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Measurement of Indoor Radon (Rn-222) and Determination of Annual Effective Dose to Dwellers of Rijau, North-central, Nigeria

Salihu Mohammed [a]*, Mohammed Ahmed[a]

[a)] Department of Physical Sciences, Niger State Polytechnic, Zungeru, Nigeria

Corresponding Author's Email: salmedangle@yahoo.co.uk

Abstract: **In the present work, a total of ninety seven (97) randomly selected residential buildings across sixteen (16) linked villages of Rijau city were investigated. Solid track detectors; CR-37 were each exposed for a period of twelve (12) months after which they were etched and analyzed to determine their respective track densities. The detectors were etched in a 6.25 M solution of NaOH at 90 ^{o}C for 3 hours. The concentrations were used to compute exposures to dwellers and other radiological parameters per dwelling. Result of the survey yielded least, average and peak radon concentrations of 158.00±28.38 at Gyalle Area, 125.61±24.10 and 87.67±16.26 Bqm^{-3} at Low-cost Area respectively. This translated to least, average and peak Annual Effective Dose of 2.66, 3.13 and 3.99 mSvy^{-1} respectively. When compared with the standards set by International Centre for Ionizing Radiation (ICRP), both the measured Concentration and consequent Annual Effective Dose were within safe limit. The result from this work shall serve as a baseline radon data in the study area.**

Keywords: **Radon gas, CR-37, Annual Effective Dose, Rijau.**

1. INTRODUCTION

Radon gas is significantly influenced by geological bed rock, topography, house construction type, soil Radium content, soil density, radioactivity of building materials, ventilation conditions, meteorological conditions and human activities (Ursulean, 2013, Fahiminia *et al.*, 2016) which differs from place to place. More than two third of the approximately 200,000 population of Rijau dwellers are predominantly farmers living in the interior villages. The houses they dwell in are mostly the local hut type usually built with red mud. In addition to poor ventilation, the huts are almost always without flooring of any form other than the same mud compressed locally in a process traditionally referred to as *dabe*. The *dabe* flooring which is a condensed soil-on-soil flooring system renders the dwellers potentially exposed to Rn-222 gas due to infiltration arising from geological bed rock and soil radium (Ra-226) content.

Measurement is the only means of ascertaining the radiological exposure risk posed to dwellers by Radon gas and other Natural Occurring radioactive Materials (NORMS) for a given residential building or area. Indoor Radon exposure is responsible for approximately 60% of the total natural background radiation. Surveys to directly measure radon concentration in a significant and representative sample of dwellings are generally used to estimate the distribution of indoor radon concentration.

According to the United States Environmental Protection Agency (USEPA), radon is the second most frequent cause of lung cancer, after cigarette smoking, accounting for some 21,000 lung cancer deaths per year in the United States (USEPA; UNSCEAR, 2000; Shoeib and Thabayneh, 2014).

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1.1 Radon 222 Gas and Associated Risks Posed by Exposure

Radon is a chemical element with symbol Rn and atomic number 86. It is radioactive, colorless, odorless, tasteless occurring naturally as a result of the decay of Radium 226. Its most stable isotope is Ra-222 which has a half-life of 3.8 days and disintegrates by emission of alpha particle of energy 5.5 MeV. Rn-222 decays directly into Polonium–218 which following a chain of $\beta-$ $_{\text{and}}$ α decays is transformed into Polonium–214 (Farid, 2016).

2. SAMPLING LOCATION

Rijau is a Local Government Area in Niger State, Nigeria. It has an area of 3,196 km² and a population of 176,053 according to 2006 National Census. The GPS coordinates of Rijau is: 11.10621˚N 5.26352˚E (weather-forecast.com). In accordance with the sampling method established by Mahmood *et al.* (2016), a total of ninety seven (97) randomly selected residential buildings across sixteen (16) linked Areas of Rijau city were investigated; Warari, Shambo, Jamaare, Vocational, Low Cost, Tungan Anini, Ratayagiwa, Rijau Town, Danrimi, Sabon Gari, Magajiya Metropolis, Tsohon-gari, Marke, Alamberu, Gidan-dogo, Unguwan Gyalle and Tungan Bunu in Rijau LGA for the present survey. The distribution of the sampling sites encompassed settlements depicted in Figure 2.1.

