Evaluation and analysis of ^{226}Ra, ^{232}Th and ^{40}K and radon exhalation rate in the soil samples for health risk assessment

Sandeep Kansal*

Department of Physics,
Giani Zail Singh Punjab Technical University Campus,
Bathinda 151001, Punjab, India
Email: skansal2k1@yahoo.com
*Corresponding author

Rohit Mehra

Department of Physics,
Dr. B.R. Ambedkar National Institute of Technology,
Jalandhar 144001, Punjab, India
Email: mehrar@nitj.ac.in

Abstract: The measurements of radium, thorium and potassium using gamma spectrometry and radon exhalation rates using solid-state nuclear track detectors (LR-115, Type-II plastic) are carried out in the soil samples collected from some parts of western districts of Haryana, India. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K range from 13.93 to 142 Bq kg^{-1}, 35.95 to 91.78 Bq kg^{-1} and 299.57 to 1056.77 Bq kg^{-1}, respectively. The values of total absorbed dose and annual effective dose (indoors and outdoors) were found to vary from 42.12 to 140.05 nGy h^{-1}, 0.22 to 0.69 mSv y^{-1} and 0.05 to 0.17 mSv y^{-1} respectively. The radium equivalent activity (Ra_{eq}) in all the soil samples varies from 92.51 to 287.08 Bq kg^{-1} with an average of 184.15 Bq kg^{-1}. The radium values are lower than the recommended safe limit of 370 Bq kg^{-1} hence there is no radiological risk to the residents of the studied area.

Keywords: gamma spectrometry; Ra_{eq}; annual effective dose; radium; radon exhalation rate.

Reference to this paper should be made as follows: Kansal, S. and Mehra, R. (2015) 'Evaluation and analysis of ^{226}Ra, ^{232}Th and ^{40}K and radon exhalation rate in the soil samples for health risk assessment', *Int. J. Low Radiation*, Vol. 10, No. 1, pp.1–13.

Biographical notes: Sandeep Kansal is working as Associate Professor in Physics and Head, Department of Applied Physics at GZS Punjab Technical University Campus, Bathinda, India. He has 19 years of teaching and around nine years of research experience including at UG and PG level. He is working in the field of radiation dosimetry and has used various active and passive techniques for measurement of radon gas and natural radioactivity in soil, water and air. He has many publications in international and national journals of repute and also has presented research work at various international and national conferences.

Rohit Mehra is working as Associate Professor in Physics and Head, Department of Physics at Dr BRA National Institute of Technology, Jalandhar, India. He has wide experience in teaching and working in the field of radiation dosimetry in studying different areas of Punjab and Haryana states of India for the past around 17 years. He has more than 60 publications in international and national journals of repute. He has guided many students for their masters, MPhil and PhD work. He has completed the research project from Bhabha Atomic & Research Center (BARC) Mumbai and is still working on project from Govt. of India in studying radiation health effects.

1 Introduction

Human beings have always been exposed to natural radiations arising from both terrestrial and extraterrestrial sources. Terrestrial radiation is due to radioactive nuclides present in varying amounts in soil, building materials, water, rocks, and atmosphere, while the extraterrestrial radiations originate from outer space as primary cosmic rays. The world is naturally radioactive, and around 90% of human radiation exposure arises from natural sources such as cosmic radiations, exposure to radon gas and terrestrial radiations. The knowledge of radionuclides distribution and radiation level in the environment is important for assessing the effects of radiation exposure. Radiological implications of radionuclides in soil are due to not only ingestion but also external exposure and inhalation of radon and its daughters.

