Original Research Article

ESTIMATION OF RADIATION RISKS ASSOCIATED WITH RADON WITHIN RESIDENTIAL BUILDINGS IN OKRIKA, RIVERS STATE, NIGERIA

Abstract: Corentium Digital Radon Detector was used in the measurement of the indoor radon concentration in some selected residential buildings made of different building materials within Okrika local Government Area, in Rives State, Nigeria. The maximum mean value the of indoor radon concentration recorded was 19.36 ± 2.26 Bq/m^3 for mud houses, and the minimum mean value of 09.35±0.78 Bq/m^3 for houses made of cemented solid blocks and floored with ceramic tiles, with an overall mean of 11.70 ± 3.28 Bq/m^3. This value is below the range of limit of 200 and 600 Bq/m^3 recommended by ICRP for residential buildings. The computed annual absorbed dose rate varied from 0.24 ± 0.01to 0.49 ± 0.03$mSvy^1$, with an overall mean of 0.30 ± 0.08 $mSvy^{-1}$. This value is lower than the recommended ICRP intervention limit of between (3-10) $mSvy^{-1}$. The computed annual equivalent dose rate varied from 0.58 ± 0.02 to 1.17 ± 0.08 $mSvy^{-1}$, with an overall mean of 0.71 ± 0.20 $mSvy^{-1}$. This value is lower than the maximum permissible limit of 1 $mSvy^{-1}$ recommended by ICRP. The value of the excess life cancer risk computed ranged from 2.0 ± 0.07 E^{-3} to 4.1 ± 0.28 E^{-3}, with an overall mean of 2.5 ± 0.07. This value is higher than the world average of 0.29 $x10^{-3}$. The results of this research have shown that the radiological health risk of the inhabitants living in mud houses is higher compared to those living in other dwellings but, drastic measures has to put in place to discouraged the activities of oil bunkering activities, and the effluents from oil companies should be properly treated before it is discharged into the environment.

Keywords: *Corentium digital detector, radon, indoor, annual effective dose, annual equivalent dose rate, excess life cancer risk.*

1. Introduction

Radon is a tasteless and odorless radioactive gas and is found majorly in rock samples, bedrock formations and soils throughout the whole world [1]. The major source of radon is the decay of ^{238}Uranium which is chiefly found in rocks, soils, building materials, and gravel. Radon-222 which is a progeny of U-238 is formed at the intermediate stage of the decay chain with Radium-226 releasing an alpha particle to yield Radon-222. As a result of the interaction of groundwater with uranium bearing soils and rock bearing formations, radon find its way into the groundwater and is highly soluble in it. Humans are naturally exposed to radiation in our environments. One major source of radiation to man is the naturally occurring radiation from indoor radon, and since radon gas emits alpha particles, its accumulation in buildings can pose a serious health hazard when continuously inhale especially above a permissible limit, it can result to lungs cancer. Radon can seep into buildings from the ground through cracks and other openings in floors or walls [2]. According to the United Nations Scientific Committee on the Effects of Atomic Radiation, most people are exposed to high radon gas in small houses than in big buildings [3]. The alpha particles emitted by radon gas may not constitute much nuisance in terms of absorption through the skin because of its short penetrating capacity. The bulk of the radiation gets into the human system through ingestion and inhalation and can result to severe malfunction of the human cells with which it makes direct contact first, owing to the fact that its movement is restricted penetration-wise [4]. Radon decays to a number of short lived decay products that are themselves radioactive and may attach to available aerosol particles in the atmosphere. If inhaled, both unattached and attached radon progeny may deposit in the lungs and irradiate lung's tissues as they decay [5].

Since radon gas penetrates indoors through porous soils underneath buildings and enters through openings and cracks in the foundation or insulation and through transport by means of pipes, drains, walls or other openings, the concentration of radon in houses is imminent but decreases with good ventilation rate [4]. According to the United States Surgeon General, when radon levels reach 4 pCi/l (148 Bq/m^3) or higher, it is recommended that homeowners should swing into action to curtail further build -up. It is estimated that nearly one in 15 American homes has a radon level that should be reduced and the only way to find out the level of radon in any home is to test for it through the use of radon meters [2]. The population weighted worldwide arithmetic mean concentration of Radon-222 of all origins in dwellings is estimated to be 39 Bq/m^3 [6].

Industrial effluents from the Nigeria National Petroleum Corporation (NNPC) refining company are disposed within the Okrika environment. Oil bunkering and illegal refining activities also go on within this locality. The crude and waste from the aforementioned activities expose the environment to uranium and other natural radioactive substances of which radon forms part of their decay chain. The radon gases generated due to these industrial activities are said to be technologically enhanced and could escape into the dwellings and distort the state of radioactive equilibrium there in.

In order to control excessive exposure to radon gas, an action level has been set up by international organizations. This refers to the concentration level at which remedial or protective actions need to be undertaken to reduce excessive exposures to radon in homes and workplaces. The action level may also be regarded as the level at which the system of protection for practices becomes applicable to the continuing control of radon exposures in the workplace. Action levels for dwellings in many countries are set in the range of 200–600 Bq/m^3 as recommended by the ICRP [5]. Also, the World Health Organization proposes a reference level of 100 Bq/m^3 to minimize health hazards due to indoor radon exposure [7].
Records of measurement of indoor radon concentration in residential buildings in Okirika municipality and its environs are not available. Knowledge of the indoor radon levels and its associated health risk parameters are completely lacking as the researchers could not find this in any existing literature. It is needful to ascertain the level of radon concentration in residential dwellings in Okrika, the results obtained will enable us to evaluate the extent to which inhabitants of this study area are exposed to radon concentration.