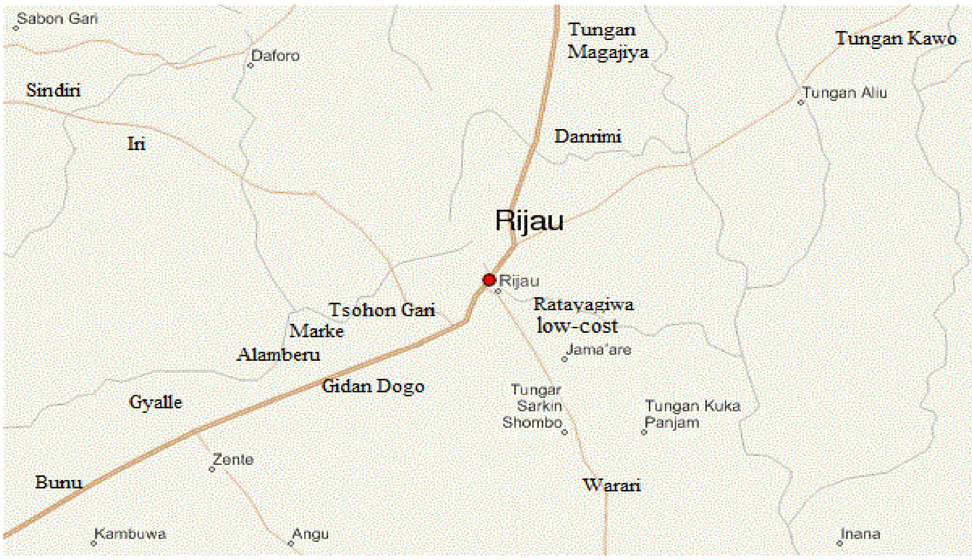

Figure 2.1: Google map for sampling area (weather-forecast.com)

The selection criteria included geological feature and building type. The research only considered buildings and dwellings of traditional hut type which are usually built without cemented floor and sufficient ventilation. The measurement was carried out over a period of twelve consecutive (12) months spanning September, 2018 - August, 2019.

2.1 Sampling

To achieve the goals of the research, dwellings of interest were identified and marked with the cooperation of traditional leaders and literate volunteers among the indigenous people who aided in educating the stakeholders on the purpose of the research after which agreement to place the detectors in the dwellings of interest was granted. In order to obtain results representative of dwellers' exposure, radon detectors were placed in inhabited rooms only.

3. TREND OF INDOOR RADON

A number of reviews on Indoor Radon concentration trends from reviewed literatures are presented in Table 3.1.

Table 3.1: Trends of Indoor Radon Concentration

Place	No. of Houses	Rn 222 (Bqm^{-3})	DT ($mSvy^{-1}$)	Reference
Dar es salam	32	166±12	-	Mlay and Makundi, 2018
Iran	24	55.19	1.9	Hassan *et al.*, 2019

Jordan	-	26.28	-	Abu-Haija *et al.*, 2010.
Nigeria	-	176.15±21.15	1.114±0.134	Obed *et al.*, 2018
Iraq	-	59.93	1.43	Battawy *et al.*, 2013
Iran	123	95.83	-	Fahiminia *et al.*, 2016
Rijau		125.61	3.17	Present work
Iran		-	0.47	Mirdoraghi *et al.*, 2018
Iran	50	117.4 ±97.7	1.4	Sherafat *et al.*, 2019
Nigeria		91.62±5.9	0.87	Okeji and Agwu, 2012
Nigeria		293.3±79.6	1.85	Obed *et al.*, 2010
Nigeria	77	259±67	6.5	Obed *et al.*, 2011
Nigeria	30	448.98	-	Yusuf and Adamu, 2014

Results of the preliminary measurements in Table 3.1 indicated a trend of interest. This begs the need for measurements in the area under review.

The survey will enable the scientific community to determine mean concentration in places of interest, determine the annual effective and absorbed doses due to inhalation of radon. This will help to established baseline survey data on Radon concentration and distribution in places of interest thereby alerting both policy makers and public on radon exposure prone areas.

