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Assessment of Excess Lifetime Cancer Risk from Indoor Radon Exposure in Obio-Akpor Local Government Area, Rivers State, Nigeria

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ABSTRACT
Radon ($^{222}_{86}Rn$) is a naturally occurring radioactive gas and the second leading cause of lung cancer globally, with indoor accumulation in residential buildings recognized as a significant public health concern, particularly in areas where local geological and environmental data remain scarce. Analysis of indoor radon levels and associated health risk parameters was carried out in residential areas of Obio-Akpor Local Government Area, Rivers State, Nigeria. Indoor radon concentrations were measured using a Corentium Arthings digital radon detector over a monitoring period of 60 days. Geographical coordinates of each sampling location were recorded using a handheld GPS device. A total of ten houses were sampled across three major communities, resulting in 30 sample points. In Eneka, radon concentration ranged from 2 − 30 $Bq\ m^{-3}$, with an annual effective dose rate ranged from 0.050576 − 0.758640 mSv/yr. The excess lifetime cancer risk (ELCR) over 70 years ranged from 0.177− 2.301. In Rumuokwurshi, radon concentration ranged from 3 − 19 $Bq\ m^{-3}$, the annual effective dose varied from 0.075864 − 0.480472 mSv/yr and the ELCR ranged from 0.266− 1.682. In Elimgbu, radon levels ranged from 2 − 102 $Bq\ m^{-3}$, annual effective dose ranged from 0.05058 − 2.57938 mSv/yr, and ELCR ranged from 0.177 − 3.869. The indoor radon concentrations and dose rates are within the ICRP recommended safety limits, but the calculated ELCR values indicate a need for awareness and mitigation strategies to reduce long-term health risks.

INTRODUCTION

Indoor radon ($^{222}_{86}Rn$) is a naturally occurring, colourless, odourless radioactive gas produced by the decay of uranium in soil, rocks, and building materials (ICRP, 2010). It can enter buildings through cracks in foundations, gaps around pipes, and other openings, accumulating in enclosed spaces with limited ventilation (Ademola, 2008). Once inhaled, radon decay products emit alpha particles that can damage lung tissue DNA and significantly increase the risk of lung cancer over long exposures (Darby *et al.*, 2005). According to the World Health Organization (2009), radon is the second leading cause of lung cancer after smoking, contributing to an estimated 3–14 % of all lung cancer cases globally, depending on regional radon levels and smoking prevalence.

Indoor radon levels vary widely based on geological formations, soil uranium content, housing design, ventilation patterns, and local environmental factors (Orlunta *et al.*, 2021). Systematic analysis of indoor radon studies across Nigeria indicates a weighted mean indoor radon concentration of about 104 $Bq\ m^{-3}$, which exceeds the WHO reference level of 100 $Bq\ m^{-3}$ in many locations. Elevated concentrations in specific areas such as Odo-Ona, Ibadan have been associated with annual effective doses above 10 mSv/yr and excess lifetime cancer risks above conservative international action thresholds (Briggs-Kamara *et al.*, 2021).

Several localized Nigerian studies have examined indoor radon and associated radiological health risk parameters. For instance, research in selected towns within Port Harcourt, Rivers State, measured indoor radon concentrations, annual absorbed doses, annual effective doses, and excess lifetime cancer risk (ELCR) in residential buildings (Orlunta *et al.*, 2021). The study identified significant variations between communities, showing that ELCR values in some cases surpassed safe benchmark levels despite radon concentrations being below some recommended limits (Adesina *et al.*, 2025). Another investigation of indoor radon in Azuabie, Trans-Amadi, and Nkpogu reported health risk parameters that, while within some dose limits, indicated potential radiological concern based on

ELCR estimates above international safety limits (Briggs-Kamara *et al*., 2021). Seasonal variations in indoor radon concentrations have further highlighted the importance of continuous monitoring for accurate risk assessment (UNSCEAR, 2008). Other seasonal studies in university residential buildings have also highlighted the variability of radon concentrations and the importance of regular monitoring for accurate health risk estimation (Ademola, 2008).

