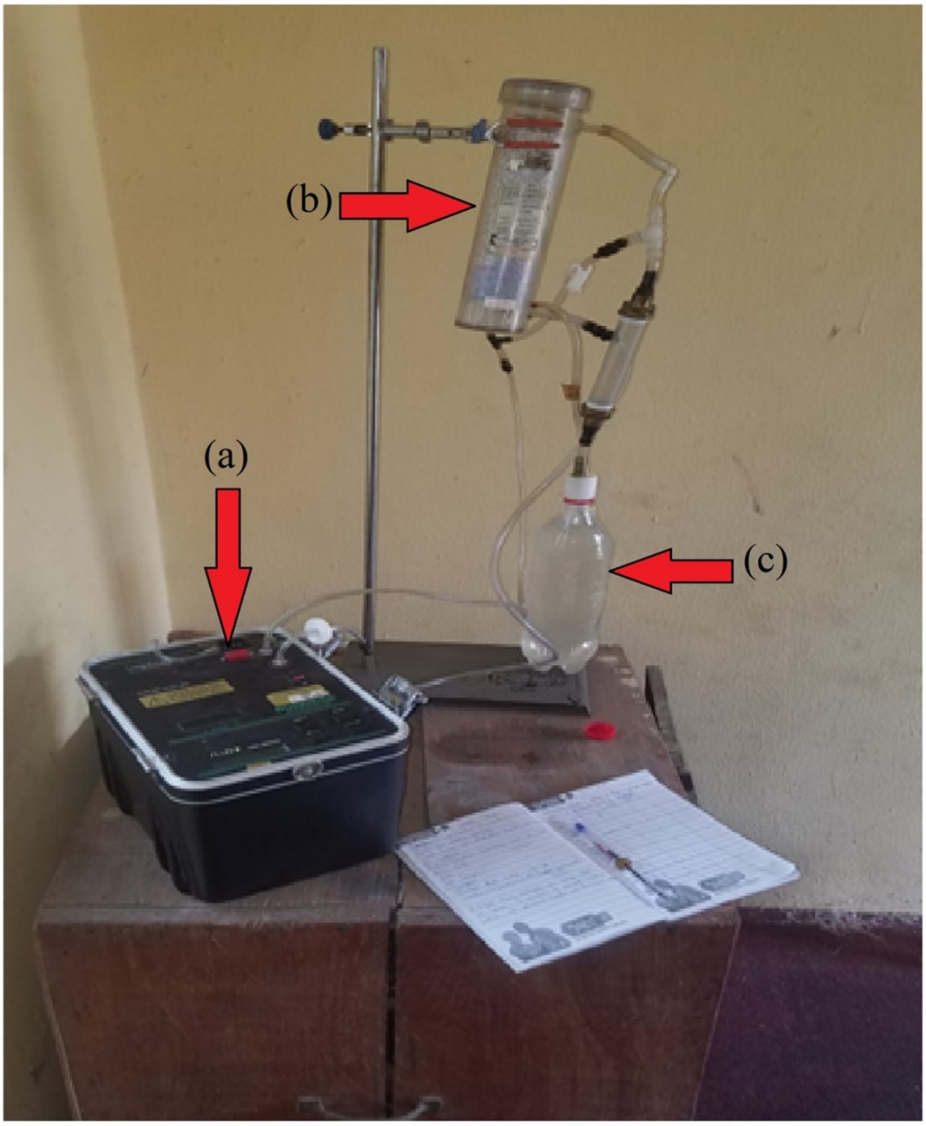

FIG. 4. A typical RAD-7 radon detector: (a) a Rad-7 monitor, (b) a desiccant tube supported by a retort stand, and (c) a watertight aerator [9, 19].

To assess the level of exposure among different age groups (infants, children, and adults), the annual effective dose (AED) from both inhalation and ingestion is a central aspect of radiological protection. It sums up various exposure levels into a single value that reflects the overall risk, making the concept practical for radiological safety, despite its complexity. The total annual effective doses ($\text{AED}_{\text{total}}$) were calculated due to the potential for ^{222}Rn gas to enter homes via air when water is used for domestic purposes.

The mathematical expression for $\text{AED}_{\text{ingestion}}$ rate (μSvy^{-1}) of groundwater is given as [9]:

$$\text{AED}_{\text{ing}} = T * K * C_{Rn} * C_w \qquad (1)$$

where T is time span in a year, K is the dose per unit consumption from the ingested water, which varies among different age groups (infants, children, and adults), C_w is daily water consumption, also varying by age group, and C_{Rn} is the concentration of ^{222}Rn in each of the samples obtained from the laboratory.

