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RESEARCH ARTICLE - SPECIAL ISSUE

Assessment of radionuclide concentration and exhalation studies in soil of lesser Himalayas of Jammu and Kashmir, India

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Abstract
Because to extensive utilization of soil as a building/construction stuff, the activities of ^{238}U, ^{40}K, ^{232}Th, and exhalation studies in solid samples have been measured using thallium activated sodium iodide (NaI(Tl)) gamma detector and scintillation-based smart RnDuo monitor. The measured activity concentration of radionuclides lies in the range of 2.76–38.96, 12.47–65.70, and 199–450 Bq/kg for uranium (C_U), thorium (C_{Th}), and potassium (C_K), respectively. The annual effective dose rate due to radionuclides is within the secure limit suggested by ICRP. The radium equivalent activity of all the samples is under 100 Bq/kg. The maximum outward and inside risk indices of all these samples are below the values of 0.37 and 0.43. No direct correlation has been seen between ^{238}U and its mass exhalation rate as well as ^{232}Th and its surface exhalation rate in soil samples.

Keywords Radionuclide concentration · Exhalation rate · RnDuo monitor · Air absorbed dose

Introduction

Since its formation, earth is radioactive in nature. Various radioactive elements such as uranium, radium, thorium, etc., are present in its abiotic components, i.e., rocks, soil, and water. Some of the radionuclides (^{238}U, ^{232}Th, and ^{40}K) of these elements have very long half-lives even in hundreds of years. The inhalation and ingestion of these radionuclides above the permissible level is a serious health hazard (Singh et al. 2007). Therefore, assessment of these radionuclides in any environment is of the level of interest due to its harmful effects. Inhalation of high uranium content increases the risk of lung and bone tumor and damage to internal organs particularly the kidneys (Lussenhop et al. 1958; Hursh and Spoor 1973; ATSDR 1999).

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According to UNSCEAR report, ^{40}K, ^{238}U, and ^{232}Th contributes 35, 25, and 40%, respectively, to the total radiation dose a population receives (UNSCEAR 1982). Soil and rocks are the one of the main sources of these background radiations. Radionuclides present in rocks are carried to soil through rain and the subsequent water streams (Taskin et al. 2009). When these radionuclides come in association with the soil, these can absorb the reactive layer of particles, perform ion interchange, precipitate as an oxide-hydroxide or sulphide, and form complexes with organic compounds or remain as such (Schulz 1965). Hence, once reached, these radionuclides remain in soil in one form or another. Now, these nuclides and their decay products come in contact with public mainly through ingestion and inhalation. Along with natural radioactivity, anthropogenic activities like industrial wastes and extensive use of phosphate fertilizers are also responsible for soil radioactivity (Abbady et al. 2008).

Prime contribution of the ionizing radiation (more than 50%) received by human population comes from Radon (^{222}Rn), thoron (^{220}Rn), and their naturally radioactive short-lived decay products taking all sources of radiation into account (Mazur and Kozak 2014). Therefore, this field has gained a lot of importance for last many years, both in terms of their transport properties and their influence on

human health (United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000).

Radon exhalation rate amount to the emission of radon or thoron gas from a unit mass or surface area with respect to time. It depends upon many factors like radium (^{226}Ra) concentration in soil or rock, porosity, permeability, humidity, temperature, and meteorological conditions (Schery et al. 1984). In the present effort, the newly developed active quantification approach RnDuo monitor (Gaware et al. 2011) has been employed to display exhalation studies in solid samples.

The purpose of the present investigation is to quantify radionuclide contents, viz., ^{238}U, ^{232}Th, and ^{40}K, in composed samples of Reasi district of Jammu and Kashmir state using NaI(Tl) gamma spectrometry. Various radiological parameters are determined thereafter and the annual effective dose encountered by the inhabitants of the region is also calculated. The scintillation-based smart RnDuo monitor (SRM) is used to assess exhalation rates due to radon and thoron.

