ESTIMATION OF RADON CONCENTRATION AROUND PUBLIC SPACES AND RESIDENTIAL HOMES WITH ALTITUDE WITHIN CITIES OF DELTA STATE, NIGERIA

ABSTRACT

This study evaluates the radon concentrations in public places and private residences with different altitudes in selected locations in Delta State. These measurements were carried out using a professional radon monitoring instrument (Alpha GUARD PQ2000 PRO) and a geographical positioning system (GPS-Garmin GPS Map 76S). The recorded mean radon concentration varied from 11.70 ± 5.20 Bq/m^3 to 23.90 ±16.60 Bq/m^3, which is within the WHO acceptable range (100 Bq/m^3). The basement had greater radon concentrations than the upper floors in most situations, although there were few exceptions. The average values of the estimated radiation risk parameters, which include equilibrium equivalent radon concentration, the potential alpha energy concentration, radon exhalation rates, and excess lifetime cancer risk due to exposure to radon radiation from their progeny are 4.7 Bq/m^3 to 9.5Bq/m^3, 1.20×10^{-3}mWL to 2.60×10^{-3}mWL, 0.04×10^{-3}WML/y to 0.09×10^{-3} WML/y, 3.7Bq/m^2/h to 7.52Bq/m^2/h and 2.10×10^{-3} to 3.30×10^{-3} respectively. The calculated radiation risk factors were all found to be within the recommended limits based on the data obtained. The research region is deemed safe and poses no threat to people.

Keywords: Radon concentration, Altitude, Risks, Alpha GUARD detector.

1.0 INTRODUCTION

The health impacts of indoor air pollution have recently increased due to anthropological activities and industrialization. Exposure to contaminants in indoor air can be difficult, if not dangerous if the concentration of radon level increases (Dehghani et al., 2018). Radon is a vital source of natural radiation. It accounts for around half of all-natural exposure to individuals globally (Khan et al., 2014; Kumar et al., 2014). Radon is produced naturally as a byproduct of the decay of uranium 238, thorium 232, and uranium 235 and it is a radioactive, colorless, odorless, and tasteless noble gas present mostly in soils, rocks, and underground water (Keramati et al.,2018; Moreno et al., 2018).

As a noble gas, radon is quickly exhaled after inhalation; nevertheless, radon progeny can accumulate in the lungs' airways when they interact with other airborne molecules, including dust, aerosol, or smoke particles. The progeny emits alpha particles, ionizing radiation, when trapped in the lungs, which might harm the cells lining the airways (Ingrid and Jiri, 2017). The primary way that radon exposure may impair one's health is through the inhalation of alpha particles. The degree of radon exposure will determine these health impacts. Radon (^{222}Rn) is a radiological health risk gas that may cause leukemia, genetic damage, and harm to human fertility in addition to thousands of lung cancer fatalities recorded each year (Mamta et al., 2012).

Radon is one of the soil gases that has raised a lot of concerns for the building sector, the environment, and public health. Radon has long been recognized as a significant factor in human lung cancer (IARC, 2001). In many nations, radon exposure is frequently regarded as the principal source of ionizing radiation prior to medical exposure (HERCA, 2015). Normally, soil gas generally escapes harmlessly into the ambient atmosphere, but it may also gain access through foundational cracks and gaps, ultimately accumulating to dangerous amounts in basements and lower floors (Amissah, 2005).

It becomes an indoor air pollution problem when it penetrates into buildings directly from the soil, cracks from the floor, and accumulates inside the buildings (Grimsrud et al.,1994). Radon (^{222}Rn) has a half-life of 3.8 days and tends to concentrate in enclosed spaces like underground mines, basements, and crawl spaces (Fisk, 2000; OSHA, 2011). ^{222}Rn concentrations are influenced by geological and climatic factors, building materials, and ventilation (Obed et al., 2010).

Various international organizations, including the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP), and the European Commission (EC), have identified radon as one of the most pervasive and serious global indoor air threats.

