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Estimation of ^{222}Rn exhalation rate and assessment of radiological risk from activity concentration of ^{226}Ra, ^{232}Th and ^{40}K

Pargin Bangotra[a], Rohit Mehra[a,*], Rajan Jakhu[a], Kirandeep Kaur[a], Pragya Pandit[b], Sandeep Kanse[c]

[a] Radiation Physics Laboratory, Dr. B.R. Ambedkar National Institute of Technology, Punjab, India
[b] Atomic Minerals Directorate For Exploration and Research, New Delhi, India
[c] Radiological Physics & Advisory Division, Bhabha Atomic Research Centre, Mumbai, India

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ABSTRACT

The activity concentration of natural radionuclides and ^{222}Rn (Radon) exhalation rate in soil samples were determined using NaI gamma detector and Scintillation based Smart Radon Monitor (SRM). Soil samples were collected from different geological formations of the same area. The concentration of three radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the studied area has been varied from 25 Bq kg^{-1} to 48 Bq kg^{-1}, 28 Bq kg^{-1} to 47 Bq kg^{-1} and 356 Bq kg^{-1} to 598 Bq kg^{-1} respectively. The average value of ^{226}Ra (Radium) equivalent activity in soil samples of the studied area was 125 Bq kg^{-1}. The ^{226}Ra equivalent activities of soil samples have been calculated to assess the radiation hazards arising due to the use of these soils in the construction of dwellings. The exhalation of ^{222}Rn from the earth's crust and building material are the main source of ^{222}Rn in indoor environment. The ^{222}Rn exhalation rate in the studied area was varied from 16.9 ± 0.5 mBq Kg^{-1} h^{-1} to 38.2 ± 0.9 mBq Kg^{-1} h^{-1}. A weak correlation was obtained between the ^{226}Ra and ^{222}Rn exhalation rate. The annual effective doses for different organs and radiation hazards have been also calculated in the studied area. The overall average annual effective dose in the studied is lower than the world recommended value of 1.0 mSva^{-1}.

1. Introduction

Primordial radionuclides ^{238}U (Uranium), ^{232}Th (Thorium) and ^{40}K (Potassium) are existed since the creation of earth. Especially ^{40}K and the radionuclides of ^{238}U - ^{226}Ra and ^{232}Th series are relevant with respect to radiological dose to human beings (UNSCEAR, 1988, 2000). The worldwide average natural dose to human is 1.4–2.4 mSv y^{-1}. The distribution of natural radionuclides and its radiological effects is most important factor for affecting the human environment. The dose rate varies from place to place depending on concentration of natural radionuclides in the soil. Natural radioactivity concentration depends mainly on geological and geographical conditions and appears at different levels in soils from different geological regions (UNSCEAR, 2000). The presence of radionuclides above a certain permissible level in soil becomes a health hazard. Their exposure is associated with the risk of leukemia and certain other cancer such as melanoma, cancers of kidney and prostate (Henshaw et al., 1972).

There are few regions in the world known to High Background Radiation Areas (HBRAs) due to local geology and geochemical effects that cause enhanced level of terrestrial radiation (UNSCEAR, 1993, 2000). Very high background radiation areas are found at Guarapari, the coastal region of Espirito Santo and the Morro Do Forro in Mines Gerais in Brazil (Veiga et al., 1999; Paschoa, 2000), Yangjiang in China (Wei and Sugahara, 2000), the southwest coast of India (Sunta et al., 1982; Sunta, 1993; Ghiassi-Nejad et al., 2012), in the United States and Canada and in some other countries (UNSCEAR, 2000).

The dwellings in India have been constructed with bricks mixed with nearly 80% of soil, which may contain highly occurred concentrations of natural radionuclides (Ferdoas et al., 2007). Every building construction material contains different quantities of natural radioactive nuclides. Radiation exposure due to building materials can be further divided into external and internal exposure. External gamma dose estimation due to the terrestrial sources is essential not only because it contributes considerably to the collective dose but also because of variations of the individual dose related to this pathway. The external exposure is caused by direct gamma radiation, whereas internal exposure is caused by inhalation of ^{222}Rn (Radon), ^{220}Rn (Thoron) and their decay products (Bangotra et al., 2015; Mehra et al.,

* Corresponding author.
E-mail address: mehrar@nitj.ac.in (R. Mehra).