Geology of the area

Reasi district (Fig. 1) is located at 33.08°N and 74.83°E with a mean elevation of 466 m. It is predominantly a hilly District, which enjoys variable climatic conditions, ranging from subtropical to the semi temperate. It has a total area of nearly 1700 km^2 and is surrounded by Udhampur district on the eastern, Ramban district on northern eastern fringes, Rajouri district on its western and north western ends, and Jammu district on its southern ends. A part of the district also touches Shopian district on Northern fringes. One of the major rivers "Chenab" flows through the district. Some of the small rivers/rivulets like Ans, Rudd, Plassu, Ban Ganga, Pai, and Anji also flow in the district, which finally merge into Chenab. Reasi has abundance of bauxite, iron, and precious stones. The district is underlain by rock formations ranging in age from pre-cambrian to quaternary period.

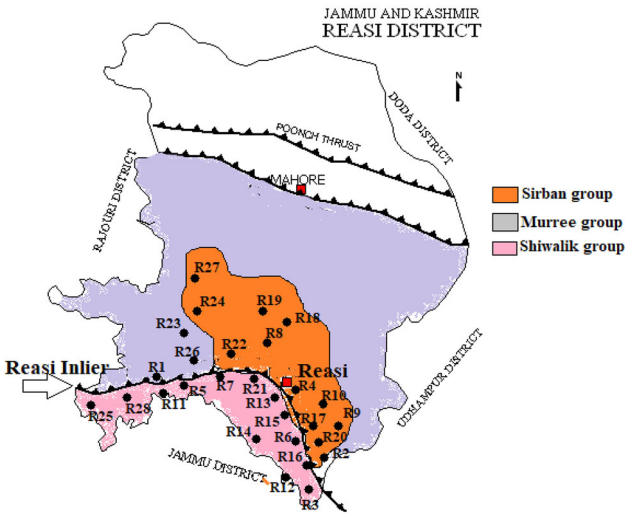

Fig. 1 Map showing the area surveyed during present investigation

The regional structure in the central part of the area displays the Riasi–Katra inlier as a south-easterly plunging anticline with Sirban group in the core and younger Tertiaries fringing it. The northern limb is normal, whereas southern limb is faulted. This thrust is called Katra/Reasi Thrust, which is of great magnitude and corresponds to Main Boundary Fault bringing the Murree and Siwalik Group in direct contact with the Sirban Group in this part of the area.

Experimental technique

Sampling

Soil samples were collected from 28 distinct locations of different areas of Reasi district of Jammu and Kashmir state, India, below 30 cm from the surface for the estimation of radionuclides concentration and exhalation. The soil samples were first dried and then converted into a fine powder using mortar and pestle. Then, these are sieved through 200 μm mesh.

Quantification of ^{222}Rn mass exhalation rate

Radon concentration in soil samples has been calculated by smart RnDuo monitor (Gaware et al. 2011). The samples were put to dry before setting them in the stainless steel exhalation chamber with dimensions 8 cm length and 9 cm diameter. The measurement technique is explained elsewhere (Singh et al. 2016, 2017; Bangotra et al. 2017). ZnS(Ag) is used as a scintillation material having volume 150 cc. Soil sample is connected to scintillation cell through progeny filter and ^{220}Rn discriminator. This discriminator eliminates the ^{220}Rn gas and ^{222}Rn progeny. The total alpha counts obtained are converted into ^{222}Rn activity concentration (Bq/m^3) through micro-processor based algorithm. The monitor has a sensitivity limit of 1.2 counts/h/Bqm^3 and calculation range of 8 Bq/m^3 to 10 MBq/m^3.

The growth of radon concentration in compartment has been achieved for each sample till it saturates and radon mass exhalation rate (J_m) is estimated using the exponential equation (Sahoo et al. 2007):

$$C_R(t) = \frac{J_m m}{\lambda_e V}(1 - e^{-\lambda_e t}) + C_0 e^{-\lambda_e t},$$

where $C_R(t)$ = radon concentration at any instant in Bq/m^3, J_m shows the radon mass exhalation rate (Bq/kg/h). m = mass of sample (kg), V = volume of the compartment and the scintillation cell (m^3), and λ_e = disintegration constant for radon.

