Indoor radon concentration measurements in houses of selected communities in Delta Central of Delta State

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Radon is a naturally occurring and radioactive gas having no colour, odour or taste and found in indoor environment. The World Health Organization (WHO) has reported that radon is the major cause of lung cancer after smoking. This fact is the reason why scientists, researchers and governments have channeled their study and resources to the health effects of human exposure to radon gas. This study measured the indoor-environment radon gas in selected communities in Delta Central of Delta State. This was done using a Corentium Radon detector of model type; BQM-Digital. Results show that the average indoor radon concentration measured varies from 0 to 49.85 Bqm^{-3} with a mean of 19.71 Bqm^{-3}. The annual effective dose to lungs (E_T) and whole body (H_T) calculated from these indoor measurements varies from 0 to 1.82 mSvy^{-1} and 0 to 15.2 mSvy^{-1}, respectively with the mean values as 0.57 and 4.9 mSvy^{-1}. The Excess Lifetime Cancer Risk (ELCR) calculated varied from 0 to 7.95×10^{-6} with a mean value of 5.54×10^{-6}. Each of these values is less than the internationally recommended value. This is an indication that occupants of these selected houses are not presently under any radiological threat arising from exposure to indoor radon.

Key words: Radon, Corentium detector, Delta State.

INTRODUCTION

Radon gas consists of three of the 39 isotopes of radon element (www.chemistry.Pomona.edu, 2019): ^{222}Rn (radon, Rn), ^{220}Rn (thoron, Tn) and ^{219}Rn (actinium, An). They are formed during the three natural decay series (Figure 1). Due to the short half-life of Tn and An, the gas is essentially considered as ^{222}Rn. Its entry routes into indoor air are as shown in Figure 2 and its concentration is a function of the type of building materials and type of building, ventilation system adopted, the geology and climatic condition of the environment (Nigus, 2017; Usikalu et al., 2017). Despite its useful applications such as its use for therapeutic purposes in hospitals, in photographing the interior of opaque materials for locating the defects in steel casting, and in earthquake prediction (Mokobia, 2004; Jae et al., 2018; www.chemistry.Pomona.edu, 2019), this radioactive gas is recognized by the World Health Organization (WHO) as a human lung carcinogen (WHO, 2009). According to Pankaj et al. (2017), it is the second leading cause of lung cancer after tobacco smoking if inhaled. The United States Environmental Protection Agency (USEPA) has also reported that it is attributable to well over 20,000 lung cancer related deaths in that country (USEPA, 2004). This associated health concern has resulted in a number of investigations in varying countries of the world as suggested by the International Commission on Radiological Protection (ICRP, 2010). This resulted in the world radon map (Zielinski, 2014) which represents a pictorial summary of the radon levels in different countries. Here in Nigeria, a few investigations such as Oni et al. (2012), Muhammad (2016), Ajayi and Olubi (2016), Usikalu et al. (2017), Ononugbo and Osiga (2018), and Obed et al. (2018), have been reported. There appears to be however, no evidence of such measurements in Delta State. This work then seek to determine the indoor

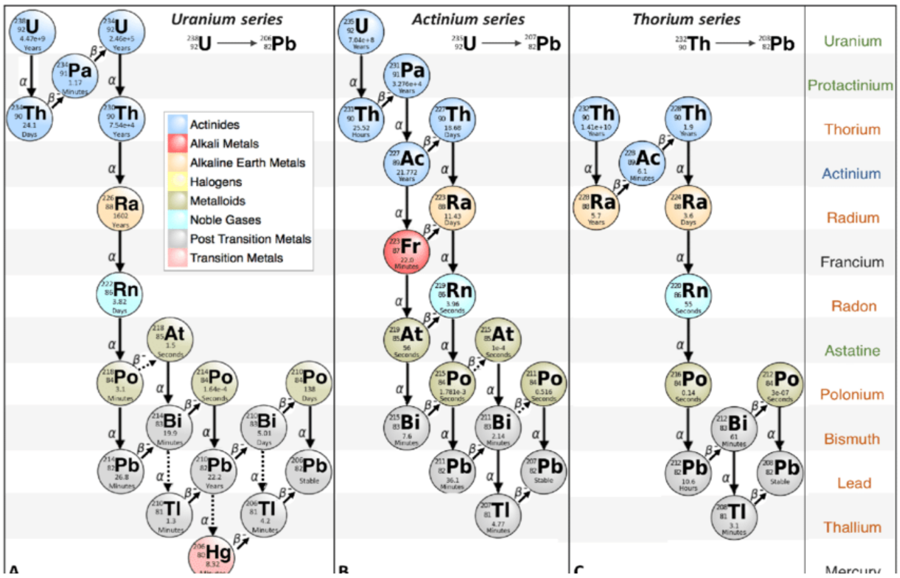

Figure 1. Illustration of the production of radon gas from the three natural decay series (metadata.berkeley.edu, 2020).

