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Gamma dose monitoring to assess the excess lifetime cancer risk in western Himalaya

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Abstract
The present work focussed on demarcation of areas with cancer development risk through excess lifetime cancer risk (ELCR) by assessing spatial variability of gamma dose in outdoor and indoor environment in western Himalaya. Average outdoor gamma dose and outdoor annual effective dose exceed the corresponding world averages. An indoor gamma dose (barring Budgam, Ganderbal and Kashmir University of Kashmir division and Reasi city of Jammu division) also exceed the world average. The probability of cancer development is higher in main-Shopian (3.65×10^{-3}), Mala Bagh (2.80×10^{-3}), Bundoda (2.88×10^{-3}) and Dhadpeta (2.89×10^{-3}), as total ELCR exceeds the world average.

Keywords Gamma dose · Annual effective dose · Excess lifetime cancer risk · Western Himalaya

Introduction

Background radiation in outdoor and indoor environments to which humans are continuously exposed in natural environment has cosmic, anthropogenic and terrestrial origin. Cosmic ray and naturally occurring radioactive material (NORM) are two main natural sources of radiation leading to human exposure [1]. An annual exposure of a person to natural background radiation has been estimated to be equal to 2.4 mSv accounting 80% of total annual radiation dose exposure [2]. The world population-weighted cosmic ray annual effective dose excluding cosmogenic radionuclide contribution (accounting 0.01 mSv), extends from 0.3 to 2 mSv with an average of 0.38 mSv (0.28 mSv from directly ionizing and photon component and 0.10 mSv from neutron component), thus contributes 16% to the total annual exposure of the population. The cosmic ray dose received varies, depends on the latitude and altitude, which increases with their increase [1]. Negligible contribution is from anthropogenic activities like nuclear tests and accidents, whose fission product is Cs-137. However, terrestrial radiation from naturally occurring radioactive materials (NORM) like uranium-238, thorium-232 and potassium-40 possessed in soils, rocks, water, salts etc. and also in various food substances accounts for major contribution to total annual effective dose (0.48 mSv) received by population after radon and its decay progeny inhalation (1.15 mSv). The radon and its daughter products are naturally occurring radionuclides emanating from ^{238}U decay series. The terrestrial radiation and radon constitute more than 60% of natural background radiation. The significant proportion of terrestrial radiation which depend on activity concentrations of ^{238}U, ^{232}Th and ^{40}K, varies with geo-environmental conditions including type and composition of soil, rocks and earth's crust material of an area [1, 2]. Humans spending 80% of their time inside (houses, offices and other places) are also exposed to gamma radiations from ground surfaces and materials used for the construction. The major proportion of annual effective dose (1.15 mSv) in an indoor environment is attributed to radon and its short lived daughter products [1]. Their concentration levels within infrastructures is directly associated with radionuclide concentrations in building materials and also on ventilation rate [3]. As low ventilation rate in the buildings results in an enhanced accumulation of radon, thus increasing internal exposure and proliferates the health risks.

An increase in the probability of cancer development, despite of an infinitesimal increase in radiation dose is referred to as linear, no-threshold (LNT) relationship [4]. LNT dose response model, basis for radiation protection at

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low dose and dose rates, enables the progressive and sustainable development of radiation protection programs to safeguard humans from health oriented risks ICRP-103[5]. So, estimation of background radiation in an area has become of utmost importance due to an increase in various types of cancers at an alarming rate which may be considered to be associated with ionizing radiations from various sources. The time gap, referred as latent period between cancer diagnosis and radiation exposure, making excess lifetime cancer risk (ELCR) as prognostic of cancer development. So, to predefine the risk of cancer development, ELCR is significant prognostic parameter. Several studies have been carried out in the other parts of India and through-out the world [6–18]. In Jammu, Kashmir and Ladakh divisions, there has been as such no presentable and convincing work with regard to gamma radiations, except on a village level in district Udhumpur [19, 20]. So, the present study has put its focus on gamma radiation monitoring in all three divisions.

The present study which will act as a base for further studies from environmental and health perspective in monitoring area has concentrated on:

1. Assessment and spatial variability of outdoor and indoor gamma absorbed dose rates and annual effective dose.
2. Identification of areas with higher risk of cancer development through ELCR assessment.
3. Comparative evaluation of study area with respect to other monitored areas in India and world.

Materials and methods

Study area

The study area lying in NW part of India with an area of 101,387 km^2 stretches between 32° 17′ N to 37° 05′ N latitudes and 72° 31′ E to 80° 20′ E longitudes. Jammu, Kashmir and Ladakh divisions are characterized by sub-tropical, temperate and arid to semi-arid (cold) type of climates respectively. The SW monsoon influences Jammu and Kashmir divisions from June to September [21, 22]. However, the Ladakh division is a rain shadow region during Indian summer monsoons [23].

Geologically, area surveyed with regard to gamma radiation dose rate comprises; Outer-Himalayas, Lesser-Himalayas, Higher-Himalayas and Trans-Himalayas covering Jammu, Kashmir and Ladakh divisions. The southern part of Himalaya (i.e., Outer-Himalayas), represented by Jammu division, consists of Shiwalik Group of rocks [24].

The litho-stratigraphy of Kashmir division hosts the rocks of all ages from Precambrian to Holocene represented by Salkhalas, Dogra Slates, Muth-Quartizite, Syringothyris Limestone, Fenestella Shale, Agglomeratic Slate, Panjal Traps, Gangmopteris beds, Zewan Formation, Triassic Limestone, Karewa Formation and Recent Alluvium. Among all the geological formations, Panjal Traps and Triassic limestones form the two main formations in Kashmir division [25].

The Ladakh Himalaya from south to north comprises Zanskar zone, Indus Suture zone (ISZ), Shyok Suture zone (SSZ) and Karakoram Zone [26, 27]. The Zanskar zone comprises of Zanskar crystalline complex, Zanskar Supergroup and Tso-Morari crystalline complex [26]. The ISZ marking convergence zone between Indian and Eurasian plate encompasses assortment of deep marine sediments, Dras volcanics, ophiolites, Indus molasses and Ladakh batholith [28]. The SSZ is delimited by Ladakh batholith and Karakoram zone on south and north respectively.

Land-use/land-cover (LULC) statistics

The description of terrestrial environment from natural processes and human activities perspective is projected through land use land cover statistics [29]. Terrestrial environment with different built-up, forest, barren land, wet-land, water body etc. area will result in variable exposure of humans to gamma dose in an area. As the change in built-up area results in corresponding change in radiation levels and risk to humans due to utilization of construction material, composed of varied radionuclide concentrations [30]. Similarly, the forest-cover decrease and increase in an area consequently results in increase or decrease of exposure to extra-terrestrial radiation. So, this land use land cover data will help us to further refine the understanding about the variability and controls of gamma doses in study area. The LULC of study region is presented in Table 1 [31].