Quantification of ^{220}Rn surface exhalation rate

For measuring ^{220}Rn surface exhalation, dehydrated samples were put in the exhalation compartment and scintillation-based smart RnDuo monitor was set on Thoron mode for estimation of thoron concentration (Gaware et al. 2011). The exhalation compartment was attached to the monitor by way of a closed circuit loop and pump is automatically set for 5 min (Singh et al. 2016, 2017; Bangotra et al. 2017). The ^{220}Rn surface exhalation rate (J_S) (Bq/m^2/s) in soil samples can be obtained from the following expression (Sahoo et al. 2014; Kanse et al. 2013):

$$J_S = \frac{C_T V \lambda}{A},$$

where C_T is the average thoron concentration in soil samples. V is the residual air volume (m^3), λ is ^{220}Rn decay constant, and A is the sample surface area (m^2).

Estimation of natural radioactivity

The prepared samples were dehydrated in an electric furnace at 110 °C to minimize the moisture content. The dried samples were accumulated in impermeable PVC vessels of 300 ml capacity having configuration as that of IAEA standard gamma sources employed for efficiency calibration (IAEA 1987). These sealed containers are kept aside for a span of 30 days before gamma spectrometric investigation, so as to permit radioactive stability among the decay products of radon (^{222}Rn) and thoron (^{220}Rn). The composed samples were put in a spectrometry unit and the spectra were analysed. The gamma ray lines of 1460.8, 1764.5, and 2614.6 keV were employed for ^{40}K, ^{238}U, and ^{232}Th analysis. The detector was fixed to a computer program MAESTRO window that complemented gamma energies to a collection of possible isotopes. The activity concentration of soil specimens was estimated from the strength of each peak, considering the sample mass, the configuration of samples, counting time, and effectiveness of the detector.

The specific activity (A) was computed by the following equation (Saini and Bajwa 2017):

$$A(\mathrm{Bq/kg}) = \frac{N - B}{\gamma \varepsilon t M}, \quad (1)$$

where N = net counts of the respective nuclide in a photo peak, B is the background count, ε = detection efficiency of crystal at energy E, t = counting live time (86,400 s), γ = gamma ray abundance per disintegration, and M is mass of sample in kg.

Theoretical formalism

Radium equivalent activity ($Ra_{activity}$)

The equivalent activity has been calculated by taking the 4810, 370, and 259 Bq/kg for ^{40}K, ^{238}U, and ^{232}Th to produce a uniform gamma dose (OECD 1979). Following relation has been used for the calculation:

$$\mathrm{Ra_{activity}} = C_U + 1.43C_{Th} + 0.07C_K, \quad (2)$$

where C_U, C_{Th}, and C_K are the activity amounts of the subscript denoted radionuclides. According to OECD, the maximum recommended limit for radium activity concentration is 370 Bq/kg.

Dose rate (D_R)

The earthly absorbed dose rates have been computed using the following conversion factors given by UNSCEAR (2000):

$$D_R(\mathrm{nGy/h}) = 0.461C_U + 0.623C_{Th} + 0.0414C_K. \quad (3)$$

Annual effective dose equivalent

This dose equivalent has been estimated using the factor of 0.7 and occupancy factor (taking 80% for indoor environment and 20% for outdoor environment) recommended by UNSCEAR (2000, 2008). Following relations have been used for the calculations of annual effective dose:

$$D_{AE_{Indoor}}(\mathrm{mSv/year}) = D_R(\mathrm{nGy/h}) \times 8760 \times 0.7 \times 0.8 \times 10^{-6} \quad (4)$$

$$D_{AE_{Outdoor}}(\mathrm{mSv/year}) = D_R(\mathrm{nGy/h}) \times 8760 \times 0.7 \times 0.2 \times 10^{-6}. \quad (5)$$

External and internal hazard index

Internal and external hazards are radiation dose risk used to measure the activity of the building material and soil expected to deliver internally and externally. This radiation exposure is interlinked with the gamma radiations emitted

from ^{238}U, ^{232}Th, and ^{40}K. Following relations have been used to determine the external (H_{ex}) and internal (H_{in}) hazard index (Beretka and Mathew 1985):

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (6)$$

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810}. \quad (7)$$

Excess lifetime cancer risk (ECR)

It is the parameter which monitors the possibility of originating cancer over one's lifetime at a given subjection level. A rise in ECR results in a relative rise in the rate at which a person can get affected with prostate, breast or even blood leukaemia. This risk has been calculated as follows (Taskin et al. 2009):

$$\text{ECR} = D_{AE} \times L_{duration} \times R_{factor}, \quad (8)$$

where D_{AE} = annual effective dose equivalent. $L_{duration}$ = average lifetime, and R_{factor} = risk factor (0.05 Sv^{-1}) respectively.