2. Materials and Methods

2.1 Study Area

This study was conducted in Okrika Local Government Area of Rivers state, Nigeria. Okirika town is a small island located in the southern part of Port Harcourt, Nigeria. The major occupation of the residents is fishing with other minor activities like farming, speed boat transportation and commercial trading. Okirika is geographically located within the latitude range of 4^{0}.43'44" N to 4^{0}.45'57" N and longitude range of 7^{0}.3'20" E to 7^{0}.6'42" E. This town plays host to the Port Harcourt Refining Company (PHRC), a subsidiary of Nigerian National Petroleum Corporation (NNPC) and other oil and gas companies. In addition, it has a jetty and terminal for loading and off-loading crude oil products. The map of Okrika town showing the sampled locations is presented in Figure1.

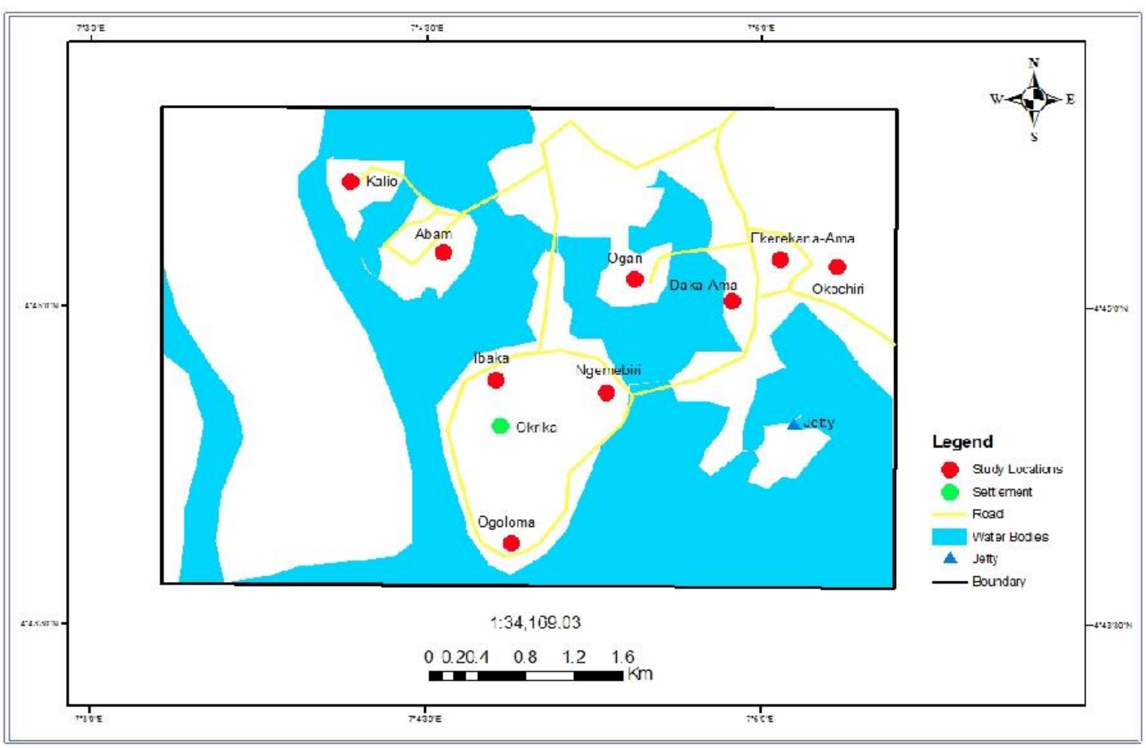

Figure1. The Sampled locations in Okirika Town

2.2 Method of Measurement of Radon Concentration

The detector used for the survey is a pocket sized Corentium Digital Radon Detector. It is a passive detector and is powered by a 3 x 1.5volt LR03, alkaline AAA batteries. It can measure indoor radon Concentrations for a minimum duration of between 24 and 48 hrs. The picture of the Corentium Digital Radon Detector is shown in Figure 2.

Figure 2. A Corentium Digital Radon Detector

Radon gas concentration measurements were carried out at 30 sampling points within 30 residential dwellings (made up of various; walls, roofs and floor types) in Okirika. Refer to Table 1 to see the building types surveyed. During the measurements, the Corentium Digital Radon Detector was placed on a lying position and at a least distance of 25 cm from the wall, 50 cm above the floor and 150 cm from doors and windows respectively [8]. These measurements were carried out in a closed building, in other words the windows and doors of the buildings were closed to ensure that the indoor air was not distorted to achieve maximum accuracy.

For each of the sampled points, measurements were carried out on a short term period which lasted for 2 days (48 hours) giving a total sampling period of 60 days within the months of November to January, 2017. The Corentium Radon Digital Device works on the principle that radon gas diffuses into a detection chamber and emits energetic alpha particles which are detected by a silicon photodiode within the chamber. The energy of the radon alpha particles detected is translated into mean radon concentration through the electronic circuitry system of the radon meter [9]. Finally, the mean radon concentration during a period of 2 days is display on the Liquid Crystal Display (LCD) screen of the radon digital meter.