Despite these studies, there remains a paucity of data on indoor radon exposure in many Local Government Areas of Nigeria, including Obio-Akpor LGA, Rivers State (Briggs-Kamara *et al*., 2021). The limited regional data constrains understanding of the actual magnitude of public exposure and associated cancer risk among residents. Therefore, this study aims to measure indoor radon concentration levels in residential buildings of Obio-Akpor LGA, estimate annual effective doses and excess lifetime cancer risk, and provide baseline data to inform public health awareness and mitigation strategies.

MATERIALS AND METHODS

The radon detector used in this study was the Airthings Corentium Digital Radon Detector, designed in Oslo, Norway in 2019 (Airthings, 2019). The detector is factory calibrated to measure radon-222 in $Bq\, m^{-3}$ and can monitor radon concentrations over a minimum period of 48 hours, as well as daily, weekly, monthly, and yearly (Orlunta *et al*., 2021). The detector operates on the principle that radon gas diffuses into a detection chamber, where its decay emits alpha particles. These energetic alpha particles strike a silicon photodiode, generating a small signal current that is amplified and converted to a voltage signal by an analogue-to-digital converter (ADC). The microcontroller of the detector records the time and energy of each detected particle to calculate mean radon concentrations for the monitoring period (EPA, 2012).

2.1 Study Area and Sampling

Indoor radon measurements were conducted in residential buildings across three major communities in Obio-Akpor LGA, Rivers State, with a total of 30 sample points. The georeferenced map (Figure 1) of Obio-Akpor LGA was produced using these GPS coordinates to accurately display the sampled buildings and their spatial distribution within the study area. Each community had 10 houses selected randomly for measurement. The geographical coordinates of each sampling point were recorded using a handheld GPS device (Garmin Ltd., 2020) to facilitate spatial mapping of radon distribution. These coordinates and their corresponding locations are shown in Tables 1,2 and 3 to provide spatial reference for the sampling sites and ensure traceability of the measurement locations.

The Airthings Corentium digital detector was placed in the dwelling room of each house at a height of approximately 2m above the floor, away from windows, doors, and ventilation sources to minimize airflow effects on radon accumulation (Orlunta *et al*., 2021). The detectors were deployed for a minimum of 48 hours to capture representative radon concentrations.

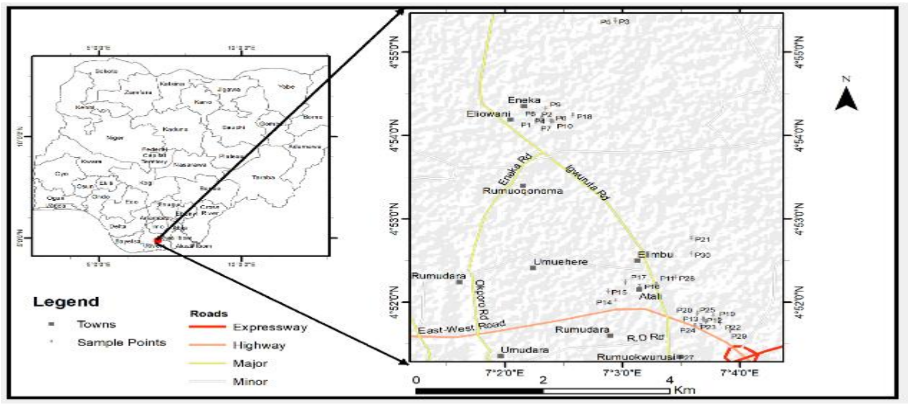

Figure 1: Map of Obio-Akpor LGA Showing Georeferenced Sampling Sites

Dose Assessment

Annual Effective Dose Rate (AED)

The measured indoor radon concentrations were converted into estimates of the annual effective dose (AED) using Equation 1 (Indoor Radon Concentration and Excess Lifetime Cancer Risk, 2019).

$$AED\left(\frac{mSv}{y}\right) = C \times F \times T \times H \times Q \qquad (1)$$

This equation relates the observed radon concentration to the effective radiation dose received by an individual over one year, while accounting for occupancy time and the dose conversion factor. For each sampling location, the recorded radon concentration values were substituted into Equation 1 to obtain the corresponding AED. The calculated doses were systematically documented and subsequently subjected to statistical analysis. These results provided a basis for evaluating the potential health risk from radon exposure and for comparing the estimated doses with internationally recommended safety limits set by organizations such as the ICRP and WHO.