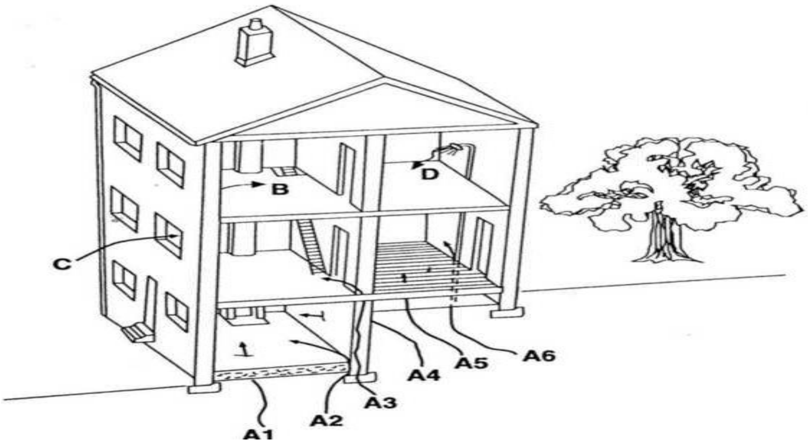

Figure 2. Typical Radon Source entry route. A1: Cracks in solid floors, A2: Cracks in joints, A3: Cracks and cavities in walls, A4: Cracks below ground level, A5: Gaps in suspended floors, A6: Gaps around service pipes, B: Emissions from building materials, C: Addition from outdoor air, D: Release from water.
Source: Westside-Radonservices (2020).

radon levels in the central part of Delta State as part of the ongoing effort of the Radiation and Health Physics unit in the Department of Physics of the Delta State University to carry out a radon survey in the state.

MATERIALS AND METHODS

Delta Central of Delta State located on latitude 19.0550° N and longitude 73.0673° E is in the South-South part of Southern Nigeria. It has eight local government areas out of which measurements were carried out in six. These are Ughelli North, Ughelli South, Ethiope East, Ethiope West, Sapele and Okpe. The map of Delta State showing this study area is presented in Figure 3.

Measurements were made using a BQM-Digital Corentium Radon Detector manufactured by a Norway-based Technology Company, which uses an Alpha Spectrometry with digital detector technology and precision at one hundred Becquerel per cubic meters (100 Bqm^{-3}) and accuracy of less than 5%. It is an active alpha particle detector which requires to be exposed for a reasonable time for it to register any incoming

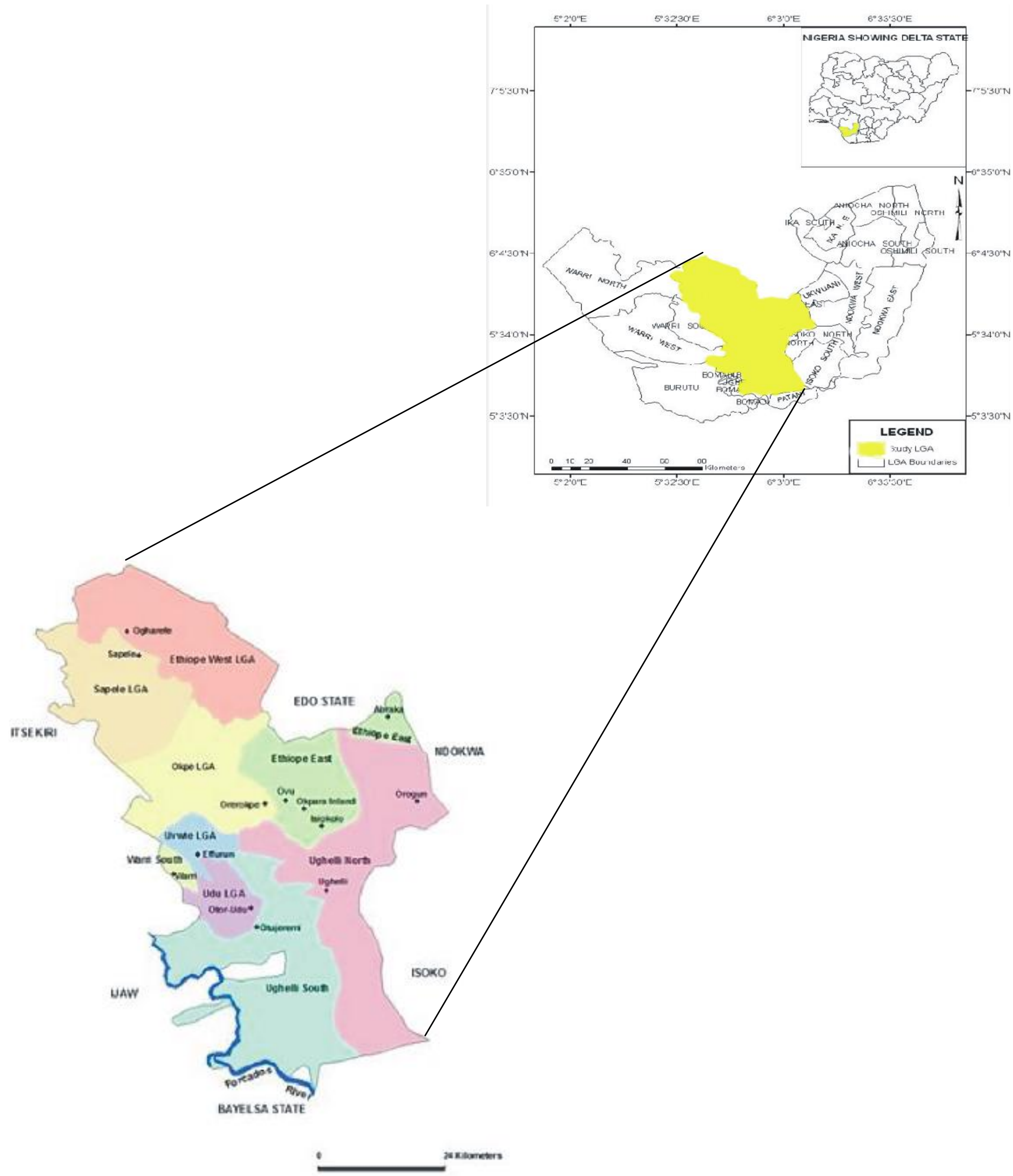

Figure 3. Map of Delta State showing Delta Central.