2.2.1 Annual effective dose from radon concentration (D_{Rn})

The effective dose rate is a term used to describe the potential biochemical changes in specific tissues in the human body; it is due to the magnitude of energy delivered in a tissue from exposure to ionizing radiation within a specified period. The effective dose rate also describes the intensity of energy delivered to a specific organ in the human body within a specified time [10]. The annual effective dose rate received by a population is calculated based on the indoor occupancy factor. The equation used in calculating the annual absorbed dose rate due to radon is based on ICRP [10].
In order to estimate the annual the annual effective rate received by the population, one has to take into account the conversion co-efficient from the absorbed dose and the indoor occupancy factor. According to UNSCEAR [2] report, the committee proposed 9.0 x 10^{--6} mSvhr $^{-1}$ per Bq m^{-3} to be used as a conversion factor, 0.4 for the equilibrium factor of Rn-222 indoors and 0.8 for the indoor occupancy factor using equation 1 [9].

$$D_{Rn}\ (mSvy^{-1}) = C_{Rn} \text{ x F x D x H x T} \quad (1)$$

Where:

C_{Rn} = the measured concentration of Rn- 222 in (Bq/m^3)
F = Rn- 222 equilibrium indoor factor (0.4)
T = occupancy time per annum (24 hrs x 365 days = 8760 hrs.)
H = indoor occupancy factor (0.8)
D = dose conversion factor ($9.0x10^{-6}$mSv/h per Bq/m^3)

2.2.2. Annual equivalent dose rate

In general terms, the annual equivalent dose rate measures the probable biochemical changes in specific tissues in the body (lungs: for radon), calculated in $mSvy^{-1}$.

The annual equivalent dose rate (AEDR) is computed using equation 2 [9].

$$AEDR = D_{RN} \text{ x } W_R \text{ x } W_T \quad (2)$$

Where:

W_R = Radiation Weighting Factor for Alpha Particles (20)
W_T = Tissue Weighting Factor for the Lungs (0.12)

2.2.2. Excess life time cancer risk (ELCR)

The excess life time cancer risk (ELCR) describes the potential Carcinogenic effects, from the calculation based on probability of cancer induced incidence in a population. This is as a result of exposure to ionizing radiation or the intakes of harmful chemical substances for a lifetime. In other words the ELCR indicates the chances of contracting a cancer from the exposure to radiation or toxic chemical substances for a specific period of time. According to [9], for low dose background radiations which are considered to produce stochastic effects, ICRP 60 uses values of 0.05 for the public exposure. The excess life time risk is calculated using equation 3.

$$ECLR = AEDR \text{ x DL x RF} \quad (3)$$

Where:
DL = Average Duration of Life (estimated to be 70 years)
RF = Risk Factor (0.05)

3. Results and Discussion

The results of the measurements of the indoor radon concentration in the selected residential homes made of diverse building materials ; the computed radon risk parameters of based on individual dwelling , and the computed mean values of the radon risk parametres based on the type of dwelling are tabulated in Table 1-3.The histograms showing the radon risk parametres are presented in Figure 3 - 6, and the bar charts of the radon risk parameters based on the types of dwelling are shown in Figure 7- 10.
The Results presented were computed based on 30 sampled locations within the communities of Okrika. The locations where randomly selected from different areas within the communities in Okrika, base on the availability of the type of dwelling present. The average indoor radon concentration level in a type of dwelling is computed by finding the mean value of the same kind of dwellings taken into consideration. Table 1 Describes the nature of the dwellings taken into consideration, the description includes the types of; floor, wall and the kind roof observed when the measurements were carried out, and the level of the indoor radon concentration. Table 2 shows the computed health risk parameters, based on every sampled point using equation 1, 2 and 3. The mean indoor radon concentration for the different types of dwelling ranged from (9.53 ± 0.7 to 19.36 ± 2.26) Bqm^{-3} with an overall mean of 11.70 ± 3.28 Bqm^{-3} indicated in Table3. These values were below the lower limit of the recommendation action level (ICRP) from 200-600 Bq/m^3 for residential buildings [9]. The mean annual effective dose for the different types of dwelling ranged from 0.49 ± 0.03 to 0.24 ± 0.01$mSvy^{-1}$ with an overall mean of 0.30 ± 0.08 $mSvy^{-1}$. These values were below the recommended ICRP intervention