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2015; Mehra et al., 2016; Evans et al., 1981). Higher values of uranium concentration in water samples and its radiological risk along with higher concentration of ^{222}Rn, ^{220}Rn and their decay products have been reported in neighbouring districts (Punjab) of studied area (Sharma and Singh, 2017; Bangotra et al., 2015; Mehra et al., 2014). So an initiative has been taken to study the radiation hazards and radiological risk from soil in Barnala and Sangrur districts for health risk assessment. The main objective of the present study was to study the level of radioactive element viz. ^{226}Ra, ^{232}Th, and ^{40}K in the Barnala and Sangrur region of Punjab (India). The doses of organs and tissues have been also calculated for health risk assessment. In this region, soil is main constituent of brick material used in construction of dwellings.

In this manuscript, the ^{222}Rn exhalation from the soil samples has been also taken into consideration for the health hazard studies. The rate at which ^{222}Rn escapes or emanates from the solid into surrounding air is known as ^{222}Rn emanation or ^{222}Rn exhalation. Many previous studies for ^{222}Rn exhalation rate have been conducted using Can technique (Saad et al., 2013; Sharma and Virk, 2001; Kumar et al., 2005; Menon et al., 2015). Can technique was discarded due interference of ^{220}Rn and tiny leaks from the can. Since the 'cans' are closed with gaskets (not hermetically sealed), it cannot guarantee the zero leakage of the ^{222}Rn during the course of its equilibrium and build– up over a period of 90 days in the can (Menon et al., 2015). In this paper, a Smart Radon Monitor (SRM) has been used for the estimation of ^{222}Rn exhalation rate (Gaware et al., 2011). This method refer to as dynamic method in which the ^{222}Rn monitor, placed in a re-circulating closed loop connected to the soil chamber and inbuilt pump, monitors the ^{222}Rn concentration at regular intervals. The present investigation will be helpful to determine whether the soil of the studied area can be used for construction purpose without posing any health hazard. The obtained data may be the baseline for future research and useful for radiation protection and radiological mapping in Northern India.

2. Geology

The state of Punjab is a vast alluvial plain which is composed of Quaternary Alluvium deposits- Older alluvium, Newer Alluvium and the Aeolian deposits. The scattered outcrops of the Aravali- Delhi Subgroup occur at Tosham (Haryana) just south of the study area i.e. Barnala and Sangrur Districts of Punjab, India (Fig. 1). The soil in the study area falls in the arid and moisture regime. The soils associated with alluvial planes shows better indurations and mature development of soil profile. They are composed of different layers of clay, sticky clay and fine to coarse grained micaceous sandstone (Kochhar et al., 2006).

3. Material and methodology

3.1. Sampling

The soil samples were collected from the different locations of Barnala and Sangrur districts of Punjab, India. In order to collect the natural soil, the soil samples have been collected from an auger hole at a depth of 0.75 m from the ground. The collected samples were crushed into fine powder using pestle and then soil passed through a scientific sieve of 150 μ mesh to obtain sample for measurement. The samples were then dried in an oven at a temperature of 383 K for 24 h. Before measurement each sample was packed in airtight PVC container and kept for a period of four weeks in order to obtain a radioactive equilibrium.

3.2. Measurement of natural radioactivity

Gamma spectroscopy has been used for the measurement of activity concentration of the soil samples due to its salient feature of less time consuming and non- destructive method. The ^{226}Ra, ^{232}Th and ^{40}K has been estimated in studied area using NaI (Tl) gamma detection detector of size 63 mm × 63 mm with a multichannel analyzer. The samples were counted for a period of 10,800 s and analyzed the photo peak of gamma ray of energy 1764 keV, 2610 keV and 1460 keV emitted from ^{226}Ra, ^{232}Th and ^{40}K respectively. The spectral analysis was done with the help of Gamma radiation computer software SPTR – ATC (AT–1315). The peak energies of the gamma ray spectra were measured in reference to the 661-keV photo peak of ^{137}Cs. The activity concentrations of these soil samples were calculated from the intensity of each line in the spectrum, taking into account the mass, geometry of the samples, counting time and efficiency of the detector. The detection limits of the radionuclides, ^{226}Ra, ^{232}Th and ^{40}K are 3 Bq kg^{-1}, 3 Bq kg^{-1} and 30 Bq kg^{-1} respectively. The air absorbed dose rate