Table 1: Sampling Locations, Coordinates, Measured Indoor Radon Concentrations (CRn) and Calculated Annual Effective Dose (AED) for Eneka

S/N	Location	GPS Co-ordinate		CRn(Bq/m³)	AED (mSv·y⁻¹)
	Eneka (ENE)	Latitude	Longitude		
1	ENE RES 1	N 4 °54′10.692"	E 7 °2′16.098"	30	0.75864
2	ENE RES 2	N 4 °54′10.72908"	E 7 °2′19.14216"	8	0.202304
3	ENE RES 3	N 4 °55′22.63008"	E 7 °2′56.24484"	15	0.37932
4	ENE RES 4	N 4 °55′22.50552"	E 7 °2′56.1444"	16	0.404608
5	ENE RES 5	N 4 °54′10.19556"	E 7 °2′23.39088"	26	0.657488
6	ENE RES 6	N 4 °54′9.40788"	E 7 °2′24.36072"	26	0.657488
7	ENE RES 7	N 4 °54′10.15164"	E 7 °2′23.29656"	4	0.101152
8	ENE RES 8	N 4 °54′12.21624"	E 7 °2′18.40992"	2	0.050576
9	ENE RES 9	N 4 °54′19.00548"	E 7 °2′20.56668"	5	0.12644
10	ENE RES 10	N 4 °54′9.89568"	E 7 °2′23.87148"	8	0.202304
	AVERAGE			14.00 ± 10.25	0.35 ± 0.26

Table 2: Sampling Locations, Coordinates, Measured Indoor Radon Concentrations (CRn) and Calculated Annual Effective Dose (AED) for Rumuokwurshi

S/N	Location	GPS Co-ordinate		CRN (Bq/m3)	AED (mSv y-1)
	Rumuokwurshi (RUM)	Latitude	Longitude		
1	RUM RES 1	N 4 °51′47.25288"	E 7 °3′49.04712"	13	0.328744
2	RUM RES 2	N 4 °51′46.42848"	E 7 °3′42.39468"	4	0.101152
3	RUM RES 3	N 4 °51′42.9768"	E 7 °3′39.9744"	5	0.12644
4	RUM RES 4	N 4 °51′50.1552"	E 7 °3′46.27944"	5	0.12644
5	RUM RES 5	N 4 °51′47.8800"	E 7 °3′47.41764"	6	0.151728
6	RUM RES 6	N 4 °51′19.0000"	E 7 °3′26.0000"	6	0.151728
7	RUM RES 7	N 4 °51′43.0000"	E 7 °3′37.0000"	3	0.075864
8	RUM RES 8	N 4 °51′47.82132"	E 7 °3′41.01804"	3	0.075864
9	RUM RES 9	N 4 °51′40.0000"	E 7 °3′55.0000"	4	0.101152
10	RUM RES 10	N 4 °51′52.07508"	E 7 °3′38.27664"	19	0.480472
	AVERAGE			6.80±5.16	0.17±0.13

Excess Lifetime Cancer Risk (ELCR)

The Excess Lifetime Cancer Risk (ELCR) was determined to estimate the likelihood of developing cancer from long-term exposure to indoor radon. In this study, the calculation of ELCR was based on the measured indoor radon concentrations obtained from the Corentium Pro by Airthings detector. These values were first used to determine the annual effective dose for each sampled location using Equation 2. (Singh & Khan, 2016).

Excess Lifetime Cancer Risk ($ELCR$)

$$ELCR = D \times DL \times RF \quad (2)$$

Using the annual effective dose as the foundation, the ELCR was then calculated to reflect a 70-year lifetime exposure period, which represents the average human lifespan. The standard risk factor recommended by the International Commission on Radiological Protection (ICRP) was applied in this process. This approach allowed the estimation of the lifetime cancer risk associated with the mean radon levels recorded in the study areas, providing an understanding of how long-term exposure could impact residents' health.