Results and discussion

The observed activity content in soil of 28 locations of Reasi district, Jammu and Kashmir varied from 2.76 to 38.96 Bq/kg for ^{238}U, from 12.47 to 65.7 Bq/kg for ^{232}Th, and from 199 to 450 Bq/kg for ^{40}K (Table 1). The variation in radionuclide levels in soil samples of the study region from location to location is may be due to the difference in the geological setting. ^{238}U, ^{232}Th, and ^{40}K concentrations in three locations (10.71% samples), two locations (7.14% samples), and four locations (14.28% samples), respectively, are elevated than the global values (32, 45, and 420 Bq/kg for U, Th, and K) (UNSCEAR 2008). The high concentrations of radionuclides in these few samples are due to the presence of sedimentary rocks and different geological structures in the study area. Figure 2 represents a box whisker plot which displays the variation of radionuclide concentrations and is positively skewed. A positive correlation between ^{238}U & ^{40}K and ^{232}Th & ^{40}K in soil samples is may be due to high retaining capability of these radionuclides under different geographical/atmospheric conditions.

The ^{222}Rn mass and ^{220}Rn surface exhalation rate in soil of the examined area has been calculated and shown in Table 1. The ^{222}Rn mass and ^{220}Rn surface exhalation rate varied from 8.38 to 62.32 mBq/kg/h and from 82 to 1009 mBq/m^2/s, respectively. The variation of ^{222}Rn mass and ^{220}Rn surface exhalation rate is given in Fig. 3. No correlation has been observed between ^{222}Rn mass exhalation and ^{238}U concentration as well as between the ^{220}Rn surface exhalation and ^{232}Th concentration in soil samples of the study region. There is no fixed trend for correlation between ^{238}U concentration and ^{222}Rn mass exhalation rate in observed samples. Both positive as well as negative correlations have been observed earlier (Yadav et al. 2015; Righi and Bruzzi 2006; Ramola et al. 2011).The negative interconnection of parent and daughter nuclei may be due to the difference in soil texture and geological and chemical properties of the radionuclides. It also depends upon the location of collection of soil samples. If collection is done at the depth of 10–20 cm from the soil surface (upper layer), then there is low radionuclide activity; whereas deep in the earth, radionuclides concentration is predominantly high.

Activity concentrations of radionuclides (^{40}K, ^{226}U, and ^{232}Th) and mass exhalation rate in the samples gathered from the studied region of Jammu and Kashmir have been compared with neighbouring states as given in Table 2. The measured average activities of radionuclides are less than the reported values presented in Table 2.

A parameter known as Radium Equivalent Activity ($Ra_{activity}$) jointly represents the radiation threats linked with activities of U, Th, and K and the suitability of soil for agriculture. For radium equivalent activity, U has been substituted by Ra, decay product of U (Iqbal et al. 2000). $Ra_{activity}$ ranges from 41.20 to 136.43 Bq/kg with an average value of 82.41 ± 23.45 Bq/kg, respectively, as given in Table 3. The mean value of $Ra_{activity}$ of the collected soil samples is below 370 Bq/kg, which is the recognised limit of safe use (OECD 1979).

The gamma radiations and radionuclide concentration are directly connected with each other. The major share of gamma radiations comes from radionuclide concentrations. The D_R in air has been computed using the conversion factors given by UNSCEAR (2000). The total absorbed dose rate in the observed area varied from 20.25 to 63.50 nGy/h with a mean of 40.05 ± 10.92 nGy/h (Table 3). The average value of air absorbed dose rate is lower than global average dose rate of 59 nGy/h (UNSCEAR 2000) and also from the national mean dose rate of 88.4 nGy/h (Nambi et al. 1987).