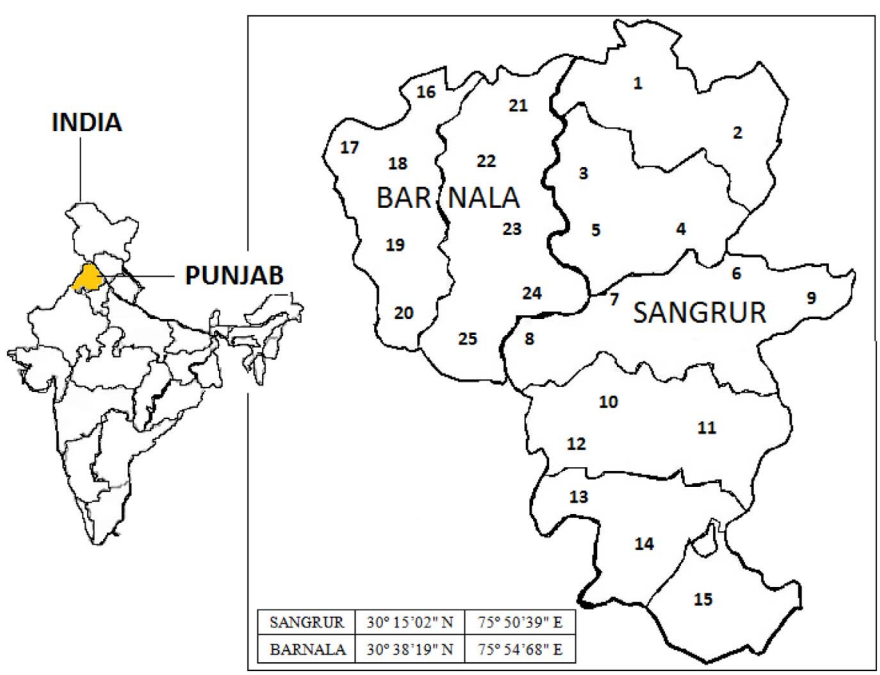

Fig. 1. Map of the investigated area (Barnala and Sangrur) of Punjab (India).

(ADR), annual effective dose (AED), Hazard Indices, Gamma and Alpha activity indices have been calculated using the conversion factors given by UNSCEAR and other agencies as discussed in results and discussion part of the manuscript (UNSCEAR, 1982, 1988, 1993; Beretka and Mathew, 1985).

3.3. Measurement of ^{222}Rn exhalation rate

The exhalation rate of ^{222}Rn has been calculated using SRM (Gaware et al., 2011). ^{222}Rn is sampled into the ZnS (Ag) based scintillation cell (150 cm^3) through a progeny filter and ^{220}Rn discriminator eliminating ^{222}Rn progenies and ^{220}Rn. The ^{220}Rn discriminator based on diffusion-time delay and does not allow the short lived ^{220}Rn to pass thorough. The total scintillation counts obtained in measurement cycle are converted to ^{222}Rn activity concentration (Bq m^{-3}) at the end of each cycle by built in Micro- Controller based smart algorithm. Since this monitor is purely based on direct scintillation counting of alpha particle with buildup and decay corrections achieved through software. The SRM is not affected by humidity and trace gases.

The monitor has a sensitivity factor of 1.2 counts h^{-1} Bq m^{-3} and measurement range of 8 Bq m^{-3} to 10 MBq m^{-3}. The Soil samples (400–500 g) of studied area were dried and enclosed in the leak tight metallic chamber that coupled to continuous SRM. The measurement of data has been taken for longer duration (25–30 h) for the proper ^{222}Rn growth and saturation. ^{222}Rn build up data inside the closed chamber was measured until it reaches a saturation concentration for each sample. The ^{222}Rn exhalation rate has been calculated by fitting the growth data to Eq. (1) as shown in Fig. 2.

$$C(t) = \frac{J_m}{\lambda_e}\frac{M}{V}(1 - e^{-\lambda_e t}) + C_o e^{-\lambda_e t} \quad (1)$$

where J_m is the ^{222}Rn mass exhalation rate (Bq kg^{-1} h^{-1}) and C_o is the ^{222}Rn concentration (Bq m^{-3}) in the chamber volume at $t = 0$. M is the total mass of the dry sample. λ_e is the effective decay constant for ^{222}Rn and t is the measurement time (h).