Table 3: Sampling Locations, Coordinates, Measured Indoor Radon Concentrations (CRn) and Calculated Annual Effective Dose (AED) for Elimgbu

S/N	Location	GPS Co-ordinate		CRn (Bq/m3)	AEDR (mSv y-1)
	Elimgbu (ELI)	Latitude	Longitude		
1	ELI RES 1	N 4 °52′12.83196"	E 7 °3′17.18712"	2	0.05058
2	ELI RES 2	N 4 °52′18.00000"	E 7 °3′27.00000"	15	0.37932
3	ELI RES 3	N 4 °52′0.81804"	E 7 °2′56.4144"	20	0.50576
4	ELI RES 4	N 4 °52′7.99788"	E 7 °2′52.53972"	3	0.07586
5	ELI RES 5	N 4 °52′12.83196"	E 7 °3′17.18712"	24	0.60691
6	ELI RES 6	N 4 °52′11.23212"	E 7 °3′8.55612"	30	0.75864
7	ELI RES 7	N 4 °52′14.58624"	E 7 °3′1.4922"	8	0.2023
8	ELI RES 8	N 4 °52′46.04952"	E 7 °3′35.1594"	11	0.27817
9	ELI RES 9	N 4 °51′45.20376"	E 7 °3′49.66668"	102	2.57938
10	ELI RES 10	N 4° 52'34.77000"	E 7° 3'35.09280"	9	0.22759

S/N	Location Elimgbu (ELI)	GPS Co-ordinate Latitude	Longitude	CRn (Bq/m3)	AEDR (mSv y-1)
	AVERAGE			22.40±29.38	0.57±0.74

RESULTS AND DISCUSSION

Indoor radon concentrations and the computed values of annual effective dose (AED) for the three locations Eneka, Rumuokwurushi, and Elimgbu are presented in Tables 1, 2, and 3, respectively. Table 4, 5 and 6 shows the values of excess lifetime cancer risk (ELCR) for exposure durations of 70, 60, 50, 40, and 30 years for the three locations. From the results obtained, the measured indoor radon concentration levels for the three locations were as follows: Eneka ranged from 2 to 30 Bq/m^3, Rumuokwurushi ranged from 3 to 19 Bq/m^3, and Elimgbu ranged from 2 to 102 Bq/m³, The annual absorbed dose for the three communities varied as $0.050576 - 0.758640\ mSv/yr$ (Eneka), $0.075864 - 0.480472\ mSv/yr$ (Rumuokwurushi), and $0.05058 - 2.57938\ mSv/yr$ (Elimgbu), respectively. The ELCR values for a 70-year exposure varied from 0.177− 2.301 $\times10^{-3}$ (Eneka), 0.266− 1.682 $\times10^{-3}$ (Rumuokwurushi), and 0.177 − 3.869 $\times10^{-3}$ (Elimgbu), respectively (Tables 4, 5 and 6). The measured values of indoor radon concentration, along with the calculated annual absorbed dose and annual equivalent dose rate, are all below the safe limits recommended by the International Commission on Radiological Protection (ICRP). However, the calculated ELCR values for 70, 60, 50, 40, and 30-year exposures in some dwellings were observed to exceed the recommended limits, although no lung cancer epidemics have been reported in these areas. The maps of the study area is shown in Figure 1. Similarly, the values of average indoor radon concentrations, annual equivalent dose rate, and ELCR for the three locations are visualized in Figures 3-4. From the results obtained, there are no significant differences between the three locations. This may be due to similarities in building designs, construction materials, ventilation rates, and lifestyle factors of the residents. The highest radon concentration recorded (102 Bq/m^3) occurred in a poorly ventilated dwelling in Elimgbu, suggesting that local environmental factors, such as limited ventilation or proximity to radon sources, can influence indoor radon accumulation. The measured values in Eneka, Rumuokwurushi, and Elimgbu confirm that indoor radon levels in these areas remain within acceptable international safety limits, though continuous monitoring is recommended to detect potential seasonal variations or localized increases.