stimulus. For each measurement, the detector was placed at least a 0.5 m above the ground and 1.5 m away from windows and doors (Airthings, 2019). The screen was made to face upwards for ease of reading and exposure time was 24 h. Necessary arrangements were made to ensure that it was not tampered with during the exposure period in any of the building in the locations. Recalibration of the meter after each use was not necessary because the manufacturers recommended that this is only necessary if it was not in use for more than one year. Measurements were obtained in two painted and two unpainted block houses in two towns for each of the six local government areas. The obtained concentration values were used to estimate the radiological health parameters due to indoor radon in the respective buildings employing appropriate expressions.

Radon exposure (E_R)

This was determined by the measured radon concentration (Charles et al., 2018):

$$E_R = n \times C_{Rn} \times 2.7 \times 10^{-4} \times 8760/170 \qquad (1)$$

where n is the indoor occupancy factor (0.4) and C_{Rn} is the average radon concentration (Bqm^{-3}).

Annual absorbed dose (AAD)

The annual absorbed dose was obtained using Equation 2 (Charles et al., 2018):

$$D_T\,(mSvy^{-1}) = C_{Rn} \times D_{cf} \times F \times H \times T \qquad (2)$$

where D_T is the annual absorbed dose, D_{cf} is the dose conversion factor (9.0×10^{-6} mSvh^{-1}/Bqm^{-3}), F is the indoor radon equilibrium factor (0.4), H is the indoor occupancy factor (0.4), T is the number of hours in a year (24 h × 365 days = 8760 h/year).

Annual equivalent dose (AED)

The annual equivalent dose was obtained using Equation 3 (Ononugbo and Osiga, 2018):

$$D_E\,(mSvy^{-1}) = T_o \times C_{Rn} \times D_{cf} \times F \qquad (3)$$

where T_o is the occupancy time for indoor radon is 7008 h/year.

Annual equivalent dose to whole body (AEDWB)

The annual equivalent dose to whole body was obtained using Equation 4 (ICRP, 1991):

$$H_T = W_R \times D_T\,(mSvy^{-1}) \qquad (4)$$

Where H_T is the annual equivalent dose to whole body and W_R is the radiation weighting factor (for alpha particle is 20).

Annual equivalent dose in soft tissue (AEDST) excluding lung

This was obtained using Equation 5 (Ononugbo and Osiga, 2018):

$$D_{E(softtissue)}(mSvy^{-1}) = W_T \times C_{Rn} \qquad (5)$$

where $D_{E(\text{soft tissue})}$ is the annual equivalent dose to soft tissue and W_T is the weighting factor (0.09×10^{-9}) for soft tissue.

Annual equivalent dose to lung (AEDL)

This was obtained using Equation 6 (Ononugbo and Osiga, 2018):

$$D_{E(lung)}(mSvy^{-1}) = W_T \times C_{Rn} \qquad (6)$$

where $D_{E(\text{lung})}$ is annual equivalent dose to lung and W_T is the weighting factor (0.80×10^{-9}) for lung.

Annual effective dose to lung (AE$_f$DL)

The annual effective dose to lung was obtained using Equation 7 (Charles et al., 2018; ICRP, 1991):

$$E_T = W_T \times H_T\,(mSvy^{-1}) \qquad (7)$$

where W_T is the tissue weighting factor for lung (given as 0.12) and H_T is the annual equivalent dose to whole body.

Excess life cancer risk (ELCR)

The excess life cancer risk was obtained using Equation 8 (Nigus, 2017; Charles et al., 2018; Vanguardngr, 2018; ICRP, 1991):

$$ELCR = E_R \times T \times F_R \qquad (8)$$

where E_R is the exposure to radon WLM/year, T is the average lifetime expectancy for Nigeria (given as 54.7 for male, 55.7 for female with average as 55.2), and F_R is the risk coefficient for exposure to radon in equilibrium with its progeny (5×10^{-4} per WLM).

Equilibrium equivalent radon concentration (EERC)

The equilibrium equivalent radon concentration was obtained using Equation 9 (Ononugbo and Osiga, 2018):

$$C_{EERn} = C_{Rn} \times F \qquad (9)$$

Equivalent dose (ED)

The equivalent dose can be obtained using Equation 10:

$$E_D = C_{EERn} \times D_{cf} \times F \qquad (10)$$

where C_{EERn} is equilibrium equivalent radon concentration.

Working level month (WLMy)

The working level month can be obtained using Equation 11 (Ononugbo and Osiga, 2018):

$$WLM(y) = C_{Rn} \times F \times 2.7 \times 10^{-4} \times S \times 8760/170 \qquad (11)$$

RESULTS AND DISCUSSION

The variation in indoor radon concentration and their corresponding radiological parameters in some houses of selected communities in Delta Central of Delta State has been obtained and presented in Tables 1 to 4.

