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Estimation of Lung Cancer Risk Due to Radon Exposure in Natural Food Spices

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Authors' contributions

This work was carried out in collaboration between both authors. Author CPO designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript and managed the analyses of the study. Author GOA managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Estimation of lung cancer risk for internal exposure to naturally occurring ^{222}Rn gas in natural food spices was done using mathematical models. A series of equations were used to estimate Rn concentrations indoor and outdoor and the associated annual effective doses and lung cancer risk in some specified population according to their smoking habit. Activity concentration of ^{222}Rn in the natural food spices range from 0.57 Bqm^{-3} (in white onions) to 686.19 Bqm^{-3} (in Tomatoes). Green pepper also recorded high value of 583.34 Bqm^{-3} while ^{222}Rn in air ranges from 0.0018 to 2.17 Bqm^{-3}. ^{222}Rn exposure (WLM) in indoor due to ingestion of the natural food spices ranged from 0.0000127 WLM/y in white onions to 0.0153 WLM/y in tomatoes. The exposure from outdoor air due to radon inhalation ranged from 0.00000063 WLM/y in white onions to 0.0000724 WLM/y in tomatoes. The maximum indoor and outdoor values were 137.32 and 651.0 µSv/y respectively, detected in tomatoes. The minimum indoor and outdoor values were 0.114 and 0.0.54 µSv/y respectively, detected in white onions. The mean annual effective dose from ingestion of ^{222}Rn and inhalation from the food spices are 15.39 and 0.72 µSvy^{-1} respectively. As regards the estimation of lung cancer attributable to exposure to ^{222}Rn and its progeny to the general public, current

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smokers, ever smoker and never smoker recorded the maximum indoor and outdoor lung cancer risks of 381, 1144, 738 and 127 per million population and 54, 162, 105 and 4 per thousand populations respectively. The minimum indoor and outdoor risks were 32, 95, 61 and 11 per million population and 4, 13, 8 and 1 per thousand populations respectively. The result revealed a significant lung cancer risk for the current smokers.

Keywords: Indoor radon; lung cancer; food spices; effective dose.

1. INTRODUCTION

Radon is a naturally occurring radioactive gas with the chemical symbols of Rn and atomic number of 86. ^{222}Rn is the most stable isotope of radon with a half-life of 3.8 days [1]. ^{222}Rn originates from the decay of ^{226}Ra, an element in the decay series of ^{238}U and it is the heaviest gaseous element in natural sequential decay series of uranium, thorium, and actinium. ^{222}Rn and its progeny are major factors for radiation exposure to humans, and are what increases the risk of lung cancer [2]. DNA damage caused by the interaction of the charged alpha particles from the inhalation of radon with lung tissue can increase the risk of lung cancer, depending on the radon concentration and exposure time [3,4]; however, in accordance to the United States Environmental Protection Agency (EPA) report, radon is the second leading cause of lung cancer, after smoking [5]. ^{226}Ra is one of the commonly naturally occurring radioactive materials in the Earth's crust (rocks, stones, soils, etc.) [6].

Exposure to a low level of outdoors radon concentration, due to its naturally occurring property, is likely impossible to avoid, while most exposure to radon originates from being within dwellings [7]. Several studies show that cigarette smoke and radon exposure can separately increase the risk of lung cancer; however, exposure to both greatly enhances the risk of lung cancer [8]. It is well known that inhalation of the short-lived decay products of ^{222}Rn provides the main pathways for radiation exposure of the lungs [3,7]. When ^{222}Rn gas itself is inhaled, most of it is exhaled before it decays but ^{222}Rn progeny may be deposited on the cells lining the airways where they can damage the DNA and potentially cause lung cancer. It is recognized that ^{222}Rn is a health hazard in both mining and non-mining environments [9,10]. ^{222}Rn is the second most important risk factor for lung cancer after smoking, and causes between 6% and 15% of all cases [11]. Exposure to ^{222}Rn in the home and workplace is one of the main risks of exposure to ionizing radiation, causing tens of thousands of deaths from lung cancer each year [12,13]. The concentration of ^{222}Rn and ^{222}Rn daughters in the indoor air depends on the amount of ^{226}Ra in the soil and how easily ^{222}Rn products can move through soil and walls and mix with room air. Because ^{222}Rn is a gas, changes in the atmospheric pressure also affect its emission from the ground and its accumulation in the indoor air [14].