The majority of high-rise structures are made of concrete, and everything that goes into concrete originates from the earth. Some concrete, granite, and other stone finishes have been shown to emit radon, however, the concentration is normally low or diminished by ventilation. Several researchers have reported high and low dose rates of radon in dwellings and construction materials, but there is still not a lot studied on radon in building with altitude in the Niger Delta. Thus, the investigation of radon concentration around public spaces and residential homes with altitude within cities of Delta State to ascertain the radiological health risks on the populace and the environment were examined.

2.0 MATERIALS AND METHODS

2.1 Study Area

The research was conducted in residential structures, hotels, and workplaces at altitude in Delta State, Nigeria. Delta State, of the Niger, Delta region of Nigeria lies between latitudes 5˚18’’N to 5˚86’’N and longitude 5˚33’’E to 6˚40’’E (Audu et al 2019).

Delta State is an oil and agricultural-producing state of Nigeria. It is situated in the region known as South-South geo-political zone. The capital city is Asaba, located at the Northern end of the state, with an estimated area of 762 square kilometers (294 sq mi), while Warri is the economic nerve center of the state and also the most populated. It is bounded in the north and the west by Edo State, the east by Anambra, Imo, and Rivers State, southeast by Bayelsa State, and on the southern flank is the Bight of Benin which covers about 160 kilometers of the state’s coastline. There are various solid mineral deposits within the state-industrial clay, silica, lignite, kaolin, tar sand, decorative rocks, limestone, etc. These are raw materials for industries such as brick making, ceramics, bottle manufacturing, glass manufacturing, decorative stone cutting, and quarrying. This has caused some environmental issues of which risk from radiation is paramount.

Figure 1: Map of Delta state showing the study area.

2.2 Method of Sampling

Measurements were carried out in 15 locations with altitude in selected areas of Delta State, Nigeria. All the buildings had their heights to the 5th floor with the exception of one location, and one of the locations has a basement attached to it. All the buildings had sand, cement, and concrete walls. The building height at the location ranged from 2.50m to 20.25m.

A professional radon monitoring equipment (Alpha GUARD PQ2000 PRO) made by Saphymo GmbH, Germany, in 2015 and a geographical positioning system (GPS-Garmin GPS Map 76S) were employed. It contains an ionization chamber and utilizes alpha spectroscopy to determine radon levels. The used AlphaGUARD radon detector has a temperature range of -10˚ C to +50˚ C, an air pressure range of 700 mbar to 1100 mbar, and an air humidity range of 0% to 99%. It provides optimum sensitivity and can run for 10 days on an internal battery. This detector monitors the radioactivity of the air in normal operation by permitting gas to diffuse via the wide surface of the glass fiber filter positioned within the ionization chamber. The filter enables just ^{222} Rn to pass through and prevents radon decay products from entering the ionization chamber due to dust particle contamination (Correa et al., 2011). This radon monitor is designed for continuous monitoring of radon concentrations ranging from 2 to 2000000 Bq/m^3. It is suitable for both short- and long-term testing indoors (e.g., in buildings) and outside, and it can operate in two modes: firstly, a diffusion mode with a measurement cycle of 10 or 60 minutes, and secondly, a flow mode with a measuring period of 1 or 10 minutes. The diffusion mode with a 10-minute measurement cycle was employed in this investigation, and data were obtained every hour during the duration. In addition, GPS readings were acquired in each of the buildings to determine the geographical location of the sample point. For the device's safety, the detector was situated at least 1.5m above (ground) level, with its LCD screen facing up, 0.5m from the window and roof, and 0.4m from the wall. The detector was set so that the sides of the screen were clearly exposed to the radon emergence, allowing it to detect and record alpha particle emission, which results in radon decay across the room. The detector was positioned so that the surfaces with the screen directly faced the radon emergence, permitting it to observe and record alpha particle emission, which results in radon decay across the room.

2.3 Estimation of the Radiation Risk Parameters

To quantify the radiological risks associated with the measured values, the following were calculated. They are the equilibrium equivalent concentration (EEC_{RN}), the potential alpha energy concentration, radon exhalation rates, and excess lifetime cancer risk due to exposure to radon radiation from their progeny.