Table 1. Measured Indoor Radon Concentration in the Study Locations

S/N	LGA	Community	Location	Age of Building (yrs)	Type of Building	Long Term Average (Bqm^{-3})	Short Term Average (Bqm^{-3})
1.	Ughelli South	Ewu-Orah (Populated)	$5^{0}22'$ 55.7 " N $5^{0}59'$ 22.6 " E	19+	PBH	10.73	0.74
		Ewu-Orah (Populated)	$5^{0}22'$ 56.8 " N $5^{0}59'$ 23.6 " E	29+	UBH	11.84	0.74
		Okparabe (Unpopulated)	5021' 02.1 " N 5056' 20.1 " E	30+	UBH	14.80	0.74
		Okparabe (Unpopulated)	5020' 49.3 " N 5056' 25.8 " E	15+	PBH	17.76	0.74
2.	Ughelli North	Orogun (Populated)	$5^{0}18'$ 25.8 " N $6^{0}09'$06.5 " E	15+	PBH	29.97	0.74
		Orogun (Populated)	$5^{0}18'$ 25.8 " N $6^{0}09'$06.5 " E	35+	UBH	9.99	0.74
		Idjerhe (Unpopulated)	$5^{0}38'$ 37.8 " N $6^{0}08'$ 62.2 " E	20+	PBH	14.80	0.74
		Idjerhe (Unpopulated)	$5^{0}38'$ 36.9 " N $6^{0}08'$ 54.4 " E	4+	UBH	35.89	0.74
		Abraka (Populated)	$5^{0}47'$ 07.6 " N $6^{0}05'$ 05.8 " E	3+	PBH	0	0.74
		Abraka (Populated)	$5^{0}46'$ 58.8 " N $6^{0}05'$ 10.6 " E	3+	UBH	5.92	0.74
3.	Ethiope East	Erho (Unpopulated)	$5^{0}46'$ 16.4 " N $6^{0}04'$ 09.0 " E	15+	PBH	21.83	20.7
		Erho (Unpopulated)	$5^{0}46'$ 03.8 " N $6^{0}04'$ 19.2 " E	7+	UBH	15.54	12.58
		Oghara (Populated)	$5^{0}56'$ 05.0 " N $5^{0}39'$ 38.1 " E	20+	UBH	6.66	6.66
		Oghara (Populated)	$5^{0}56'$ 05.8 " N $5^{0}39'$ 26.2 " E	10+	PBH	0	0.74
4.	Ethiope West	Ogharaefe (Unpopulated)	$5^{0}56'$ 14.0 " N $5^{0}40'$ 36.6 " E	15+	PBH	8.88	5.92
		Ogharaefe (Unpopulated)	$5^{0}56'$ 41.2 " N $5^{0}39'$ 41.5 " E	4+	UBH	34.04	0.74
		Sapele (Populated)	$5^{0}52'$ 55.1 " N $5^{0}41'$ 44.4 " E	7+	PBH	3.70	0.74
		Sapele (Populated)	$5^{0}52'$ 55.4 " N $5^{0}41'$ 40.4 " E	3+	UBH	16.65	0.74
5.	Sapele	Amukpe (Unpopulated)	$5^{0}50'$ 29.2 " N $5^{0}43'$ 33.8 " E	5+	PBH	12.95	0.74
		Amukpe (Unpopulated)	$5^{0}51'$ 44.8 " N $5^{0}51'$ 44.8 " N	5+	UBH	49.85	0.74

Table 1. Continue

6.	Okpe	Osubi (Populated)	$5^0$38′ 11.3″N $5^0$49′ 35.0″E	12+	PBH	9.99	0.74
		Osubi (Populated)	$5^0$35′ 41.8″N $5^0$49′ 35.0″E	17+	UBH	10.73	0.74
		Ovwiri (Unpopulated)	$5^0$38′ 23.1″N $5^0$53′ 27.5″E	5+	PBH	8.51	0.74
		Ovwiri (Unpopulated)	$5^0$35′ 43.6″N $5^0$35′ 43.6″N	6+	UBH	4.81	0.74

Table 2. Measured indoor radon levels according to nature and age of buildings.

Painted block houses		Unpainted block houses	
Age (year)	**Concentration (Bqm^{-3})**	**Age (year)**	**Concentration (Bqm^{-3})**
	Urban		
3	0.00	3	16.65
7	3.70	4	5.92
10	0.00	17	10.73
12	9.99	20	6.66
15	29.77	29	11.89
19	10.73	35	9.99
	Rural		
5	8.51	4	34.04
15	17.16	4	35.89
15	21.83	6	4.81
15	8.88	7	15.54
15	12.95	15	49.85
20	14.80	30	14.80

