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Indoor Radon Levels and Contributory Factors in Southwest Nigeria

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ABSTRACT

Radon-222 has been found to be the main contributor to lung cancer after smoking. This makes the determination of the level of indoor radon activity concentration in dwellings an important health issue. This research was conducted to measure radon concentrations using alpha track detectors in dwellings in selected areas in Ondo State, Southwest Nigeria. Detectors were exposed in the area for a 90-day period. Radon concentration was related to the age of buildings, ventilation status, heating source and materials used for construction. Likewise, radiological health indices were calculated. Results showed that old buildings built with mud blocks and poorly ventilated had higher radon concentration than modern buildings built with cement blocks with good ventilation. Homes using natural gas had higher radon concentration than homes using charcoal and fire wood as cooking source. The average annual effective dose and other calculated radiological indices did not exceed the recommended limit. This showed that most of the dwellings in the area were safe for dwelling purposes.

Keywords: Radon, Indoor, Contributing factors, Radiological indices

1. Introduction

Radon (^{222}Rn), is a radioactive gas that occurs naturally from the decay of uranium in rocks and soils [1]. Also, radon is a natural inert gas that has a density 7.5 times higher than that of air. It is water soluble and can promptly circulate with gases and water vapour. This makes the concentration of radon steadily accumulate substantially [2]. Radon is a major contributor to the ionizing radiation dose received by the whole number of people [2,3]. When radon gas is inhaled or ingested, the radon daughters can interact with biological tissue in the lungs leading to deoxyribonucleic acid damage in the cells of tender organs like lungs and stomach. Exposure to radon could be carcinogenic [2]. Based on the epidemiological studies of underground miners exposed to high radon concentrations in their workplaces, radon has been identifed as a radioactive gas causing cancer in human beings [2,4].

The factors that could affect the chance of having lung cancer from radon are age, exposure period, smoking of cigarette, gender, physical condition, geographical location etc. [5-7]. The population who spends time indoors is exposed to natural radionuclides present in the building which may be influenced by factors and parameters such as materials, radon from ground water, natural gas, living style of the occupants and meteorological parameters such as humidity, temperature and pressure [7-10]. The concentrations of radon and its daughter products indoor depend mainly on the ventilation rate, entry point or rate of production from various sources [9,10]. It can also depend on soil, the nature of building materials and water used for domestic purposes [7,11,12]. Radon also gets into the buildings through floor joints, narrow openings, walls, pipelines below the building, fittings, crack in floor, water and sewage pipes, and the ground water utilized in buildings [5,13].

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The concentration of radon indoors is always higher than the radon concentration outdoors. The sealing of buildings to preserve energy limits the intake of outdoor air and reduces the ventilation inside. Usually inside buildings are at a lower pressure than the environmental atmosphere, that tends to suck in radon from the soil through cracks or narrow openings in the floor [14-16]. Most of the energy released by the radon decay series is in the form of an alpha particle. The radio-toxicity of radon in ambient air depends on the aggregate of all the energies of the emitted alpha particles from the decay of all the radon daughters existing in that volume of air and not on the radon concentration [4]. Exposure to radon would pose a risk at any threshold concentration. Even at low concentrations, radon could result in a small risk of lung cancer.

Despite the fact that radon concentration in Nigeria had been measured in several places and in different environments [13,17-20], very sparse data still exist. Likewise, a review has been done on radon, radon risk, public view, awareness, and so many more have been done by many researchers [16,21-26]. However, due to the large area of Nigeria, there is little documented research on radon studies in the research area. This research would add to the baseline data and knowledge of radon levels in the study area.

In this research, a long term passive alpha track test kits were used to measure the concentration of radon in the dwellings and their relationship with age of building, the type of materials used in constructing the buildings (block, cement), ventilation status and heating source [27] were determined. Also related risks such as exposure to radon progeny, annual effective dose, lung cancer cases per year per million people, potential alpha energy concentration and equilibrium equivalent daughter concentration were estimated.