2.3.1 Equilibrium Equivalent Radon Concentration (EEC_{RN})

The equilibrium equivalent radon concentration (EEC_{RN}) is a useful statistic for assessing the radiological risk of all the daughters in the radon decay line. Radon and its decay products, or their equivalent concentrations (EEC_{RN}), were calculated using the relation (Kranrod et al., 2009).

$$EEC_{RN} = C_{RN} \times F \qquad (1)$$

Where,

C_{RN} is the mean radon concentration and F is the equilibrium factor between radon and its daughter (F = 0.4).

2.3.2 Potential Alpha Energy (PAE)

The annual exposure due to radon progeny described the total concentration of short-lived radon progeny with a lone entity. It eliminates the requirement to assign the concentration of each decay product.It is estimated in mWL using the expression proposed by Abojassim and Husain (2015):

$$\text{PAE (mWL)} = \frac{EECRN}{3700} \qquad (2)$$

2.3.3 Annual Human Exposure Rate or Working Level Month (WLM)

The Working Level Month is its practical measuring unit (WLM).

It corresponds to a one-month working exposure to 3700 Bq.m-^{3} of radon progeny concentration in equilibrium with radon gas (170 hours). The yearly radon progeny exposure is calculated using the following relationship. In the lack of experimental evidence on the equilibrium factor between radon and its daughter cells, the EPA suggested value was used to calculate the working level month in relation to the yearly human exposure rate (Abojassim and Husain, 2015):

$$WLM_{(Y)} = C_{RN} \times F \times 2.7 \times 10^{-4} \times S \times \frac{8760}{170} \qquad (3)$$

Where,

$WLM_{(Y)}$ is the annual exposure to radon progeny,

C_{RN} is the radon concentration measured (Bq.m^{-3}),

F is the equilibrium factor between radon and its daughter and is equal to (0.4), 2.7×10^{-4} is the radon progeny concentration in equilibrium (WL/Bq.m^{-3}),

S = 0.7 is the fraction of spending time indoors and 8670 is the total hours per year, and 170 is the total working hours per month (USEPA, 1993).

2.3.4 Estimation of Radon Exhalation Rate (Bqm^{-2}h^{-1})

The radon exhalation rate is defined as the rate of radon that escapes from the soil into the atmosphere, and it can be measured by the exhalation of radon gas per unit mass of soil or per unit area of the surface (Soares et al., 2020).

The estimation of dose in Bqm^{-2}h^{-1} due to radon and its progeny can be obtained from the expression (Nisha et al., 2014):

$$E_S = \frac{C \text{ x } V \text{ x } \lambda_v}{S} \qquad (4)$$

Where,

C is the radon concentration (Bq.m^{-3}), E_S is the radon exhalation rate (Bqm^{-2}h^{-1}),

V is the room volume (m^{2}),

λ_v are radon concentration (Bq.m^{-3}) and air exchange rate (h^{-1}) respectively and the radon concentration from the building material is assessed by assuming the room as a cavity with S/V= 2.0 m^{-1} and an air exchange rate of 0.63 h^{-1}.

2.3.5 Estimation of Excess Lifetime Cancer Risk (ELCR)

Excess lifetime cancer risks (ELCR) is the possible carcinogenic consequences depending on the probability of cancer-induced incidence in a population. It represents the likelihood of developing cancer as a result of lifetime exposure to radiation or harmful chemical compounds. The increased lifetime cancer risk from inhaled radon and its offspring is calculated using the relationship (Amin et al., 2015)

$$ELCR = WLM_{(Y)} \times T \times R \qquad (5)$$

Where,

$WLM_{(Y)}$ is the annual exposure to radon progeny, T is the exposure time (Year) and R is the risk factor. The risk factor used to estimate the risk of lung cancer from radon inhalation for dwellers is 5 × 10^{-4} (ICRP, 2014).