The indoor radon concentration measured in the two house types in the study locations ranges from 0 to 49.85 Bqm^{-3} with the highest indoor radon concentrations for unpainted block houses (UBH) in rural dwellings were obtained in Amukpe with the value of 49.85 Bqm^{-3} followed by Idjerhe with the value of 35.89 Bqm^{-3} while the lowest indoor radon concentration for UBH in rural dwellings with the value of 4.81 Bqm^{-3} was obtained in Ovwori followed by UBH in Abraka with the value of 5.92 Bqm^{-3}. The highest indoor radon concentrations for painted block houses (PBH) in rural dwellings were obtained in Erho with the value of 21.83 Bqm^{-3} followed by Okparabe with the value of 17.76 Bqm^{-3}. The high radon levels obtained in the two UBHs may be due to poor ventilation, untilled floors, cracks on the walls and floors, unpainted and old pattern of building as these houses were seen almost as an underground building. For urban dwellings, the highest indoor radon concentration measured for PBH was measured in Orogun with value of 29.97 Bqm^{-3} followed by PBH in Eghwu with value of 10.73 Bqm^{-3} while the lowest indoor radon concentration measured for a PBH is 3.7 Bqm^{-3} followed by another PBH in Ogharaefe with value of 8.88 Bqm^{-3} while for highest radon concentration measured for UBH in urban dwellings was obtained in Sapele with a value of 16.65 Bqm^{-3} while the lowest measured was in Sapele with value of 3.7 Bqm^{-3}. It was observed that two PBHs in Abraka, Ethiope East and Oghara, Ethiope West recorded zero long term average radon concentration. The results obtained could be as a result of the tiled floor and the pattern of plastering, painting pattern used "screeding" and enough ventilation allowed into the living room. The average mean of indoor radon concentration obtained for PBH is 9.07 Bqm^{-3} and for UBH is 10.3 Bqm^{-3} both in urban dwellings. The average mean of indoor

Table 3. Calculated radiological health parameters for varying C_{Rn} in painted block houses (PBH)

		Urban						Rural					
Parameters	**Unit**	**US**	**UN**	**EE**	**EW**	**S**	**O**	**US**	**UN**	**EE**	**EW**	**S**	**O**
E_R	$mSvy^{-1}$	0.02	0.07	0	0	8.4×10^{-3}	0.02	0.04	0.03	0.02	0.02	0.03	0.02
AAD	$mSvy^{-1}$	0.14	0.38	0	0	0.05	0.13	0.2	0.19	0.30	0 .11	0.16	0.11
AED	$mSvy^{-1}$	0.30	0.76	0	0	0.10	0.25	0.45	0.37	0.55	0.22	0.33	0.21
AEDWB	$mSvy^{-1}$	6	15.2	0	0	1	2.6	4.4	3.8	6	2.2	3.2	2.2
AEDST	$mSvy^{-1}$	9.7×10^{-10}	2.7×10^{-9}	0	0	3.3×10^{-10}	8.9×10^{-10}	1.6×10^{-9}	1.3×10^{-9}	1.9×10^{-9}	7.9×10^{-10}	1.2×10^{-9}	7.7×10^{-10}
AEDL	$mSvy^{-1}$	8.6×10^{-9}	2.4×10^{-8}	0	0	2.9×10^{-9}	8.0×10^{-9}	1.4×10^{-8}	1.2×10^{-8}	1.8×10^{-8}	7.1×10^{-9}	1.0×10^{-8}	6.8×10^{-9}
AE_FDL	$mSvy^{-1}$	0.72	1.82	0	0	0.12	0.31	0.53	0.50	0.72	0.26	0.38	0.3
ELCR	$mSvy^{-1}$	3.3×10^{-6}	1.1×10^{-5}	0	0	1.3×10^{-6}	3.2×10^{-6}	6.5×10^{-6}	4.9×10^{-6}	8.1×10^{-6}	3.3×10^{-6}	4.9×10^{-6}	3.2×10^{-6}
AEDDI	$mSvy^{-1}$	0.36	1.08	0	0	0.09	0.36	0.36	0.54	0.72	0.27	0.45	0.27
EERC	Bqm-3	4.30	11.99	0	0	1.48	4.00	7.10	5.92	8.73	3.55	5.18	3.40
ED	mSv/Bqm^{-3}	1.7×10^{-5}	4.8×10^{-5}	0	0	5.9×10^{-6}	1.6×10^{-5}	2.8×10^{-5}	2.4×10^{-5}	3.5×10^{-5}	1.4×10^{-5}	2.1×10^{-5}	1.3×10^{-5}
WLM		0.04	0.12	0	0	0.01	0.04	0.04	0.06	0.08	0.08	0.05	0.03

Table 4. Calculated Radiological Health Parameters for Varying C_{Rn} in Unpainted Block Houses (UBH).