Risk assessment is a method to assess the likelihood that exposure to hazardous agents will harm people or the environment and is conducted to estimate the probability of specific harm to an exposed individual or population [15]. The purpose of our study was to calculate the radon concentration from the activity concentration of ^{226}Ra in all the food spices in order to determine the health risk of exposure to radon. This will estimation the lung cancer risk associated with internal radon exposure for different categories of population; the general population, current smokers, those who have ever smoked and never smokers. The annual effective dose received by consumers was calculated to assess the potential of long term effects.

2. MATERIALS AND METHODS

2.1 Sampling and Sample Preparation

The activity concentration of ^{226}Ra in all the natural food spices was measured by means of a high resolution, low background gamma spectrometer. A total of nineteen natural food spices samples were purchased from different traders at the mile 1 market. They includes; Achi, Tomatoes, Ehuru, Garlic, Ginger, Ashanti Pepper, Green Pepper, Uda, Offor. Ogbono, Uziza seed, Cameroon pepper, Red Onions, Short pepper, Tatashey, White Onions, Chobo, Nutmeg, Egusi, and four liquid natural samples includes Vegetable oil, groundnut oil and Palm oil. These samples were taken to National Institute for Radiation Protection and Research (NIRPR), University of Ibadan, Nigeria. The samples were open air dried on trays for a period of one week and then oven dried at a temperature of 105°C (± 5°C) for 2 to 4 hours at the laboratory. The oven dried samples were then grounded into fine powder with a stainless steel ball grinder. The prepared samples, in powdered form, were packed into weighed one (1) liter Marinelli plastic beaker, hermetically sealed, reweighed and stored prior to counting [16,17,18]. The containers were sealed to avoid any possibility of out-gassing of radon and kept for a period of 1 month to make sure the samples attained radioactive equilibrium between Ra-226 and its decay products in the uranium series, and Ra-228 and its decay products in the thorium series [19].

2.2 Gamma Spectroscopy

The samples were counted using a gamma-ray spectrometry. The gamma-ray spectrometry system consists 3” × 3” Thallium-activated Sodium Iodide [NaI (Tl)] detector and installed in a 100 mm thick lead castle. The detector is connected to an amplifier linked to a computer program GENIE 2K Window that correlated gamma energies to a number of possible isotopes. The sample was placed the marginally beaker and then made to sit on the NaI (Tl) detector. Shielding from background (environmental) radiation was achieved by counting in Canberra 100 mm thick lead castle. The energy resolution for the detector using Cs-137 from International Atomic Energy Agency (IAEA) is 7.5% at 662 Kev Cs-137 line [20]. The energy and efficiency calibration of the system was carried out before sample analysis using the multinuclear reference standard solution supplied by the International Atomic Energy Agency, IAEA. This was to enable identification and quantification of the radionuclides. The standard and the sample were counted for a period of 36,000 seconds to acquire spectral data for a better counting statistics and evaluation. The activity concentration of ^{238}U, ^{232}Th and ^{40}K were determined after correction for background and inhomogeneity [21,22].

The specific activity concentration of ^{238}U (^{226}Ra), ^{232}Th and ^{40}K in the medicinal plants were determined from the quantitative analysis of the spectra acquired from the Gamma-ray spectrometry using the Gamma-ray spectrum analysis software, Ortec MAESTRO–32 at specific energies. ^{238}U was calculated from the average of ^{214}Pb at energies of 251.9 Kev and 295.2 Kev and ^{214}Bi at energies of 609.3 Kev and 1764.5 Kev. ^{232}Th was determined from the average of ^{208}Tl at energies of 2614.5 Kev and 583.2 Kev, ^{212}Pb at the energy of 238.6 Kev and ^{228}Ac at the energy of 911.2 Kev and ^{40}K at 1460.0 Kev. The specific activity (A_{sp} *(E, i)* in Bq kg^{-1}) of the radionuclide *i* in the samples were calculated after decay correction using the expression in equation [23].

$$A_{sp}\,(E,\,i) = \frac{N_{sam}\,(E,i)}{\varepsilon\gamma(E)T_cP\gamma(E,i)\,M_{sam}} \tag{1}$$

where; N_{sam} (E,,i) is the net counts for the radionuclide *i* at energy *E*, $\varepsilon_\gamma(E)$ is the photo peak efficiency at energy *E*, T_c is the counting live-time (s), Pγ(E, i) is the gamma emission probability of the radionuclide *i* for a transition at energy *E*, M_{sam} is the dry-weight of samples (kg).