4.0 RESULTS AND DISCUSSION

Table 1 shows the estimated radon concentrations in buildings with altitude from the various sample locations and their corresponding 15 locations. Figure 2 and 3 shows the comparison of the indoor radon concentration in the sampling locations and WHO standard.

The mean radon concentrations varied from 11.70 ± 5.20 Bq/m^3 to 23.90 ± 16.60 Bq/m^3. The highest radon concentration was obtained in Location 2 with a mean value of 23.90 ± 16.60 Bq/m^3, while the lowest was found in Location 10 with a mean value of 11.70 ± 5.20 Bq/m^3. The highest value may be due to the basement location in that locality. While in Location 10, there is good ventilation in which the radon concentration is mixed with air to reduce the concentration level. Soil is a source of radon, and the basement is located quite near the soil, hence high radon readings were reported when compared to others. Soil samples are the main source of exposing radon gases (ionizing radiation) as a result of the disintegration of ^{238}U and ^{232}Th in the earth's crust (UNSCEAR, 1993), and these may be related to the fact that all are associated with radon and its progenies emanation and transition in an indoor environment (in the earth and atmosphere), and the amount of radon in an indoor environment depends on the type of the material soil, ventilation systems, and type building used. The use of a suitable ventilation system, or simply taking advantage of natural air exchange by opening windows and doors regularly, can aid in the prevention of radon buildup.

Furthermore, the radon levels obtained at different levels varied greatly. This finding indicates a decreasing tendency in radon concentration with height, which is most likely owing to improved air cleansing and ventilation. This is in line with the research, which shows that the higher the elevation of a structure, the lower the radon level (Shirav et al., 1997), and that basement and ground-floor buildings have greater radon concentrations because radon emission occurs by diffusion, and the farther away from the contact source, the lower the concentration; that is, the higher you go, the lower the concentration of radon (Afolabi, 2015).

All of the results obtained are below the ICRP action threshold and also below the USEPA reference level of 148 Bq/m^3 (2004). The average indoor radon concentration measured was significantly lower than the WHO action threshold of 100 Bq/m^3 (2009).

The values of radon concentrations recorded in this work were less than values obtained by Amin et al., (2017) in the Basrah governorate of southern Iraq for sediments (985.26 Bq/m^3) and soil (1215 Bq/m^3), Askari et al., (2019) in residential homes and public places in Tehran, Iran (60.3 and 55.8 Bq/m^3) and Mohammed et al., (2021) in Abu Ali-Khaseb and Ad Dayer of Southern Iraq for soil (64.8 ± 0.9) and (80.9 ± 0.9 Bq/m^3) respectively.

Radon concentrations vary seasonally but are often greater in the winter than in the summer, and at night than during the day. This is because building sealing (to save energy) and locking doors and windows (at night) restrict the intake of outside air and allow radon to build up (WHO 2005, EPA 2013).

The mean equilibrium equivalent radon concentration in the sample locations varied from 4.7 Bq/m^{-3} to 9.5 Bq/m^{-3}. The obtained values are comparable to those reported by Khan (2016) for homes in various villages of the Hardoi district, where values ranged from 7.93 to 20.09 Bq/m^{3}, but they are significantly lower than those reported by Mohammed et al., (2021) in southern Iraq, with values ranging from 48.4 to 83.0 Bq/m^{3}, and those reported by Abd-Elzaher (2012) for homes in various Alexandria, Egypt, districts, where values ranged from 50.93 to 105 Bq/m^{3}. The obtained results are however within the range of 16.070 Bq/m^{3} reported by Avwiri et al., (2020) in some selected basement buildings in Port Harcourt, River state. The values obtained from the study are 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 Bq/m^{3}.