		Urban						Rural					
Parameters	**Unit**	**US**	**UN**	**EE**	**EW**	**S**	**O**	**US**	**UN**	**EE**	**EW**	**S**	**O**
E_R		0.03	0.02	0.01	0.01	0.04	0.02	0.03	0.08	0.03	0.08	0.11	0.01
AAD	$mSvy^{-1}$	0.15	0.13	0.07	0.08	0.21	0.14	0.20	0.45	0.20	0.43	0.63	0.06
AED	$mSvy^{-1}$	0.15	0.25	0.15	0.17	0.42	0.27	0.37	0.91	0.40	0.86	1.26	0.12
AEDWB	$mSvy^{-1}$	5.8	5	3	3.4	8.4	6	4	9	4	8.6	12.6	1.2
AEDST	$mSvy^{-1}$	1.1×10^{-9}	$8 .0\times10^{-9}$	5.3×10^{-9}	5.1×10^{-8}	1.5×10^{-9}	8.9×10^{-10}	1.3×10^{-9}	3.2×10^{-9}	1.4×19^{-9}	3.1×10^{-9}	4.5×10^{-9}	4.3×10^{-10}
AEDL	$mSvy^{-1}$	9.5×10^{-9}	$8 .0\times10^{-9}$	4.7×10^{-9}	5.3×10^{-9}	1.3×10^{-9}	8.0×10^{-9}	1.2×10^{-9}	2.9×10^{-8}	1.2×10^{-8}	2.7×10^{-8}	4.0×10^{-8}	3.8×10^{-9}
AEDL	$mSvy^{-1}$	0.70	0.6	0.36	0.41	1.01	0.31	0.48	1.08	0.48	1.03	1.51	0.14
ELCR		4.9×10^{-6}	3.3×10^{-6}	1.6×10^{-6}	1.6×10^{-6}	6.5×10^{-6}	3.2×10^{-6}	$4,9\times10^{-6}$	1.3×10^{-5}	4.9×10^{-6}	1.3×10^{-5}	1.8×10-5	1.6×10^{-6}
AEDDI	$mSvy^{-1}$	0.45	0.36	0.18	0.27	0.54	0.36	0.54	1.26	0.54	1.17	1.8	0.18
EECR	Bqm^{-3}	4.74	4	2.37	2.66	6.66	4.00	5.92	14.36	6.22	13.62	19.94	1.92
ED	mSv/Bqm^{-3}	1.9×10^{-5}	1.6×10^{-5}	9.5×10^{-6}	1.1×10^{-5}	2.7×10^{-5}	1.6×10^{-5}	2.4×10^{-5}	5.7×10^{-5}	2.5×10^{-5}	5.5×10^{-5}	8.0×10^{-5}	7.7×10^{-6}
WLM		0.05	0.04	0.02	0.03	0.06	0.04	0.06	0.14	0.06	0.13	0.20	0.02

radon concentration obtained for PBH is 14.12 Bqm^{-3} and for UBH is 25.82 Bqm^{-3} both in rural dwellings which may be as a result of poor ventilation and no screeding. This high values relative to results obtained in urban dwellings may be as a result of poor ventilation, nature and pattern of the buildings. The average mean of indoor radon concentration for both painted and unpainted block house in this study is 14.83 Bqm^{-3} which is relatively less than the 100 Bqm^{-3} suggested by the WHO (2019) for indoor radon concentration.

The indoor equilibrium equivalent concentration of radon varies from 0 to 11.99 Bqm^{-3} for PBH and 2.37 to 19.94 Bqm^{-3} for UBH.

The result obtained in this work appears to be less than the values reported by Ononugbo and Osiga (2018) for different types of residential buildings in Ahoada West with values ranging from 0.74 to 40.70 Bqm^{-3}. The obtained values are however within the range of 3.67 to 42.54 Bqm^{-3} reported by Usikalu et al. (2017) for selected houses in Ibadan. The values obtained in this study are less than the 5 to 255 Bqm^{-3} ranges reported by Ajayi and Olubi (2016) for some selected dwellings in South Western Nigeria and 49.95 to 307.84 Bqm^{-3} by Nigus (2017) in Wolaita Sodo.

The indoor radon concentration progeny obtained ranged from 0 to 0.9 WL for PBH and 0.02 to 0.19 WL for UBH while for indoor annual exposure of occupants in houses

in the study area to radiation varied from 0.03 for PBH to 0.04 WLMy^{-1} for UBH. Figures 4 and 6 are graphs showing the relationship between radon concentration and age of building of PBHs and UBHs in urban and rural dwellings. For the relationship between radon concentration and age of buildings of PBHs, an increasing linear trend was observed as shown in Figure 4 which means that the level of radon concentration is proportional to the age of the PBHs with a positive regression of 0.393 indicating the presence of radon in the PBHs while a slight increase in the linear trend for PBHs with a positive regression of 0.155 observed.

For the relationship between radon concentration and age of building of UBHs, a slight decreasing linear trend with a positive yet small regression of value 0.092 was observed for Figure 4 while a sharp decreasing linear trend and a weak but positive regression of 0.133 was observed for Figure 6 indicating that the radon concentration is inversely proportional to the age of the building.