3. RESULTS AND DISCUSSION

The original values used in these calculations are taken from published data of radionuclide concentration in natural food spices consumed in Nigeria [24]. The activity concentration of ^{226}Ra in natural food spices were measured by means of a high resolution, low background gamma spectrometry [25].

3.1 Determination of the Activity Concentration of ^{222}Rn

The activity concentration of ^{222}Rn present in the sample was calculated from the activity concentration of ^{226}Ra in the spices, dose from inhaling radon gas and doses resulting from these food spices consumption.

$$Gs(n) = Fr\,.\,\rho\,.\,C_{Ra}(n) \tag{2}$$

where Gs(n) is the radon concentration (Bqm^{-3}), Fr is the constant of emission of ^{222}Rn from the sample, given as 0.1 [26], ρ is the bulk density of sample and C_{Ra}(n) is the activity concentration of ^{226}Ra in sample (Bqkg^{-1}).

The expense radioactivity in samples can be calculated by using:

$$C_p = A_n\,.\,C_{Ra}(n) \tag{3}$$

C_p = the concentration of ^{226}Ra in sample in Bq/Kg and A_n = transfer coefficient of ^{226}Ra which is given as 0.04 [26].

The concentration of ^{222}Rn in air can be calculated using Quindos et al, [27]:

$$Ca(n) = Gs(n)\,.\,(d_{sample}/D_{air})^{1/2} \tag{4}$$

Where Ca (n) is the activity concentration of ^{222}Rn in air for sample (Bq/m^3), d_{sample} = diffusion rate constant of ^{222}Rn in sample which is given as (0.5×10^{-4} m^2/s) [26] and D_{air} = diffusion rate constant of ^{222}Rn in air given as ($5m^2/s$). The results are presented in Table 2.

3.2 Risk Assessment from Radon

The absence of experimental data on equilibrium factor between radon and its progeny in the representative houses, the EPA recommended value was used to estimate annual human exposure rate [28].

$$WLM(Y) = CRn \times F\times (2.7\times10^{-4}) \times S\times(H_{Year}/170) \quad (5)$$

Where WLM(Y) is the annual human exposure rate to radon decay products, C*Rn* is the average of radon concentration ($Bq.m^{-3}$), F is the equilibrium factor as 0.4 for indoor and 0.6 for outdoor, 2.7×10^{-4} is the radon progeny concentration in equilibrium ($WL.Bq.m^{-3}$), S as 0.7 is the fraction of spending time indoors, and H_{Year} is annual hours.

The annual effective dose from inhaled radon is calculated with Equation (6) [29,30]:

$$HA = WLM(Y) \times I \quad (6)$$

Where H*A* is annual effective dose ($mSv.y^{-1}$) and I is the conversion factor of 9 (mSv per WLM).

The risk factors provided by ICRP and EPA were used to estimate the risk of lung cancer from radon inhalation for: the general population, current smokers, ever smokers, and never smokers. Table 1 presents the risk factors in terms of organizations and individual status.

Table 1. The lung cancer risk factors by individual status

Organization	Status	Risk factor
ICRP	General Population	5×10-4
	Current Smoker	1.5×10-3
EPA	Ever Smoker	9.68×10-4
	Never Smoker	1.67×10-4

Table 2. Calculated radon concentration from the activity concentration of ^{226}Ra

S/N	Sample	Initial mass of sample in gram (g)	Volume of sample ml	Density of sample kg/m^3	^{222}Rn conc in sample Bqm^{-3}	^{222}Rn conc in air (Bqm^{-3}
1	Achi	132.9g	305	435.74	167.76	0.53
2	Chobo	88.9g	335	265.37	0.61	0.0019
3	Tomato	37.6g	120	313.33	686.19	2.17
4	Egusi	156.3g	325	480.92	1.01	0.0032
5	Ehuru	135.4g	360	376.11	0.75	0.0024
6	Garlic	168.5g	270	624.07	1.44	0.0046
7	Ginger	132.6g	330	401.82	0.88	0.0028
8	Green pepper	15.8g	50	316	583.34	1.84
9	Nut meg	131.1g	290	452.07	0.90	0.0028
10	Long pepper	116.7g	375	311.2	0.65	0.0021
11	Uda	153.5g	370	414.86	1.00	0.0032
12	Offor	161.1g	335	480.90	1.11	0.0035
13	Ogbono	102.5g	205	500	0.95	0.0030
14	Vegetable oil 1	200g	215	930.23	2.23	0.0071
15	Vegetable oil 2	200g	215	930.23	2.23	0.0071
16	Groundnut oil	200g	215	930.23	2.23	0.0071
17	Uziza seed	163.7g	320	511.56	0.92	0.0029
18	Palm oil	200g	215	930.23	168.37	0.53
19	Cameroon pepper	108.7g	325	334.46	0.77	0.0024
20	Red onion	86.2g	260	331.54	37.46	0.12
21	Short papper	102.9g	315	326.67	106.17	0.34
22	Tatashey	66.2g	215	307.91	0.77	0.0024
23	White onion	69.6g	245	284.08	0.57	0.0018