4. Result and discussion

The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples of Barnala and Sangrur districts are given in Table 1. The concentration of three radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the studied area has varied from 25 Bq kg^{-1} to 48 Bq kg^{-1}, 28 Bq kg^{-1} to 47 Bq kg^{-1} and 356 Bq kg^{-1} to 598 Bq kg^{-1} with an average value of 37 Bq kg^{-1}, 40 Bq kg^{-1} and 451 Bq kg^{-1} respectively. The variation of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the studied area was caused by different chemical and physical properties of radionuclides in soil. The world average concentration of ^{226}Ra, ^{232}Th and ^{40}K are 32 Bq kg^{-1}, 45 Bq kg^{-1} and 420 Bq kg^{-1} (UNSCEAR, 2008). It has been observed that the activity concentration of ^{226}Ra and ^{40}Kwas higher than the world average value of 32 Bq kg^{-1} and 420 Bq kg^{-1}. The activity concentration of ^{40}K was higher due to the excess use of potassium rich fertilizers in the studied area. A comparison of average activity concentration of natural radionuclide (^{226}Ra, ^{232}Th and ^{40}K) in soil samples (in Bq kg^{-1}) from different parts of world and other states of India is shown in Table 2.

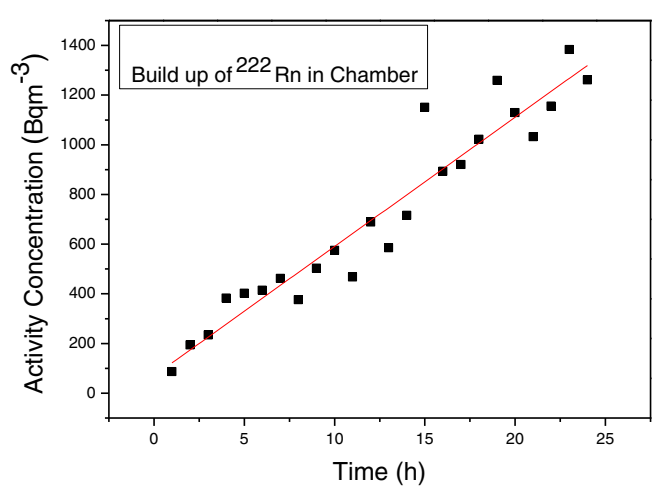

Fig. 2. Growth of ^{222}Rn in exhalation chamber.

The ^{222}Rn exhalation rate in the studied area has been calculated using Eq. 1. The ^{222}Rn exhalation rate in the studied area varied from 16.9 ± 0.5 mBq Kg^{-1} h^{-1} to 38.2 ± 0.9 mBq Kg^{-1} h^{-1} (Table 1). The overall average ^{222}Rn exhalation rate value in the studied area was 29 ± 6 mBq Kg^{-1} h^{-1}. A weak and positive correlation (0.31) was observed between the ^{222}Rn exhalation rate and radium activity as shown in Fig. 2. The previous studies reported both positive as well as negative correlation between ^{226}Ra content and ^{222}Rn exhalation rate (Yadav et al., 2015; Righi and Bruzzi, 2006; Ramola et al., 2011). The weak correlation between these parameters showed that the radionuclides concentration was associated with different chemical and geological properties of radionuclides (Fig. 3). The exhalation rate in the neighbouring state (Haryana) was calculated using sealed canister technique (LR - 115 based) and varied from 50 ± 1 to 143 ± 6 mBq Kg^{-1} h^{-1} (Chauhan et al., 2014). The previous study of exhalation rate conducted by sealed canister technique was shown higher values as compared to SRM due to interference of ^{220}Rn and their decay products.

4.1. Radium equivalent activity (Ra_{eq})

The gamma transitions of energy 609 keV or 1760 keV (due to ^{214}Bi) is used to determine the concentration of ^{226}Ra. Radium Equivalent Activity (Ra_{eq}) is a common index used to compare the specific activities of samples containing different concentration of ^{226}Ra, ^{232}Th and ^{40}K. The Ra_{eq} activity index is widely used as radiological hazard index and has been calculated by Eq. (2).

$$Ra_{eq} = C_{Ra} + 1.43\ C_{Th} + 0.07\ C_K \quad (2)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively. It is assumed that the same gamma dose rate has been produced by 370 Bq kg^{-1} of ^{238}U, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K. The Ra_{eq} activity of the soil samples has been tabulated in Table 1. The Ra_{eq}activity in the studied area varied from 107 Bq kg^{-1} to 143 Bq kg^{-1} with an average value of 125 Bq kg^{-1}. The average value was lower than 370 Bq kg^{-1}, which is accepted limit for safe use as recommended by the Organization for Economic Cooperation and Development (OECD, 1979).