2. Materials and Methods

2.1 Geography and Geology of the Study Area

The study area for this research work is Akoko area in Ondo State, Southwestern Nigeria. The area consists of 4 Local Government areas (LGA) out of the 18 LGA in Ondo State. The study covers 19 communities in the 4 Local Government Areas (LGAs). The LGAs include Akoko North East (AKNE) with the headquarters in Ikare Akoko, Akoko North West (AKNW) with the headquarters in Oke Agbe, Akoko South West (AKSW) with the headquarters in Oka Akoko and Akoko South East (AKSE) with the headquarters in Isua Akoko. Akoko area is situated in the Northern Senatorial District of Ondo State, Southwestern Nigeria. It lies between longitude 5°30^1 and 6°30^1 of Greenwich meridian and latitude 7°20^1 and 7°45^1 north of the equator. The study area comprises of undulating lowlands with separated hills. It is situated within the transition zone of the tropical equatorial climate of Southern Nigeria and tropical continental climate of Northern Nigeria. The area has a total rainfall nearly 1200 mm and mean temperature of around 21°C. The annual temperature range is roughly 3°C [28]. Akoko area lies in the basement complex of Southwestern Nigeria [28]. In some parts of the area, there are quarry industries, as the area is endowed with igneous rock such as the granite gneiss. This type of rock had been identified to contain high level of radionuclides [3]. The geology map of Ondo state, Nigeria is shown in Fig.1.

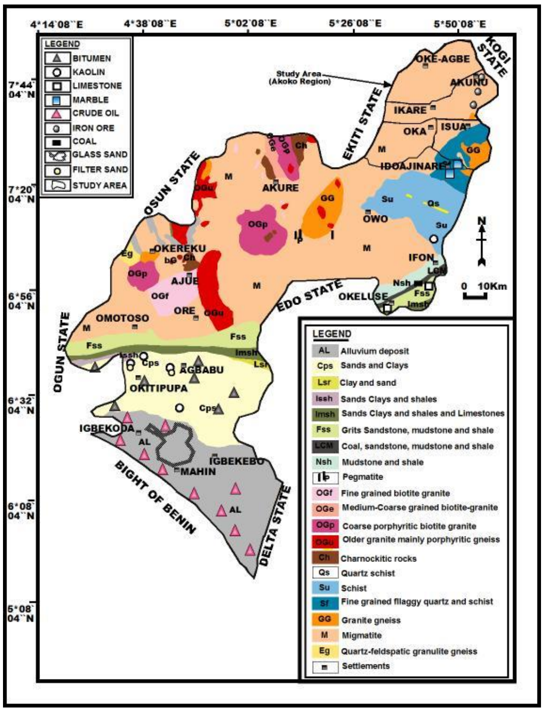

Fig. 1 *Geological Map of Ondo State*

2.2 Description of the Measurement Technique

The dosimeters used to measure indoor radon in this study were previously calibrated long term passive Alpha Track Test kits AT-100 of size (2.3 by 5.3) cm^2 in area, manufactured by the ACCUSTAR Laboratory, in the United States of America. The picture of this detector is in Fig.2. A total of one hundred and two detectors were distributed in the 4 (LGAs) of Akoko area, Ondo State. The choice of the locations was based on the stratified random sampling. To start the test, the sealed bags containing the device were torn open but for a blank test the bag was not opened. The detectors were hanged at least three feet away from the exterior doors or windows and two meters from the ground level (breathing zone). Each detector was exposed for a minimum undisturbed period of nine months. The long term test provides a closer representation of the radon concentration over different seasons, living conditions and building conditions. One of the relevant purposes of radon survey is to try to identify the dwelling characteristics and other parameters that could explain part of the variability observed in radon concentration levels. For this purpose, questionnaires were set up in order to collect information on such parameters.

Before sampling was done, the house owners were adequately sensitized, and their consent sought. Questionnaires was distributed to them to gather certain information about their houses. Such information includes block used, ventilation status, age of building, natural energy used for cooking [29]. After filling of the questionnaires, the detectors were installed at the desirable locations. The detectors' serial number, location and information about each house were filled in the spaces provided in the questionnaire. The detectors were removed after nine months of exposure and immediately placed inside a sealed nylon so that no new track will be recorded on it prior to etching. The detectors with filled datasheets were packed in a plastic zip top bag and shipped back to ACCUSTAR Laboratory, Canada, immediately after complete removal of all detectors where the detectors were etched, scanned and analyzed for radon concentration.