The annual risk of lung cancer from inhaled radon and its progeny is calculated by equation number (7) [31]:

$$R = WLM(Y) \times D \times K \quad (7)$$

where R is the risk of lung cancer per year, WLM(Y) is the annual cumulative radon and its progeny exposure rate, D is the exposure time (Year) and K is the risk factor.

3.3 Discussion

The investigation of ^{222}Rn emanation and exhalation rates showed the same patterns between the ingested radon through food spices and inhalation from the spices. This may be due to the presence of uranium in the natural food spices emanating from the soil. The concentration of ^{222}Rn present in the food spices samples was calculated from the activity concentration of ^{226}Ra (^{238}U) in the food spices and in the air using equations 2 and 4 and are presented in Table 2. Health risk assessment was determined from radon and its progeny using equation 5 for the general population and their smoking habits.

Activity concentration of ^{222}Rn in the natural food spices range from 0.57 Bqm^{-3} (in white onions) to 686.19 Bqm^{-3} (in Tomatoes). Green pepper also recorded high value of 583.34 Bqm^{-3} while ^{222}Rn in air ranges from 0.0018 to 2.17 Bqm^{-3}. ^{222}Rn exposure (WLM) in indoor due to ingestion of the natural food spices ranged from 0.0000127 WLM/y in white onions to 0.0153 WLM/y in tomatoes. The exposure from outdoor air due to radon inhalation ranged from 0.00000063 WLM/y in white onions to 0.0000724 WLM/y in tomatoes (Table 3). The annual effective doses from ^{222}Rn exposure both indoor (ingestion) and outdoor (inhalation) are shown in Tables 3 and 4 respectively. The maximum indoor and outdoor values were 137.32 and 651.0 µSv/y respectively, detected in tomatoes. The minimum indoor and outdoor values were 0.114 and 0.0.54 µSv/y respectively, detected in white onions. The mean annual effective dose from ingestion of ^{222}Rn and inhalation from the food spices are 15.39 and 0.72 µSvy^{-1} respectively.

As regards the estimation of lung cancer attributable to exposure to ^{222}Rn and its progeny to the general public, current smokers, ever smoker and never smoker recorded the maximum indoor and outdoor lung cancer risks of 381, 1144, 738 and 127 per million population and 54, 162, 105 and 4 per thousand populations respectively. The minimum indoor and outdoor risks were 32, 95, 61 and 11 per million population and 4, 13, 8 and 1 per thousand populations respectively (Tables 3, 4). As seen in the Tables, large differences were observed between the smokers and never smoked. Figs. 1 and 2 show the variations in the lung cancer risk according to smoking status with annual effective dose from the samples (indoor) and air (outdoor) respectively. The lowest risk was detected in white onions for all the population class while tomatoes presented the highest risk of lung cancer especially to current smokers.

The estimated indoor ^{222}Rn concentration were higher than the recommended upper limit of 148 Bqm^{-3} [8] and 200-400 Bqm^{-3} ICRP, [18] in some natural food spices. Tomatoes, green peppers, Achi and palm oil recorded higher activity concentration of ^{222}Rn (686.19, 583.34, 167.76 and 168.37 Bqm^{-3}) respectively. The main contribution to the exposure of population to natural radiation comes from ingestion and inhalation of short-lived decay products of ^{222}Rn decay products. Direct measurements of the concentration of all short-lived decay products of ^{222}Rn are difficult and limited. They are estimated from consideration of equilibrium between ^{222}Rn and its decay products. Applying the classification of indoor exposure of Walsh and Lowder [32], where an exposure around 0.05 WL is considered high and 0.5WL extremely high, the estimated exposure levels in this study are all less than this guidelines. Walsh and Lowder also noted that the outdoor exposure is generally near 0.001 WL. The outdoor exposure levels are below this guidelines and EPA recommended value of 0.004 WL.