Annual effective dose rate has been computed in indoor and outdoor environment and is reported in Table 3. The annual effective dose rate has been found to be varying from 99.35 to 311.53 μSv/year with a mean value of 196.47 ± 53.56 μSv/year for indoor and from 24.84 to 77.88 μSv/year with a mean value of 49.12 ± 13.39 μSv/year for outdoor, respectively. The total annual effective dose is seen to be below than the world's average dose of 0.52 mSv/year and criterion limit of 1000 μSv/year (ICRP 1990). The variation of annual effective dose is shown in stack plot (Fig. 4). Each bar in the chart represents a total

Table 1 Activity concentration of ^{238}U, ^{232}Th, ^{40}K, and exhalation rates in soil samples of Reasi districts

Location ID	Villages	GPS	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Mass exhalation rate (mBq/kg/h)	Surface exhalation rate (mBq/m^2/s)
R1	Dabh Khalsa	33°04.646′74°39.874′	38.96 ± 0.31	12.53 ± 0.35	381 ± 0.10	27.09 ± 1.11	198 ± 41
R2	Dhirti	32°54.136′74°57.458′	33.99 ± 0.40	23.87 ± 0.31	331 ± 0.06	36.53 ± 2.17	786 ± 75
R3	Dhroal	32°54.395′74°56.399′	14.60 ± 0.33	43.02 ± 0.35	395 ± 0.08	8.37 ± 0.51	992 ± 96
R4	Garn	33°00.534′74°54.478′	38.64 ± 0.27	12.47 ± 0.30	381 ± 0.10	50.46 ± 2.01	199 ± 47
R5	Jadli	33°05.113′74°43.606′	24.55 ± 0.38	29.77 ± 0.21	377 ± 0.23	34.85 ± 2.42	348 ± 76
R6	Karoa	33°01.588′74°52.786′	29.07 ± 0.49	44.06 ± 0.35	450 ± 0.25	62.32 ± 3.34	428 ± 34
R7	Malat	33°04.337′74°44.425′	22.80 ± 0.27	37.92 ± 0.23	402 ± 0.17	18.61 ± 0.57	590 ± 78
R8	Mari	33°05.981′74°51.441′	24.25 ± 0.27	17.56 ± 0.09	293 ± 0.87	23.86 ± 1.29	566 ± 74
R9	Panthal	32°58.448′74°58.499′	27.5 ± 0.25	27.54 ± 0.08	322 ± 0.04	15.82 ± 0.13	642 ± 76
R10	Parthal	32°59.777′74°55.119′	33.32 ± 0.27	25.74 ± 0.19	331 ± 0.29	51.78 ± 2.93	285 ± 78
R11	Pouni	33°05.459′74°41.225′	23.46 ± 0.27	35.58 ± 0.17	428 ± 0.27	27.36 ± 1.79	258 ± 59
R12	Sarna	32°56.656′74°54.607′	19.31 ± 0.31	38.48 ± 0.16	418 ± 0.27	35.69 ± 1.10	773 ± 85
R13	Silla	33°04.989′74°49.295′	19.53 ± 0.55	65.70 ± 0.27	328 ± 0.33	29.79 ± 0.33	217 ± 54
R14	Simbal Chowk	33°03.220′74°50.717′	23.01 ± 0.24	37.92 ± 0.08	392 ± 1.0	33.82 ± 0.89	83 ± 31
R15	Sulla saketar	33°04.383′74°50.013′	13.63 ± 0.30	25.08 ± 0.06	416 ± 0.21	20.17 ± 0.55	315 ± 58
R16	Nomain	32°57.999′74°54.528′	8.64 ± 0.36	22.68 ± 0.02	340 ± 0.10	9.44 ± 0.95	128 ± 50
R17	Chamba	32°59.171′74°57.528′	29.17 ± 0.28	29.14 ± 0.14	320 ± 0.25	15.82 ± 0.13	861 ± 91
R18	Bidda	33°07.098′74°48.715′	18.07 ± 0.19	46.98 ± 0.09	331 ± 0.09	23.15 ± 0.96	511 ± 78
R19	Gujar koti	33°07.525′74°48.760′	12.76 ± 0.21	29.64 ± 0.24	447 ± 0.15	9.91 ± 0.63	82 ± 40
R20	Kakrial	32°55.632′74°57.008′	14.74 ± 0.49	24.53 ± 0.14	449 ± 0.67	25.26 ± 1.18	346 ± 56
R21	Kans khasan	33°04.466′74°46.791′	18.53 ± 0.28	26.89 ± 0.13	311 ± 0.49	17.63 ± 0.67	1008 ± 116
R22	Talwara	33°06.245′74°47.676′	13.17 ± 0.09	29.94 ± 0.17	248 ± 0.14	24.45 ± 0.57	105 ± 68
R23	Bharakh	33°07.350′74°38.325′	11.18 ± 0.42	15.43 ± 0.43	199 ± 1.04	14.05 ± 0.56	292 ± 63
R24	Kantha	33°08.282′74°36.642′	11.69 ± 0.53	28.39 ± 0.33	284 ± 1.21	30.60 ± 0.59	500 ± 91
R25	Bhambla	33°03.147′74°34.552′	12.21 ± 0.61	14.87 ± 0.37	228 ± 1.16	18.04 ± 0.54	380 ± 59
R26	Khaira lair	33°05.928′74°39.499′	15.16 ± 0.60	15.33 ± 0.35	201 ± 0.98	18.82 ± 0.99	508 ± 69
R27	Ransoo	33°09.963′74°36.211′	14.41 ± 0.68	26.75 ± 0.37	227 ± 1.14	17.57 ± 0.85	227 ± 54
R28	Garn Jagir	33°04.268′74°38.886′	13.86 ± 0.63	13.52 ± 0.41	228 ± 1.08	35.92 ± 1.25	300 ± 64