4.2. Estimation of air-absorbed dose rate

There is a direct connection between terrestrial gamma radiation and radionuclide concentration. The major part of the gamma radiation comes from terrestrial radionuclides. The external terrestrial gamma – radiation absorbed dose rates in air at a height of about 1 m above the ground has been calculated using the conversion factor 0.0414 nGy h^{-1} Bq^{-1} kg^{-1} for ^{40}K, 0.461 nGy h^{-1} Bq^{-1} kg^{-1} for ^{226}Ra and 0.623 nGy h^{-1} Bq^{-1} kg^{-1} for ^{232}Th as given in Eq. (3).

$$D\,(\text{nGy h}^{-1}) = 0.461\ \ C_{Ra} + 0.623\ \ C_{Th} + 0.0414\ \ C_K \quad (3)$$

The absorbed dose rate has been calculated from the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K listed in Table 3. The absorbed dose rate has been calculated from the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K and ranged from 11 nGy h^{-1} to 22 nGy h^{-1}, 18 nGy h^{-1} to 29 nGy h^{-1} and 15 nGy h^{-1} to 25 nGy h^{-1} respectively. The total absorbed dose rate in the studied area has varied from 52 nGy h^{-1} to

Table 1
Activity concentration of ^{226}Ra, ^{232}Th, ^{40}K and Ra_{eq} activity index in Barnala and Sangrur districts.

Sr. no.	^{226}Ra	^{232}Th	^{40}K	Ra	Hazard indices		I_γ	I_α	Exhalation
	(Bq kg^{-1})	(Bq kg-^{1})	(Bq kg^{-1})	(Bq kg^{-1})	H_{ex}	H_{in}	(Bq kg^{-1})	(Bq kg^{-1})	(Bq kg^{-1} h^{-1})
1	43 ± 7	40 ± 5	514 ± 32	137	0.38	0.39	0.52	0.22	31.5 ± 0.8
2	38 ± 5	42 ± 9	598 ± 53	140	0.39	0.37	0.54	0.19	22.1 ± 0.5
3	36 ± 4	47 ± 6	475 ± 35	136	0.38	0.37	0.51	0.18	27.4 ± 1.2
4	39 ± 8	35 ± 8	417 ± 43	119	0.33	0.35	0.45	0.20	23.6 ± 1.7
5	41 ± 7	33 ± 6	408 ± 53	117	0.32	0.35	0.44	0.21	34.3 ± 2.1
6	39 ± 9	40 ± 10	489 ± 24	131	0.36	0.37	0.49	0.20	26.3 ± 1.2
7	32 ± 5	35 ± 5	356 ± 29	107	0.30	0.31	0.40	0.16	19.2 ± 1.1
8	36 ± 8	39 ± 7	498 ± 47	127	0.35	0.35	0.48	0.18	22.1 ± 0.7
9	48 ± 6	28 ± 8	512 ± 70	124	0.34	0.37	0.47	0.24	37.5 ± 0.9
10	25 ± 5	38 ± 6	457 ± 34	112	0.31	0.28	0.43	0.12	16.9 ± 0.5
11	41 ± 7	47 ± 6	502 ± 58	143	0.40	0.51	0.54	0.21	33.2 ± 2.3
12	33 ± 4	44 ± 9	444 ± 55	127	0.35	0.44	0.48	0.17	29.4 ± 1.5
13	37 ± 8	37 ± 8	468 ± 42	123	0.34	0.44	0.46	0.19	34.6 ± 1.1
14	28 ± 7	37 ± 7	521 ± 61	118	0.33	0.40	0.45	0.14	35.6 ± 0.5
15	40 ± 5	40 ± 6	412 ± 51	126	0.35	0.46	0.47	0.20	35.7 ± 1.8
16	36 ± 5	40 ± 10	435 ± 30	124	0.34	0.44	0.47	0.18	31.6 ± 1.3
17	33 ± 6	44 ± 5	400 ± 45	124	0.34	0.43	0.46	0.17	24.3 ± 1.7
18	40 ± 8	36 ± 7	384 ± 35	119	0.33	0.44	0.44	0.20	38.2 ± 0.9
19	40 ± 5	35 ± 8	413 ± 58	119	0.33	0.44	0.44	0.20	37.1 ± 0.6
20	32 ± 7	41 ± 5	373 ± 35	117	0.32	0.41	0.44	0.16	27.6 ± 1.3
21	35 ± 9	44 ± 6	394 ± 24	125	0.35	0.44	0.47	0.18	29.4 ± 1.8
22	35 ± 7	47 ± 11	412 ± 38	130	0.36	0.45	0.49	0.17	26.2 ± 0.3
23	38 ± 6	39 ± 5	525 ± 57	131	0.36	0.47	0.50	0.19	31.5 ± 0.9
24	30 ± 5	42 ± 7	468 ± 37	122	0.34	0.42	0.46	0.15	23.7 ± 1.3
25	41 ± 9	38 ± 9	418 ± 40	124	0.34	0.45	0.46	0.20	33.7 ± 2

Table 2
Comparison of activity concentration of ^{226}Ra, ^{232}Th, ^{40}K with other countries and states of India.