Dosimeter and dosimetry

Thermoluminscent dosimeters (TLD's) being sensitive and inexpensive have been utilized in assessment of gamma dose in outdoor as well as in indoor environments. These TLD's were prepared by Bhabha Atomic Research Centre (BARC), Mumbai using CaF_2 powder as phosphorescent material. The preparation of material for TLD's to measure dose is discussed in [32] and the calibration to analyse thermoluminscent output signal is discussed elsewhere [33]. The net gamma dose is retrieved from TLD's after subtracting the additional exposures received during the storage in laboratory and transit from laboratory to deployment site and back, with further detailed procedure discussed elsewhere [32, 34, 35].

The newly prepared batch of dosimeters for outdoor and indoor dose assessment was procured from BARC and were immediately deployed to the selected locations. The dosimeters for outdoor gamma dose assessment were then

Table 1 Land-use/land-cover statistics (Area in km^2)

Class	Anantnag	Budgam	Baramulla	Doda	Jammu	Kargil	Kathua	Kupwara	Leh	Poonch	Pulwama	Rajouri	Srinagar	Udhumpur
Agriculture	977.9	643.4	808.4	887.5	1549.6	43.5	931.1	377.8	156	434	807.9	759	246.4	1587.6
Barren/Uncultura-ble lands	687.9	67	704.6	2761.3	147.5	8828.5	475.9	169.3	35,491	331.7	102.3	535.7	369	607.4
Built-up	54.3	99.1	95.3	15.8	186.2	3.5	42.4	16.2	7.2	17.5	56.4	16.5	94.9	21.8
Forest	1566.1	403.7	2431.5	6001.1	987.5	0.09	987	1594.7	5.8	794.9	366	1241.5	1156.9	2112
Grass/Grazing	125.4	45.1	91.6	18.2	0.03		4.5	32.5		27.6	14.2	11.3	40.7	65.8
Snow and Glacier	487	69	300.4	1954.3		5082.7	14.2	168.7	8736.4	47.2	17.6	15.4	128.3	20.7
Wetland/Water bodies	85.5	43.9	156.3	53.4	226.2	81.7	192.1	20.2	712.8	20.2	33.6	50.7	113.4	134.4

installed, pendant from a support in open places, away from walls and trees at least 1 m above the ground. However, indoor dosimeters were kept inside the houses with different make like concrete, wooden, mixed framework made of concrete, wooden and muddy material, hanging from ceiling away from walls. The houses selected varied in their ventilation rate. The TLDs were deployed to the selected sites and retrieved therefrom on quarterly basis. After retrieval, these were immediately delivered to BARC for appraisal of gamma doses. Outdoor environmental monitoring of gamma radiation was carried out from December (2014) to March (2017) at systematically selected 90,74 and 89 sites distributed among 21 districts of Kashmir, Jammu and Ladakh divisions respectively with number of sites in each district of all divisions given in Tables 2, 3. In-order to ascertain indoor–outdoor gamma dose ratio, the outdoor dose was taken from TLD's that were installed for outdoor monitoring and were contiguous to indoor selected sites. The indoor dose assessment was carried out at 15 and 13 sites in Kashmir and Jammu divisions respectively.

Calculations

Annual effective dose (AED)

Outdoor, Indoor and total annual effective dose (AED) was calculated from absorbed gamma dose rates by inputting values in Eqs. (1, 1a, 1b and 1c) [1]:

$$\mathrm{AED_o(mSv/y)} = \mathrm{D_o} \times \mathrm{T} \times \mathrm{OF} \times \mathrm{CC} = \mathrm{D_o} \times 8760 \times 0.2 \times 0.7 \quad (1)$$

$$\mathrm{AED_i(mSv/y)} = \mathrm{D_i} + \mathrm{T} \times \mathrm{OF} \times \mathrm{CC} = \mathrm{D_i} \times 8760 \times 0.8 \times 0.7 \quad (1a)$$

$$\mathrm{AED_t(mSv/y)} = (\mathrm{Do} \times \mathrm{T} \times \mathrm{OF} \times \mathrm{CC}) + (\mathrm{Di} \times \mathrm{T} \times \mathrm{OF} \times \mathrm{CC}) \quad (1b)$$

$$= \mathrm{AED_o} + \mathrm{AED_i} \quad (1c)$$

where D_o and D_i refer to outdoor and indoor absorbed dose rates in nGy/h. T (24 h × 365 days) is the time in hours in one year; OF is occupancy factor which is 20% and 80% of 8760 h for outdoor and indoor exposures respectively; CC is conversion coefficient of 0.7 $\mathrm{SvGy^{-1}}$used to calculate effective dose received by an adult from absorbed gamma dose as reported in [36].

Excess lifetime cancer risk (ELCR)

ELCR elucidates the risk of instigating any type of cancer in inhabited areas. The risk of cancer development may be from the exposure to long term gamma radiation doses. In-order to assess these risks, ELCR was calculated for

Table 2 Statistical summary of minimum, maximum, average, uncertainty, standard deviation, geometric mean and geometric standard deviation of outdoor gamma dose rates in Kashmir, Jammu and Ladakh

Outdoor								
Districts	Monitoring sites	Gamma dose rate (nGy/h)						
		Min	Max	Average	Uncertainty	Standard Deviation	Geometric mean	Geometric Standard. Deviation
Kashmir Division (10 districts)								
Anantnag	9	95.5	143.2	112.8	0.05	17.7	111.7	1.2
Bandipora	9	92.0	131.1	110.6	0.04	12.2	110.0	1.1
Baramulla	9	88.4	140.3	107.9	0.05	16.9	106.7	1.2
Budgam	8	97.8	137.0	113.5	0.04	13.4	112.9	1.1
Ganderbal	8	93.4	143.9	117.3	0.06	17.5	116.1	1.2
Kulgam	9	104.3	152.1	116.9	0.04	15.8	116.1	1.1
Kupwara	8	60.3	141.3	109.0	0.09	23.7	106.2	1.3
Pulwama	8	90.9	181.7	117.5	0.08	29.4	114.8	1.3
Shopian	13	86.5	143.8	119.2	0.04	16.0	118.2	1.1
Srinagar	9	103.1	140.9	119.6	0.04	14.4	118.9	1.1
Jammu division (9 districts)								
Doda	8	87.8	154.8	123.4	0.08	26.2	120.8	1.3
Kathua	6	76.3	121.0	97.8	0.07	16.7	98.4	1.2
Kishtawar	7	85.8	157.5	115.1	0.07	23.4	113.1	1.2
Poonch	5	84.8	114.2	102.4	0.05	10.9	101.9	1.1
Ramban	9	68.6	129.8	108.1	0.07	19.5	106.3	1.2
Reasi	9	76.5	129.6	107.8	0.06	20.1	109.5	1.2
Udhumpur	9	72.4	115.3	88.9	0.06	17	87.6	1.2
Jammu	13	73.1	109.2	90.6	0.03	10.4	90	1.1
Rajouri	8	80.6	139.0	104.9	0.07	21.2	103.1	1.2
Ladakh division (2 districts)								
Kargil	35	79.9	295.7	145.7	0.06	52.0	137.6	1.4
Leh	54	95.9	367.6	176.4	0.05	70.3	165.1	1.4