4. RADON MEASUREMENT TECHNIQUE

Measurement of the indoor radon concentration measurements was achieved using CR-39 solid track detector. The CR-39 detector is made up of a cylindrical plastic, the plastic cover and a one square centimeter CR-39 strip. The detectors were placed at a height of at least 1 m from the floor of the dwelling during a twelve (12) months exposure. In order to ensure that the maximum Ra-222 concentration was obtained, drought–free areas of the marked dwellings were selected for detector placement. As Rn-222 decays, the emitted alpha particles interact with the CR-39 strip and leave behind tracks that would be revealed by etching with aqueous alkaline solutions of sodium hydroxide (NaOH). The etching of the exposed detectors was conducted using a 6.25 M solution of NaOH heated at a fixed temperature of 90 °C for a period 3 hours. Based on *track effect*, the solution of NaOH etches the surface of the CR-39 strip, but with a faster rate in the region of the tracks which made it possible to see the ‘‘track’’ of the particle under an optical microscope. After the etching, the etched detectors were placed under an optical microscope of 100× magnification were the visible tracks were counted and used to determine the track density using equation 4.1.

$$Track\ density\ (\rho_x) = \frac{Average\ number\ of\ total\ track}{Area\ of\ field\ view} \qquad [4.1]$$

Finally the computed track densities were converted using calibrated standards to determine the required concentration of Rn-222 for each location investigated. Table 4.1 gives the summary of the location description and measured activity.

Table 4.1: Location Description and Measured Activity

Areas	**House Code**	**Location Latitude, Longitude**	**C_{Rn} (Bqm^{-3}) Min.,Max.**	**C_{Rn} (Bqm^{-3}) Annual Average**
Warari	H1	10.92102˚N 5.31895˚E	67,145	99
	H2	10.92091˚N 5.31912˚E	81,148	113
	H3	10.92076˚N 5.31903˚E	78,189	144
Mean				**118.67**
Shambo	H4	11.01437˚N 5.29593˚E	78,155	117
	H5	11.01449˚N 5.29593˚E	56,145	108
	H6	11.01464˚N 5.29586˚E	55,108	89
	H7	11.01596˚N 5.29427˚E	88,134	109

	H8	11.01618˚N 5.29505˚E	78,111	98
	H9	11.01596˚N 5.29507˚E	77,156	105
Mean				**104.33**
Jama'are	H10	11.04915˚N 5.28138˚E	103,211	154
	H11	11.04930˚N 5.28128˚E	87,132	109
	H12	11.04924˚N 5.28114˚E	56,102	67
	H13	11.07000˚N 5.27107˚E	77,156	123
	H14	11.06950˚N 5.27141˚E	99,149	125
Mean				**115.60**
Low Cost	H15	11.08270˚N 5.26521˚E	49,132	77
	H16	11.08298˚N 5.26511˚E	89,177	108
	H17	11.08313˚N 5.26517˚E	67,156	84
Mean				**89.67**
Tungan Anini	H18	11.08915˚N 5.26482˚E	56,143	112
	H19	11.08930˚N 5.26468˚E	56,201	115
	H20	11.08954˚N 5.26475˚E	67,133	81
Mean				**102.67**
Rataya Giwa	H21	11.09839˚N 5.26428˚E	67,205	123
	H22	11.09852˚N 5.26406˚E	56,123	82
	H23	11.09852˚N 5.26408˚E	95,212	125
Mean				**110.00**
Rijau	H24	11.10337˚N 5.26412˚E	97,234	119
	H25	11.10329˚N 5.26436˚E	98,123	106
	H26	11.10337˚N 5.26389˚E	87,183	123
	H27	11.10573˚N 5.26355˚E	87,234	145
	H28	11.10602˚N 5.26361˚E	89,235	136
	H29	11.10621˚N 5.26352˚E	87,286	234
	H30	11.11646˚N 5.26309˚E	56,102	84
	H31	11.11639˚N 5.26287˚E	62,187	156
	H32	11.11679˚N 5.26288˚E	98,167	135
	H33	11.10825˚N 5.26306˚E	56,145	109
	H34	11.10802˚N 5.26338˚E	87,246	117
	H35	11.10825˚N 5.26344˚E	98,146	128
Mean				**132.67**
Danrimi	H36	11.12501˚N 5.26273˚E	86,168	146
	H37	11.12560˚N 5.26265˚E	125,197	167
	H38	11.12617˚N 5.26241˚E	122,167	117
	H39	11.13908˚N 5.26280˚E	118,189	156
	H40	11.13858˚N 5.26265˚E	123,189	176
	H41	11.13786˚N 5.26257˚E	99,167	133
Mean				**149.17**