To calculate the AED from inhalation, the following expression is used [9]:

$$\text{AED}_{\text{inh}} = Dose\ Conversion\ Factor\ (DCF) * O * C_{Rn} * F \qquad (2)$$

where O is the mean indoor occupancy time per individual and F is the equilibrium factor between ^{222}Rn and the offspring (0.4).

Finally, the total annual effective dose AED_{total} can be expressed mathematically as[9]:

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

Results and Discussion

The laboratory investigation of ^{222}Rn samples is summarized in Table 1. This table includes labeled samples (1–9), as well as the latitude, longitude, and elevation of the study area, alongside the activity concentrations of ^{222}Rn gas and their associated errors. The results indicate that the concentration of ^{222}Rn ranges from a minimum value of 3.08 Bq. L^{-1} in Well 4 to a maximum value of 9.18 Bq. L^{-1} in Well 9.

The observed levels of ^{222}Rn concentrations in groundwater are primarily influenced by the activity concentration of Radium-226 in the host rock and its distribution within the rock cycle. Generally, activity concentrations of Radium-226 are relatively low in rocks such as gneiss, while they tend to be higher in sandstones and weathered granite rocks [4]. Consequently, the low values of ^{222}Rn concentrations recorded in this study can be attributed to the presence of granite-gneiss, banded-gneiss, migmatite-gneiss, and banded iron formations in the area.

TABLE 1. ^{222}Rn concentrations for each water sample.

Water Samples	Latitude (^{0}N)	Longitude (^{0}E)	Elevation (M)	Radon (^{222}Rn) [Bq. L^{-1}]	Error±
WELL 1	8.3731	4.665	344	3.97	0.64
WELL 2	8.3645	4.6021	347	5.09	0.92
WELL 3	8.3942	4.6011	349	3.33	0.76
WELL 4	8.3983	4.681	346	3.08	0.73
WELL 5	8.3977	4.682	348	5.44	0.94
WELL 6	8.3042	4.6815	347	5.26	0.94
WELL 7	8.3823	4.6805	349	4.61	0.88
WELL 8	8.3897	4.671	346	5.04	0.92
WELL 9	8.3055	4.6801	345	9.18	1.20
Min.				3.08	0.64
Max.				9.18	1.20
Mean				5.00	0.88
S.D				1.68	0.15

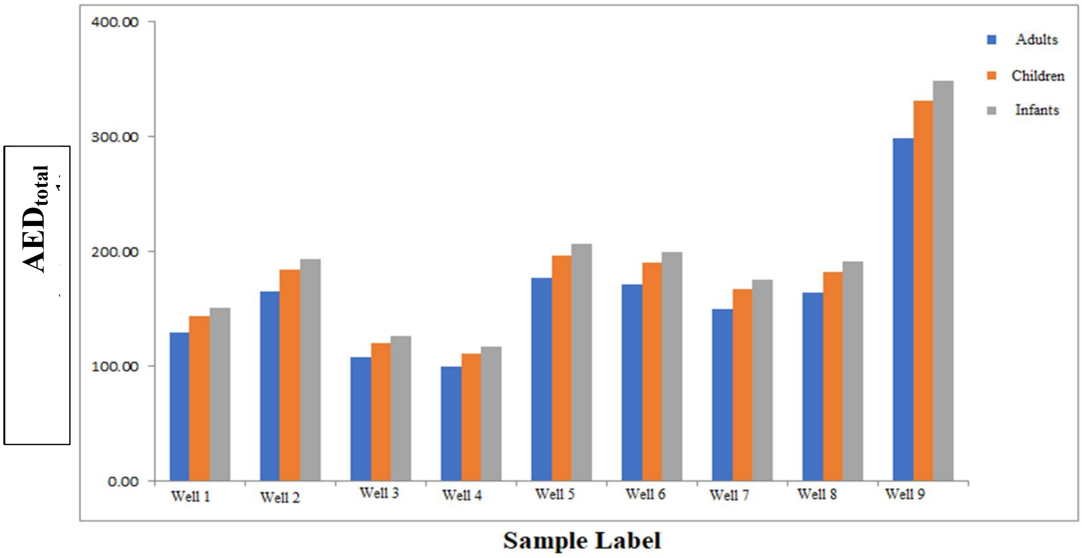

FIG. 5. Estimated total AED ($\mu Sv.y^{-1}$) for all age groups.