indoor and outdoor exposures in monitored areas using Eqs. (2, 2a and 2b):

$$ELCR_{(o)} = AED_o \times RF \times DL \times 10^{-3} \quad (2)$$

$$ELCR_{(i)} = AED_i \times RF \times DL \times 10^{-3} \quad (2a)$$

$$ELCR_{(t)} = ELCR_{(o)} + ELCR_{(i)} \quad (2b)$$

where $ELCR_{(o)}$, $ELCR_{(i)}$ and $ELCR_{(t)}$ represent outdoor, indoor and total excess lifetime cancer risk. AED_o and AED_i represents outdoor and indoor annual effective dose, RF is the risk factor calculated to be 0.05 (Sv^{-1}) according to [12, 37] for stochastic effects in whole population, which is detriment adjusted nominal risk coefficient for cancer after exposure to low dose rate and DL is average life duration of people taken as 70 years in an area.

Results and discussion

Outdoor gamma dose rate

Statistical summary of minimum, maximum and average of outdoor gamma dose rates, AED_o and $ELCR_{(o)}$ is presented in Tables 2, 3. Average outdoor absorbed gamma dose rate (D_o) in Kashmir, Jammu and Ladakh divisions extended from 107.9 (Baramulla) to 119.6 (Srinagar), 88.9 (Udhum-pur) to 123.4 (Doda) and 145.7 (Kargil) to 176.4 nGy/h (Leh). Variation of outdoor gamma dose rates in Kashmir,

Table 3 Statistical summary of minimum, maximum and average of outdoor annual effective dose (AED) and outdoor excess lifetime cancer risk (ELCR) in Kashmir, Jammu and Ladakh

Outdoor						
Districts	AED (mSv/y)			ELCR * 10^{-3}		
	Min	Max	Avg	Min	Max	Avg
Kashmir division						
Anantnag	0.12	0.18	0.14	0.41	0.61	0.48
Bandipora	0.11	0.16	0.14	0.39	0.56	0.47
Baramulla	0.11	0.17	0.13	0.38	0.60	0.46
Budgam	0.12	0.17	0.14	0.42	0.59	0.49
Ganderbal	0.11	0.18	0.14	0.40	0.62	0.50
Kulgam	0.13	0.19	0.14	0.45	0.65	0.50
Kupwara	0.07	0.17	0.13	0.26	0.61	0.47
Pulwama	0.11	0.22	0.14	0.39	0.78	0.50
Shopian	0.11	0.18	0.15	0.37	0.62	0.51
Srinagar	0.13	0.17	0.15	0.44	0.60	0.51
Jammu division						
Doda	0.11	0.19	0.15	0.38	0.66	0.53
Kathua	0.09	0.15	0.12	0.33	0.52	0.42
Kishtawar	0.11	0.19	0.14	0.37	0.68	0.49
Poonch	0.10	0.14	0.13	0.36	0.49	0.44
Ramban	0.08	0.16	0.13	0.29	0.56	0.46
Reasi	0.09	0.16	0.13	0.33	0.56	0.46
Udhumpur	0.09	0.14	0.11	0.31	0.49	0.38
Jammu	0.09	0.13	0.11	0.31	0.47	0.39
Rajouri	0.10	0.17	0.13	0.35	0.60	0.45
Ladakh division						
Kargil	0.10	0.36	0.18	0.34	1.27	0.63
Leh	0.12	0.45	0.22	0.41	1.58	0.76

Jammu and Ladakh are presented in Figs. 1, 2 and Tables 2, 3. The analysis of data depicted high average gamma dose rates in Srinagar and Shopian districts of Kashmir division and Doda district of Jammu division which may be due to higher radionuclide concentration in lithology. Higher doses in Shopian may not only be ascribed to lithology but also to fertilizers high in K-40 utilized in horticultural and agricultural sector. The highest values among all monitored sites are reported from areas of Tral (181.7 nGy/h), Dhadpeta (157.5 nGy/h) and near to Kargil university (367.6 nGy/h) respectively, which may be imputed to lithology. As the lithology in these areas is dominated by igneous rocks, which are generally high in radionuclide concentrations [38–42]. Also, in addition to lithological control in an area near to Kargil university, high gamma dose may also be the result of higher altitude. On other side, low average gamma dose rates were observed in Baramulla & Kupwara districts of Kashmir division and Udhumpur, Jammu and Kathua districts of Jammu division. The lowest values observed in Lolab area (60.3 nGy/h), near upper-bazar Ramban (68.6 nGy/h) of Kupwara and Ramban districts respectively, Thasgam and near Chanigound (79.9 nGy/h) of Kargil district; may be imputed to low natural activity of radioactive material in the lithology. However, low dose in Lolab may also be outcome of good forest cover (Table 1) and higher moisture content in the soil. Among all districts in Kashmir and Jammu divisions, Srinagar and Poonch manifested lowest range of 103.1 to 140.9 and 84.8 to 114.2 nGy/h respectively. On other side, highest range was exhibited by Pulwama (90.9–181.7 nGy/h) and Kishtawar (85.8–157.5 nGy/h). Kargil and Leh districts of Ladakh division show considerably wider ranges extending from 79.9 to 295.7 and 95.9 to 367.7 nGy/h respectively and show very high values as compared to Kashmir and Jammu divisions. This wide variability observed may be ascribed to variation in natural radionuclide diaspora due to variation in the geological processes. Weathering processes as considered one of the important dispersing agents of radionuclides may also have been reason for wide variability in