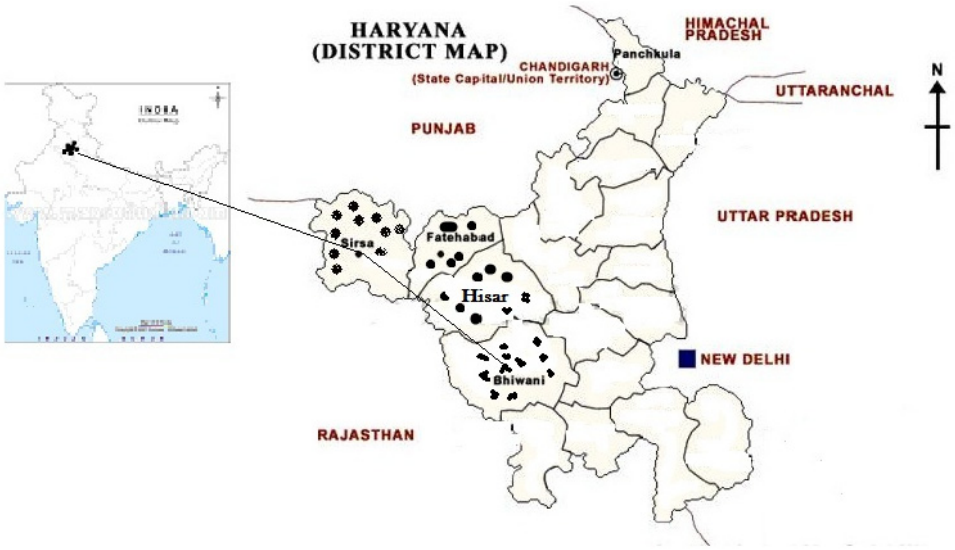
To evaluate the terrestrial gamma dose rate for outdoor occupations, it is very important to estimate the natural radioactivity level in soils. The natural radioactivity of soil samples is usually determined from the ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K contents (Khan et al., 1998; Singh et al., 2009). Since 98.5% of the radiological effects of the uranium series are produced by radium and its daughter products, the contributions from the ^{238}U and the other ^{226}Ra precursors are normally ignored. The measurement from the dose rate of natural radioactivity due to gamma rays is needed to implement precautionary measures whenever the dose is found to be above the recommended limits. Therefore, the analysis and assessment of gamma radiation dose from natural sources are of particular importance as natural radiation is the largest contributor to the external dose of the world population (Radhakrishna et al., 1993). External gamma dose estimation due to the terrestrial sources is essential as these doses vary depending upon the concentrations of the natural radionuclides, ^{238}U, ^{232}Th, their daughter products and ^{40}K, present in the soils and rocks, which further depend upon the local geology of each region in the world (Quindos et al., 1994). External gamma dose estimation due to terrestrial sources is essential not only because it contributes considerably (0.46 mSv y^{-1}) to the collective dose but also because of the variations of individual doses related to these pathways. The levels of background radiations vary from 1.4 mSv to 2.4 mSv per year depending on the concentrations of primordial radionuclides in soil, and the latitude and longitude of the place (Gusain et al., 2009).

Radon (^{222}Rn), a decay product of radium in the naturally occurring uranium series, is a radioactive inert gas and is responsible for about half of the radiation dose received by the general population (UNSCEAR, 1994). In all natural soils, radon atoms are continuously produced in the alpha-decay chains of uranium and thorium. A fraction of them disperse into the air-filled pores of the soil and eventually escape to the atmosphere.

Radon and its progeny attached to aerosols present in the ambient air constitute significant radioactive hazards to human lungs. During respiration radon progeny deposits in the lungs and irradiates the tissue, thereby damaging the cells, and may cause lung cancer. Henshaw et al. (1990) claimed that indoor radon exposure is associated with the risk of leukaemia and certain other cancers, such as melanoma and cancers of the kidney and prostate. The concentration of radon and its decay products shows large temporal and local fluctuations in the indoor atmosphere due to variations in temperature, pressure, nature of building materials, ventilation conditions, wind speed, etc.

The growing worldwide interest in natural radiation exposure has led to extensive surveys in many countries. Many studies have been carried out worldwide (Rahman et al., 2007; Sohrabi, 1998; UNSCEAR, 2000) and also in India in order to determine the risks and effects of long-term, low-level and natural radiation exposure. From literature review it is observed that though some studies have been done in the adjoining states of Punjab (Bajwa et al., 2003) and Himachal Pradesh (Sharma et al., 2003), Rajasthan (Nageswara Rao et al., 1996) and also for the Indian soils (Sadasivan et al., 2003) and the data on the contents of radioactive elements are available for some states of India, the data available for western districts of Haryana are quite meagre. The detailed evaluation and analysis of naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) and radon exhalation rate have been carried out for the first time in the soil samples collected from some parts of Western Haryana, India, for health risk assessment.