Locations	^{226} Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	References
Brazil (Rio Grande do Norte)	29.2	47.8	704	Malanca et al., 1996
United States	40	35	370	Myrick et al., 1983
Jordan	52.9	24	443	Ahmad et al., 1998
Vietnam	42.7	59.8	411.9	Huy et al., 2012
China	42.7	46.3	578	Ziqiang et al., 1988
Pakistan	25.8	49.2	561.6	Akhtar et al., 2005
Kerala (River bank Soil)	603	98.1	343.4	Venunathan et al., 2016
Kerala (River Sediments)	48.6	88	432.2	Venunathan et al., 2016
Uttrakhand (Garhwal Himalaya)	31	30	583	Yadav et al., 2015
Rajasthan	24	55	549	Rani et al., 2015
Haryana	31–63	53–78	472–630	Chauhan et al., 2014
Punjab (Barnala an Sangrur)	37	40	452	Present Study

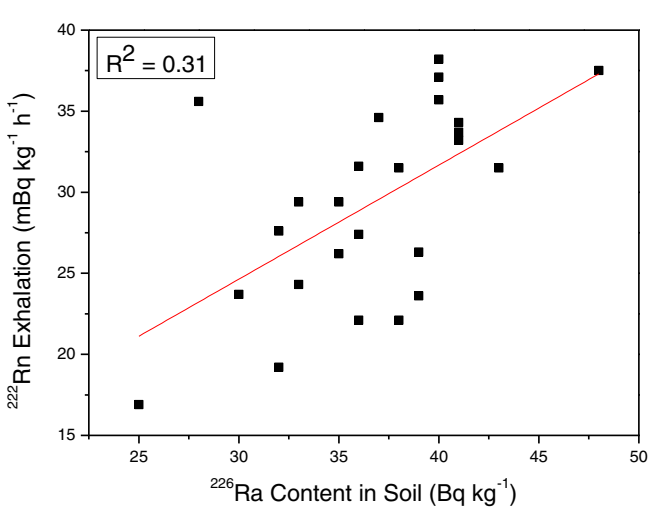

Fig. 3. Correlation between ^{226}Ra content and ^{222}Rn exhalation rate.

69 nGy h^{-1} with an average value of 60 nGy h^{-1}. The average value of absorbed dose rate was found to be lower than the Indian and Global average value 90 nGy h^{-1} and 86 nGy h^{-1} as reported by UNSCEAR (UNSCEAR, 2000).

4.3. Estimation of annual effective dose equivalent (AEDE)

The annual effective dose has been calculated in the studied area using the conversion coefficient (0.7 Sv Gy^{-1}) and occupancy factor (80% for indoor occupancy and 20% for outdoor occupancy Factor) as discussed by UNSCEAR (UNSCEAR, 2000; UNSCEAR, 2008). The annual effective dose equivalent (mSv y^{-1}) calculated from absorbed dose values (D_R) using Eqs. (4) and (5).

$$\text{For Indoor: } AEDE\ (\text{mSv y}^{-1}) = D\,(\text{nGy h}^{-1}) \times 8760\ \text{h} \times 0.8 \times 0.7\,(\text{Sv Gy}^{-1}) \quad (4)$$

$$\text{For Outdoor: } AEDE\ (\text{mSv y}^{-1}) = D\,(\text{nGy h}^{-1}) \times 8760\ \text{h} \times 0.2 \times 0.7\,(\text{Sv Gy}^{-1}) \quad (5)$$

The annual effective dose has been estimated and tabulated in Table 3. The corresponding indoor and outdoor annual effective doses have varied from 0.25 mSv to 0.34 mSv and 0.06 mSv to 0.08 mSv with

Table 3
Absorbed Dose rate, annual effective dose and radiation hazards in Barnala and Sangrur districts.

