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Studies on Indoor Radon Activity Concentration in two villages of West-Khasi Hills District of Meghalaya, India

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Abstract: Studies on radon aregenerally perceived from two perspectives, one from the aspect of hazard and the other as a tracer, of which in this paper our study is focused on the former. In this paper, we estimate whether the level of measured indoor radon activity concentration of the two villages under the study area has any impact on the well-being of the populace. The measured average radon activity concentration in the two villages (Nongkasen and Markasa) is found to be 101.74 ± 2.42Bq.m^{-3}(G.M.) and 148.26 ± 2.57 Bq.m^{-3}(G.M.)respectively. We have also measured its seasonal variation and found that the radon concentration is maximum during winter seasonviz.181.34±1.69 Bq.m^{-3} and 226.22±1.63 Bq.m^{-3}and minimum viz.66.31±2.75 Bq.m^{-3} and 83.32±3.26 Bq.m^{-3}during the rainy season for Nongkasen and Markasa respectively.

INTRODUCTION

One of the most important sources of natural background radioactivity is soil as it contains the precursors to most of the naturally occurring radioactive isotopes [1-2]. Exhalation of alpha-radioactive radoninert gas from soil is associated with the presence of radium atoms in the earth's crust**[**3]. As radon is the immediate decay product of radium, it is the concentration of radium that governs the amount of radon atoms formed [4]. Only a certain fraction of the totalradon atoms formed from the decay of the embedded radium leave the rocks or soil matrix. The fraction of radon atoms that actually emanate from the mineral grain or matter and enter the pore spaces, depends on many factors including proximity of the radium atom to the surface of the grain, the texture and the permeability of the grain, temperature etc. The amount of radon released per unit surface area per unit time from material (such as soil) is termed as the exhalation rate [5-8].

Radon has been extensively studiedas a hazard [3]; according to UNSCEAR reports, out of the total radiation dose received by the general population from natural ionizing radiation, radon alone contribute about 50-55% [9].Outdoor radon has no impact on human health as atmospheric mixing quickly dilutes it to insignificant levels. However, in confined spaces such as homes and workplaces, it accumulates to avery high concentration that can be hazardous to the general population**[**6-7].

The importance of indoor radon study from this aspect is evident from the interest shown by reputed health organizations such as US-EPA, WHO, UNSCEAR, NCRP, ICRP to name a few. Inhalation of high-level radon concentration can lead to deposition of its decay products in the lung epithelium that in turn can increase the risk of developing lung cancer**[7]**. According to World Health Organisation (WHO) publication, 2009, radon gas is the second most common cause of lung cancer after smoking **[**10]. The International Agency for Research on Cancer (IARC) in 1988 declared radon to as carcinogenic gas [11]. Initial studies on underground miners exposed to high radon levels have shown its association with lung cancer [12**]**. However, several studies, since the early 1980's which have investigated radon concentrations in homes and other buildings, have concluded that sufficient indirect evidence exists to link lung cancer in the general population on radon levels commonly found in buildings [10**]**.In this paper, we have reported soil radium content and indoor radon activity concentration in the Markasa and

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Nongkasenvillages of West-Khasi Hills district of Meghalaya. The total population of the two villagesis estimated to be about 2000 according to the 2011 census.The soil type of the two study sites consists of mostly red gravelly soil. The localization of coal, iron, granite, etc., around the study area and the uranium deposits in Kylleng-PyndensohiongMawthabah(KPM) area (at ~68 km by road from the study site) in the district might show thepeculiar distribution of radon in the area. [13].Although it is hard to perceive a direct functional relationship between radon in indoors and the radium content of the soil samples, indisputably radium content is an important variable determining radon concentration, therefore, we have made attempt to estimate the statistical correlation values between the two.

Further, the nature and structure of buildings can have an important bearing on the influx and accumulation of radon. Therefore, we have categorized the house structure in the study area into three types- wooden, semi-concrete and concrete.

- Wooden house: In this type of house, flooring and walls are completely wooden and roofs are constructed with the combination of wood and tin sheets.
- Semi-Concrete house: In this type of house, either floor or walls are made of concrete/bricks/woods or both are wooden/concrete and roofs are made with the combination of wood and tin-sheets.
- Concrete house: In this type of house, all flooring, walls and roof are completely made of concrete or bricks.