Additionally, the level of radon hazards among different age groups was assessed using Eqs. (1), (2), and (3). For Eq. (1), 365 days were used to represent the time span throughout the year. K varies by age group: it is 7 x 10^{-8} SvBq^{-1} for infants, 2 x 10^{-8} SvBq^{-1} for children, and 10^{-8} SvBq^{-1} for adults [9]. C_w also differs among age groups: infants are expected to consume 0.5 liters, children 1.5 liters, and adults 2.0 liters a day. C_{Rn} is the concentration ^{222}Rn in each of the samples obtained from the laboratory [11]. For Eq. (2), the dose conversion factor (DCF) was set at 9 ($\mu Sv.y^{-1}$), with an average indoor occupancy time of 7,000 hours per year and an equilibrium factor (F) of 0.4 [20]. Equation (3) provides the total annual effective dose (AED) by summing the values from both equations. Table 2 presents the results, including columns for AED via ingestion and inhalation, along with the total AED for each age group (infants, children, and adults). The average AED values for water ingestion are 63.88, 54.75, and 36.50 $\mu Sv.y^{-1}$ for infants, children, and adults, respectively. The inhalation values range from 77.62 to 231.34 μSvy^{-1}, with a mean value of 126.00 μSvy^{-1}.

TABLE 2. Estimated AED from ingestion and inhalation, along with the total AED for all age groups (infants, children, and adults).

Water Samples	AED $_{\text{ingested}}$ $(\mu Sv.y^{-1})$			AED $_{\text{inh}}$ $(\mu Sv.y^{-1})$	AED $_{\text{TOTAL}}$ $(\mu Sv.y^{-1})$		
	Infants	Children	Adults		Infants	Children	Adult
WELL 1	50.72	43.47	28.98	100.04	150.76	143.52	129.03
WELL 2	65.02	55.74	37.16	128.27	193.29	184.00	165.43
WELL 3	42.54	36.46	24.31	83.92	126.46	120.38	108.23
WELL 4	39.35	33.73	22.48	77.62	116.96	111.34	100.10
WELL 5	69.50	59.57	39.71	137.09	206.58	196.66	176.80
WELL 6	67.20	57.60	38.40	132.55	199.75	190.15	170.95
WELL 7	58.89	50.48	33.65	116.17	175.06	166.65	149.83
WELL 8	64.39	55.19	36.79	127.01	191.39	182.20	163.80
WELL 9	117.27	100.52	67.01	231.34	348.61	331.86	298.35
Min.	39.35	33.73	22.48	77.62	116.96	111.34	100.10
Max.	117.27	100.52	67.01	231.34	348.61	331.86	298.35
Average	63.88	54.75	36.50	126.00	189.88	180.75	162.50

The AED$_{\text{total}}$ calculated using Eq. (3) shows variations in the estimated dose rates among different age groups, as illustrated in Fig. 5. The average values obtained are 189.88 $\mu Sv.y^{-1}$ for infants, 180.75 $\mu Sv.y^{-1}$ for children, and 162.50 $\mu Sv.y^{-1}$ for adults (Table 2). These values indicate that the estimated dose for infants exceeds the recommended permissible limit of 100 $\mu Sv.y^{-1}$, while the values for children and adults are within the acceptable limit of 200 $\mu Sv.y^{-1}$ [21]. This suggests that the health risks associated with radiological hazards are acceptable for children and adults, but pose a significant risk for infants. It is crucial to ensure that infants receive proper care, as their systems and organs are still developing. Greater attention should be given to the water consumption of this age group to prevent potential adverse effects from radiological hazards, including cancer and skin diseases. Furthermore, it is important to note that the results may not be directly linked to the mining company; rather, they could be attributed to naturally occurring radioactive elements that have leached into the groundwater.

Conclusion

An investigation into the levels and potential radon radiation risks of randomly selected groundwater samples from Jimba-Oja, Kwara State, was conducted using a Rad-7 electronic detector in the laboratory. This study aimed to provide baseline information on ^{222}Rn concentrations across different age groups, particularly in light of the newly established KAM iron and steel company in the area. The results indicate that the mean ^{222}Rn concentration is low compared to the recommended value [21, 22]. However, the total annual effective dose (AED) for infants was found to be higher than the recommended limit, while the doses for children and adults remained within acceptable levels.

It is recommended that this measurement be repeated across all seasons to determine if the newly established KAM Iron and Steel Company has any radiological impact on these age groups. Additionally, ^{222}Rn should be assessed in all sources of drinking water throughout the state and the country. This approach would enable the establishment of state or national maximum permissible limits for all age groups, safeguarding public health from radiological pollution. Although the values obtained serve as baseline data for this area, the presence of the KAM Iron and Steel Company may pose radiological hazards in the future. Currently, however, the groundwater in this area is safe for drinking and domestic use, as the average ^{222}Rn values from this study are below recommended limits [21, 22].

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