Sr. no.	Absorbed dose (nGy h^{-1})				Annual effective dose (mSv)		Annual effective dose to organs or body tissues (mSv)				
	^{226}Ra	^{232}Th	^{40}K	Total	Indoor	Outdoor	Lungs	Ovaries	RBM*	Testes	WB#
1	20	25	21	66	0.32	0.08	0.21	0.19	0.22	0.27	0.22
2	18	26	25	69	0.34	0.08	0.22	0.20	0.23	0.28	0.23
3	16	29	20	65	0.32	0.08	0.21	0.19	0.22	0.26	0.22
4	18	22	17	57	0.28	0.07	0.18	0.16	0.19	0.23	0.19
5	19	21	17	57	0.28	0.07	0.18	0.16	0.19	0.23	0.19
6	18	25	20	63	0.31	0.08	0.20	0.18	0.21	0.25	0.21
7	15	22	15	51	0.25	0.06	0.16	0.15	0.17	0.21	0.17
8	17	24	21	62	0.30	0.08	0.19	0.18	0.21	0.25	0.21
9	22	18	21	61	0.30	0.07	0.19	0.17	0.21	0.24	0.20
10	11	24	19	54	0.27	0.07	0.17	0.15	0.18	0.22	0.18
11	19	29	21	69	0.34	0.08	0.22	0.20	0.23	0.28	0.23
12	15	27	18	61	0.30	0.07	0.19	0.17	0.21	0.25	0.20
13	17	23	19	60	0.29	0.07	0.19	0.17	0.20	0.24	0.20
14	13	23	22	58	0.28	0.07	0.18	0.16	0.20	0.23	0.19
15	18	25	17	61	0.30	0.07	0.19	0.17	0.21	0.24	0.20
16	17	25	18	60	0.29	0.07	0.19	0.17	0.20	0.24	0.20
17	15	28	17	59	0.29	0.07	0.19	0.17	0.20	0.24	0.20
18	18	23	16	57	0.28	0.07	0.18	0.16	0.19	0.23	0.19
19	18	22	17	57	0.28	0.07	0.18	0.16	0.19	0.23	0.19
20	15	26	15	56	0.27	0.07	0.18	0.16	0.19	0.22	0.19
21	16	27	16	60	0.29	0.07	0.19	0.17	0.20	0.24	0.20
22	16	29	17	62	0.30	0.08	0.19	0.18	0.21	0.25	0.21
23	18	24	22	64	0.31	0.08	0.20	0.18	0.22	0.26	0.21
24	14	26	19	59	0.29	0.07	0.19	0.17	0.20	0.24	0.20
25	19	23	17	59	0.29	0.07	0.19	0.17	0.20	0.24	0.20

* Red Bone Marrow.
\# Whole body.

average values of 0.29 mSv and 0.07 mSv respectively. The average annual indoor dose from terrestrial radionuclides is 0.46 mSv y^{-1} in the normal background areas (UNSCEAR, 1993). The total average annual effective dose (0.36) value was lower than 0.46 mSv y^{-1} as recommended by UNSCEAR.

The local soil has been used for the formation of bricks as construction material, construction of mud houses and for flooring and labelling the walls. In radiation protection point of view, the doses for different organs and tissues have been calculated for health risk assessment using Eq. 6 (Tufail et al., 1994; Ahmad et al., 1998).

$$H^{\cdot} = Indoor\ accupancy \times D\,(\mathrm{nGy\ h^{-1}}) \times \left(\frac{\left(\frac{\mu_2}{\rho}\right)^{Organ}}{\left(\frac{\mu_1}{\rho}\right)^{air}} \right) \tag{6}$$

where $\left(\frac{\mu_2}{\rho}\right)^{Organ}$ and $\left(\frac{\mu_1}{\rho}\right)^{air}$ are the mass absorption coefficients for organ and air. This fraction is generally denoted by factor f which is nearly independent of energy. The dose equivalent rate in particular organ and tissue from the gamma dose rate has been given in Table 3.

4.4. External (H_{ex}) and internal hazards (H_{in})

External hazards is used to measure the activities in building material for the estimation of radiation dose expected to be delivered externally if building is constructed using these materials. This index is another criterion to assess the radiological suitability of material. The external radiation exposure is usually associated with the gamma radiation emitted by ^{226}Ra, ^{232}Th and ^{40}K. The H_{ex} has been calculated using Eq. (7) (Beretka and Mathew, 1985).

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{7}$$

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{8}$$

The gaseous short- lived decay product of ^{226}Ra called ^{222}Rn, poses a threat to respiratory organs. The internal exposure to ^{222}Rn and its decay is quantified by estimating the internal hazard index in addition of external hazard index. The internal hazard index (H_{in}) has been calculated using the Eq. (8). The value of H_{ex} and H_{in} indices must be < 1 mSv y^{-1} in order to not cause any harmful effects to residents (Quindos et al., 1987).