Figure 1 The dotted area studied in western districts of Haryana



Source: Maps of India site via internet

It is important to mention that Haryana is one of the northern states of India. The latitude of the study area lies between 29.14° and 30.30°N and longitude lies between 74.29° and 76.28°E as shown in Figure 1 (dotted). Physiographically, the study area is characterised by three distinct features, i.e. upland plain, alluvial bed (flood plain) of river Ghaggar and sand dune clusters. Soil of the study area is alluvium in nature. It has two types of soils, namely Sierozem (found in major parts) and Desert soils (found in smaller parts). The

geological formations mainly comprise unconsolidated alluvial deposits of Quaternary age. The alluvial deposits comprise sand, silt, clay associated with kankar. The alluvium forms the principal ground water reservoir and the principal aquifer material comprises fine to medium sand and sand mixed with kankar. The thickness of the alluvium varies from 200 to 300 m. Apart from this, the Tusham ring complex in Bhiwani district of Haryana is known to be composed of acidic volcanic and the associated granites (Kochhar, 1989).

2 Material and method

2.1 Measuring the activity concentration of radium, thorium and potassium

Soil samples were collected from different locations in the Bhiwani, Fatehabad, Hisar and Sirsa districts of Western Haryana, India. The soil was collected from an auger hole at a depth of about 0.75 m from the ground so as to get the natural soil. After collection, samples were crushed into fine powder using a mortar and pestle. A fine quality of the sample was obtained using a scientific sieve with a 150 micron mesh size. Before measurement samples were dried in an oven at about 383 K for 24 hrs, each sample was packed and sealed in an airtight PVC container and kept for about a four-week period to allow radioactive equilibrium between radon (^{222}Rn), thoron (^{220}Rn), and their short-lived progenies. On an average 0.25 kg of soil was taken for each sample. For calibration of the low background counting system, a secondary standard was obtained and calibrated with the primary standard obtained from the International Atomic Energy Agency. The concentration of ^{226}Ra was determined using a photon peak of 609 keV (46.1%) from ^{214}Bi. The 186 keV photon peak of ^{226}Ra was not used because of the interfering peak of ^{235}U with an energy of 185.7 keV. The ^{232}Th concentration was determined using the gamma transitions of 583 keV (86%) from ^{208}Tl. The ^{40}K concentration was determined using the gamma transition of 1461 keV (10.7%). Using an HP-Ge detector with a high-resolution gamma spectrometry system, the activity of samples was counted. The detector was a co-axial *n*-type high-purity germanium detector (make EG&G, ORTEC, Oak Ridge, USA). The detector had a resolution of 2.0 keV at 1332 keV and relative efficiency of 20%. The output of the detector was analysed using a 4K ADC system connected to a PC. The spectrum was analysed using the locally developed software CANDLE (Collection and Analysis of Nuclear Data using Linux nEtwork). The detector was shielded using 4 inch of lead on all sides to reduce the background level of the system (Mehra et al., 2009). The efficiency calibration for the system was carried out using a secondary standard source of uranium ore in geometry available for sample counting. Efficiency values were plotted against energy for a particular geometry and were fitted by the least squares method to an empirical relation that takes care of the nature of the efficiency curve for the HP-Ge detector. The samples were counted for a period of 72,000 s and the spectra were analysed for the photo peak of uranium and thorium daughter products and ^{40}K. The net count rate under the most prominent photo peaks of radium and thorium daughter peaks was calculated by subtracting the respective count rate from the background spectrum obtained for the same counting time. Then the activity of the radionuclides was calculated from the background subtracted area of the prominent gamma ray energies of interest.

2.2 Measurement of radon exhalation rate

For radon exhalation measurements the samples were collected in clean, dry polyethylene bags. These samples were chosen to understand particularly the migration and exhalation of radon in naturally occurring soils. A glass bottle of about 1-litre capacity was used as an emanation chamber. The samples (0.25 kg) were placed at the bottom of the bottles, which were then closed for about one month in order to establish equilibrium between radium and radon members of the decay series. After one month the bottles were opened and LR-115 type-II plastic track detectors were suspended inside the bottles in a bare mode. The height of the detector was selected such that direct alpha particles do not reach the detectors. The bottles were then closed for about three months to record alpha activity under secular equilibrium conditions (Shanbag et al., 2005). After exposure the detectors were removed and etched in 2.5 N NaOH solution at 60°C for 90 min, using a constant temperature bath. The tracks were counted using an Olympus microscope at a magnification of 400. The resulting track density was then converted into Bq m^{-3} by appropriate calibration factor (Ramola et al., 1996). The 'radon exhalation rate' in terms of area is obtained from the expression (Abu-Jarad et al., 1980):

$$E_A = \frac{CV\lambda}{A\left[T + 1/\lambda\left(e^{-\lambda T-1}\right)\right]}$$

where:

E_A = radon exhalation rate in terms of area (mBq m^{-2} hr^{-1}),

C = the integrated radon exposure as measured by a LR-115 plastic track detector (Bq m^{-3} hr),

V = the effective volume of the bottle (m^3),

λ = the decay constant for radon (hr^{-1}),

T = the exposure time (hr),

A = the area of the bottle (m^2).

Now to calculate the radon exhalation rate in terms of mass (mBq kg^{-1} hr^{-1}):

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

where E_M is the radon exhalation rate in terms of mass (mBq kg^{-1} hr^{-1}) and M is the mass of the sample (0.25 kg).

3 Results and discussion

3.1 Estimation of radium, thorium and potassium in soil samples

The concentrations of radium, thorium and potassium in the collected soil samples were calculated using the following equation:

$$\text{Activity(Bq)} = \frac{\text{CPS}\times 100\times 100}{\text{B.I.}\times\text{Eff}} \pm \frac{\text{CPS}_{\text{error}}\times 100\times 100}{\text{B.I.}\times\text{Eff}}$$

where:

CPS = the net count rate per second,

B.I. = the branching intensity,

Eff = the efficiency of the detector.

Table 1 shows the concentration of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples which varies from 13.93 to 142 Bq kg^{-1}, 35.95 to 91.78 Bq kg^{-1} and 299.57 to 1056.77 Bq kg^{-1} with average values of 48.02, 66.21 and 591.98 Bq kg^{-1}, respectively. World average concentrations for ^{226}Ra, ^{232}Th and ^{40}K are 35 Bq kg^{-1}, 30 Bq kg^{-1} and 400 Bq kg^{-1}, respectively (UNSCEAR, 2000). The errors shown in the results are the statistical uncertainties in track counting. Table 1 shows that, in general, the averages and ranges of the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil in these areas are higher than the world average values as reported above. The values of ^{226}Ra in all the soil samples are below the range (2.5–207.0 Bq kg^{-1}) reported for Indian soils (Nageswara Rao et al., 1996) using gamma ray spectrometry and also the values are less than the permissible value (370 Bq kg^{-1}) which is acceptable as a safety limit (OECD, 1979). These values reported for the radium content in soils of the study areas are generally higher as compared with the values in Malwa region of Punjab (Mehra et al., 2007) and in the Bathinda district of Punjab (Singh et al., 2005). The values of activity concentrations of ^{226}Ra and ^{232}Th are less than, and the value of activity concentrations of ^{40}K is higher than, those reported earlier for the Kullu area by Kaul et al. (1993). However, a detailed investigation is required to reach a conclusion.

Table1 Activity concentration of radium, thorium, potassium and radium equivalent in western districts of Haryana

S. no.	*Sample location (village)*	*Radium concentration in soil (C_{Radium}) (Bq kg^{-1})*	*Thorium concentration in soil ($C_{Thorium}$) (Bq kg^{-1})*	*Potassium concentration in soil ($C_{Potassium}$) (Bq kg^{-1})*	*Radium equivalent (R_{eq})*
1	Bhattu Kalan	14.23	41.67	405.67	102.22
2	Sampla	16.43	45.65	398.23	109.59
3	Bhodiya Khera	22.43	67.34	312.45	140.6
4	Dhanger	24.67	56.78	384.34	132.77
5	Jandli Khurd	20.34	35.95	299.57	92.72
6	Bigher	17.33	37.39	310.12	92.51
7	Bhuna	21.41	47.55	324.18	112.1
8	Dadam	13.93	65.36	351.35	131.99
9	Aharwan	24.13	61.56	332.43	135.43
10	Gorakhpur	14.81	55.67	399.62	122.39
11	Khanak	55.07	88.77	835.68	240.51
12	Riwasa	58.02	88.5	697.73	233.42
13	Tosham	75.57	88.89	640.82	247.54
14	Biran	56.93	79.26	801.92	226.41

Table1 Activity concentration of radium, thorium, potassium and radium equivalent in western districts of Haryana (continued)