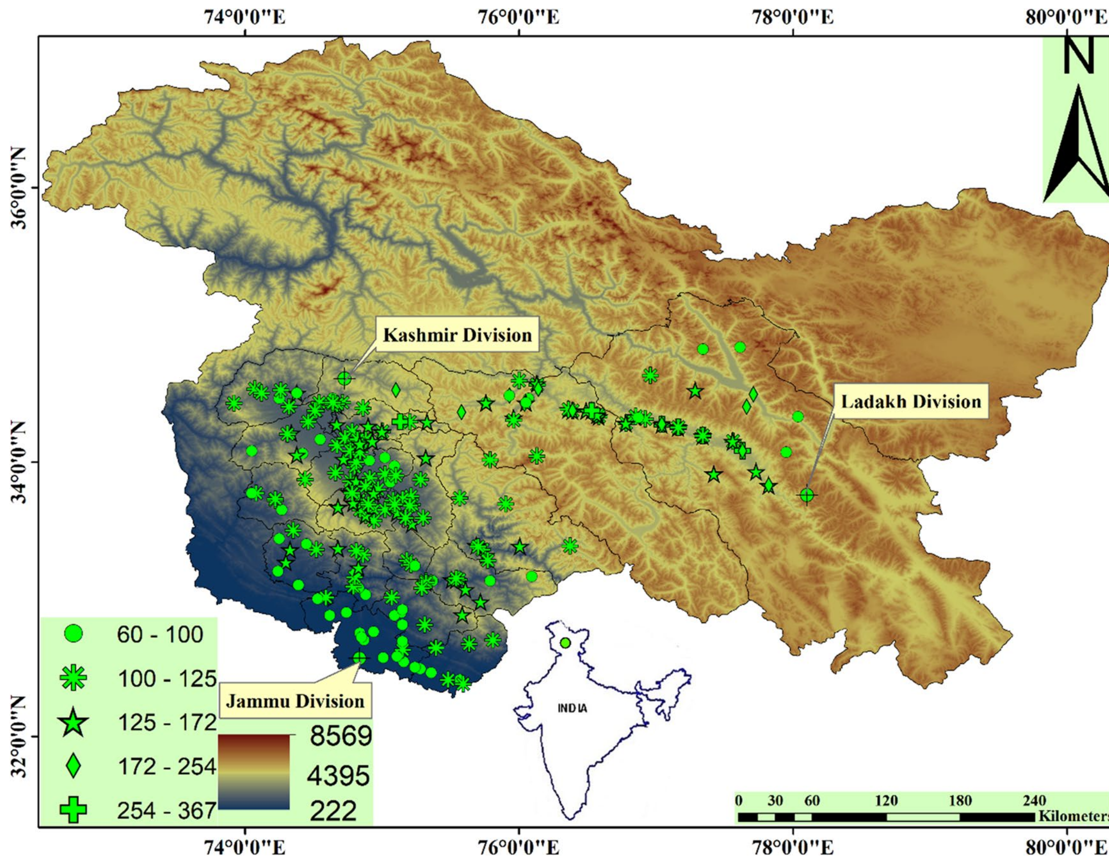


Fig. 1 Study area map showing monitoring sites along with corresponding gamma radiation doses (nGy/h) in Kashmir, Jammu and Ladakh divisions

the gamma dose rates. The data exhibits very high absorbed gamma dose rates from all monitored sites as compared to Kashmir and Jammu divisions. Since, the region being tectonically active and at higher elevation dominated by acidic and basic igneous rocks (high in radionuclide concentrations) [17, 40–42] may have resulted in high–very high gamma doses. The other factor in region that enhances exposure to gamma doses is sparse vegetation cover and large barren-land area (Table 1).

The gamma dose rate shows positive trend while correlating it with altitude which advocates to increase of dose with increase in altitude (Fig. 3). Albeit prominent altitude range (234–7630 m) in western Himalaya, gamma dose rate doesn't show significant correlation because of subduing effect from other controlling factors like vegetation, soil moisture etc.

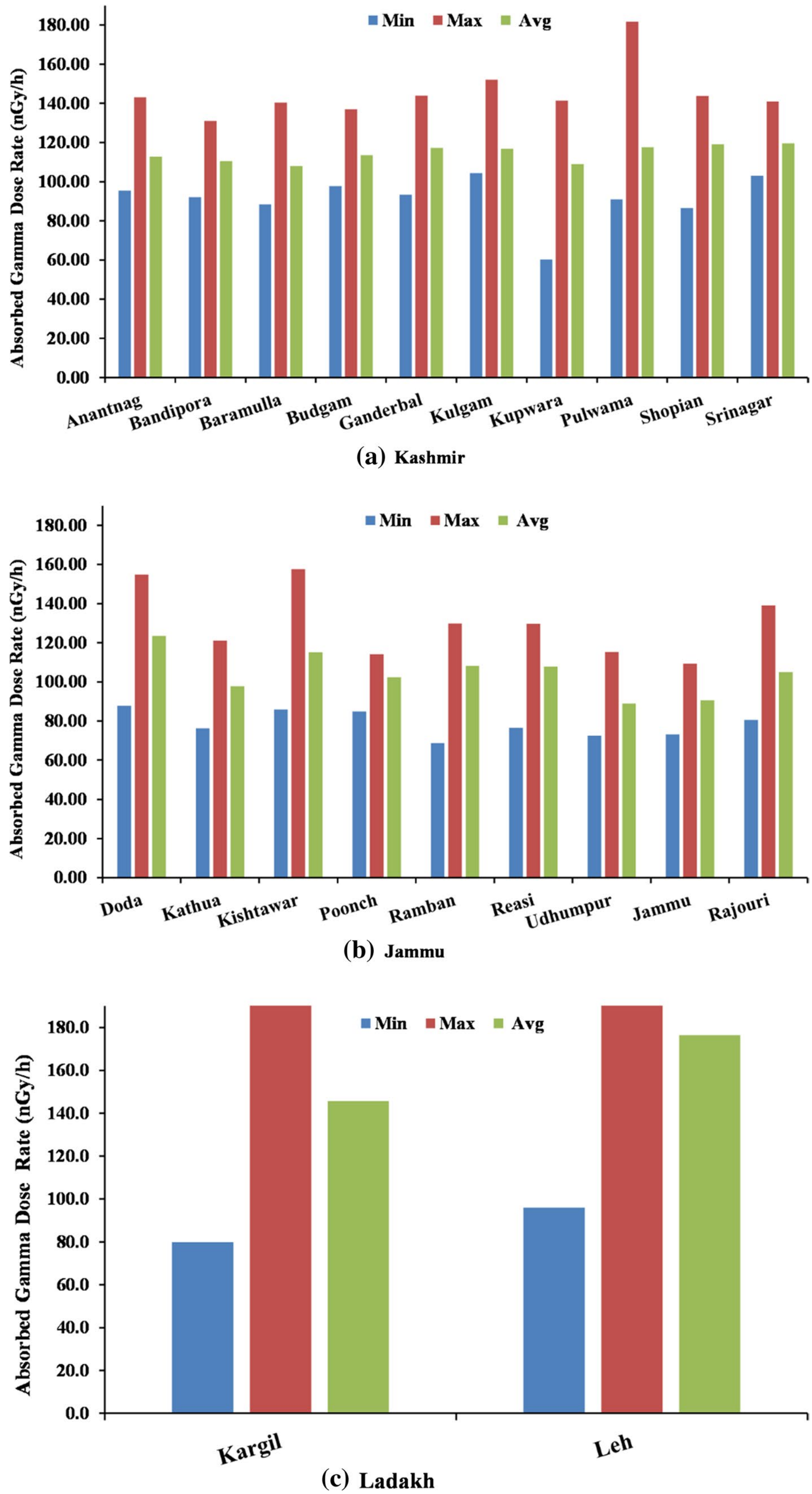
The present study depicting average outdoor gamma dose rate of 90.3 nGy/h in district Udhumpur (Jammu division) is lower than average value of 196 nGy/h obtained by [20]. This comparatively low average outdoor gamma dose rate may be due to less number of monitoring sites taken up in district.