The mean concentrations of potential alpha energy (PAEC) varied from 1.20 × 10^{-3} mWL (Location 10) to 2.60 ×10^{-3} mWL (Location 2), The annual human exposure rate, or working levels month (WLM) ranged from 0.04 ×10^{-3} WL M/Y (Location 10) to 0.09 × 10^{-3} WLM/y (Location 2). The concentration of radon progeny and monthly level of exposure were less than the values reported by Salim et al. (2019) in Baghdad's Ibn Al- Haitham buildings whose value ranged from 0.018 mWL to 0.0482 mWL and those reported by Ismail et al. (2010) in Iraqi Kurdistan with the range of 4.98 ± 15.54 mWL. The ventilation rates, type of dwellings/construction, and geological formation are the key factors causing all values to be below the permissible limits of 53.33 mWL (UNSCEAR, 1993) and 1-2 WLM/y (NCRP, 1989; Ismail et al., 2010).

The radon exhalation rates obtained ranged from 3.70 Bq/m$^{2/}$h to 7.52 Bq/m^{2}/h. The greatest mean value was found in Location 2, which was 7.52 Bq/m^{2}h^{1}, while the lowest value was obtained in Location 10, which was 3.7 Bq/m$^{2/}$h. The radon exhalation rate from the sample sites was found to be lower than the global average of 56 Bq/m^{2}/h and within the ranges recorded by Saleh et al., (2021). Furthermore, the excess lifetime cancer risk value was found to range from 1.80 ×10^{-3} to 3.30 ×10^{-3}. The ELCR values are within those reported by Orlunta et al., (2021) in three selected towns in Port Harcourt, Rivers State, Nigeria with the range of 0.863×10^{-3} to 2.745×10^{-3} .The estimated excess lifetime cancer risk revealed that the chance of contracting cancer for residents of the study area who will spend all their lives in the study area is low, the residents of these houses are generally radiologically safe.

Figures 2 and 3 show a chart with the level of radon concentration for the various sampling locations. From the displayed chat, Location 2 gave the highest value of 23.90 Bq/m^{3} and Location 10 gave the lowest value of 11.70 Bq/m^{3}. The values obtained are lower than the recommended permissible limit and do not pose any likelihood of immediate health risk to the residents of the study area.

Table1. Results of the Radiological Health Parameters computed from Indoor ^{222}RnConcentration

S/N	Locations/ Height (m)	^{222}Rn (Bq/m^3)	EEC$_{RN}$ (Bq/m^3)	PAE (mWL)	E$_P$ (WLM/Y)	E$_S$ (Bqm^{-2}h^{-1})	ELCR×10^{-3}
	Location 1						
A	3.00	33 ± 14	13.2	3.60	0.13	10.40	4.6
B	5.75	20± 16	8.0	2.20	0.08	6.30	2.8
C	8.50	18 ± 8	7.2	1.90	0.07	5.70	2.5
D	11.25	15 ± 7	6.0	1.60	0.06	4.70	2.1
E	14.00	11 ± 6	4.4	1.20	0.04	3.50	1.4
F	16.75	11 ± 6	4.4	1.20	0.04	3.50	1.4
G	20.25	8 ± 5	3.2	0.86	0.03	2.50	1.1
	Mean	**16.60 ±8.40**	**6.6**	**1.80**	**0.06**	**5.10**	**2.3**
	Location 2						
A	2.7	44 ± 16	17.6	4.80	0.17	13.90	6.0
B	5.6	45 ± 17	18.0	4.90	0.18	14.20	6.3
C	8.3	34 ± 12	13.6	3.70	0.13	10.70	4.6
D	11.0	15 ± 8	6.0	1.60	0.06	4.70	2.1
E	13.7	13 ± 6	5.2	1.40	0.05	4.10	1.8
F	16.4	10 ± 6	4.0	1.10	0.04	3.20	1.4
H	19.55	6 ± 4	2.4	0.65	0.02	1.90	0.7
	Mean	**23.90±16.60**	**9.5**	**2.60**	**0.09**	**7.50**	**3.3**
	Location 3						
A	2.50	45 ± 15	18.0	4.90	0.18	14.20	6.3
B	4.75	21 ± 9	8.4	2.30	0.08	6.60	2.8
C	7.00	15 ± 7	6.0	1.60	0.06	4.70	2.1
D	9.25	12 ± 9	4.8	1.30	0.05	3.80	1.8
E	11.50	9 ± 5	3.6	0.10	0.04	2.80	1.4
F	13.75	6 ± 4	2.4	0.65	0.02	1.90	0.7
	Mean	**18 ± 14.20**	**7.2**	**1.80**	**0.07**	**5.70**	**2.5**
	Location 4						
A	2.6	31 ± 30	12.4	3.40	0.12	9.80	4.2
B	5.0	22 ± 30	8.8	2.40	0.09	6.90	3.2
C	7.4	12 ± 10	4.8	1.30	0.05	3.80	1.8
D	9.8	12 ± 7	4.8	1.30	0.05	3.80	1.8
E	12.2	8 ± 5	3.2	0.86	0.03	2.50	1.1
F	14.9	11 ± 6	4.4	1.20	0.04	3.50	1.4
	Mean	**16.00 ±8.70**	**6.4**	**1.70**	**0.06**	**5.00**	**2.1**
	Location 5						
A	2.55	35 ± 12	14.0	3.80	0.14	11.00	4.9
B	4.85	27 ± 10	10.8	2.90	0.11	8.50	3.9
C	7.15	13 ± 6	5.2	1.40	0.05	4.10	1.8
D	9.45	10 ± 6	4.0	1.10	0.04	3.20	1.4