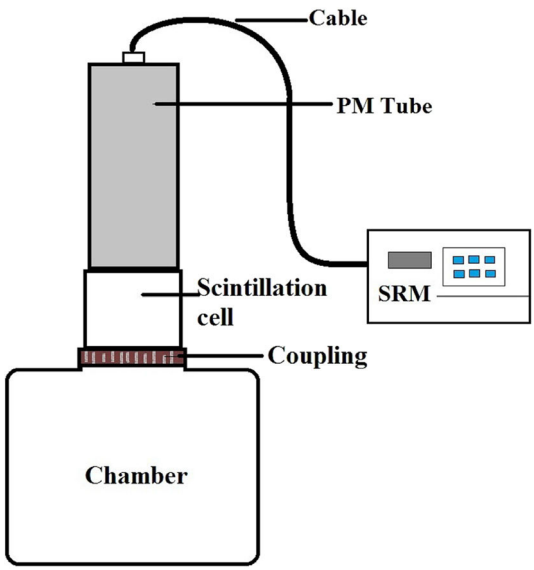

Fig. 2 Systematic diagram of radon mass exhalation setup

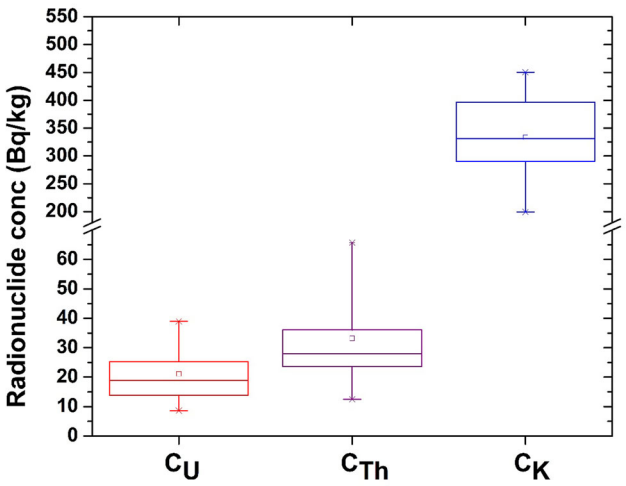

Fig. 3 Box–Whisker plot of radionuclide concentration

Table 2 Range of activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples of Northern regions of India

Regions	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{222}Rn mass exhalation (mBq/kg/h)	References
Barnala, Punjab	37	40	452	29	Bangotra et al. (2017)
Hamirpur	34.8	53.2	434	22.51	Singh et al. (2016)
Rajasthan	69	55	874	14.75	Jakhu et al. (2017)
Garhwal, Himalaya	31	30	538		Yadav et al. (2015)
Haryana	31–63	53–78	472–630		Chauhan et al. (2014)
Southeast Haryana	1.6–23.3	22–157	228–389	8.2–18.4	Singh et al. (2017)
Reasi, Jammu and Kashmir	21	29	338	26.44	Present study