The annual effective doses from ^{222}Rn exposure in the samples and air in this study are consistent with the world wide values of 1.0 and 0.1 mSvy^{-1} for indoor and outdoor exposures respectively. The calculated annual effective doses are below the recommended dose. The US regulatory agencies assumed in cancer risk assessment that risk is directly proportional to dose and that there is no threshold of carcinogenesis [9,11,26]. In recent years, it has been established that there is a threshold of lung cancer induction by ^{222}Rn inn humans of around 600 to 1000 Bqm-3 in air for permanent intake in particular at home and offices. All the estimated values in this work were below this threshold range. For current smokers the risk of lung cancer is significantly higher than nonsmokers due to synergistic effects of ^{222}Rn and smoking [8,17] as shown in the result of this study.

Table 3. Health risk assessment due to ingestion of the samples

S/N	Sample Id	^{222}Rn conc. in sample (Bqm^{-3})	Human exposure rate WLM$_{(y)}$	Annual effective dose (H$_A$) µSvy^{-1}	Annual risk of lung cancer per year			
					General population	**Current smokers**	**Ever smoker**	**Never smoker**
1	AC	167.76	3.73E-03	33.572	9.32548E-05	0.28E-03	181.0E-06	3.11471E-05
2	CH	0.61	1.36E-05	0.122	3.39088E-07	1.02E-06	6.56E-07	1.13255E-07
3	TO	686.19	15.258E-03	137.319	3814.41E-07	1.144E-03	738.0E-6	1274.01E-07
4	EG	1.01	2.25E-05	0.202	5.61441E-07	1.68E-06	1.09E-06	1.87521E-07
5	EH	0.75	1.67E-05	0.150	4.16912E-07	1.25E-06	8.07E-07	1.39249E-07
6	GA	1.44	3.2E-05	0.288	8.00471E-07	2.4E-06	1.55E-06	2.67357E-07
7	GI	0.88	1.96E-05	0.176	4.89176E-07	1.47E-06	9.47E-07	1.63385E-07
8	GP	583.34	12.971E-03	116.737	3242.68E-07	0.973E-03	628.0E-06	1083.06E-07
9	NM	0.9	2.00E-05	0.180	5.00294E-07	1.5E-06	9.69E-07	1.67098E-07
10	LP	0.65	1.45E-05	0.130	3.61324E-07	1.08E-06	7E-07	1.20682E-07
11	UD	1.00	2.22E-05	0.20	5.55882E-07	1.67E-06	1.08E-06	1.85665E-07
12	OF	1.11	2.47E-05	0.222	6.17029E-07	1.85E-06	1.19E-06	2.06088E-07
13	OG	0.95	2.11E-05	0.190	5.28088E-07	1.58E-06	1.02E-06	1.76381E-07
14	VO1	2.23	4.96E-05	0.446	1.23962E-06	3.72E-06	2.4E-06	4.14032E-07
15	VO2	2.23	4.96E-05	0.446	1.23962E-06	3.72E-06	2.4E-06	4.14032E-07
16	GO	2.23	4.96E-05	0.446	1.23962E-06	3.72E-06	2.4E-06	4.14032E-07
17	UZ	0.92	2.05E-05	0.184	5.11412E-07	1.53E-06	9.9E-07	1.70812E-07
18	PO	168.37	3.744E-03	33.694	9.35939E-05	0.281E-03	0.000181	3.12604E-05
19	CP	0.77	1.71E-05	0.154	4.28029E-07	1.28E-06	8.29E-07	1.42962E-07
20	RO	37.46	0.833E-03	7.496	2.08234E-05	6.25E-05	4.03E-05	6.955E-06
21	SP	106.17	2.361E-03	21.246	5.9018E-05	0.177E-03	0.000114	1.9712E-05
22	TT	0.77	1.71E-05	0.154	4.28029E-07	1.28E-06	8.29E-07	1.42962E-07
23	WO	0.57	1.27E-05	0.114	3.16853E-07	9.51E-07	6.13E-07	1.05829E-07
AV.		76.88	1.709E-03	15.385	4.27362E-05	0.128E-03	8.27E-05	1.42739E-05