E	11.75	4 ± 3	1.6	0.43	0.02	1.30	0.7
F	14.51	3 ± 1	1.2	0.32	0.01	0.90	0.4
	Mean	**15.3 ±12.90**	**6.0**	**1.70**	**0.06**	**4.80**	**2.1**
Location 6							
A	2.70	33 ± 12	13.2	3.60	0.13	10.40	4.6
B	5.28	16 ± 9	6.4	1.70	0.06	5.00	2.1
C	7.86	11 ± 6	4.4	1.20	0.04	3.50	1.4
D	10.44	8 ± 5	3.2	0.86	0.03	2.50	1.1
E	13.30	3 ± 3	1.2	0.32	0.01	0.90	0.4
	Mean	**14.2 ±11.50**	**5.6**	**1.50**	**0.05**	**4.50**	**1.9**
Location 7							
A	2.70	20 ± 16	8.0	2.20	0.08	6.30	2.8
B	5.18	20 ± 8	8.0	2.20	0.08	6.30	2.8
C	7.66	18 ± 8	7.2	1.90	0.07	5.70	2.5
D	10.14	15 ± 7	6.0	1.60	0.06	4.70	2.1
E	12.62	12 ± 9	4.8	1.30	0.05	3.80	1.8
F	15.10	9 ± 5	3.6	0.10	0.04	2.80	1.4
	Mean	**15.70 ±4.50**	**6.0**	**1.60**	**0.06**	**4.90**	**2.2**
Location 8							
A	2.93	43 ± 13	17.2	4.60	0.17	13.50	6.0
B	5.63	21 ± 8	8.4	2.30	0.08	6.60	2.8
C	8.33	18 ± 8	7.2	1.90	0.07	5.70	2.5
D	11.03	13 ± 7	5.2	1.40	0.05	4.10	1.8
E	13.73	12 ± 7	4.8	1.30	0.05	3.80	1.8
F	16.43	11 ± 7	4.4	1.20	0.04	3.50	1.4
G	19.58	5 ± 11	2.0	0.50	0.02	1.60	0.7
	Mean	**17.6 ±12.30**	**7.0**	**1.80**	**0.07**	**5.50**	**2.4**
Location 9							
A	2.55	53 ± 30	21.2	5.70	0.21	16.70	7.4
B	5.31	34 ± 13	13.6	3.70	0.13	10.70	4.6
C	7.86	18 ± 8	7.2	1.90	0.07	5.70	2.5
D	10.41	13 ± 7	5.2	1.40	0.05	4.10	1.8
E	12.96	13 ± 6	5.2	1.40	0.05	4.10	1.8
F	15.51	10 ± 5	4.0	1.10	0.04	3.20	1.4
G	18.49	6 ± 4	2.4	0.65	0.02	1.90	0.7
	Mean	**21 ± 16.70**	**8.4**	**2.30**	**0.08**	**6.60**	**2.8**
Location 10							
A	2.8	18 ± 13	7.2	1.90	0.07	5.70	2.5
B	5.3	12 ± 9	4.8	1.30	0.05	3.80	1.8
C	7.8	17 ± 8	6.8	1.80	0.07	5.40	2.5
D	10.3	11 ± 7	4.4	1.20	0.04	3.50	1.4
E	12.8	7 ± 5	2.8	0.76	0.03	2.20	1.1
F	15.8	5 ± 4	2.0	0.50	0.02	1.60	0.7
	Mean	**11.70 ±5.20**	**4.7**	**1.20**	**0.04**	**3.70**	**2.1**
Location 11							
A	2.93	31 ± 11	12.4	3.40	0.12	9.80	4.2