EXPERIMENTAL TECHNIQUE

For Radium Content Study

The method of 'Can Technique' [14] has been used for the measurement of radium content in the soil samples collected from various locations of the two villages (Fig 1). The samples are processed and sieved through 90-micron mesh sieve. After sieving the sample (~100g) are then placed and kept sealed in bottles (of 1-litre capacity, considered the emanation chamber) for 30 days so that secular equilibrium is attained. LR-115 type 2 plastic track detectors are then carefully fixed inside the lid of the bottles and the set-up is left undisturbed again for 90 days. The detectors are retrieved from the emanation chamber and etched in 2.5N NaOH solution at 60^{o}C for 120 minutes using a constant temperature water bath. The resulting alpha tracks are then counted using images captured from a CCD camera mounted on an optical microscope at the magnification of ~650x. Higher magnification is used here due to thehigher density of tracks, compared to indoor radon.

The exhalation rates in terms of mass (Bq.kg^{-1} h^{-1}) and area (Bq.m^{-2} .h^{-1}) are estimated respectively using the relations,

$$E_M = \frac{CV\lambda}{M(t+1)/\lambda\left(e^{-\lambda t}-t\right)} \tag{1}$$

$$E_A = \frac{CV\lambda}{A(t+1)/\lambda\left(e^{-\lambda t}-t\right)} \tag{2}$$

where, C is the integrated radon concentration (Bq.m^{-3}.h^{-1}), V is the effective volume of the can (m^3), λis the decay constant for radon (h^{-1}), t is the exposure time (h), Mis the mass of the soil sample and A is the area of thecross-section of the bottle.

The radium concentration in soil samples is computed using the relation,

$$C_{Ra} = \frac{\rho h A}{k t_e M} \tag{3}$$

whereC_{Ra} is the effective radium content of the soil sample (Bq.kg^{-1}), Mis the mass of the soil sample, Ais the area of cross-section of the bottle (5.9×10^{-3} m^2), h is the distance between the detector and the top of the soil sample and t_e is the effective exposure time, ρis the background corrected track density (tracks.cm^{-2}) and kis the sensitivity factor (0.0245 tracks.cm^{-2} d^{-1} (Bq.m^{-3})$^{-1}$ [15].

The Alpha index value is calculated using the relation [16],

$$I_\alpha = \frac{C_{Ra}}{200(Bq.kg^{-1})} \tag{4}$$

For Indoor Radon Study

Solid State Nuclear Track Detectors, namely LR-115 Type 2 films are used for our study. The indoor sites are chosen at close proximity (about 1- 2 meters) from where soil samples are collected for radium content analysis. The films are cut into small sizes about $2.5 \times 2.5\ cm^2$ sizes, pasted onto a cardboard of dimension $6 \times 9\ cm^2$, and hung at thecentre of the rooms. The detectors are placedmore than 10 cm away from the roof and about 2 meters from the ground. The detectors are retrievedafter a period of exposure of about three months; these exposed films are then chemically etched in 2.5N NaOH solution at 60ºC for 120 minutes. The perforated holes or tracks that appear asbright spots in thereddish background are counted manually using an optical microscope at 150x magnification.

The track density obtained is then converted into radon activity concentration using the following equation,

$$C_{Rn} = \frac{\rho}{kT} \tag{5}$$

where ρ is the density of tracks (number of tracks counted per area of the film), k is the calibration factor used with a value of 0.02 tracks.$cm^{-2}\ d^{-1}\ (Bq.m^{-3})^{-1}$[17]and T is the duration in days for which the detectors havebeenexposed.