Fig. 2 *Alpha Track Test Kits*

The buildings were then grouped into two categories based on the factors that could contribute to the indoor radon concentrations. These contributing factors includes:

- The ventilation status: A room with two or more windows and a door is considered to have good ventilation, as there would be cross ventilation, while a room with no window or one window and a door is considered to be poorly ventilated.
- The type of block used for the building: Buildings with cement block plastered with cement were grouped as modern buildings while buildings with mud block plastered with cement or not plastered at all as old buildings.
- Age of the buildings at the time of measurements were taken: Buildings with ages below 30 were grouped as modern buildings while buildings with ages 30 and above were grouped as old buildings.
- The heating source: Homes where natural gas and kerosene are used were grouped together while homes where kerosene, fire woods and charcoal were used were equally grouped together.
- Buildings with good ventilations, low age, and built with cement blocks and plastered with cement were grouped as modern buildings while buildings built mud blocks of old age coupled with poor ventilation were grouped as old buildings.

3. Calculation of Radiological Health Indices

3.1 The Potential Alpha Energy Concentration (PAEC)

The PAEC in WLM was determined using [11,30,31]

$$PAEC\ (WLM) = \frac{C_{rn} \times F}{3700} \quad (1)$$

Where C_{rn} is the radon concentration, F, which is (0.4), is the equilibrium factor of radon and its daughter products [3]

3.2 Exposure to Radon Progeny

Exposure to radon progeny (EP) in $WLMY^{-1}$ was determined by relating it to the radon concentration using the following expression [31]

$$EP\ (WLMY^{-1}) = \frac{8760 \times n \times F \times C_{rn}}{170 \times 3700} \quad (2)$$

Where C_{rn} is concentration of radon in Bqm^{-3}, n is the indoor occupancy fraction of time (0.8), 8760 is the numbers of hours per year, 170 is the hours per working month and F is the radon equilibrium factor.

3.3 Annual Effective Dose, He ($mSvy^{-1}$)

The annual mean dosage ($mSvy^{-1}$) to the residents due to indoor radon was determined using the equation [13,15,32,33].

$$H_E = C \times F \times H \times T \times D \quad (3)$$

Where C is the concentration of indoor radon in Bqm^{-3}, F is the indoor ^{222}Rn equilibrium factor. This is 0.4 for the indoor measurement. T is the occupancy time (8760 hours for occupying the house for one year), H is the occupancy factor which is 0.8 for the indoor measurement, D is the dose conversion factor for the whole body dose calculation (9.0×10^{-6} $mSvh^{-1}$ per Bqm^{-3}).

3.4 The Lung Cancer Cases Per Year Per Million Persons, CPPP (MPY)

Radon disintegrates quickly giving tiny particles that are radioactive. These radioactive particles have the tendency to damage or mutilate the lung cells if breathed in. Radon can be carcinogenic. The risk factor of lung cancer induction, 18×10^{-6} mSv, was used to estimate the lung cancer cases per million persons using the expression [31,33].

$$CPPP = 18 \times 10^{-6} \times H_E \quad (4)$$

4. Results and Discussions

Natural exposure to radon gas and progeny has become a state of difficulty that needs to be resolved world-wide as a result of their harmful effect on human health. Table 1 presents the results of the measured radon activity concentrations in the 4 LGAs. The radon concentration ranges from a minimum value of 15 Bqm^{-3} to a maximum value of 211 Bqm^{-3}. Akoko South East (AKSE) LGA had the highest average radon concentration value of 59.46 Bqm^{-3} which is higher than the 40 Bqm^{-3} world. KNE LGAs dwellings are below the 100 Bqm^{-3}.

Table 2 presents the average radon concentrations by the determining factors. The variant in radon concentrations observed among different dwellings could be attributed to geological composition of the area, the kind of materials used for building, the heating system, the exchange of air, the effect of the aging on the buildings and the social behaviour of the dwellers [29]. The buildings with good ventilation had a mean radon concentration value of 29.95 Bqm^{-3} while those with poor ventilation had a higher mean value of 39.42 Bqm^{-3}. This could be attributed to the little exchange of air in the buildings [34]. Considering the age, buildings with ages of 30 years and above had a mean radon concentration value of 34.21 Bqm^{-3} while buildings with ages less than 30 years had lower mean radon concentration value of 31.49 Bqm^{-3}. This could be attributed to the aging of the buildings.