Sabon Gari	H42	11.20518˚N 5.14473˚E	100,156	123
	H43	11.20583˚N 5.15343˚E	97,177	146
	H44	11.20577˚N 5.15126˚E	67,166	112
Mean	H45	11.20557˚N 5.14957˚E	67,145	118
				124.75
Magajiya	H46	11.15915˚N 5.27199˚E	78,156	127
	H47	11.16136˚N 5.27323˚E	78,158	126
	H48	11.15999˚N 5.27248˚E	78,156	118
	H49	11.16817˚N 5.27595˚E	123,190	178
	H50	11.16824˚N 5.27563˚E	89,156	119
	H51	11.16903˚N 5.27575˚E	97,187	145
	H52	11.17428˚N 5.27692˚E	67,156	106
	H53	11.17408˚N 5.27688˚E	87,154	129
	H54	11.17389˚N 5.27679˚E	98,188	167
	H55	11.17994˚N 5.27798˚E	67,133	104
	H57	11.17995˚N 5.27746˚E	111,201	134
	H57	11.18001˚N 5.27682˚E	122,187	156
Mean				**134.08**
Tsohon Gari	H58	11.10282˚N 5.25572˚E	79,167	137
	H59	11.10252˚N 5.25608˚E	111,186	134
	H60	11.10235˚N 5.25589˚E	99,189	136
	H61	11.10233˚N 5.25559˚E	87,156	124
	H62	11.09930˚N 5.25397˚E	85,178	143
	H63	11.09926˚N 5.25226˚E	56,134	95
	H64	11.09939˚N 5.25443˚E	78,167	121
Mean				**127.14**
Marke	H65	11.05727˚N 5.18055˚E	112,178	145
	H66	11.05703˚N 5.18084˚E	79,167	135
	H67	11.05703˚N 5.18006˚E	133,206	186
	H68	11.05730˚N 5.18027˚E	56,133	99
	H69	11.05742˚N 5.17992˚E	90,185	165
	H70	11.05712˚N 5.17957˚E	88,177	145
	H71	11.05592˚N 5.17810˚E	67,122	94
	H72	11.05569˚N 5.17832˚E	54,143	81
	H73	11.05565˚N 5.17806˚E	76,166	143
Mean				**132.56**
Alamberu	H74	11.21608˚N 5.16342˚E	99,198	156
	H75	11.21189˚N 5.16393˚E	88,144	113
	H76	11.20710˚N 5.16558˚E	78,133	123
Mean				**130.67**
Gidan Dogo	H77	11. 04083˚N 5.13299˚E	141,202	187

	H78	11.04098˚N 5.13286˚E	56,144	117
	H79	11.04090˚N 5.13265˚E	77,174	126
Mean				**143.33**
Gyalle	H80	11.00236˚N 5.10743˚E	82,237	196
	H81	11.00218˚N 5.10759˚E	108,213	155
	H82	11.00195˚N 5.10744˚E	90,187	143
	H83	11.00250˚N 5.10717˚E	122,231	188
	H84	11.00279˚N 5.10726˚E	97,172	143
	H85	11.00313˚N 5.10704˚E	88,177	123
Mean				**158.00**
Bunu	H86	10.98698˚N 5.09158˚E	89,145	143
	H87	10.98669˚N 5.09152˚E	57,234	151
	H88	10.98651˚N 5.09127˚E	113,223	175
	H89	10. 98338˚N 5.08924˚E	123,221	144
	H90	10.98357˚N 5.08892˚E	96,154	122
	H91	10.98308˚N 5.08882˚E	78,144	109
	H92	10.97864˚N 5.08603˚E	133,233	175
	H93	10.97883˚N 5.08590˚E	56,154	101
	H94	10.97854˚N 5.08584˚E	67,155	132
	H95	10.97165˚N 5.08024˚E	78,149	123
	H96	10.97146˚N 5.07990˚E	77,147	108
	H97	10.97181˚N 5.07954˚E	88,186	155
Mean				**136.50**

Table 4.2: Summary of Measured Activity and Standard Deviations (SD)