level that ranges from (3-10) mSvy^{1} [9]. Also the mean annual equivalent dose rate for the different types of dwelling varied from 0.58 ± 0.02 to 1.17± 0.08 mSvy^{-1} with an overall mean of 0.71 ± 0.198 mSvy^{-1}. These values were lesser than the maximum permissible limit of 1 mSvy^{-1} recommended for the public [9]. Finally the maximum and minimum values of the excess life cancer risk (ELCR) for the different types of dwelling ranged from 4.1 E^{-3} ± 0.28 E^{-3} to 2.0 E^{-3} ± 0.07 E^{-3} with an overall mean of 2.5 E^{-3} ± 0.7 E^{-3}. These values were above the world average of 0.29 E^{-3} [11]. The estimation of the risks associated with radon within the measured residential buildings in Okrika, are all lesser than the international recommended limits. The histograms from the indoor radon concentration, annual effective dose , annual equivalent dose rate and the excess life cancer risk from the measured sampled points are shown from Figure 3 to Figure 6. In Figure 3 the histogram indicates a positive skeweness; the tail of the histogram approximates to the right while the hump is on the left hand side. This means that, in consideration of the entire residents in Okrika from a small population, most of the residents are exposed to lower level of indoor radon concentration while fewer number are exposed to high level of radon gas above the mean value of 11.7± 3.28.Bq/m^{3}. In Figure 4 the hump is on the left side and the tail of the histogram approximates to the right. The result indicates that most residents in okrika (high population) are exposed to a low level of absorbed dose rate, while a few number (low population) are exposed to a high level of effective dose above the mean value of 0.15 ± 0.42 mSvy^{-1}. Similar trend in also observed in the annual equivalent dose rate in Figure 5, the tail of the histogram graph approximates to the right while the hump is on the left hand side which shows that it is a positively skewed histogram. This reveals that few residents in Okrika are exposed to high level of annual equivalent dose rate, especially those living in mud houses, while a large number of residents are exposed to a lower level lesser than the mean value of 0.36 ± 0.10 mSv/y^{1}.The histogram of the ELCR in Figure 6, shows similar trend to the histograms in Figure 3 - Figure 4, It is equally positively skewed and indicates that most of the residents in Okrika have a lower probability of contracting lung cancer from the low ionizing radiation to radon exposure, while a few number of the residents are exposed to higher probability of contracting lung cancer above the mean value of the 0.0025 ± 0.0007. The mean values of the radon radiation risk parameters of the various types of dwelling are displayed in the bar charts from Figure 7 to Figure 10. In Figure 7, we have a peak mean value of the indoor radon level of 19.36 ± 2.26 Bq/m^{3} in H6 type of dwelling and the lowest mean indoor radon concentration value of 09.53± 0.70 Bq/m^{3} was found in H8 type of dwelling. In Figure 8 the annual effective dose indicates that the highest value lies in H6 type of building with a value of 0.49 ± 0.03 mSvy^{-1} and the least value of 0. 24 ± 0.01 mSvy^{-1} in H8 type of dwelling. The maximum value of the annual equivalent dose rate of 1.17 ± 0.08 mSvy^{-1} was found in H6 type of dwelling home and the lowest value is obtained in the H8 type of dwelling with a value of 0.58 ± 0.02 mSvy^{-1}. Finally the bar chart of the ELCR gives a maximum value of 4.1 E^{-3} ± 0.28 E^{-3} in H6 type of dwelling with a least value of 2.0 ± 0.07 E^{-3} in H8 type of dwelling.

Table 1 ***In - situ* measurements of the indoor radon concentration of the various types of home made of diverse building materials**.

Types of dwelling (home)	Floor Type	Wall Type	Roof Type	Location	S/n	Latitude	Longitude
H1	Cemented	Burnt Clay bricks(cemented)	Zinc Roofing Sheet	Okochiri	H1.1	4°44'34.23"	7° 7'40.21"
					H1.2	4°44'39.49"	7° 7'00.96"
					H1.3	4°44'49.23"	7° 7'01.11"
H2	Marble	Hollow Block (Cemented,painted)	Aluminium sheet	Ogoloma	H2.1	4°44'04.52"	7° 4'55.22"
					H2.2	4°44'07.21"	7° 4'57.98"
					H2.3	4°44'07.22"	7° 4'57.15"
H3	Cemented	Hollow Block (Cemented,painted)	Cement and Concrete	Ibaka	H3.1	4°44'39.43"	7° 4'57.45"
					H3.2	4°44'39.72"	7° 4'55.25"
					H3.3	4°44'41.51"	7° 4'53.78"
					H3.4	4°44'36.48"	7° 4'57.45"
					H3.5	4°44'36.78"	7° 5'00.19"
H4	Cemented	Hollow block (not Cemented)	Alunimium roofing sheet	Abam	H4.1	4°45'32.77"	7° 4'58.20"
					H4.2	4°45'32.60"	7° 5'00.89"
					H4.3	4°45'30.84"	7° 5'00.74"
H5	Mud + cemented	Mud (Cemented)	Aluminium Roofing sheet	Ekerekana	H5.1	4°44'49.65"	7° 6'45.98"
					H5.2	4°45'03.78"	7° 6'08.15"
					H5.3	4°45'04.27"	7° 6'01.66"
H6	Mud	Mud (mud wash)	Zinc Roofing Sheet	Ngemebiri	H6.1	4°44'31.94"	7° 5'18.11"
					H6.2	4°44'31.49"	7° 5'22.71"
					H6.3	4°44'32.16"	7° 5'22.72"

H7	Cemented	Non Hollow Block (Cemented,painted)	Roofing Sheet	Daka-Ama	H7.1	4°44'58.83"	7° 5'55.34"
					H7.2	4°45'01.51"	7° 5'55.27"
					H7.3	4°45'00.60"	7° 5'54.53"
H8	Cemented + tiles	Hollow Block (Cemented,Painted)	Zinc Roofing Sheet.	Kalio	H8.1	4°45'38.95"	7° 4'18.37"
					H8.2	4°45'32.40"	7° 4'18.36"
					H8.3	4°45'34.04"	7° 4'11.68"
					H8.4	4°45'37.22"	7° 4'13.22"
H9	Cemented + tiles	Non Hollow Block(Cemented)	Aluminium Roofing Sheet	Ogan	H9.1	4°45'04.71"	7° 5'31.38"
					H9.2	4°45'5.92"	7° 5'25.99"
					H9.3	4°45'7.39"	7° 5'27.00"

Table 2. Computed values of annual effective dose , annual equivalent dose rate and the excess life time cancer risk