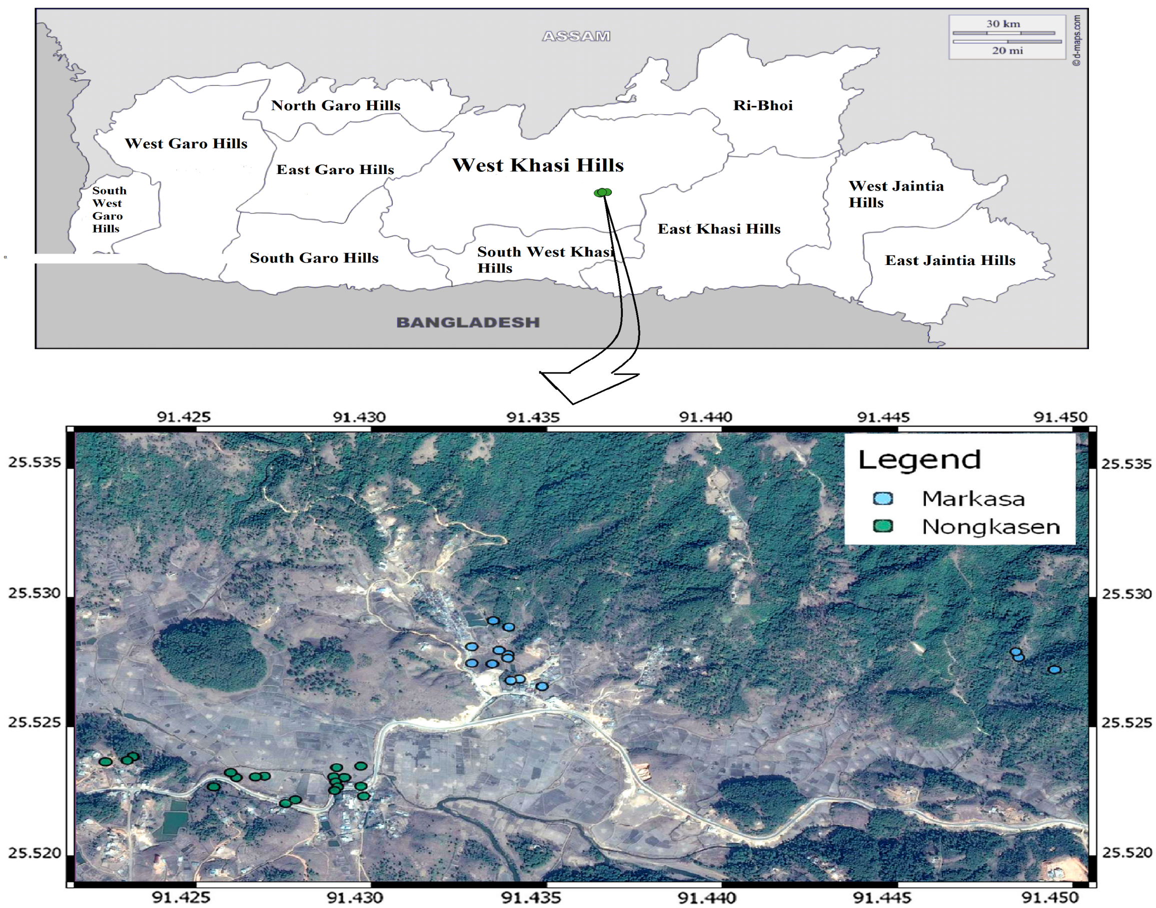

Figure 1. Map depicting the study area with locations.

RESULTS AND DISCUSSION

The results of the estimated radium content of the soil samples collected from different locations of the two villages, the radon exhalation rates in terms of mass along withthe calculated alpha index values aregiven in Table 1**.** The radium content of Nongkasen village was found to vary from 13.22 ± 10.43 to 165.84±2.31 Bq.kg^{-1} with average values of 89.27± 38.24 Bq.kg^{-1} (A.M.) and of 77.41± 1.87Bq.kg^{-1}(G.M.).The radium content of Markasavillagewas found to vary from 3.74±7.56to 55.62±1.95Bq.kg^{-1} with average values of29.42± 14.97 Bq.kg^{-1} (A.M.) and 24.56± 1.99Bq.kg^{-1}(G.M.).In the preceding lines, A.M. represents Arithmetic Mean and G.M. represents Geometric Mean.

The measuredvalues of radon activity concentration from thehousehold, annual radon activity concentration, annual exposure andestimated lifetime fatality risk of the two villages are given in Table 2.Our study has been carried out for one complete year divided into four seasons *viz.* spring (March to May), rainy (June to August), autumn (September to November) and winter (December to February).In Nongkasen village, the average values of the radon activity concentrationare 66.31±2.75 Bq.m^{-3} (Rainy), 87.94±2.46 Bq.m^{-3}(Spring), 101.33±2.00 Bq.m^{-3}(Autumn) and 181.34±1.69 Bq.m^{-3}(Winter) with average value of 101.74 ± 2.42 (G.M.). In Markasavillage, the average values of the radon activity concentration are 83.32 ± 3.26 Bq.m^{-3}(Rainy), 131.25 ± 2.85 Bq.m^{-3} (Spring), 195.29 ± 1.60Bq.m^{-3}(Autumn) and 226.22 ± 1.63Bq.m^{-3}(Winter) with average value of 148.26 ± 2.57 Bq.m^{-3}(G.M.).Lowest to highestmeasured radon activity concentration has been found in the order: Rainy < Spring < Autumn < Winter season respectively in both the study areas. This trend in the seasonal variationof the radon concentration has also been observed by many authors and is usually attributed to poor ventilation in thewinter season and better ventilation in rainy season [3, 18-22]. The seasonal variation of radon activity concentration measured is shownin figure 4with amaximum observed in winter season and minimum in therainy season.