The findings of this study were compared with results from related studies conducted in Nigerian environments. Orlunta *et al.* (2021) reported mean indoor radon concentrations of 15.8 $Bq\ m^{-3}$, 18.4 $Bq\ m^{-3}$, and 21.6 $Bq\ m^{-3}$ in Azuabie, Trans-Amadi, and Nkpogu towns in Port Harcourt, with corresponding mean annual effective doses of 0.40 mSv/yr, 0.46 mSv/yr, and 0.55 mSv/yr respectively. These values are generally comparable to the results obtained in the present study, where the mean radon concentrations for Eneka (14 $Bq\ m^{-3}$), Rumuokwurshi (6.8 $Bq\ m^{-3}$), and Elimgbu (22.4 $Bq\ m^{-3}$) all remain below the WHO reference level of 100 $Bq\ m^{-3}$ (WHO, 2009). Similarly, Briggs-Kamara *et al.* (2021) investigated indoor radon and health risk parameters in selected residential buildings within Obio-Akpor LGA and found ELCR values that, while within permissible dose limits for annual effective dose, showed elevated excess lifetime cancer risk in some locations. The ELCR values obtained in the present study for a 70-year exposure period, ranging from 0.177 to 3.869 $\times10^{-3}$, are consistent with this trend. Adesina *et al.* (2025) conducted a broader national-level investigation of residential and occupational radon exposure in Nigerian buildings and noted that ELCR values in excess of the ICRP-recommended level of 0.29 $\times10^{-3}$ were observed in several locations, even where radon concentrations were below action levels. This is consistent with the findings of the present study, where a number of dwellings, particularly in Elimgbu, recorded ELCR values above the conservative safety benchmark despite radon concentrations remaining below 300 $Bq\ m^{-3}$. Ademola (2008) reported indoor radon concentrations in Nigerian buildings ranging from 6.9 to 104.8 $Bq\ m^{-3}$, with the corresponding annual effective doses generally within acceptable limits. The mean values obtained in the present study fall within this range. Singh and Khan (2016) reported ELCR values in the range of 0.15 to 4.20 $\times10^{-3}$ in residential buildings, noting that dwellings with poor ventilation consistently recorded higher ELCR values, which aligns with the observation in the present study that the highest radon concentration of 102 $Bq\ m^{-3}$ was recorded in a poorly ventilated dwelling in Elimgbu. Overall, the radon levels recorded in this study are comparable to those of similar Nigerian studies and remain within internationally accepted limits, though the ELCR estimates for certain dwellings warrant continued monitoring and public health awareness efforts.

Table 4: Excess Lifetime Cancer Risk (ELCR) for Different Exposure Years at Eneka

S/N	LOCATION	ELCR× (70 Years)	ELCR× (60 Years)	ELCR× (50 Years)	ELCR× (40 Years)	ELCR× (30 Years)
1	ENE RES 1	2.655	2.276	1.897	1.517	1.138
2	ENE RES 2	0.708	0.607	0.506	0.405	0.303
3	ENE RES 3	1.328	1.138	0.948	0.759	0.569

S/N	LOCATION	ELCR× (70 Years)	ELCR× (60 Years)	ELCR× (50 Years)	ELCR× (40 Years)	ELCR× (30 Years)
4	ENE RES 4	1.416	1.214	1.012	0.809	0.607
5	ENE RES 5	2.301	1.972	1.644	1.315	0.986
6	ENE RES 6	2.301	1.972	1.644	1.315	0.986
7	ENE RES 7	0.354	0.303	0.253	0.202	0.152
8	ENE RES 8	0.177	0.152	0.126	0.101	0.076
9	ENE RES 9	0.443	0.379	0.316	0.253	0.190
10	ENE RES 10	0.708	0.607	0.506	0.405	0.303
	AVERAGE	**1.24±0.9**	**1.06±0.8**	**0.89±0.7**	**0.71±0.5**	**0.53±0.4**

Table 5: Excess Lifetime Cancer Risk (ELCR) for Different Exposure Years at Rumuokwurshi