Place	**No. of Houses**	**SD (Ambient Gamma)**	**C_{Rn} (Bqm^{-3})**	**SD**
Warari	3	0.014142	118.67	23.03
Shambo	6	0.010435	104.33	9.71
Jama'are	5	0.001	115.60	31.71
Low Cost	3	0.002357	89.67	16.26
Tungan Anini	3	0.016499	102.67	18.82
Rataya Giwa	3	0.004714	110.00	24.27
Rijau	12	0.005025	132.67	37.13
Danrimi	6	0.004472	149.17	21.87
Sabon Gari	4	0.001443	124.75	14.86
Magajiya	12	0.003015	134.08	23.22
Tsohon Gari	7	0.006999	127.14	16.10
Marke	9	0.006285	132.56	34.65
Alamberu	3	0.004714	130.67	22.50
Gidan Dogo	3	0.002357	143.33	38.08
Gyalle	6	0.001491	158.00	28.38
Bunu	12	0.005276	136.50	24.97
Mean		**0.005639**	**125.61**	**24.10**

4.1 Computation of radiological hazards

4.1.1 Annual Effective Dose

The magnitudes the Annual Effective Dose (DT) ($mSvy^{-1}$) and Annual Effective Dose to lungs (ET) ($mSvy^{-1}$) are given by equations 4.2 and 4.3 respectively.

$$DT = C_{Rn}DFHT \qquad [4.2]$$

C_{Rn}= Radon Concentration (Bqm^{-3})

D=Dose Conversion Factor (9.0×10^{-6} $mSvh^{-1}$ per Bqm^{-3})

F=equilibrium factor (0.4)

T=hours in a year (8760 h/yr)

H= Indoor Occupancy Factor (0.4)

4.1.2 The Annual Effective Dose (E) to lungs

The Annual Effective Dose (E) to lungs is the measure of energy deposited in the human lungs by ionizing radiation arising from the emitted Alfa particle.

Annual Effective Dose to lungs (ET) ($mSvy^{-1}$)

$$ET = DW_RW_T \qquad [4.3]$$

D= Annual Effective Dose to lungs ($mSvy^{-1}$)

W_R=radiation weighing factor for Alfa particles (20)

W_T=tissue weighing factor for lungs (0.12) (Bodansky *et al.*, 1989)

4.1.3 Standard Deviations (SD)

The standard deviations were computed using equation 4.4

$$SD = \sqrt{\frac{\sum(x_i - \mu)^2}{N - 1}} \qquad [4.4]$$

Where; N is the population size

x_i is each value from the population

$\mu$is the population mean

5. DISCUSSION

5.1 Radon Concentration

The highest and least radon concentrations were recorded in Gyalle and Low cost Areas with 158.00 and 89.67 Bqm^{-3} respectively. As depicted in Figure 5.1, 100% of the areas yielded Rn-222 concentrations less than the ICRP limit of 148 Bqm^{-3}. Additionally, 87.5% of the measurements conducted fell below the 148 limit set by EPA. This also falls below the average measured concentration of the reviewed measurements of 159.61 Bqm^{-3} presented in Table 3.1.

Although overall, the highest recorded mean concentration in the present work is greater than both the world average and the limit of 100 Bqm^{-3} set by WHO, it is only a mere 33% of the 448.98 mean concentration published by Musa and Adamu (2014) in a research area which according to distancefromto.net is only 211 km away from Rijau.