It has been presented in [1] that outdoor gamma dose rates vary from 18 to 93 nGy/h with median and population-weighted average of 57 nGy/h and 59 nGy/h respectively. All locations taken up for gamma monitoring showed average absorbed gamma dose rates above than world average. Comparative evaluation of average outdoor absorbed gamma dose rate between study region and other countries is presented in Table 5.

Indoor gamma dose rate

Indoor absorbed gamma dose rates (D_i) in Kashmir and Jammu divisions branch out from 70.8 (Budgam and Ganderbal) to176.9 (Main Shopian) and 73.1 (Reasi city) to 131.3 nGy/h (Mohr) with an average of 110.9 nGy/h and 109 nGy/h respectively, presented in Table 4. All observed values in both divisions except from Reasi city crest well above the population-weighted average which is reported

Fig. 2 Variation of outdoor absorbed gamma dose rates (nGy/h) in Kashmir (2a), Jammu (2b) and Ladakh (2c) divisions



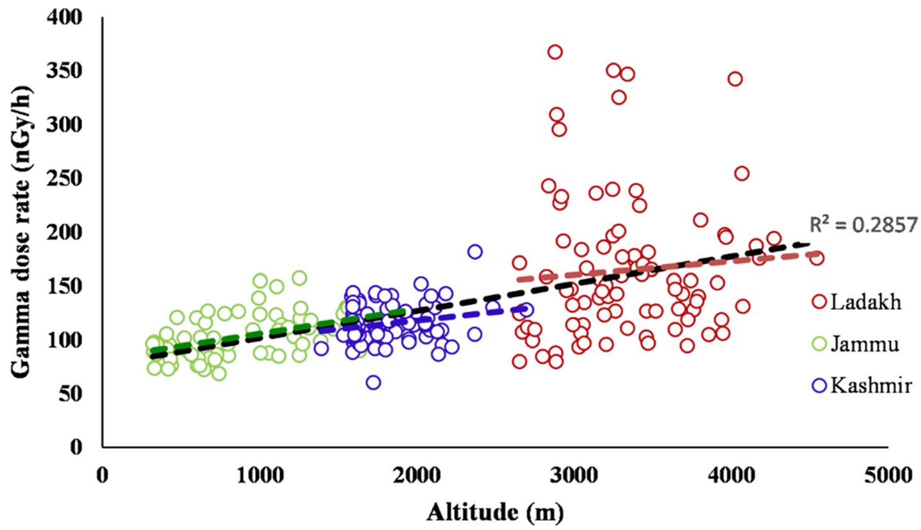


Fig. 3 Variation of outdoor absorbed gamma dose rate (nGy/h) with altitude (m)

to be 84 nGy/h in UNSCEAR, 2000 [1]. The lowest values observed at above cited locations may be because of low radionuclide concentrations in the construction material and shielding effect from the wooden framework in floors and the roofs [44]. Higher values observed in locations may be due to inadequate ventilations, as low ventilation rates result in an increased concentration of radon and its progeny concentration [3], thus may lead to high indoor gamma dose. Also, high radionuclide concentrations in construction material and the ground over which the infrastructures are built, may contribute towards higher indoor dose rate. Besides indoor, outdoor gamma dose assessment was taken from the TLD's that were installed for outdoor measurements and fell in their immediate vicinity. The results obtained and their statistical summary is shown in Fig. 4 and Table 4 respectively.

The spatial variability of outdoor and indoor gamma doses in an area may be ascribed to the variability of controlling factors like tectonics (as area fall in the Himalayan region and hence is tectonically active), variable radionuclide concentration in lithologies, altitudinal variation, agriculture and horticultural activities, vegetation, soil moisture, ventilation and infrastructural framework.

In-order to calculate indoor–outdoor ratio, outdoor gamma dose rates were measured in the immediate vicinity to the sites taken up for measurement of indoor gamma dose rates. Indoor–outdoor ratio ranged from 0.52 (Budgam) to 1.31 (Shalimar) and 0.62 (Katra bus-stop) to 1.16 (Channa Mohr) with an average values of 0.98 and 0.89 in Kashmir and Jammu divisions respectively (Fig. 5 and Table 4). Average values of indoor–outdoor ratio calculated are lower than world population weighted average of 1.4 [1]. The data of indoor–outdoor ratio obtained showed wide range in Kashmir division as compared to Jammu which may be attributed to varied construction material from varied sources, varying ventilation and wooden frameworks in the houses. In Kashmir and Jammu divisions, 7 and 11 monitored sites (out of 15 and 13) exhibiting ratio below 1 may be the result of good ventilation, wooden framework (floors, walls and roofs) and most importantly low radionuclide concentration material utilized in the buildings. It was observed that indoor gamma dose rates as such exhibited no significant correlation with outdoor absorbed gamma dose rates.

Annual effective dose (AED)

AED_o branch out from 0.07 to 0.22, 0.08 to 0.19 and 0.10 to 0.45 mSv/y with an average of 0.14 mSv/y, 0.13 mSv/y and 0.19 mSv/y in Kashmir, Jammu and Ladakh divisions respectively (Table 3). The average values of outdoor exposure to gamma doses in Kashmir, Jammu and Ladakh are approximately two times higher than the world average 0.07 mSv/y [1].

AED_i ranged from 0.35 to 0.87 and 0.36 to 0.64 mSv/y with an average of 0.54 mSv/y and 0.53 mSv/y in Kashmir and Jammu respectively (Table 4). Barring Budgam, Ganderbal and Kashmir University in Kashmir division and Reasi city in Jammu division, all sites are exposed to the gamma dose rates well above the world average of 0.41 mSv/y [1].

AED_o calculated from the absorbed gamma dose rate measurements lying in immediate vicinity to indoor sites

Table 4 Statistical summary of indoor (D_i) and outdoor (D_o) gamma dose rate, indoor–outdoor ratio (I/O), annual effective dose: indoor (AED_i), outdoor (AED_o) and total (AED_t), and excess lifetime cancer risk: indoor ($ELCR_{(i)}$), outdoor ($ELCR_{(O)}$) and total ($ELCR_{(t)}$) in Kashmir and Jammu divisions