S/N	Location	S/Pts	C_{RN} (Bq/m^3)	D_{Rn} (mSvy^{-1})	AEDR (mSvy^{-1})	ELCR x10^{-3}
1.	**Okochiri**	H1.1	07.77	0.196028	0.470467	1.647
2.		H1.2	10.73	0.270705	0.649692	2.274
3.		H1.3	11.84	0.298709	0.716902	2.509
4.	**Ogoloma**	H2.1	11.84	0.298709	0.716902	2.509
5.		H2.2	10.73	0.270705	0.649692	2.274
6.		H2.3	12.95	0.326713	0.784111	2.744
7.	**Ibaka**	H3.1	10.73	0.270705	0.649692	2.274
8.		H3.2	09.99	0.252036	0.604886	2.117
9.		H3.3	09.99	0.252036	0.604886	2.117
10.		H3.4	10.37	0.261623	0.627894	2.198
11.		H3.5	09.62	0.242701	0.582483	2.039
12.	**Abam**	H4.1	11.84	0.298709	0.716902	2.509
13.		H4.2	08.88	0.224032	0.537676	1.882
14.		H4.3	11.84	0.298709	0.716902	2.509
15.	**Ekerekana**	H5.1	11.84	0.298709	0.716902	2.509
16.		H5.2	08.88	0.224032	0.537676	1.882
17.		H5.3	18.87	0.476067	1.142562	3.999
18.	**Ngemebiri**	H6.1	18.87	0.476067	1.142562	3.999
19.		H6.2	21.83	0.550745	1.321787	4.626
20.		H6.3	17.39	0.438729	1.052949	3.685
21	**Daka-Ama**	H7.1	11.84	0.298709	0.716902	2.509
22		H7.2	10.73	0.270705	0.649692	2.274
23.		H7.3	11.84	0.298709	0.716902	2.509
24.	**Kalio**	H8.1	09.62	0.242701	0.582483	2.039
25.		H8.2	09.99	0.252036	0.604886	2.117
26.		H8.3	09.99	0.252036	0.604886	2.117
27.		H8.4	08.51	0.214697	0.515273	1.803
28.	**Ogan**	H9.1	11.10	0.280040	0.672095	2.352
29.		H9.2	10.73	0.270705	0.649692	2.274
30		H9.3	09.99	0.252036	0.604886	2.117

Table 3. Computed mean values of indoor radon concentration levels, annual absorbed dose rate, annual equivalent dose rate and the excess life time cancer risk for the various types of dwelling (home) within Okrika

Types Of Dwelling (Home)	Sampling Points	Mean CRn (Bq/m3)	Mean DRn (mSvy-1)	Mean AEDE (mSvy-1)	Mean ELCR X 10^{-3}
H1	3	10.11 ± 2.10	0.26 ± 0.03	0.61 ± 0.07	2.1 ± 0.26
H2	3	11.84 ± 1.11	0.30 ± 0.02	0.72 ± 0.04	2.5 ± 0.14
H3	5	10.14 ± 0.42	0.26 ± 0.01	0.61 ± 0.01	2.1 ± 0.04
H4	3	10.85 ± 1.71	0.27 ± 0.03	0.66 ± 0.06	2.3 ± 0.21
H5	3	13.20 ± 5.13	0.33 ± 0.08	0.80 ± 0.18	2.8 ± 0.63
H6	3	19.36 ± 2.26	0.49 ± 0.03	1.17 ± 0.08	4.1 ± 0.28
H7	3	11.45 ± 0.64	0.29 ± 0.01	0.70 ± 0.02	2.4 ± 0.08
H8	4	09.53 ± 0.70	0.24 ± 0.01	0.58 ± 0.02	2.0 ± 0.07
H9	3	10.61 ± 0.57	0.27 ± 0.01	0.64 ± 0.02	2.2 ± 0.07
	Mean	11.71 ± 3.28	0.30 ± 0.08	0.71 ± 0.20	2.5 ± 0.07

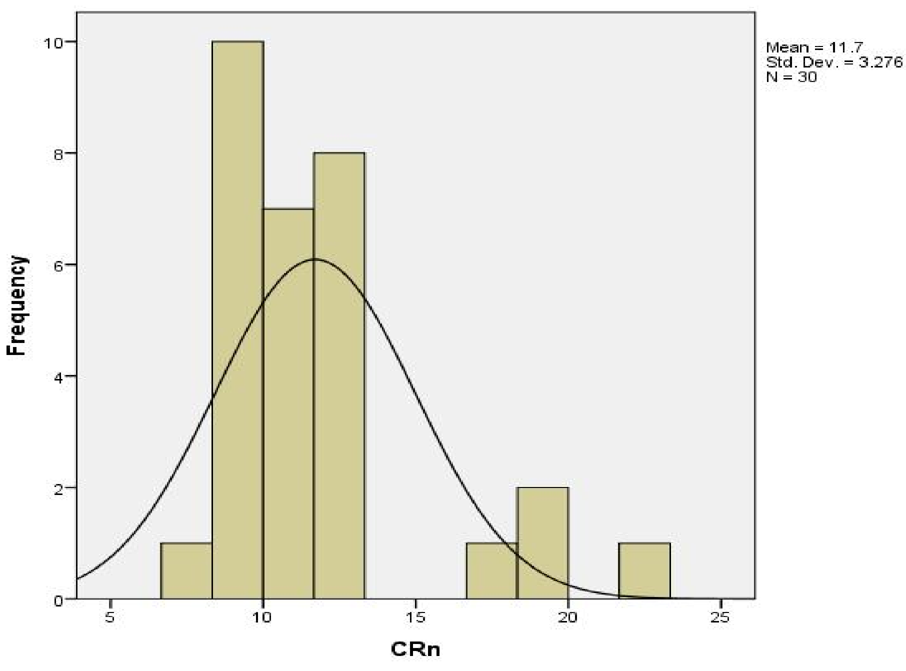

Figure 3. Indoor radon concentration (C_{rn}) of the surveyed dwellings within Okrika