B	5.43	21 ± 9	8.4	2.30	0.08	6.60	2.8
C	7.93	6 ± 4	2.4	0.65	0.02	1.90	0.7
D	10.43	10 ± 5	4.0	1.10	0.04	3.20	1.4
E	12.93	8 ± 5	3.2	0.86	0.03	2.50	1.1
F	15.86	4 ± 3	1.6	0.43	0.02	1.30	0.7
	Mean	**13.5 ±10.30**	**5.2**	**1.40**	**0.05**	**4.20**	**1.8**
Location 12							
A	2.85	31 ± 10	12.4	3.40	0.12	9.80	4.2
B	5.45	23 ± 9	9.2	2.50	0.09	7.20	3.2
C	8.05	15 ± 8	6.0	1.60	0.06	4.70	2.1
D	10.65	13 ± 7	5.2	1.40	0.05	4.10	1.8
E	13.25	13 ± 6	5.2	1.40	0.05	4.10	1.8
F	16.35	6 ± 4	2.4	0.65	0.02	1.90	0.7
	Mean	**16.80 ±8.80**	**6.8**	**1.80**	**0.07**	**5.30**	**2.3**
Location 13							
A	3.23	23 ± 9	9.2	2.50	0.09	7.20	3.2
B	5.86	20 ± 10	8.0	2.20	0.08	6.30	2.8
C	8.49	13 ± 7	5.2	1.40	0.05	4.10	1.8
D	11.12	12 ± 7	4.8	1.30	0.05	3.80	1.8
E	13.75	10 ± 6	4.0	1.10	0.04	3.20	1.4
F	16.98	8 ± 5	3.2	0.86	0.03	2.50	1.1
	Mean	**14.3 ± 5.90**	**5.5**	**1.50**	**0.05**	**4.50**	**2.0**
Location 14							
A	2.76	34 ± 12	13.6	3.70	0.13	10.70	4.6
B	5.31	14 ± 7	5.6	1.50	0.05	4.40	1.8
C	7.86	13 ± 7	5.2	1.40	0.05	4.10	1.8
D	10.41	10 ± 5	4.0	1.10	0.04	3.20	1.4
E	12.96	7 ± 17	2.8	0.76	0.03	2.20	1.1
F	15.93	5 ± 15	2.0	0.50	0.02	1.60	0.7
	Mean	**13.8 ±10.50**	**5.3**	**1.40**	**0.05**	**4.20**	**1.8**
Location 15							
A	2.6	23 ± 9	9.2	2.50	0.09	7.20	3.2
B	5.0	21 ± 8	8.4	2.30	0.08	6.60	2.8
C	7.6	15 ± 7	6.0	1.60	0.06	4.70	2.1
D	10.2	6 ± 4	2.4	0.65	0.02	1.90	0.7
E	12.8	7 ± 5	2.8	0.76	0.03	2.20	1.1
F	15.6	6 ± 5	2.4	0.65	0.02	1.90	0.7
	Mean	**13.0 ± 7.70**	**5.2**	**1.40**	**0.05**	**4.10**	**1.8**