Table 3 Calculated parameters from radionuclide (^{238}U, ^{232}Th, and ^{40}K) concentrations

Villages	$Ra_{activity}$	D (nGy/h)	Annual effective dose (μSv/year)		H_{ex}	H_{in}	ELCR
			AED_{indoor}	$AED_{outdoor}$			
Dabh Jagir	114.22	54.90	269.33	67.33	0.32	0.42	0.04
Dhirti	91.31	44.25	217.08	54.27	0.25	0.34	0.05
Dhroal	103.74	49.87	244.63	61.16	0.29	0.33	0.03
Garn	83.13	41.35	202.83	50.71	0.23	0.34	0.04
Jadli	93.51	45.47	223.08	55.78	0.26	0.33	0.03
Karoa	123.61	59.50	291.88	72.97	0.34	0.42	0.05
Malat	105.18	50.79	249.15	62.29	0.29	0.35	0.04
Mari	69.86	34.24	167.98	41.99	0.19	0.26	0.04
Panthal	89.39	43.15	211.67	52.92	0.25	0.32	0.03
Parthal	93.28	45.09	221.20	55.30	0.26	0.35	0.03
Pouni	104.28	50.69	248.66	62.12	0.29	0.35	0.03
Sarna	103.59	50.17	246.14	61.53	0.29	0.34	0.06
Silla	136.43	63.50	311.53	77.88	0.37	0.43	0.04
Simbal Chowk	104.69	50.47	247.58	61.89	0.29	0.352	0.04
Sulla saketar	78.62	39.14	191.99	47.99	0.22	0.26	0.03
Nomain	64.86	32.18	157.86	39.46	0.18	0.20	0.07
Chamba	93.25	44.85	220.03	55.01	0.26	0.34	0.03
Bidda	108.39	51.28	251.58	62.89	0.30	0.35	0.04
Gujar koti	86.44	42.86	210.24	52.56	0.24	0.28	0.04
Kakrial	81.22	40.65	199.40	49.85	0.23	0.27	0.04
Kans khasan	78.76	38.17	187.27	46.82	0.22	0.27	0.04
Talwara	73.32	34.98	171.59	42.89	0.20	0.24	0.03
Bharakh	47.20	23.02	112.92	28.23	0.13	0.16	0.03
Kantha	72.14	34.82	170.79	42.70	0.20	0.23	0.04
Bhambla	49.39	24.31	119.24	29.81	0.14	0.17	0.05
Khaira lair	51.18	24.88	122.05	30.51	0.14	0.18	0.03
Ransoo	68.53	32.69	160.38	40.09	0.19	0.23	0.04
Garn Jagir	49.17	24.26	119.02	29.75	0.14	0.17	0.02

(indoor + outdoor) annual effective dose; and lower (blue color) segments in the bar represent the $D_{AE_{Indoor}}$ and upper (yellow color) segments represent the $D_{AE_{Outdoor}}$.

The estimation of hazard index must be less than one, i.e., the exposure due to radionuclide concentration is to be restricted to 1.5 mGy/year (Iqbal et al. 2000). If the maximum value of $Ra_{activity}$ is less than the 370 Bq/kg, then maximum value of H_{ex} is also be less than one. The calculated values of H_{ex} for the soil samples have been ranged from 0.11 to 0.37, which is less than one (Table 3). In