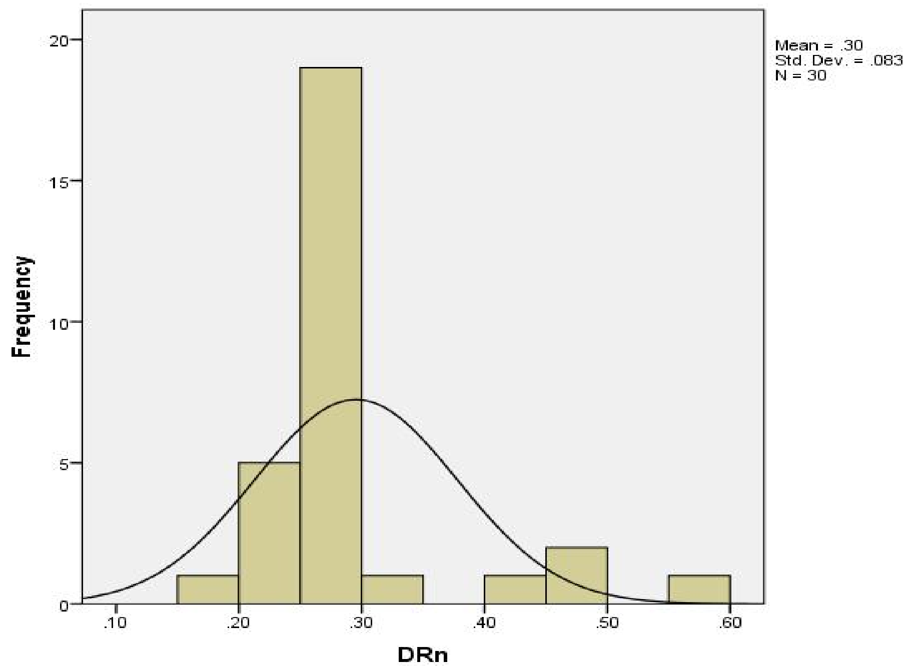

Figure 4. Annual effective dose rate (D_{Rn}) of the surveyed dwellings within Okrika

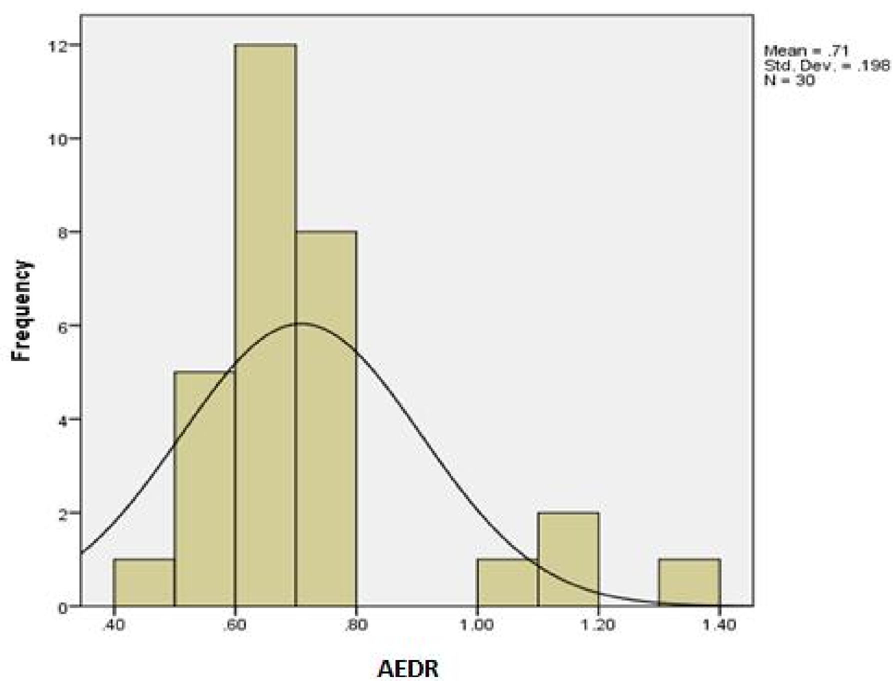

Figure 5. Annual equivalent dose rate (AEDR) of the surveyed dwellings within Okrika