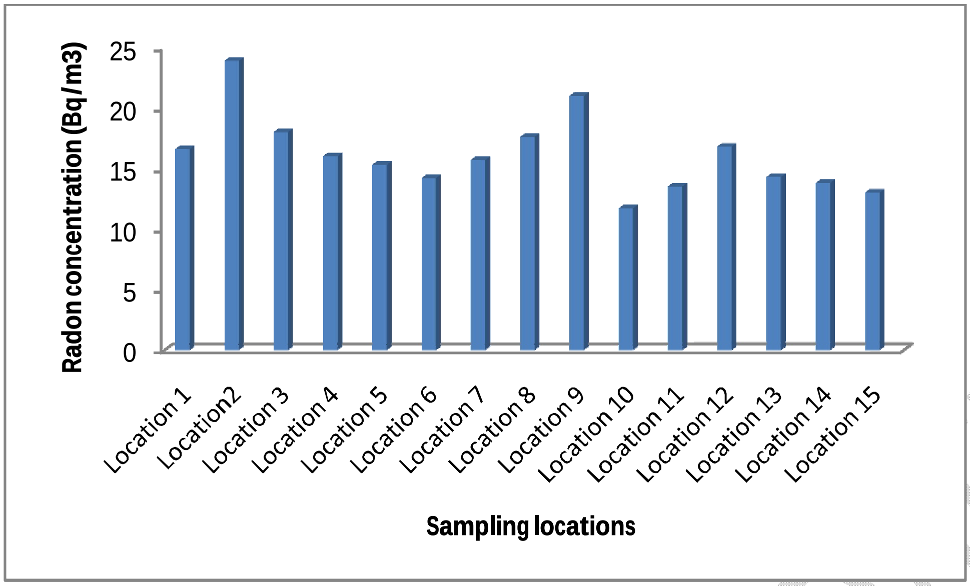

Figure 2: Bar Charts of indoor radon concentration in the sampling locations

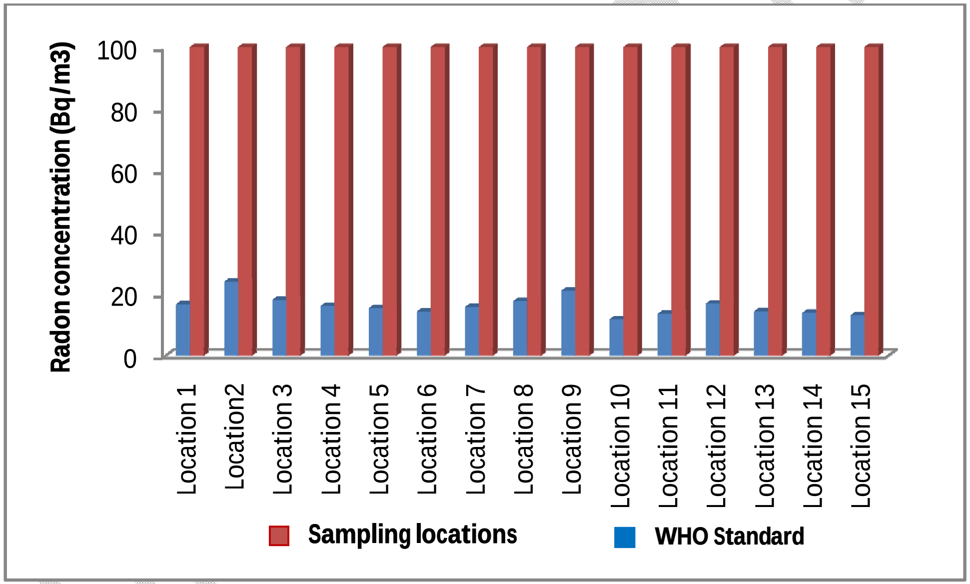

Figure 3: Comparison of indoor radon concentration and WHO standard

5.0 CONCLUSION

Radon is a naturally occurring radioactive contaminant that is always present in the environment and is one of the most hazardous threats to human health. The indoor radon concentrations recorded in this study are significantly lower than the acceptable limits and those reported in previous studies throughout the world. The calculated risk factors are relatively low, making the residents of these dwellings quite safe.

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