Indoor and outdoor										
Location	District	Gamma dose rate (nGy/hr			Annual effective dose (mSv/y)			ELCR * 10^{-3}		
		(D_i)	(D_o)	I/O	(AED_i)	(AED_o)	(AED_t)	$ELCR_{(I)}$	$ELCR_{(O)}$	($ELCR_t$)
Kashmir division										
Gundikaiser	Bandipora	118.7	131.3	0.90	0.58	0.16	0.74	2.04	0.56	2.60
Uri	Baramulla	94.7	92.5	1.02	0.46	0.11	0.58	1.63	0.40	2.02
Tangmarg	Baramulla	101.6	95.9	1.06	0.50	0.12	0.62	1.74	0.41	2.16
Budgam	Budgam	70.8	137.0	0.52	0.35	0.17	0.52	1.22	0.59	1.80
Ganderbal	Ganderbal	70.8	102.7	0.69	0.35	0.13	0.47	1.22	0.44	1.66
Kupwara	Kupwara	98.2	117.6	0.83	0.48	0.14	0.63	1.69	0.50	2.19
Pampore	Pulwama	119.9	94.7	1.27	0.59	0.12	0.70	2.06	0.41	2.46
Tujan	Pulwama	94.7	132.4	0.72	0.46	0.16	0.63	1.63	0.57	2.20
Kanipora	Shopian	116.4	109.6	1.06	0.57	0.13	0.71	2.00	0.47	2.47
Reshnagar	Shopian	126.7	143.8	0.88	0.62	0.18	0.80	2.18	0.62	2.79
Main Shopian	Shopian	176.9	141.6	1.25	0.87	0.17	1.04	3.04	0.61	3.65
Bemina	Srinagar	116.4	103.9	1.12	0.57	0.13	0.70	2.00	0.45	2.45
Mala Bagh	Srinagar	137.0	105.0	1.30	0.67	0.13	0.80	2.35	0.45	2.80
Shalimar	Srinagar	125.6	95.9	1.31	0.62	0.12	0.73	2.16	0.41	2.57
Kashmir University	Srinagar	94.7	131.3	0.72	0.46	0.16	0.63	1.63	0.56	2.19
Jammu division										
Badarwa	Doda	123.3	142.7	0.86	0.60	0.18	0.78	2.12	0.61	2.73
Bundoda	Doda	130.1	149.5	0.87	0.64	0.18	0.82	2.23	0.64	2.88
Ballistan	Kishtwar	119.9	127.9	0.94	0.59	0.16	0.74	2.06	0.55	2.61
Dhadpeta	Kishtwar	129.0	157.5	0.82	0.63	0.19	0.83	2.21	0.68	2.89
Reasi City	Reasi	73.1	76.5	0.96	0.36	0.09	0.45	1.25	0.33	1.58
Maslot	Reasi	113.0	126.7	0.89	0.55	0.16	0.71	1.94	0.54	2.48
Channa Mohur	Reasi	130.1	111.9	1.16	0.64	0.14	0.78	2.23	0.48	2.71
Katra	Reasi	97.0	117.6	0.83	0.48	0.14	0.62	1.67	0.50	2.17
Mohr	Reasi	131.3	124.4	1.06	0.64	0.15	0.80	2.25	0.53	2.79
Katra Bus Stop	Reasi	86.8	140.4	0.62	0.43	0.17	0.60	1.49	0.60	2.09
Narsoo Nalla	Udhampur	105.0	115.3	0.91	0.52	0.14	0.66	1.80	0.49	2.30
Poonch	Poonch	87.9	97.0	0.91	0.43	0.12	0.55	1.51	0.42	1.93
Oil Air field	Poonch	90.2	114.2	0.79	0.44	0.14	0.58	1.55	0.49	2.04

were summed up with AED_i to estimate the total annual effective dose. AED_t varied from 0.47 to 1.04, 0.45 to 0.83 mSv/y in Kashmir and Jammu divisions respectively with an equivalent average of 0.69 mSv/y as presented in Fig. 6 and Table 4. Average AED_t and all individual values estimated for all the sites except Ganderbal (Kashmir) and Reasi city (Jammu) crests above the world average of 0.48 mSv/y [1]. Although most of estimated values surpass the world average but do not exceed the dose limit criterion of 1 mSv/y for public [37].

Excess lifetime cancer risk

The $ELCR_{(o)}$ values extend from 0.26×10^{-3} to 0.78×10^{-3}, 0.29×10^{-3} to 0.68×10^{-3} and 0.34×10^{-3} to 1.57×10^{-3} with an average of 0.49×10^{-3}, 0.45×10^{-3} and 0.69×10^{-3} in Kashmir, Jammu and Ladakh divisions respectively (Table 2). The $ELCR_{(i)}$ values extend from 1.22×10^{-3} to 3.04×10^{-3} and 1.25×10^{-3} to 2.25×10^{-3} with an average of 1.90×10^{-3} and 1.87×10^{-3} in Kashmir and Jammu respectively presented in Table 4. $ELCR_{(t)}$ estimated from AED_t