The materials used for the structure are an important contributor to radon inside homes and among them, the materials that are obtained from the Earth are of the significant contribution [11]. Radon concentration is higher in buildings built with mud blocks, plastered or not plastered with cement, with a mean value of 48.61±39.62 Bqm^{-3} than buildings built with cement

Table 1. Radon concentration by LGA in Akoko area

LGA	Headquarter (Akoko)	Lowest radon conc. (Bqm^{-3})	Highest radon conc. (Bqm^{-3})	Mean radon conc. (Bqm^{-3})	No of detectors
AKNW	**Oke Agbe**	15	81	18.55	38
AKNE	**Ikare**	15	33	19.78	12
AKSW	**Oka**	15	70	33.68	32
AKSE	**Isua**	15	211	59.46	20

3.5 Equilibrium Equivalent Daughter Concentration, EEDC (Bqm^{-3})

The resulting concentration of short-lived radon progeny was calculated from the radon concentration by using the following relation [31].

$$EEDC = F \times C_{rn} \quad (5)$$

3.6 Field Control

5 blank detectors out of the 102 detectors were used for field background control. All of the 5 detectors recorded less than 15 Bqm^{-3} which is in agreement with the minimum detectable concentration value (MDC) of 14.8 Bqm^{-3} for the detectors. In order to ensure quality assurance, field background control measurements are used to ensure that handling, shipping or storage do not cause the alpha track detectors established by the analysis laboratory [2] to respond more strongly than the minimum detectable concentrations.

Table 2. Radon concentration by contributing factors

Determining factors	Ventilation status		Age of building		Building material		Heating source	
	Good	Poor	>30	≤30	Cement & Cement	Mud & Cement	Gas & Kerosene	Kerosene, Wood & Charcoal
No of detectors	66	31	65	32	72	23	18	55
Min. radon conc. (Bqm^{-3})	15	15	15	15	15	15	15	15
Max. radon conc. (Bqm^{-3})	211	141	211	59	141	211	141	122
Mean radon Conc. (Bqm^{-3})	29.95	39.42	31.49	34.21	28.30	48.61	34.39	28.37
Standard deviation	29.53	26.99	28.97	23.87	22.94	39.62	28.71	20.95

block, plastered with cement with a mean value of 28.30±22.94 Bqm^{-3}. Buildings in the mud block categories are characterized with cracks on the walls and faulty joints in their walls and floors which permit exhalation of radon from the walls and floors [34]. The use of natural gas in homes and the supply of kitchens are a potential source of indoor radon. Homes where natural gas is used for cooking in combination with kerosene had a mean radon value of 34.39±28.71 Bqm^{-3} while the homes where kerosene, charcoal and fire woods were used had a lower mean radon value of 28.39±20.95 Bqm^{-3}. Though the concentration of Ra-226 in different materials such as tile, cement, concrete and brick is in the range of 100-200 $BqKg^{-1}$ [2]. There is minimal effect on increment of the concentration of radon in the indoor air since the quantity of Radon-222 is very low.

Table 3. Radon concentration in modern and old buildings

Combined contributing factors	Modern buildings	Old buildings
Mean radon concentration (Bqm^{-3})	31.49±29.96	34.21±23.87

Table 3 shows further grouping of the building into old and modern buildings. Modern buildings with good ventilations, young age, and built with cement blocks had a mean value of 31.49±29.96 Bqm^{-3} while old buildings built with mud blocks of old age coupled with poor ventilation had a mean value of 34.21±22.87 Bqm^{-3}. This showed that old buildings with mud blocks and poor ventilation had the highest radon values compared with the modern buildings with cement blocks and good ventilation system. This could be attributed to age and little exchange of air in the buildings. The rate at which radon emanated from the floors, and walls in mud buildings was higher than that of the modern buildings because of the gaps and faulty joints in their floors, and walls.

Table 4 presents the calculated radiological indices as corresponded with the determining factors. The value of indoor annual effective dose (He) of ^{222}Rn varied from 0.71 to 1.23 $mSvy^{-1}$. It has a mean value of 0.87±0.86 $mSvy^{-1}$. The He average value was 1.23 $mSvy^{-1}$ in the mud and cement buildings. This is a little higher than the average value worldwide of 1.15 $mSvy^{-1}$ of [35]. The lung cancer cases (CPPP) varied between 1.29E-05 and 2.21E-05 per million persons per year with an average value of 1.56E-05±3.11E-06 per million persons per year. This is lower when compared with the limit range of 170-230 per million persons recommendation of [36]. Exposure to radon (Ep) varied from 0.13 to 0.21 with an average value of 0.15±0.03 ($WLMY^{-1}$). The results of Ep in indoors of the dwellings in Akoko area were found to be below the range (1-2 $WLMY^{-1}$), the lower limit of recommendation of NCRP. The equilibrium daughter equivalent (EEDC) concentration varied from 11.32 Bqm^{-3} to 19.44 Bqm^{-3}. It had a mean value of 13.74±2.74 Bqm^{-3}. The PAEC ranged from 3.0 mWL to 5.2 mWL and had a mean value of 3.7±0.7 mWL.