S/N	LOCATION	ELCR× (70 Years)	ELCR× (60 Years)	ELCR× (50 Years)	ELCR× (40 Years)	ELCR× (30 Years)
1	RUM RES 1	1.151	0.986	0.822	0.657	0.493
2	RUM RES 2	0.354	0.303	0.253	0.202	0.152
3	RUM RES 3	0.443	0.379	0.316	0.253	0.190
4	RUM RES 4	0.443	0.379	0.316	0.253	0.190
5	RUM RES 5	0.531	0.455	0.379	0.303	0.228
6	RUM RES 6	0.531	0.455	0.379	0.303	0.228
7	RUM RES 7	0.266	0.228	0.190	0.152	0.114
8	RUM RES 8	0.266	0.228	0.190	0.152	0.114
9	RUM RES 9	0.354	0.303	0.253	0.202	0.152
10	RUM RES 10	1.682	1.441	1.201	0.961	0.721
	AVERAGE	**0.60±0.5**	**0.52±0.4**	**0.43±0.3**	**0.34±0.3**	**0.26±0.2**

Table 6: Excess Lifetime Cancer Risk (ELCR) for Different Exposure Years at Eligmbu

S/N	LOCATION	ELCR× (70 Years)	ELCR× (60 Years)	ELCR× (50 Years)	ELCR× (40 Years)	ELCR× (30 Years)
1	ELI RES 1	0.177	0.152	0.126	0.101	0.076
2	ELI RES 2	1.328	1.138	0.948	0.759	0.569
3	ELI RES 3	1.770	1.517	1.264	1.012	0.759
4	ELI RES 4	0.266	0.228	0.190	0.152	0.114
5	ELI RES 5	2.124	1.821	1.517	1.214	0.910
6	ELI RES 6	2.655	2.276	1.897	1.517	1.138
7	ELI RES 7	0.708	0.607	0.506	0.405	0.303
8	ELI RES 8	0.974	0.835	0.695	0.556	0.417
9	ELI RES 9	3.869	5.159	6.448	7.238	9.02
10	ELI RES 10	0.797	0.683	0.569	0.455	0.341
	AVERAGE	**1.17±0.8**	**1.00±0.7**	**0.83±0.6**	**0.67±0.5**	**0.50±0.3**

CONCLUSION

The assessment of indoor radon concentration and its associated health risk parameters was carried out in Eneka, Rumuokwurshi, and Elimgbu in Obio Akpor Local Government Area of Rivers State, Nigeria using a digital radon detector. The mean indoor radon concentrations obtained for the three locations were 14 $Bq\ m^{-3}$, 6.8 $Bq\ m^{-3}$, and 22.4 $Bq\ m^{-3}$, respectively. These values are all below the recommended reference level of 100 $Bq\ m^{-3}$ the World Health Organization (WHO) and the action level of 300 $Bq\ m^{-3}$ set by the International Commission on Radiological Protection (ICRP). The corresponding annual effective dose (AED) and excess lifetime cancer risk (ELCR) values for the three locations were also found to be within acceptable safety limits. Although Elimgbu recorded relatively higher values compared to Eneka and Rumuokwurshi, there was no significant variation across the study locations. This may be attributed to similarities in building structures, ventilation conditions, and environmental characteristics. Therefore, it can be concluded that indoor radon levels in the studied areas are low and do not pose significant radiological health risks to residents. However, continuous monitoring and proper ventilation are recommended to maintain safe indoor conditions.

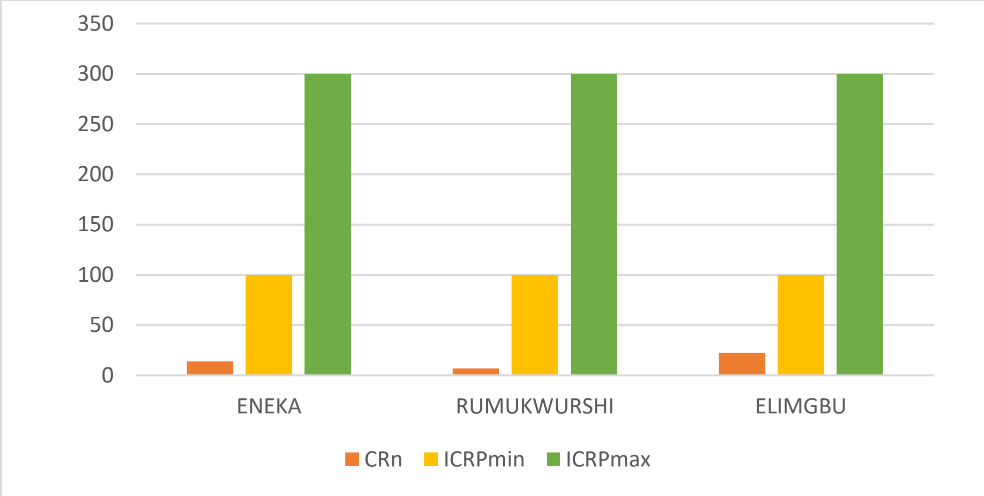

Figure 2: Comparison of Average Indoor Radon Concentrations for the Three Locations with ICRP Standards