TABLE 1. Consolidated data of the estimated Radium Content, Radon Exhalation Rates in terms of Mass and Area, and the Alpha Index value in the soil samples of the twovillages.

NONGKASEN VILLAGE					MARKASA VILLAGE				
Sl. No.	**Radium content in Bq.kg^{-1}**	**Exhalation rate in terms of**		**Alpha index**	**Sl. No.**	**Radium content in Bq.kg^{-1}**	**Exhalation rate in terms of**		**Alpha index**
		Area (Bq.m^{-2}h^{-1})	**Mass (Bq.kg^{-1}h^{-1})**				**Area (Bq.m^{-2}h^{-1})**	**Mass (Bq.kg^{-1}h^{-1})**	
1	48.12	7.99	0.48	0.24	1	31.42	5.15	0.31	0.16
2	81.69	13.57	0.81	0.41	2	3.74	0.62	0.04	0.02
3	60.48	10.05	0.6	0.3	3	11.67	1.91	0.11	0.06
4	13.22	2.2	0.13	0.07	4	51.02	8.76	0.52	0.26
5	16.84	2.8	0.17	0.08	5	26.31	4.37	0.26	0.13
6	101.76	16.9	1.01	0.51	6	32.17	5.34	0.32	0.16
7	66.46	11.04	0.66	0.33	7	34.87	5.72	0.34	0.17
8	72.5	12.04	0.72	0.36	8	36.21	6.14	0.36	0.18
9	111.19	18.47	1.1	0.56	9	11.8	2	0.12	0.06
10	98.54	16.37	0.97	0.49	10	13.73	2.25	0.13	0.07
11	95.44	15.85	0.94	0.48	11	26.78	4.45	0.26	0.13
12	57.84	9.61	0.57	0.29	12	35.65	6.04	0.36	0.18
13	120.16	19.96	1.19	0.6	13	24.03	3.99	0.24	0.12
14	121.36	20.16	1.2	0.61	14	55.62	9.3	0.55	0.28
15	121.13	20.12	1.2	0.61	15	46.32	7.59	0.45	0.23
16	89.05	14.79	0.88	0.45					
17	165.84	27.54	1.64	0.83					
18	95.84	15.92	0.95	0.48					
19	136.3	22.64	1.35	0.68					
20	111.7	18.55	1.1	0.56					

The average annual effective dose (AED) calculation has also been doneand the value is found to be 2.68±1.81 mSv and 3.91±1.73 mSvin NongkasenandMarkasa villages respectively. The average value of lifetime fatality riskshas been found to be 0.29×10^{-4} and $0.43\times10^{-4}$for Nongkasen and Markasa village respectively. Figure2 shows the radon activity concentration obtained by taking the geometric mean of the radon activity concentration measured in four seasons with the corresponding location codes used for the detectors deployed in the two villages. The error bars shown in the figure indicate only the counting error; the error from calibration and other sources is estimated to be below 21%[23]. From the results, we found that 10% (2 in number) of the household studied have radon concentration above the International Commission on Radiological Protection (ICRP) action limit (200 $Bq.m^{-3}$) and 5% (1 in number) above the WHO action limit (300 $Bq.m^{-3}$) in Nongkasen village. In Markasavillage, we found that 40% (6 in number) of the household has radon concentration above the ICRP action limit and 6% above the WHO action limit.

The correlation plot between the measured indoor radon activity concentration and estimated radium content of the soil samples has been shown in Figure 3. A better correlation in Nongkasen village (with acorrelation coefficient of about 0.35) has been observed in comparison toMarkasa village (with acorrelation coefficient of about 0.25) as shown by the slope of the trend in the figure. From Figure 3, the correlation value of 0.35 for Nongkasen and 0.25for Markasa village possibly signifies that the contribution of radium is inconsiderable in comparison to other factors affecting indoor radon.

TABLE 2. Consolidated data on measured radon activity concentration in the four seasons with annual exposure, annual effective dose and lifetime fatality risk.