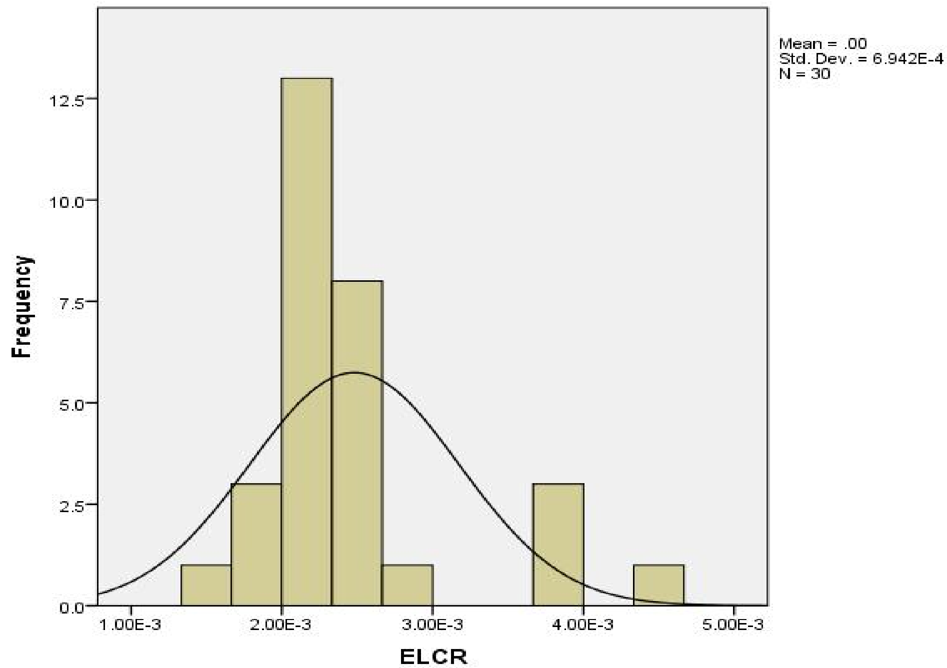

Figure 6. Excess life time cancer risk (ELCR) of the surveyed dwellings within Okrika

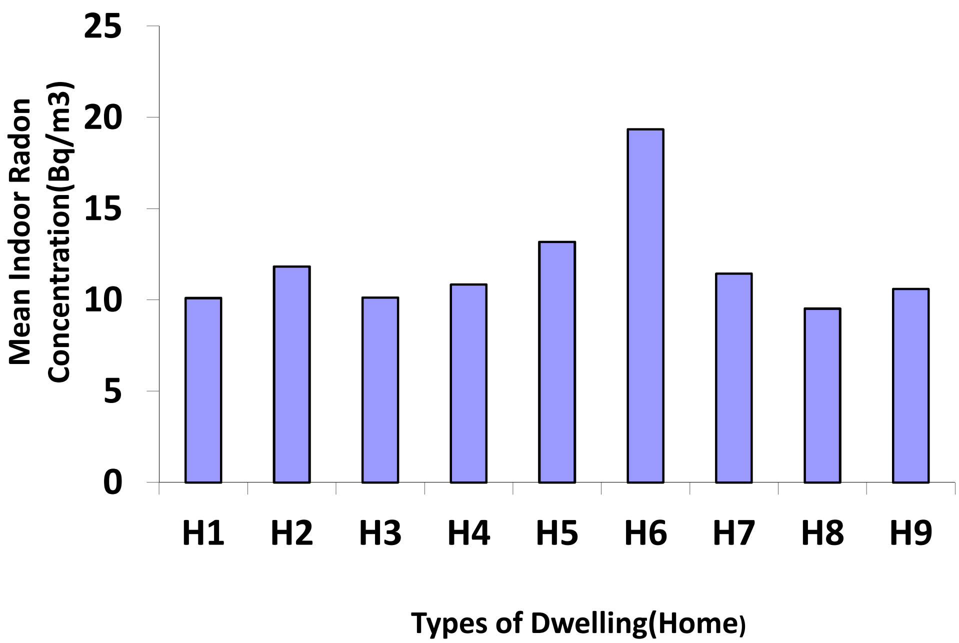

Figure 7. The mean value of the indoor radon concentration against the types of dwelling within Okrika

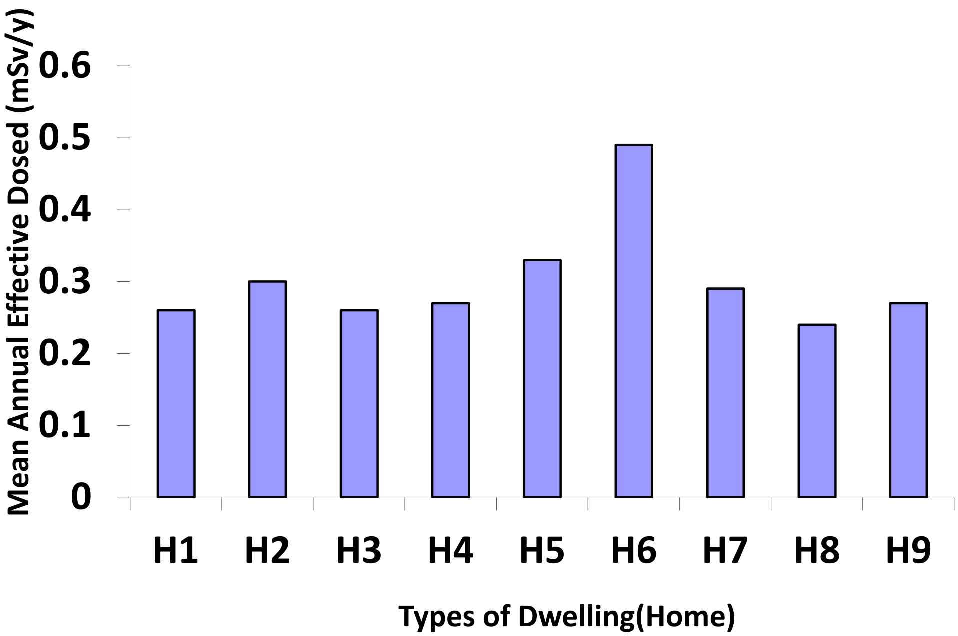

Figure 8. The value of the mean annual effective dose against the types of dwelling within Okrika