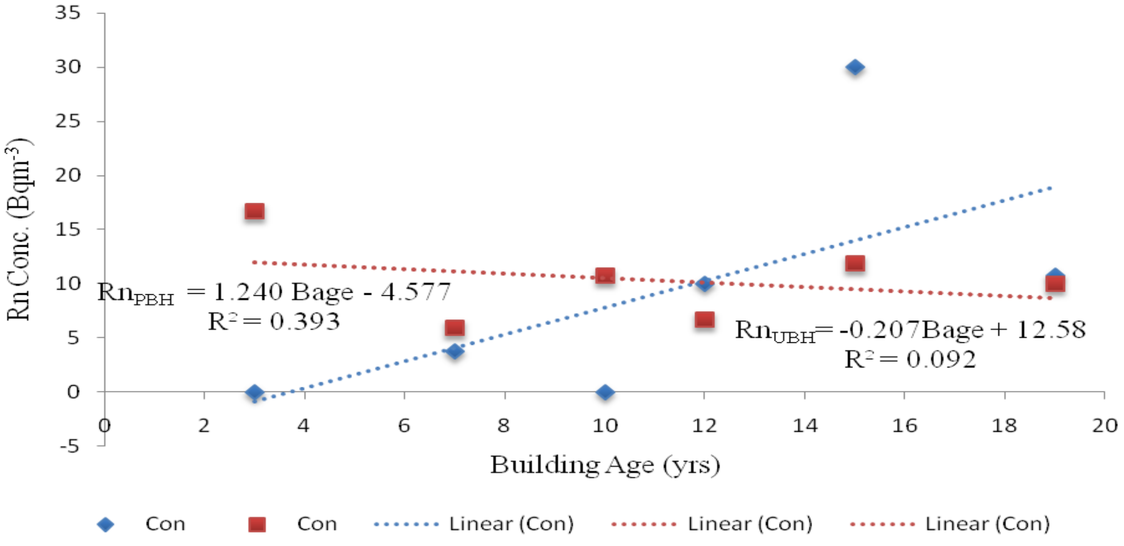

Figure 4. Graph showing the relationship between Rn concentration and age of buildings for urban dwellings. Blue line for CRn in PBH; Red line for CRn in UBH.

Figures 5 and 7 show a column chart with the level of radon concentration for PBHs and UBHs in urban and rural dwellings for different LGA.

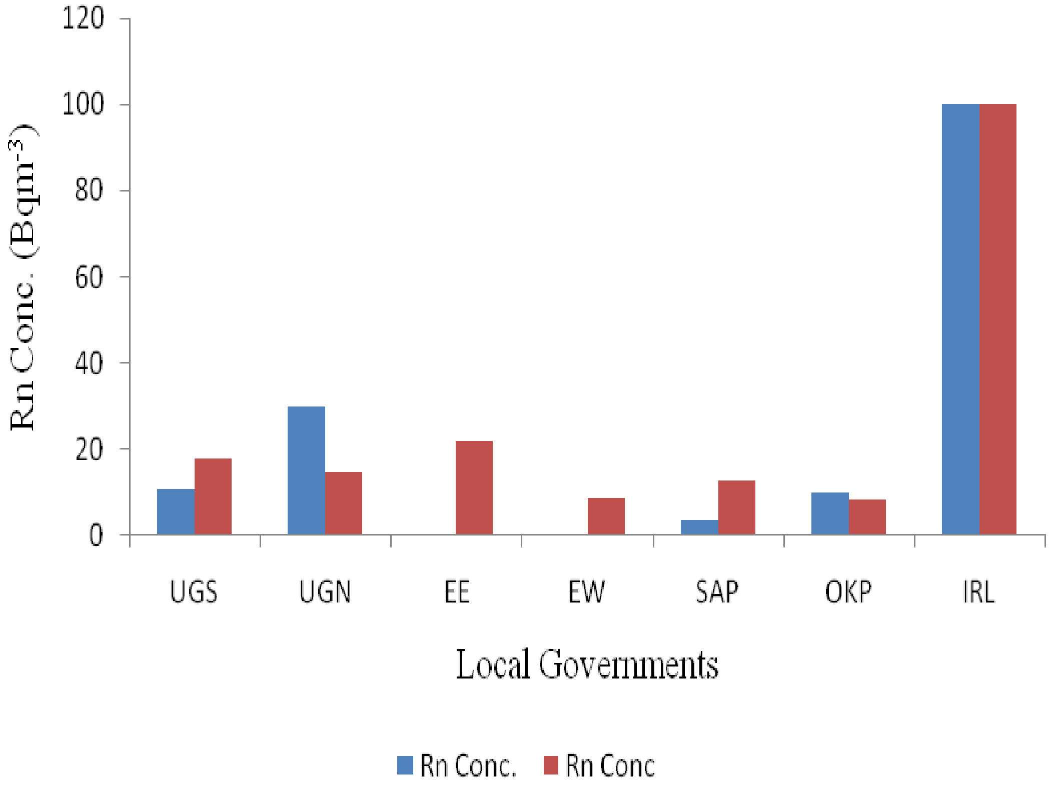

Figure 5. Column chart showing Rn concentration level for PBHs in urban and PBHs in rural dwellings of the study location. Blue line for CRn in PBH in urban; Red line for CRn in PBH rural.