Table 4. Health risk assessment due to radon inhalation

S/N	**Sample Id**	**^{222}Rn conc. in air (Bqm^{-3})**	**Human exposure rate WLM$_{(y)}$**	**Annual effective dose (H$_A$) μSvy^{-1}**	**Annual risk of lung cancer per year**			
					General population	**Current smokers**	**Ever smoker**	**Never smoker**
1	AC	0.53	1.76771E-5	159.0	13.25E-03	39.75E-03	25.65E-03	442.6E-05
2	CH	0.0019	6.33706E-8	0.57	4.75E-05	0.143E-03	9.2E-05	1.59E-05
3	TO	2.17	7.23759E-05	651.0	54.25E-03	162.75E-03	105.03E-03	442.6E-05
4	EG	0.0032	1.06729E-07	0.961	8.00E-05	0.24E-03	0.155E-03	1.59E-05
5	EH	0.0024	8.00471E-08	0.72	6.00E-05	0.18E-03	0.116E-03	181.2E-05
6	GA	0.0046	1.53424E-07	1.38	11.50E-05	0.345E-03	0.223E-03	2.67E-05
7	GI	0.0028	9.33882E-08	0.84	7.00E-05	0.21E-03	0.136E-03	2E-05
8	GP	1.84	6.13694E-05	552.0	46.0E-03	138.00E-03	89.06E-03	3.84E-05
9	NM	0.0028	9.33882E-08	0.84	7.00E-05	0.21E-03	0.136E-03	2.34E-05
10	LP	0.0021	7.00412E-08	0.63	5.25E-05	0.158E-03	0.102E-03	153.6E-05
11	UD	0.0032	1.06729E-07	0.961	8.00E-05	0.24E-03	0.155E-03	2.34E-05
12	OF	0.0035	1.16735E-07	1.05	8.75E-05	0.263E-03	0.169E-03	1.75E-05
13	OG	0.003	1.00059E-07	0.901	7.50E-05	0.225E-03	0.145E-03	2.67E-05
14	VO1	0.0071	2.36806E-07	2.13	17.80E-05	0.533E-03	0.344E-03	2.92E-05
15	VO2	0.0071	2.36806E-07	2.13	17.80E-05	0.533E-03	0.344E-03	2.51E-05
16	GO	0.0071	2.36806E-07	2.13	17.80E-05	0.533E-03	0.344E-03	5.93E-05
17	UZ	0.0029	9.67235E-08	0.871	7.25E-05	0.218E-03	0.14E-03	5.93E-05
18	PO	0.53	1.76771E-05	159.0	13.25E-03	39.75E-03	25.65E-03	5.93E-05
19	CP	0.0024	8.00471E-08	0.72	6.00E-05	0.18E-03	0.116E-03	2.42E-05
20	RO	0.12	4.00235E-06	0.36	3.00E-05	9.00E-03	5.81E-03	442.6E-05
21	SP	0.34	1.134E-05	102.0	8.50E-03	25.50E-03	16.46E-03	2E-05
22	TT	0.0024	8.00471E-08	0.72	6.00E-05	0.18E-03	0.116E-03	100.2E-5
23	WO	0.0018	6.00353E-08	0.54	4.50E-05	0.135E-03	8.71E-05	283.9E-05
AV.		**0.24**	**8.00471E-06**	**0.72**	**6.0E-03**	**18.00E-03**	**11.62E-03**	**2E-05**