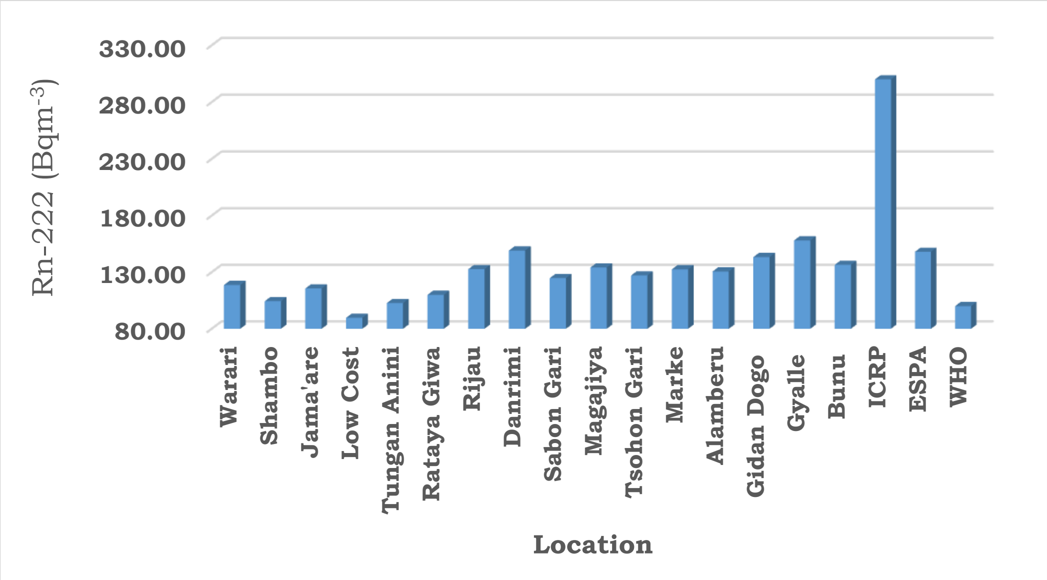

Figure 5.1: Plot of Radon Concentration (Bqm^{-3}) against Area

5.2 Annual Effective Dose (ET)

The trend of the mean of the computed DT (mSvy^{-1}) for the present study is presented in Figure 5.2.1.

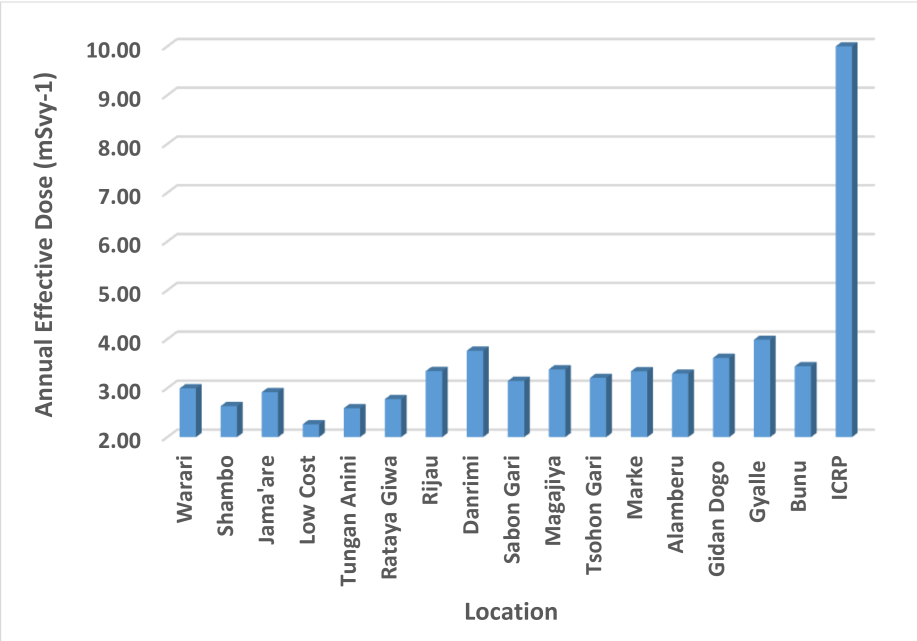

Figure 5.2.1: Plot of DT (mSvy^{-1}) against Area

As presented in Figure 5.2.1, mean values of 3.99 mSvy^{-1} and 2.66 mSvy^{-1} were obtained for Gyalle and Low-cost Areas respectively as the highest and lowest values of computed Annual Effective Dose (DT). However, in the entire study, values of computed DT were below the limit set by ICRP of 10 mSvy^{-1}.

6. CONCLUSION

An overview on radiological risks from exposure to radon gas accumulation is presented. Solid State Nuclear Track Detectors as well as underlying physics of track effect are discussed. Results of mean radon concentration and associated radiological hazards were presented. The observed trend of radon distribution in Rijau when compared with ICRP limits indicated that dwellers are not at risk of exposure to ionizing radiation due to radon.

7. RECOMMENDATIONS

a) A country with age long rampant cases of lung cancer among its population need to conducted holistic radon survey in order to establish reliable data on the distribution of radon across the country. This Radon map when placed side by side with map-based prevalence of Lung Cancer may provide some correlation between prevalence of lung cancer and radon gas distribution.

b) There is need for policy makers in Nigeria to promulgate regulations to compel housing developers to conduct radon survey in proposed residential sites in order to ascertain the level of background radon radiation and where it is observed to be within an unsafe range, necessary measures should be put in place by the stakeholders to ensure safety of occupants.

c) There is need for the scientific community to embark on sensitization of the public on the need to conduct quick assessment of radon concentration in their homes and offices, ensure proper ventilation and also insist on thick German-flooring during construction of houses.

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