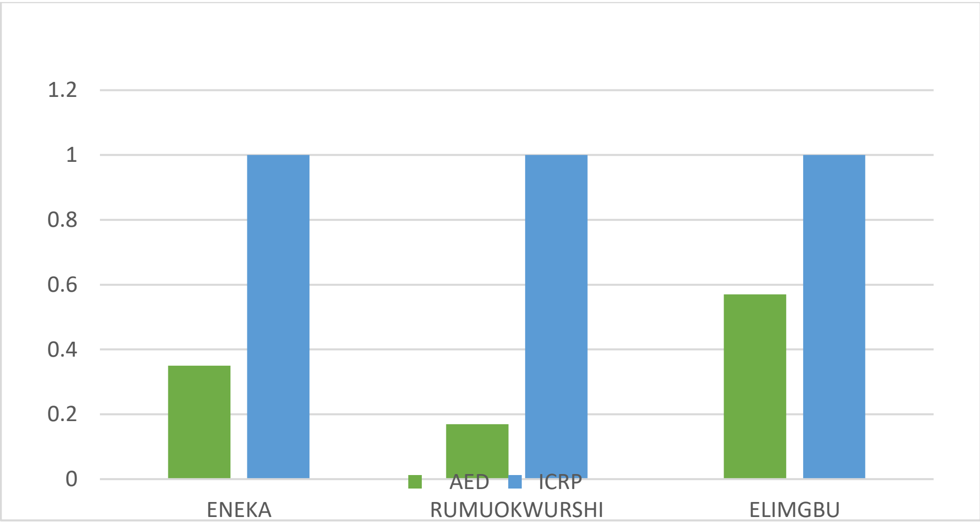

Figure 3: Comparison of Average Annual Effective Dose for the Three Locations with ICRP Standards

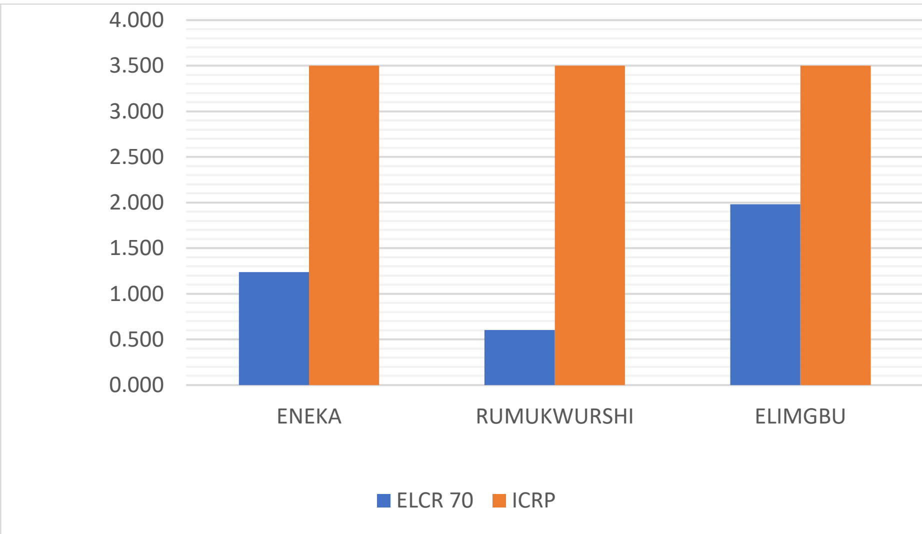

Figure 4: Mean Excess Lifetime Cancer Risk (70 years) Compared with ICRP Standards

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