S. no.	*Sample location (village)*	*Radium concentration in soil (C_{Radium}) (Bq kg^{-1})*	*Thorium concentration in soil ($C_{Thorium}$) (Bq kg^{-1})*	*Potassium concentration in soil ($C_{Potassium}$) (Bq kg^{-1})*	*Radium equivalent (R_{eq})*
15	Bhiwani	43.14	61.41	640.19	175.77
16	Halluwas	76.07	91	1056.77	280.17
17	Ladwa	76.35	89.73	752.27	257.32
18	Hansi	56.16	85.78	667.37	225.54
19	Dhana kalan	65.28	91.78	618.98	239.85
20	Panniwala Ruldu	69.63	67.68	972.34	234.48
21	Odha	142	50.31	1044.76	287.08
22	Kherpur	92.56	58.78	776.83	230.99

3.2 Evaluation of radium equivalent activity

The distribution of natural radioactivity in the soil is not uniform. Uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity (Ra_{eq}) in Bq kg^{-1} to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. About 98.5% of the radiological implications are due to ^{226}Ra and its daughter products in the ^{238}U series. The natural abundance of ^{235}U is only 0.72% of the total uranium content and hence was not considered in the present study, except its ^{226}Ra contribution at 186 keV. The gamma transitions of energy 609 keV due to ^{214}Bi were used to determine the concentration of ^{226}Ra. The criterion for this model considers the external hazard due to gamma rays corresponds to a maximum Ra_{eq} of 370 Bq kg^{-1} for the building material. This Ra_{eq} is calculated through the following relation (Yu et al., 1992):

$$Ra_{eq} = C_{Ra} + 1.43\ C_{Th} + 0.07\ C_K$$

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. When defining Ra_{eq}, it was assumed that 370 Bq kg^{-1} for ^{226}Ra, 259 Bq kg^{-1} for ^{232}Th and 4810 Bq kg^{-1} for ^{40}K produce the same gamma dose rate. Using the above equation, the Ra_{eq} found in the soil samples is given in Table 1. The Ra_{eq} calculated for the same soil samples varies from 92.51 to 287.08 Bq kg^{-1} with an average value of 184.15 Bq kg^{-1}. It is inferred that for all the soil samples analysed, the Ra_{eq} value is well within the permissible limits of 370 Bq kg^{-1}.

3.3 Estimation of absorbed and effective dose

The external terrestrial gamma radiation absorbed dose rates in air at a height of about 1 m above the ground are calculated by 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

(UNSCEAR, 1993), assuming that ^{137}Cs, ^{90}Sr and the ^{235}U decay series can be neglected as they contribute very little to the total dose from the environmental background (Kocher and Sjoreen, 1985; Jacob et al., 1986; Leung et al., 1990):

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

where C_{Ra}, C_{Th} and C_K are the activity concentrations (Bq kg^{-1}) of radium, thorium and potassium in the samples. To estimate annual effective doses, account must be taken of the conversion coefficient from the absorbed dose in air to the effective dose, and the indoor occupancy factor. The annual estimated average effective dose equivalent received by a member is calculated using a conversion factor of 0.7 Sv Gy^{-1}, which is used to convert the absorbed rate to human effective dose equivalent with an outdoor occupancy of 20% and 80% for indoors (UNSCEAR, 1993). The annual effective doses are determined as follows:

$$\text{Indoor (nSv)} = (\text{absorbed dose})\ nGy^{-1} \times 8760\ h \times 0.8 \times 0.7\ Sv\ Gy^{-1}$$

$$\text{Outdoor (nSv)} = (\text{absorbed dose})\ nGy^{-1} \times 8760\ h \times 0.2 \times 0.7\ Sv\ Gy^{-1}.$$