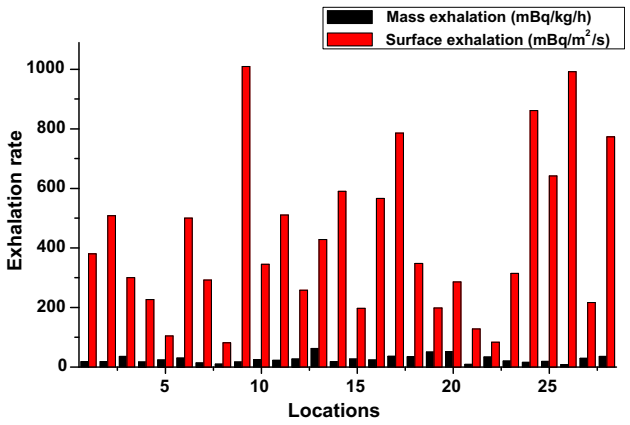

Fig. 4 Variation of ^{222}Rn mass and ^{220}Rn surface exhalation rate

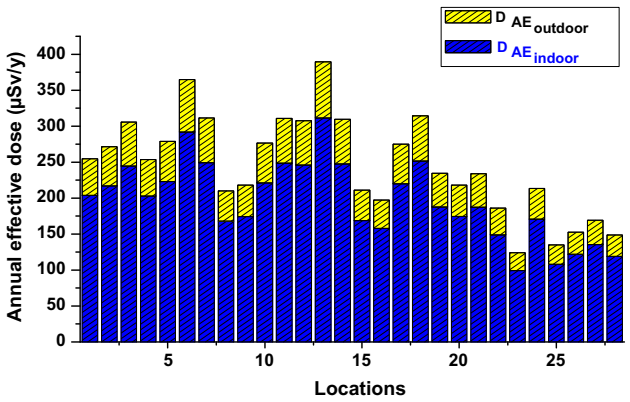

Fig. 5 Variation of indoor and outdoor annual effective dose

addition to the external hazard, the internal hazard index (H_{in}) is also assessed, because radon and its decay resultants are also dangerous for the respiratory system and the internal exposure due to radon and its daughter products is assessed by the internal hazard index. The calculated value of H_{in} ranges from 0.12 to 0.43 as shown in Fig. 5 and all these values are less than one. This figure is used to compare the H_{ex} with H_{in}, and external hazard is less than the internal hazard.

Excess lifetime cancer risk (ECR) is the prospective carcinogenic effect that is distinguished by estimating the probability of cancer occurrence in a population of individuals for a particular lifetime from extended exposures. The calculated range of ECR varied from 0.43×10^{-3} to 1.36×10^{-3} with an average of 0.86×10^{-3}, respectively. The reported values of ECR are generally more than the global mean value of 0.29×10^{-3} (Fig. 6).

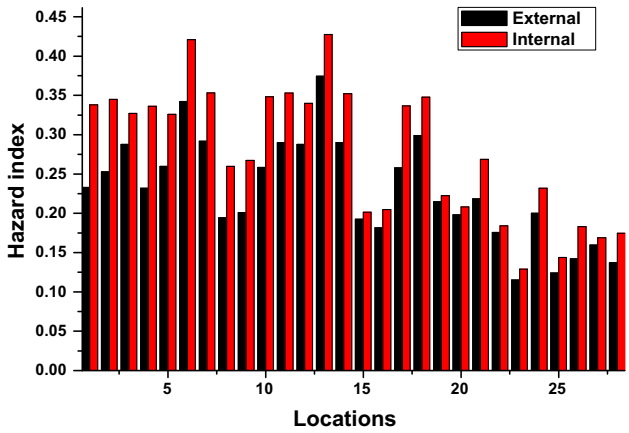

Fig. 6 Measured values of both the external and internal hazard indices for the soil samples collected from various geological sites of Reasi district

Conclusions

The present study has shown the results of measurement of exhalation studies, gamma radioactivity measurements, and their respective external exposures to soil from Reasi district of Jammu and Kashmir state, India. The observed concentrations of U, Th, and K in the soil samples have been found to be in the range of 2.76–38.96, 12.47–65.70, and 199–450 Bq/kg, respectively. The maximum value of ^{238}U is almost same as the global average of 35 Bq/kg. The $Ra_{activity}$ of these soil samples were found in the range of 41.19–136.42 Bq/kg and are below the maximum recommended value of 370 Bq/kg. No direct correlation has been found between ^{222}Rn exhalation rate and ^{238}U as well as between ^{232}Th and ^{220}Rn exhalation rate.

The results obtained from this study reveal that all the calculated parameters of radiation hazards and doses are within their suggested levels. The conclusions of this study can be used as standard data for radionuclide mapping. It is realized that the soil from the various geological locations of Reasi district is safe for using it as a construction material or for other purposes without posing any radiological hazards to the inhabitants.

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