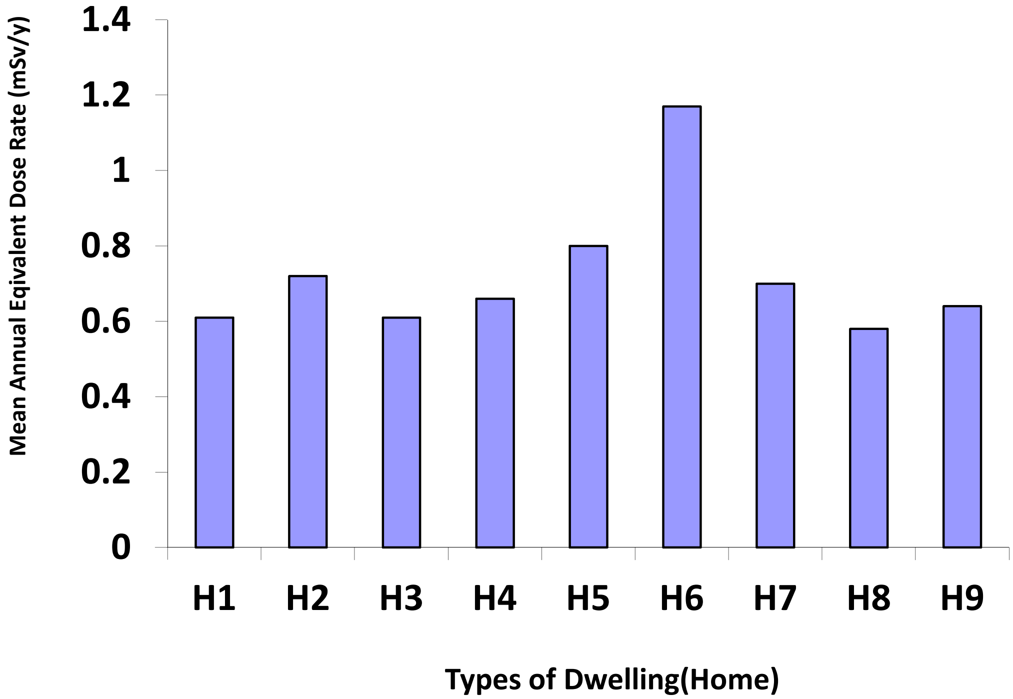

Figure 9. The mean value of the annual equivalent dose rate (AEDR) against the types of Dwelling within Okrika

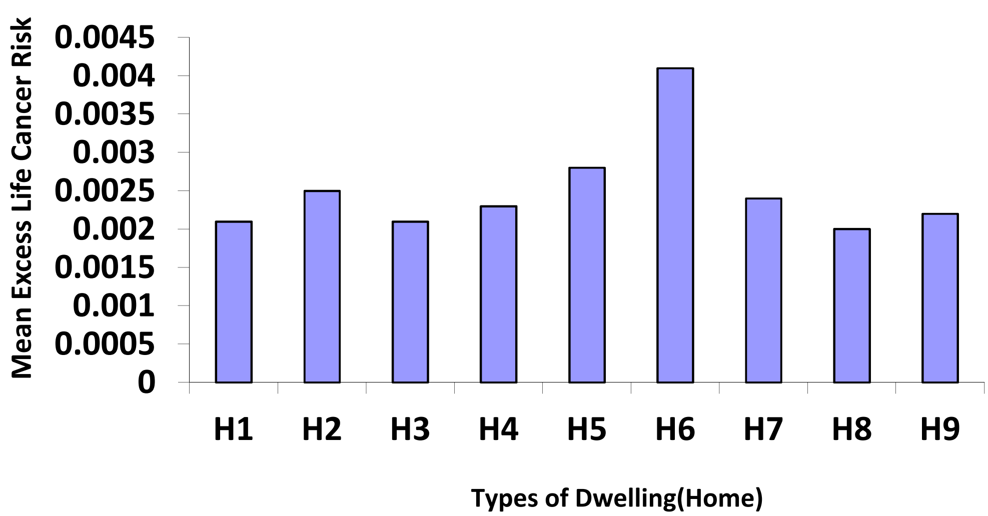

Figure 10. The mean value of the excess life cancer risk against the types of dwelling in Okrika

Conclusion

Radon concentration level in dwellings is a major route that increases the radiation health risk to any growing population [3]. Based from the computed results the maximum and the minimum values from radon radiation risk parameters were observed in H6 and H8 type of dwelling. It will be safer for people to live in residential buildings of H8 type of dwelling, where the floor is properly cemented with ceramics tiles and plastered walls with paints, rather than living in H6 type of residential building in which the floor is made of mud and the walls is also made of mud and mangrove woods. The rate of radon emanation is higher in H6 type of dwelling simply because the floor and the walls have direct exposure to the indoor environment. From the computed results, all the maximum radon radiation risk parameters were found in H6 type of dwelling. The result of the histograms based on the risks associated with radon has confirmed that the population in okrika, at higher risk of radon exposure to contract lung cancer are those inhabitants living in H6 type of dwelling (mud houses). The estimation on the radon radiation risk parameters within the measured residential buildings in Okrika, were all lesser than the international recommended limits. This implies that the existence of radon in residential buildings in Okrika posed no significant health risk to the inhabitants of okrika, but strategic measures should be put in place to discourage the use of mud houses as a dwelling home and thus, the government should encourage housing scheme projects to be executed in rural areas to make living comfortable for everyone the less privilege.

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