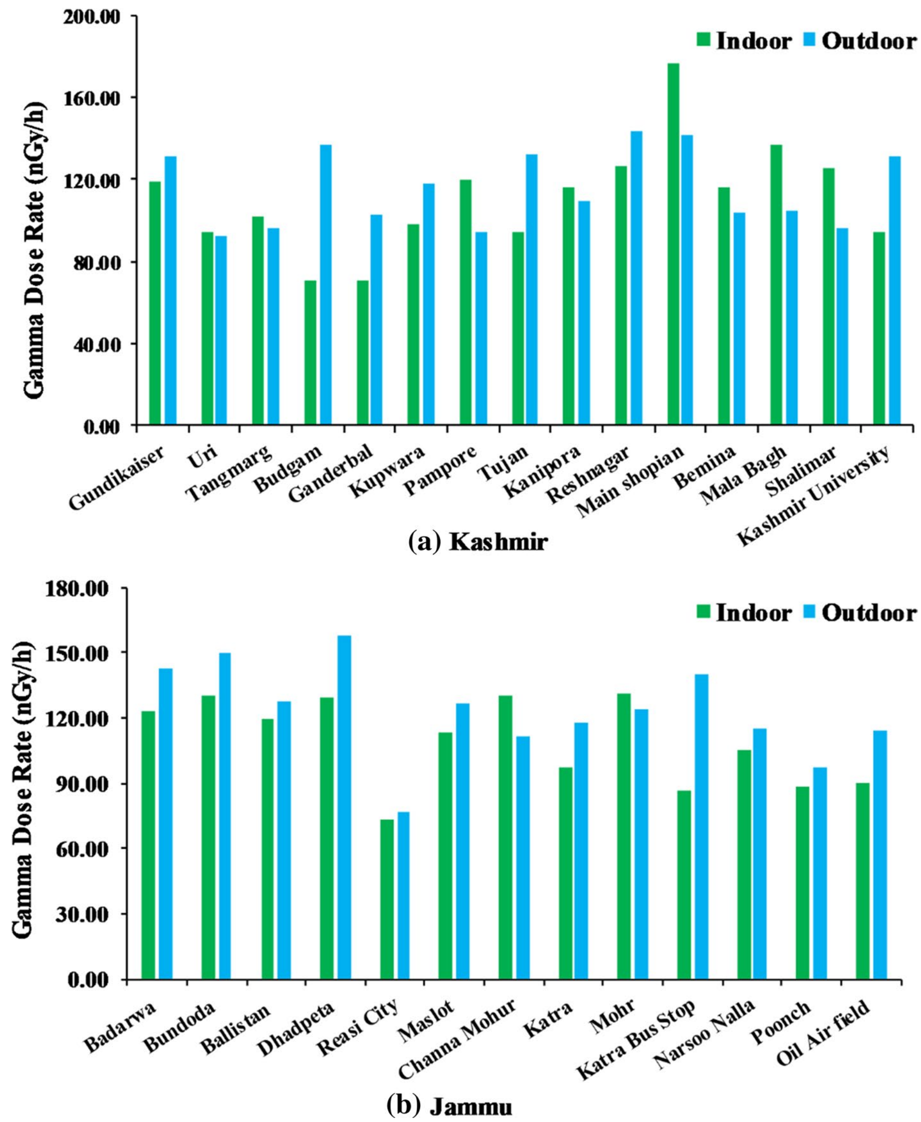
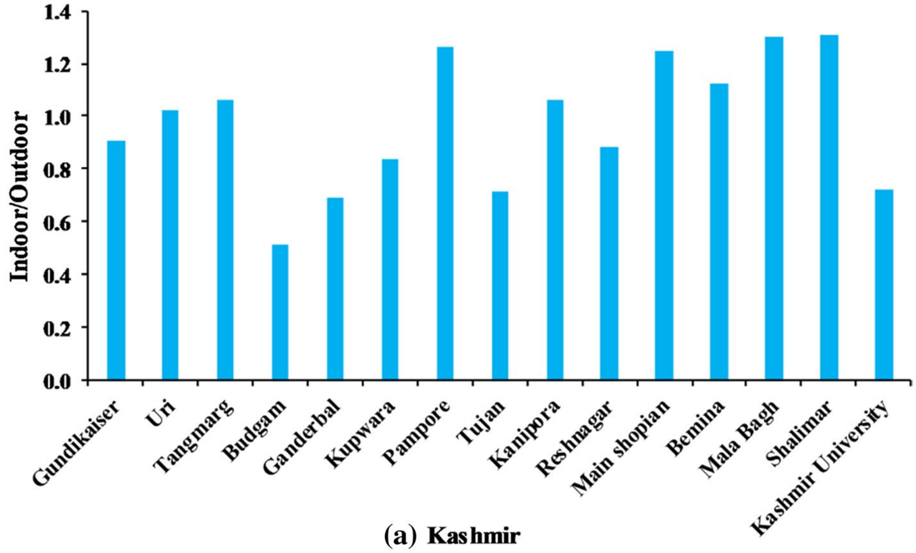


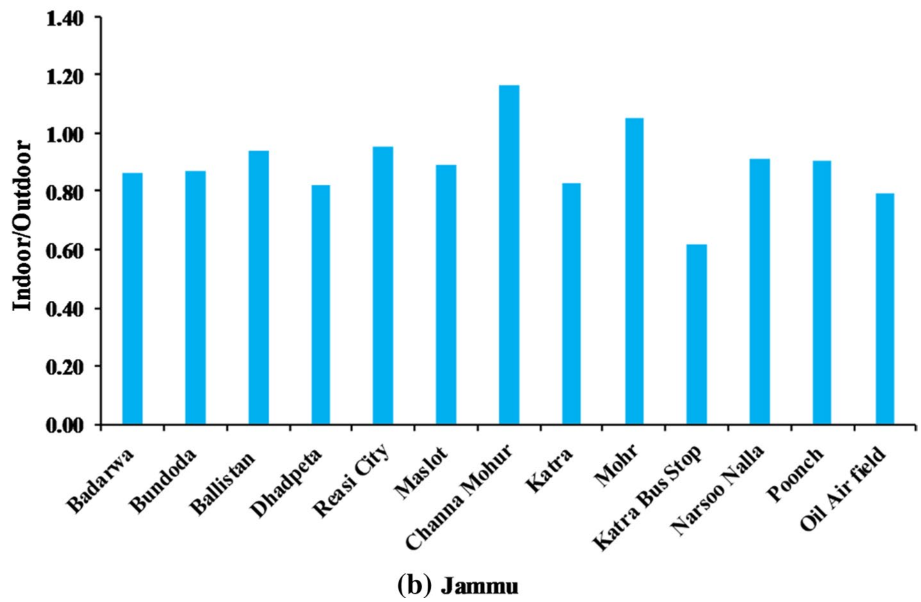
Fig. 4 Outdoor and Indoor gamma dose rate variation in Kashmir (4a) and Jammu (4b) divisions

in Kashmir and Jammu divisions varied from 1.66×10^{-3} to 3.65×10^{-3} and 1.58×10^{-3} to 2.89×10^{-3} with equivalent average of 2.40×10^{-3} respectively as presented in Fig. 6 and Table 4. The calculated values of ELCR $_{(o)}$, ELCR$_{(i)}$ and ELCR$_{(t)}$ lie above the corresponding world average values of ELCR$_{(o)}$ (0.29×10^{-3}), ELCR$_{(i)}$ (1.16×10^{-3}) and ELCR$_{(t)}$ (1.45×10^{-3}) [12, 16].

Shopian, Srinagar (Kashmir division), Doda (Jammu division), Kargil and Leh (Ladakh division) have higher average ELCR $_{(o)}$. High ELCR $_{(o)}$ values (1.27×10^{-3} and 1.58×10^{-3}) among all observed areas due to outdoor exposure were observed in areas near Faroona village and Kargil University (satellite campus of Kashmir University) in Ladakh division (may be ascribed to igneous lithology generally high in radionuclide concentration than sedimentary rocks [38, 40] and higher elevation). The ELCR$_{(t)}$ due to the combined effect of indoor and outdoor exposure is high in main-Shopian (3.65×10^{-3}), Mala Bagh (2.8×10^{-3}), Bundoda (2.88×10^{-3}) and Dhadpeta (2.89×10^{-3}) of Kashmir and Jammu divisions. Since, the Shopian area is extensively engaged in horticulture and agricultural activities and are hence using large amount of fertilizers (rich in ^{40}K). The ^{40}K in soil is taken up by the plants and transferred to humans. This high utilization of fertilizers may thus pose an additional risk towards increased exposure and thus increasing subsequently probability of cancers in the region (Table 5).

Fig. 5 Variation of Indoor–outdoor ratio in Kashmir (5a) and Jammu (5b) divisions





The statistical summary of gamma dose rate (outdoor and indoor), AED (outdoor, indoor and total AED) and ELCR (outdoor, indoor and total ELCR) Kashmir, Jammu and Ladakh is presented in Table 4. The statistical comparison of average gamma dose rate, AED and ELCR in outdoor and indoor environment with other monitored areas in India is presented in Table 6.