Table 4. Radiological indices corresponding to the determining factors

Determining factors		Mean radon conc. (Bqm^{-3})	He (mSvy^{-1})	PAEC (WL)	EP (WLMY^{-1})	CPPP (Per MPY)	EEDC (Bqm^{-3})
Age (years)	> 30	31.49	0.79	0.0034	0.14	1.43E-05	12.60
	< 30	34.21	0.86	0.0036	0.15	1.55E-05	13.68
Ventilation status	Good	29.95	0.76	0.0032	0.13	1.36E-05	11.98
	Poor	39.42	0.99	0.0042	0.18	1.79E-05	15.77
Building material	Cement & cement	28.30	0.71	0.0030	0.13	1.29E-05	11.32
	Mud & cement	48.61	1.23	0.0052	0.22	2.21E-05	19.44
Heating source	Gas & kerosene	34.39	0.87	0.0037	0.15	1.56E-05	13.76
	Kerosene wood & charcoal	28.37	0.72	0.0030	0.13	1.29E-05	11.35
	Mean	34.34	0.87	0.0037	0.15	1.56E-05	13.74
	Standard Deviation	6.86	0.17	0.0007	0.03	3.11E-06	2.74

Fig.3 presents the contribution of the determining factor to the radon concentration in the dwellings. The determining factors in column 1 were plotted against the mean radon concentration in column 2 using pie chart. The contribution of the determining factor to the mean radon concentration was: buildings with mud block and cement building, 17%; poorly ventilated buildings, 14%; buildings where gas and kerosene are used, 13%; buildings with ages less than 30 years, 13%; buildings with ages greater or equal to 30 years, 12%; buildings with good ventilation, 11%; buildings with kerosene, wood and charcoal, 10%; buildings with cement block and cement plastered, 10%.

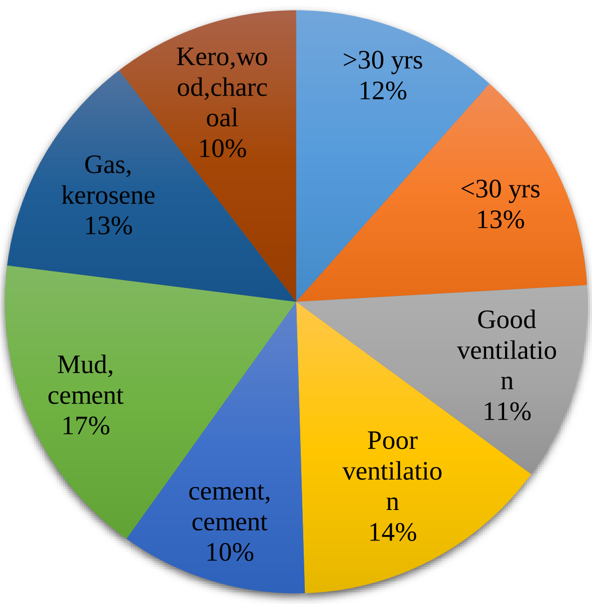

Fig. 3 % Contribution of the contributing factor to radon concentration

Conclusion

In this research, indoor radon concentrations inside the dwellings in the 4 LGAs of Akoko, Ondo State, Southwest Nigeria, were measured. The results showed that 13% of the dwellings studied in AKSE LGA had radon concentration higher than 100 Bqm^{-3}. The radon concentrations in the old buildings was higher than that of the modern buildings. The values of the annual effective dose, the lung cancer cases, exposure to radon, and other radiological risks were calculated from radon concentration values and found to be lower than the recommended limits. From the results of this work, it can be concluded that it is necessary for the population in this area to limit the use of mud blocks for the buildings. The people are also advised to improve the ventilation system in their buildings. The sealing of the surfaces, cracks and the openings through which radon enters the homes is recommended. It is absolutely essential to raise the level of public consciousness on the risk of radon gas. This research work provides results that could be added to the database of indoor radon level in Nigeria.

Conflict of Interest

The authors have no conflict of interest.

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