STUDY SITE	Location	Radon Activity Conc. in $Bq.m^{-3}$				Annual Radon Activity Conc. ($Bq.m^{-3}$)	Annual Exposure		AED ($mSv.y^{-1}$)	Life-time fatality Risk $\times10^{-4}$
		Rainy	Winter	Autumn	Spring		WLM	$mJhm^{-3}$		
NONGKASEN VILLAGE	**NS-1**	134.88	153.39	178.6	75.99	129.45	0.13	0.45	3.42	0.38
	NS-2	47.63	117.95	47.14	19.73	47.81	0.05	0.17	1.26	0.14
	NS-3	62.02	128.36	23.61	37.53	51.54	0.05	0.18	1.36	0.15
	NS-4	26.73	73.75	121.67	28.08	50.94	0.05	0.18	1.34	0.15
	NS-5	59.74	125.2	37.92	30.08	54.05	0.05	0.19	1.43	0.16
	NS-6	255.16	151.93	99.84	366.72	194.1	0.19	0.67	5.12	0.57
	NS-7	86.79	215.53	72.16	90.39	105.1	0.1	0.36	2.77	0.31
	NS-8	148.37	216.7	172.89	144.55	168.36	0.16	0.58	4.44	0.49
	NS-9	30.54	114.23	63.91	23.65	47.92	0.05	0.17	1.26	0.14
	NS-10	7.15	570.06	197.76	276.37	122.15	0.12	0.42	3.22	0.36
	NS-11	166.39	461.1	150.17	272.66	236.75	0.23	0.82	6.25	0.69
	NS-12	5.23	181.49	53.85	62.04	42.2	0.04	0.15	1.11	0.12
	NS-13	113.25	147.46	66.35	83.19	97.98	0.1	0.34	2.59	0.29
	NS-14	87.2	207.19	133.14	59.04	109.16	0.11	0.38	2.88	0.32
	NS-15	152.77	467.95	187.67	272.33	245.86	0.24	0.85	6.49	0.72
	NS-16	89.36	155.15	66.72	54.01	84.07	0.08	0.29	2.22	0.25
	NS-17	23.42	139.39	73.34	120.99	73.36	0.07	0.25	1.94	0.22
	NS-18	128.11	143.37	126.62	59.79	108.59	0.11	0.38	2.87	0.32
	NS-19	106.36	115.84	226.2	181.67	150.01	0.15	0.52	3.96	0.44
	NS-20	158.1	347.18	479.75	320.15	303.01	0.3	1.05	8	0.89
MARKASA VILLAGE	**MK-1**	12.98	134.94	79.81	151.06	67.79	0.07	0.23	1.79	0.2
	MK-2	164.42	108.59	41.42	138.09	100.53	0.1	0.35	2.65	0.29
	MK-3	11.78	113.6	75.37	77.34	52.85	0.05	0.18	1.39	0.16

MK-4	151.67	219.69	160.9	175	175.01	0.17	0.61	4.62	0.51
MK-5	66.2	145.39	248.04	262.76	158.26	0.15	0.55	4.18	0.46
MK-6	7.19	173.98	26.47	358.8	58.71	0.06	0.2	1.55	0.17
MK-7	332.06	448.73	261.49	161.05	281.45	0.28	0.97	7.43	0.83
MK-8	54.39	126.67	178.78	460.78	154.35	0.15	0.53	4.07	0.45
MK-9	291.56	151.56	9.63	404.52	114.54	0.11	0.4	3.02	0.34
MK-10	129.92	524.77	313.43	352.86	294.68	0.29	1.02	7.78	0.86
MK-11	294.42	309.52	301.66	294.66	300	0.29	1.04	7.92	0.88
MK-12	69.69	173.98	417.6	331.56	202.42	0.2	0.7	5.34	0.59
MK-13	238.77	143.87	136.22	184.54	171.43	0.17	0.59	4.52	0.5
MK-14	80.58	242.73	286.52	292.91	201.28	0.2	0.7	5.31	0.59
MK-15	132	291.32	323.68	139.67	204.22	0.2	0.71	5.39	0.6