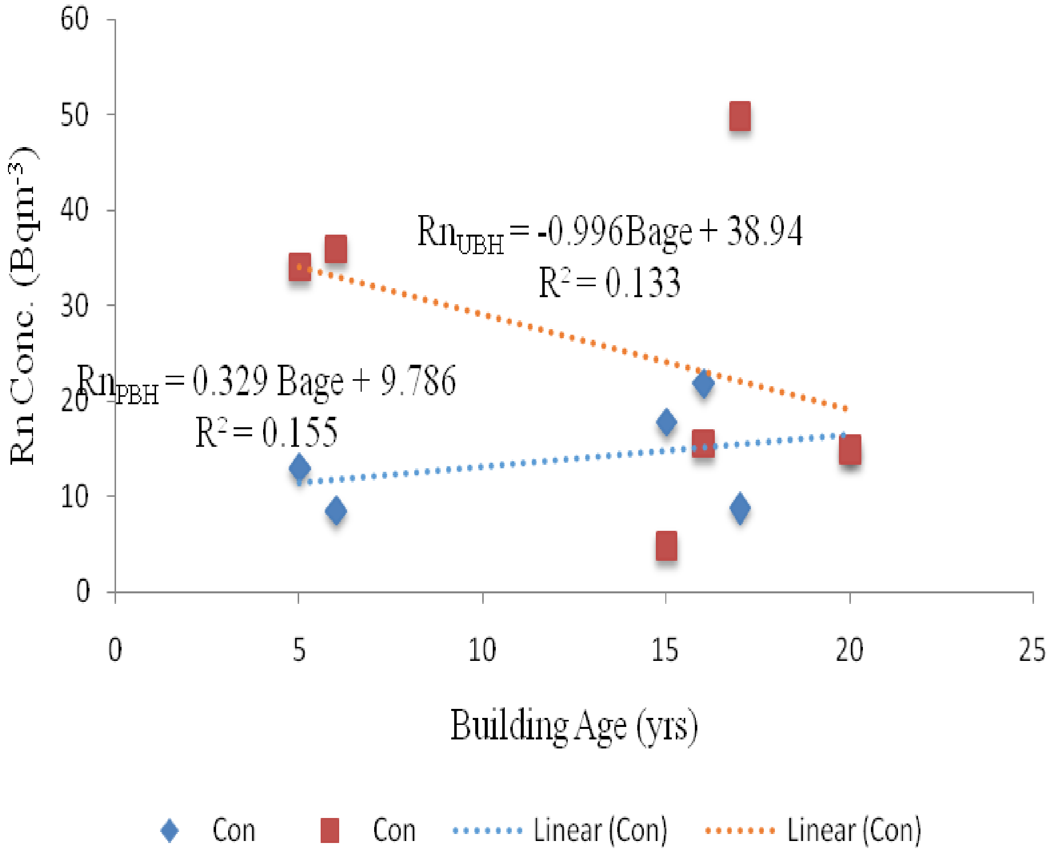

Figure 6. Graph showing the relationship between Rn concentration and age of building for rural dwellings. Blue line for CRn in PBH; Red line for CRn in UBH.

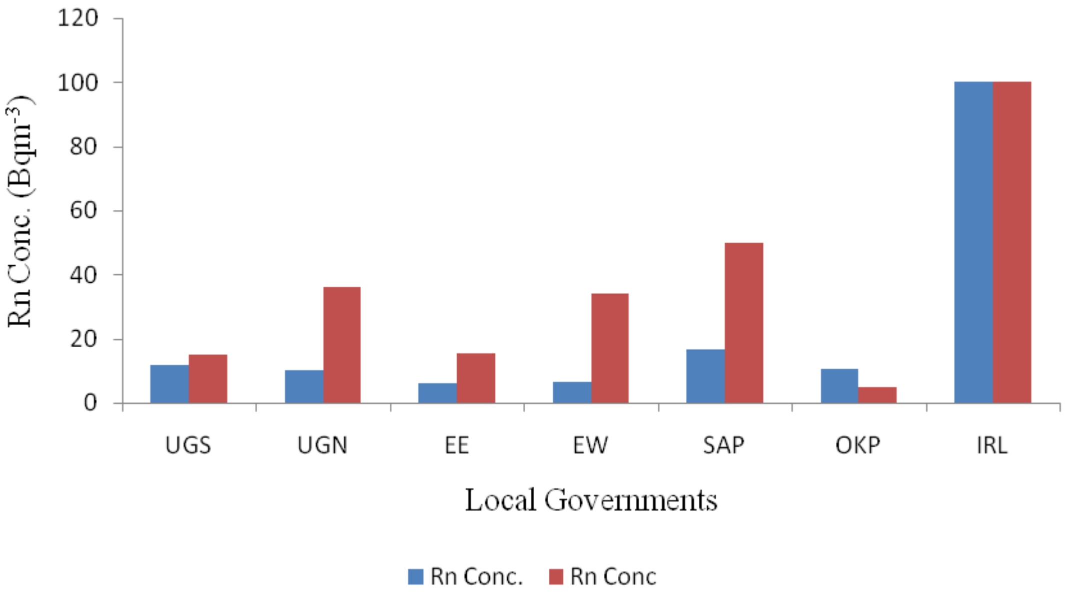

Figure 7. Column chart showing Rn concentration level for UBHs in urban and rural dwellings of the study location. Blue line for CRn in UBH in urban; Red line for CRn in UBH rural.

The chart for Figure 5 shows that the PBH in Ughelli North gave values above 30 Bqm^{-3} with lowest values below 10 Bqm^{-3} while the chart for Figure 7 shows that UBHs have higher indoor radon values than PBHs in rural dwellings.

Conclusions

The first indoor radon concentration measurements were obtained in houses of selected communities in the Delta Central of Delta State using Corentium radon detector. The mean value of indoor radon concentration of the study area was found to be 19.71 Bqm^{-3} which is lower than the recommended limit of 100 Bqm^{-3}. The annual effective dose and other radiological parameters are low. This low measured and calculated value is however due to the amount of ventilation allowed into the living rooms, the pattern of painting, the age of the building and the tiled floors which prevents radon entry into the living room. All of these factors indicate that occupants in houses of the study area are therefore safe.

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