Conclusion

Exposure to background radiation, an inevitable phenomenon has roots in cosmic, telluric and anthropogenic sources, with major proportion accounted by cosmic and telluric components. The monitoring of gamma radiation dose rate carried out in Kashmir, Jammu and Ladakh divisions was accomplished by installing TLDs in outdoor and indoor environments. An average outdoor absorbed gamma dose rates and calculated AED_o in three divisions crest well above the corresponding world averages. Indoor gamma dose in all sites (except Budgam, Ganderbal and Kashmir University in Kashmir division and Reasi city in Jammu division) exceed the world average. An estimated average $ELCR_{(o)}$ was reported to be high from Shopian and Srinagar districts (Kashmir division), Doda district (Jammu division), Kargil and Leh districts (Ladakh division). High $ELCR_{(o)}$ was reported from area near to Kargil University and Faroona village in Ladakh division. An

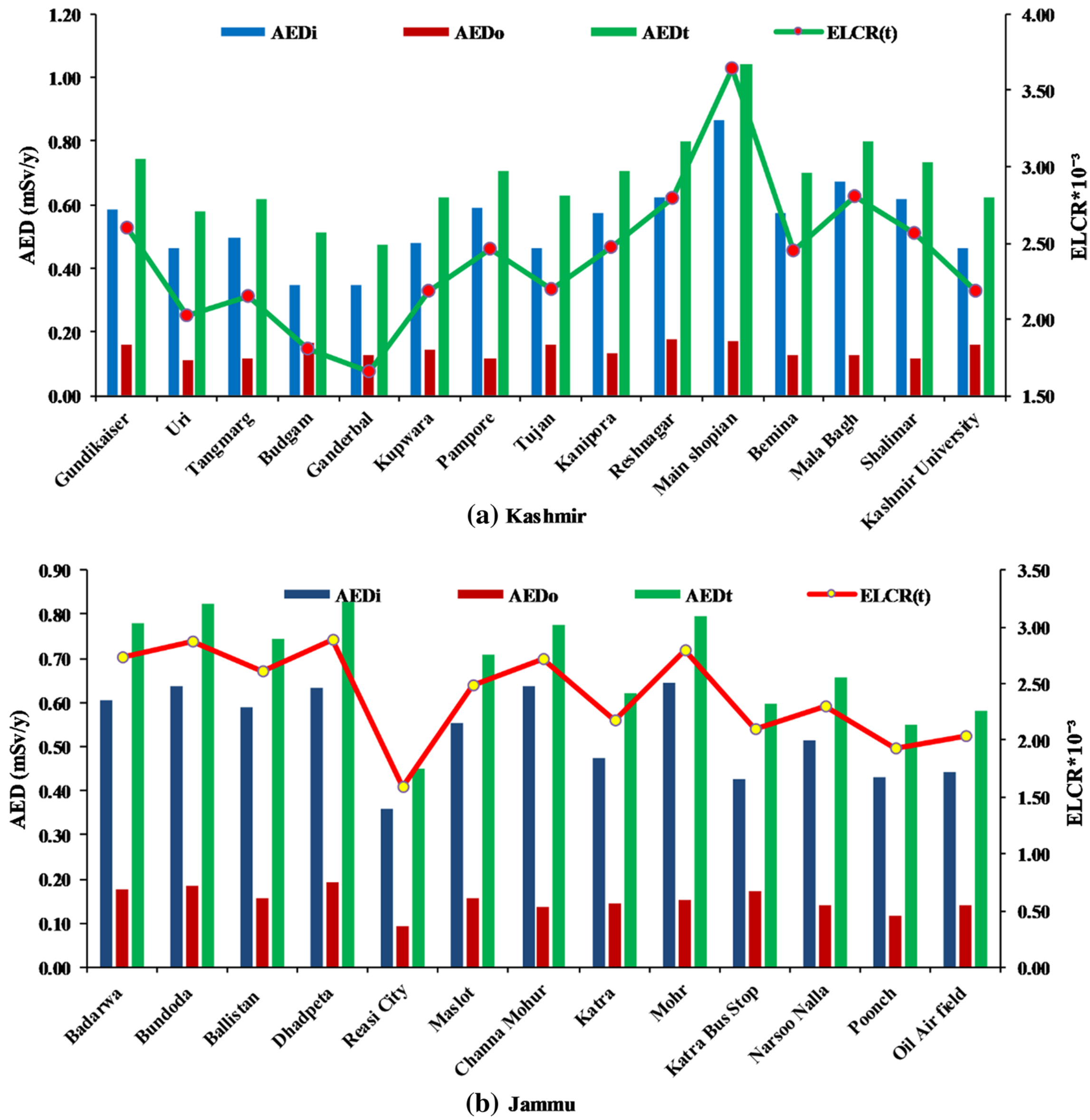


Fig. 6 Spatial variability of Indoor AED (AED_i), Outdoor AED (AED_o) and Total ELCR ($ELCR_{(t)}$) in Kashmir (6a) and Jammu (6b) divisions

Table 5 Statistical comparison of outdoor mean absorbed dose rates (nGy/h) in various countries with present study

Country	Outdoor mean absorbed dose rate (nGy/h)	References
China	62	[1]
Egypt	32	[1]
Greece	56	[1]
India	56	[1]
Japan	53	[1]
Russia	65	[1]
Present Study	126.61	–
World	59	[1]

estimated indoor–outdoor ratio extended from 0.52 to 1.31 and 0.62 to 1.16 with an average values of 0.98 and 0.89 in Kashmir and Jammu divisions respectively. The AED_t ranged from 0.47 to 1.04, 0.45 to 0.83 mSv/y in Kashmir and Jammu divisions respectively with an average of 0.69 mSv/y well above the world average. The high $ELCR_{(t)}$ values reported pictures main-Shopian and Mala Bagh of Kashmir division and Bundoda and Dhadpeta of Jammu division as areas with higher risk of cancer development.

Table 6 Statistical comparison of mean absorbed dose rates (outdoor and indoor), AED (outdoor and indoor) and ELCR (outdoor and indoor) of locations within India with present study area

Locations in India	Mean absorbed dose rate (nGy/h)		AED (mSv/y)		ELCR * 10^{-3}		References
	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	
Along river Alaknanda and Ganges	100.83	–	0.123	–	0.514	–	[15]
Eastern coastal area of Odisha (Terrestrial radiation monitoring)	230	–	0.24	0.97	–	–	[10]
Shimoga district, Karnataka (Terrestrial radiation monitoring)	177.81	192.42	0.235	0.872	–	–	[45]
Goa	64	–	–	–	–	–	[46]
Bangalore	73.9	–	–	–	–	–	[47]
Amritsar, Punjab	130	130	0.23	0.95	–	–	[48]
Kashmir	114.44	110.88	0.14	0.54	0.49	1.90	Present Study
Jammu	104.33	108.97	0.13	0.53	0.45	1.87	
Ladakh	161.06	–	0.19	–	0.69	–	
World	59	84	0.07	0.41	0.29	1.16	[1]

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