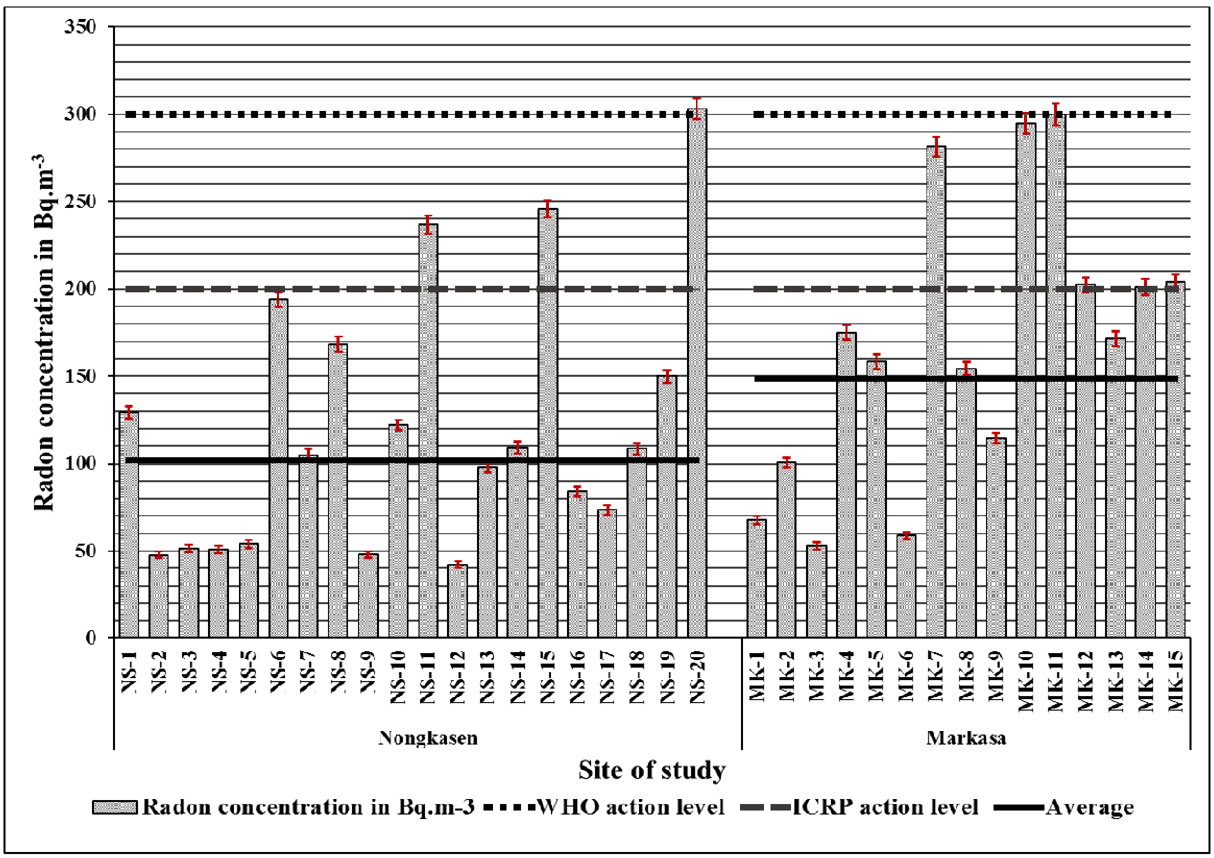

Figure 2. Comparison plot of annual radon concentration measured in the household of the villages with WHO and ICRP action level.