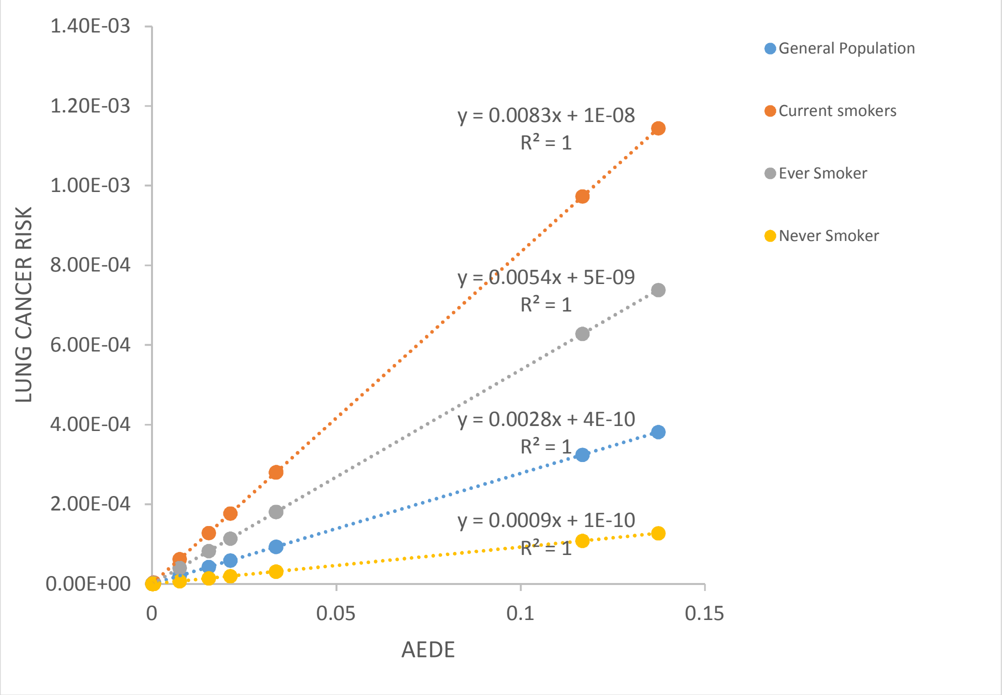

Fig. 1. The annual risk of lung cancer versus annual effective dose equivalent from samples (indoor)

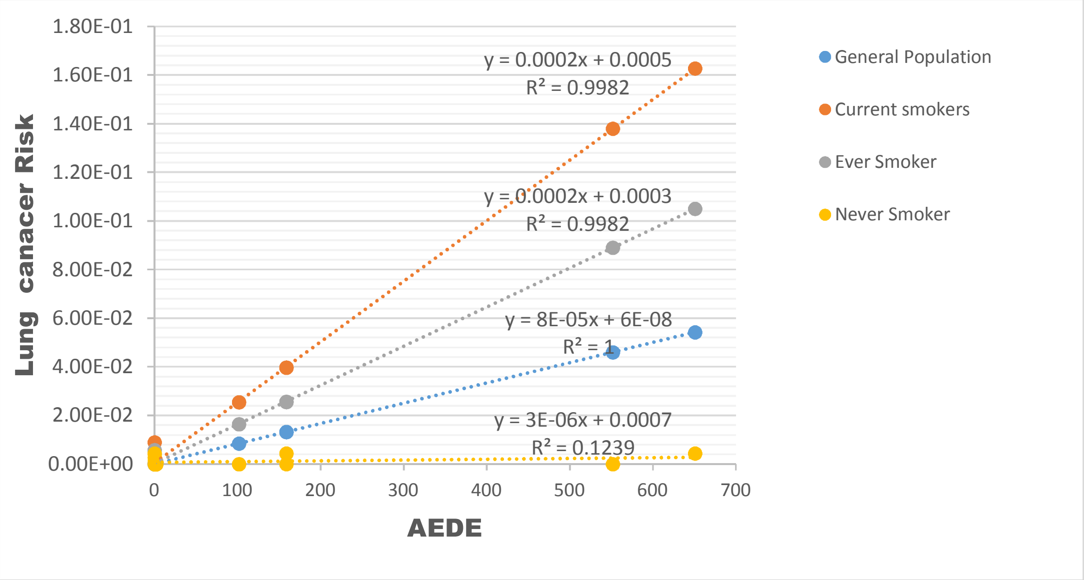

Fig. 2. The annual risk of lung cancer versus annual effective dose equivalent in Air (outdoor)

4. CONCLUSION

Radon is a naturally occurring hazardous, radioactive pollutants that is always present in our surroundings and is one of the causes of lung cancer. The estimated radon concentration in natural food spices were lower than the recommended safe limits except in Tomatoes and green pepper. The human exposure rate and annual effective dose due to ingestion of ^{222}Rn in natural food spices and the air (outdoor) were less than the upper limit. The risk of lung cancer estimated for the general population and other groups according to their smoking habits revealed a significant lung cancer risk for the current smokers. The result of this study has shown the correlation between tobacco exposure and radon exposure. There is therefore, the need to curb smoking habit of the general population and save them from death from lung cancer. It is imperative to note at this point that the results of all the radiological parameters were based on mathematical models, therefore further clinical comparative studies on patient samples are necessary before drawing definitive conclusions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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