The calculated total absorbed doses and annual effective dose rates of samples are shown in Table 2. The International Commission on Radiological Protection (ICRP) has recommended the annual effective dose equivalent limit of 1 mSv yr^{-1} for the individual members of the public and 20 mSv yr^{-1} for radiation workers (ICRP, 1993). From Table 2 it is observed that the absorbed dose rate calculated from the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K ranges between 6.42 and 65.5 nGy h^{-1}, 22.4 and 57.2 nGy h^{-1} and 12.4 and 43.75 nGy h^{-1}, respectively. The total absorbed dose in the study area ranges from 44.12 to 140.1 nGy h^{-1}, with an average value of 87.89 nGy h^{-1}. The corresponding indoor and outdoor annual effective doses range from 0.22 to 0.69 mSv and 0.05 to 0.17 mSv, with an average value of 0.43 and 0.10 mSv, respectively. The worldwide average annual effective dose is approximately 0.5 mSv, and the results for individual countries are generally within 0.3–0.6 mSv range for indoors. A generally similar trend is observed in all the samples, and no regular trend in the variation in the annual effective dose and absorbed dose rate is observed from the soil samples. Our results for average annual effective dose are within the range of worldwide average values.

Table 2 Radiation absorbed dose and annual effective dose from soil samples from western districts of Haryana

S. no.	*Sample location*	*Absorbed dose (nGy h^{-1})*				*External hazard index (H_{ex})*	*Annual effective dose (mSv)*	
	(village)	*Ra*	*Th*	*K*	*Total*		*Indoor*	*Outdoor*
1	Bhattu Kalan	6.56	25.96	16.79	49.31	0.28	0.24	0.06
2	Sampla	7.57	28.44	16.49	52.5	0.3	0.26	0.06
3	Bhodiya Khera	10.34	41.95	12.94	65.23	0.39	0.32	0.08
4	Dhanger	11.37	35.37	15.91	62.65	0.37	0.31	0.08
5	Jandli Khurd	9.38	22.4	12.4	44.18	0.26	0.22	0.05
6	Bigher	7.99	23.29	12.84	4412	0.26	0.22	0.05

Table 2 Radiation absorbed dose and annual effective dose from soil samples from western districts of Haryana (continued)

S. no.	Sample location	Absorbed dose (nGy h^{-1})				External hazard index (H_{ex})	Annual effective dose (mSv)	
	(village)	Ra	Th	K	Total		Indoor	Outdoor
7	Bhuna	9.87	29.62	13.42	52.91	0.31	0.26	0.06
8	Dadam	6.42	40.72	14.55	61.69	0.36	0.3	0.08
9	Aharwan	11.12	38.35	13.76	63.23	0.37	0.31	0.08
10	Gorakhpur	6.83	34.68	16.54	58.05	0.34	0.28	0.07
11	Khanak	25.39	55.3	34.6	115.29	0.67	0.57	0.14
12	Riwasa	26.75	55.14	28.89	110.78	0.64	0.54	0.14
13	Tosham	34.84	55.38	26.53	116.75	0.68	0.57	0.14
14	Biran	26.24	49.38	33.2	108.82	0.63	0.53	0.13
15	Bhiwani	19.89	38.26	26.5	84.65	0.49	0.42	0.1
16	Halluwas	35.07	56.69	43.75	135.51	0.78	0.66	0.17
17	Ladwa	35.2	55.9	31.14	122.24	0.71	0.6	0.15
18	Hansi	25.89	53.44	27.63	106.96	0.62	0.52	0.13
19	Dhana kalan	30.09	57.18	25.63	112.9	0.66	0.55	0.14
20	Panniwala Ruldu	32.1	42.16	40.25	114.51	0.65	0.56	0.14
21	Odha	65.46	31.34	43.25	140.05	0.8	0.69	0.17
22	Kherpur	42.67	36.62	32.16	111.45	0.64	0.55	0.14

3.4 External hazard index (H_{ex})

The external hazard index (H_{ex}) can be calculated by the following equation (Beretka and Mathew, 1985):

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_K/4810 \leq 1$$

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. The values of this index must be less than unity in order to keep the radiation hazard insignificant. The radiation exposure due to the radioactivity from a construction material is limited to 1.5 mGy yr^{-1}. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370 Bq kg^{-1}). The calculated values of H_{ex} for the soil samples studied range from 0.26 to 0.8 (Table 2). Since these values are lower than unity, therefore, soil from these regions is safe and can be used as a construction material without posing any significant radiological threat to populations.

3.5 Radon exhalation rate measurements

The calculated values of radon exhalation rate for soil samples are presented in Table 3. The radon exhalation rate varies from 6.32 to 14.25 mBq kg^{-1} h^{-1} for mass exhalation rate and from 139.55 to 500.74 mBq m^{-2} h^{-1} for surface exhalation rate in soil samples. These values are lower than those reported by Mehra et al. (2006) for the soils adjoining

the Malwa region of Punjab. The variation in values of radon exhalation rate may be due to the difference in radium content (Ramachandran and Subba Ramu, 1989) and porosity of the soil (Folkerts et al., 1984).