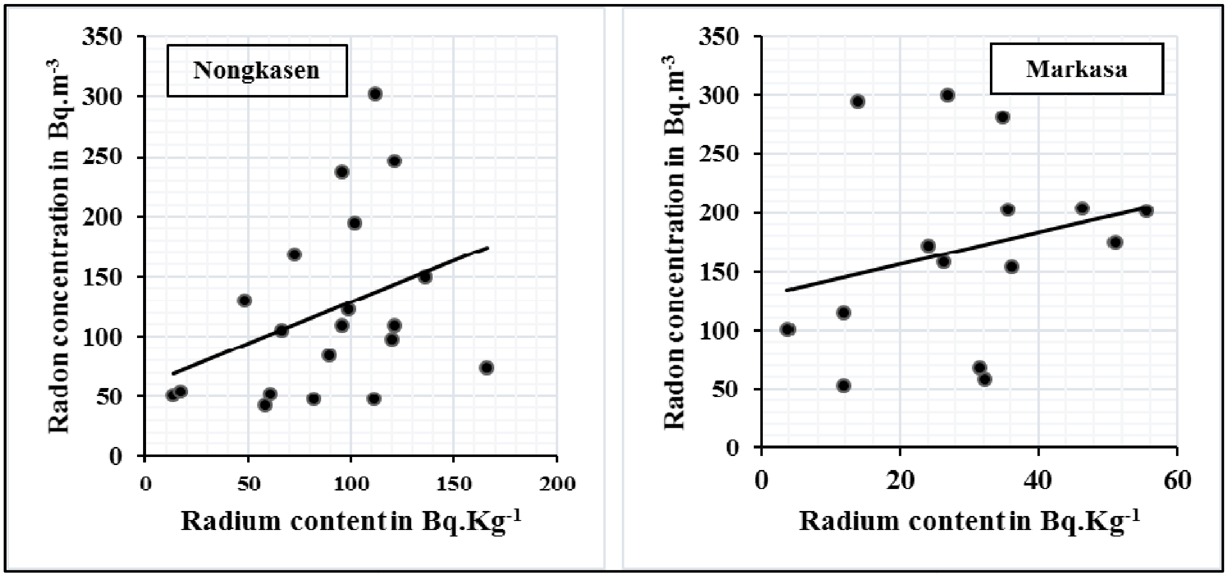

Figure 3. Correlation plot of radium content in soil sample with indoor radon activity concentrationfor the two villages of Nongkasen and Markasa.

Figure 5 shows the plot of average radon concentration for different types of houses. From Figure 5**,** we see that the indoor radon activity concentration for wooden house type is the least and semi-concrete and concrete house types are comparable and higher as expected due to the additional contribution from exhalation arising from the concrete walls and poorer ventilation.

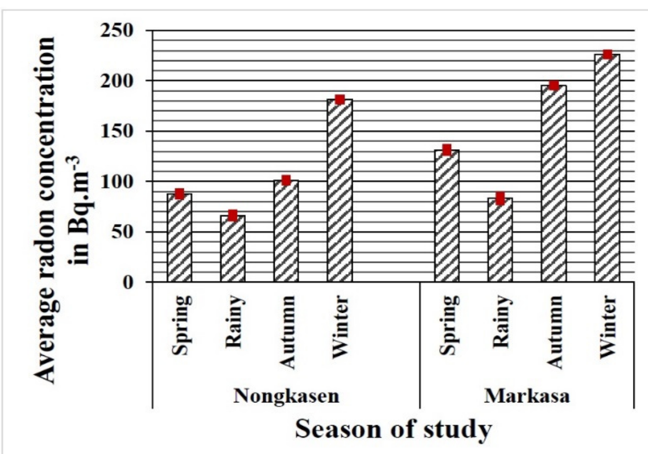

Figure 4. Seasonal variation of average (G.M.) indoor radon activity concentration in the two villages. The error bars represent geometric standard deviations.

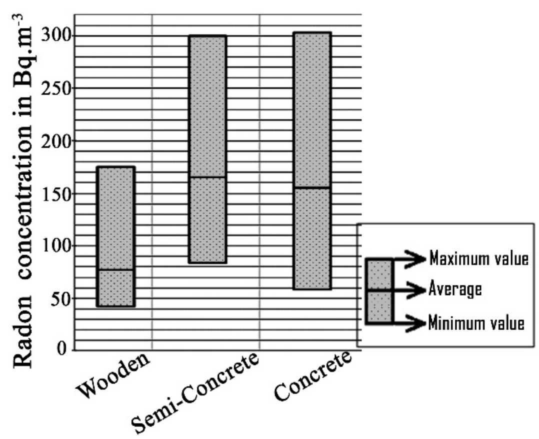

Figure 5. The average radon concentration and its extent for different house types.

CONCLUSION

Although, in some houses, the annual radon concentration is higher than that prescribed by ICRP and WHO actually, it is not beyond a significant margin.Theaverage radon activity concentration in the two villages viz. 101.74 ± 1.81Bq.m^{-3} for Nongkasen and 148.26 ±1.73 Bq.m^{-3} for Markasa were found to bebelow the action levels set by ICRP and WHO. The range of annual effective dose for both the villages is also well below the WHO recommended action level of 10 mSv.y^{-1}**.**From the alpha index valueobtained, it can be deduced that the radium activity of soil samplesalone is unlikely to produce radon concentration exceeding 200 Bq.m^{-3} inside houses. In summary, we can conclude that radon does not pose a significant health hazard to the general population of Nongkasen and Markasa.

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