The results of H_{ex} and H_{in} has been tabulated in Table 1. The estimated value of H_{ex} and H_{in} in the studied area has varied from 0.30 to 0.40 and 0.28 to 0.51 respectively. For safe use of material in the construction of human dwellings, H_{ex} and H_{in} should be less than unity (ICRP, 2000). It has been observed that the average estimated values of hazard indexes were lower than the unity and this indicates that this radiation hazards may not cause any harmful effects to the residents of the studied area.

4.5. Gamma level index (I_γ)

In specific samples, the gamma level index (I_γ) is used to estimate the level of γ – radiation hazard associated with the natural radionuclides. This index is also used to correlate the annual dose rate due to the excess external gamma radiation caused by superficial materials (Jibiri and Okeyode, 2012). The gamma level index (I_γ) in the soil samples has been calculated using Eq. (9) given by European Commission (European Commission, 1999).

$$I_\gamma = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \tag{9}$$

The values of I_γ ranged from 0.40 to 0.54 with an average mean value of 0.47 as given in Table 1. The value of $I_\gamma \leq 0.5$ correspond to dose rate criterion of 0.3 mSv y^{-1}, whereas $I_\gamma \geq 0.5$ correspond to dose rate criterion of 1 mSv y^{-1}. Materials with $I_\gamma > 1.0$ should be avoided in building construction.

4.6. Alpha index (I_α)

The Alpha Index (I_α) is used to estimate the excess alpha radiation

that originating from building material and has been calculated using Eq. (10).

$$I_\alpha = \frac{C_{Ra}}{200} \tag{10}$$

From literature, it has been assumed that when ^{226}Ra activity concentration of building materials exceeds the value of 200 Bq kg^{-1}, it is possible that ^{222}Rn exhalation from these materials may cause indoor ^{222}Rn concentration > 200 Bq m^{-3}. The recommended maximum concentration of ^{226}Ra is 200 Bq kg^{-1}, which gives $I_\alpha = 1$ (Rafique et al., 2011). The alpha index (I_α) in the soil samples of studied region ranged from 0.12 to 0.24 with an average value of 0.18 as tabulated in Table 1. These observed values are less than unity and showed that the materials are safe from the environmental radiation hazards.

4.7. Excess lifetime cancer risk (ELCR)

The Excess lifetime cancer risk (ELCR) has been calculated for the assessment of extra risk of developing cancer due to exposure of a toxic substances acquired over the lifetime. ELCR has been calculated using Eq. (11).

$$\text{ELCR} = \text{AEDE} \times \text{T} \times \text{RF} \tag{11}$$

where T and RF are the duration of life (70 years) and risk factor (0.05 Sv^{-1}) respectively. The calculated range of ELCR was varied from 0.21×10^{-3} to 0.28×10^{-3}. The average value of ELCR in the investigation area was lower than the world average value of 0.29×10^{-3}.

5. Conclusion

The concentration of ^{226}Ra and ^{40}K in soil samples of Barnala and Sangrur region of Punjab have been found to be higher than the world figures reported in UNSCEAR (2000). However, the concentrations for ^{226}Ra are almost same as world value of 35 Bq kg^{-1}. ^{226}Ra is generally deposited on the surface of soil gain in the earth's crust. ^{222}Rn comes in the environment by the decay of ^{226}Ra into ^{222}Rn and transportation from soil pores. The complex tectonic features and diverse lithology also contribute to radioactivity in the environment. A weak positive correlation was observed between the ^{222}Rn exhalation rate and radium content. The discrepancy of correlation between soil ^{222}Rn gas, ^{222}Rn and ^{220}Rn exhalation rates and natural radionuclide concentration may be figured out by considering complex structure of soil and geological parameters. It was observed that the exhalation rate calculated by SRM was much lower than the previous studies conducted by sealed canister technique.

The Ra_{eq} activity is lower than the safe limit of 370 Bq kg^{-1}. The calculated average absorbed dose rate in air (60 nGy h^{-1}) due to gamma-ray emitters in the soil samples was lower than the world average value of 86 nGy h^{-1}. The results obtained have shown that the external and internal hazard for the studied soil samples is lower than unity which is safe according to Radiation Protection 112 report (European Commission, 1999). In the present investigation, it was observed that all parameters for radiation hazards and dose were lower than their recommended values. The results of this study can be used as baseline data for observation of any possible change in Barnala and Sangrur region of Punjab (India) in future. In the light of above results the soil of the studied area can be used as a construction material without any radiological hazards to the residents.

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