Table 3 Radon exhalation rates from soil samples of western Haryana

S. no.	*Sample location*	*Radon exhalation rate*	
		E_M	E_A
		(mBq kg^{-1} hr^{-1})	*(mBqm^{-2} hr^{-1})*
1	Riwasa	9	317.64
2	Tosham	14.25	500.74
3	Bhiwani	13.34	470.24
4	Biran	9.99	351.37
5	Khanak	13.01	458.88
6	Bigher	8.18	180.5
7	Bhuna	9.69	213.83
8	Ratia	11.68	257.81
9	Dadam	11.01	292.8
10	Aharwan	6.75	148.99
11	Kheri	10.81	312.26
12	Mirzapur	8.44	186.1
13	Kandur	9.35	206.35
14	Uklana	6.32	139.55
15	Kaimri	8.3	183
16	Kherpur	11.45	402.24
17	Panniwala Ruldu	10.36	365.93
18	Sirsa	7.92	279.34
19	Vaidwala	10.59	372.44
20	Samat Khera	6.63	234.29

4 Conclusion

In general, the values of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil of the studied areas are higher than the world average values of 35 Bq kg^{-1}, 30 Bq kg^{-1} and 400 Bq kg^{-1}, respectively. Table 4 shows the comparison of natural radioactivity levels in soil and air absorbed dose at different locations of western districts of Haryana, India, with those in other countries as given in UNSCEAR (2000). The results obtained have shown that the indoor and outdoor effective doses due to natural radioactivity of soil samples are lower than the average national and world recommended value of 1.0 mSv yr^{-1}. The calculated values of H_{ex} for the soil samples are lower than unity; therefore, soil from these regions is safe and can be used as a construction material without posing any significant radiological threat to populations. Also the measurement

of exhalation rates of soil samples only can give some indication on possible exhalation rates of building material since the exhalation process is dependent on the final form of the material.

Table 4 Comparison of natural radioactivity levels in soil and air absorbed dose at different locations of western districts of Haryana, India, with those in other countries as given in UNSCEAR (2000)

Region/ country	*Concentration in soil (Bq kg^{-1})*						*Absorbed dose rate in air (nGy h^{-1})*	
	^{238}U (^{226}Ra)		*^{232}Th*		*^{40}K*			
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Egypt	17	5–64	18	2–96	320	29–650	32	20–133
USA	40	8–160	35	4–130	370	100–700	47	14–118
Argentina					650	540–750		
Bangladesh	34	21–43	41	1–360	350	130–610		
China	32	2–440	95	16–200	440	9–1800	62	2–340
Hong Kong	59	20–110	64	14–160	530	80–1100	87	51–120
India	29	7–81	28	2–88	400	38–760	56	20–1100
Japan	33	6–98			310	15–990	53	21–77
Korea			22	5–42	670	17–1500	79	18–200
Iran	28	8–55	19	8–30	640	250–980	71	36–130
Denmark	17	9–29	27	5–50	460	240–610	52	35–70
Belgium	26	5–50	50	7–70	380	70–900	43	13–80
Luxembourg	35	6–52	25	4–70	620	80–1800	49	14–73
Switzerland	40	10–900	30	7–160	370	40–1000	45	15–120
Bulgaria	45	12–210	21	4–77	400	40–800	70	48–96
Poland	26	5–120	38	11–75	410	110–970	45	18–97
Romania	32	8–60	21	1–190	490	250–1100	59	21–122
Greece	25	1–240	51	22–100	360	12–1570	56	30–109
Portugal	44	8–65	33	2–210	840	220–1230	84	4–230
Spain	32	6–250	220.5	35–125	470	25–1650	76	40–120
Present study	48	14–142	66	36–92	592	299–1056	88	44–140

Acknowledgements

The authors are grateful to Dr. Amit Roy, Director, Inter University Accelerator Centre, New Delhi, and Dr. Rajendra Sonkawade, Scientist, Health Physics Lab, Inter University Accelerator Centre, New Delhi, India, for providing the necessary support and facilities for the gamma ray spectroscopy to carry out this research work.

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