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Outdoor γ-radiation: seasonal variation and health risk assessment associated with its exposure in northern districts of Haryana, India

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Abstract

A study was conducted for the measurement of outdoor gamma dose rate (GDR) using a radiation monitor, based on Geiger-Muller technique, in Karnal, Kaithal, and Kurukshetra districts of Haryana at 214 locations during post and premonsoon season. The γ-dose rate was found to be in the range of 70 ± 4–267 ± 13 nSv/h. The data was statistical analysed and distribution was interpolated using ArcGIS software. The annual effective dose (AED) due to outdoor γ-radiation in Karnal, Kaithal, and Kurukshetra districts was computed to be in the range of 0.086 ± 0.004–0.327 ± 0.016 mSv/y. The value of excess lifetime cancer risk (ELCR) was found to be in the range of 0.322×10^{-3}–1.228×10^{-3}.

Keywords AED · ELCR · γ-radiation · Heath risk · Seasonal variation · India

Introduction

The environment contains radioactive nuclides and radioactivity ubiquitously that has existed ever since the world was formed [1–3]. Unstable nuclei produce radiation energy during the disintegration process, which travels across different materials and space. It may be discovered in the soil, rocks, plants, water, air, soil, plants, and even the bodies of living things. Daily human exposure to low-level radiation in the environment is caused by background radiation. Regardless of ethnicity, complexion, or locality, man is continually exposed to varying levels of background radiation [4]. Out of total natural source of exposure (including external exposure due to cosmic and terrestrial and internal exposure through inhalation of radon and its progenies and ingestion) received by human beings, 37.5% is contributed by both cosmogenic and terrestrial gamma radiations [5]. The extraterrestrial component is caused by cosmic rays from space, whereas the terrestrial component is caused by the ^{235}U, ^{238}U, and ^{232}Th series of terrestrial radioactive nuclides as well as non-series ^{40}K [5]. Moreover, terrestrial radiation is significantly impacted by the geological formation and geographic features of the location, extraterrestrial radiation is dependent on latitude, altitude, and the solar cycle [5]. Since it is amplified by latitude and altitude while an airplane is in the air, the cosmic radiation flux is far stronger than it is at sea level. As a result, the cosmic ray exposure doubles every 1500 m above the earth's surface [6]. The cosmic radiation dose rate is particularly high at aircraft altitude, and it should be regulated as a planned exposure condition for the flight crew and frequent flyers, according to a new European Commission recommendation [7, 8]. The average effective dose to flight crew per year, according to UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), is 3 mSv/y [5]. The use of radioactive materials for medical reasons is a major factor in the growth of background radiation, which is produced by human activity [9]. Natural resource development and exploitation consistently raise background radiation levels in different areas, increasing the danger of exposure for the general public. The main source of radiation exposure is by far natural background radiation [10]. Radon gas is the major natural source of background radiation, contributing 1.2 mSv annually, yet reports claim that it has little effect in an outdoor setting [11]. The γ-radiation from terrestrial

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and cosmic sources (0.9 mSv) makes up the second-highest percentage of background radiation after radon [12]. Yet the variation in the dose rate of terrestrial γ-radiation is larger than that of radiation coming from cosmos, with the former contributing more to the level of background radiation overall [13]. The distribution of radioactive nuclides in the geological matrix and their variable concentrations in the earth's crust are to blame for the regional variations in the amount of terrestrial radiation. The Decan lava basalt that may be found in South Gujarat and Maharashtra, India, has a negligible radioactive component. The Gangetic alluvial areas, which include areas of West Bengal, Bihar, and Uttar Pradesh, granite region of Andhra Pradesh have greater levels of natural radioactivity [14]. As a result, some areas are known as high background areas in which people have considerable γ-radiation exposure due to the high concentration of naturally occurring radioactive nuclides in the soil. Typically, the annual effective dose range falls between 1 and 10 mSv [10]. The average estimated value of the populace's exposure to γ-radiation on Earth is 59.00 nGy/h, whereas the *γ* exposure rate due to radiation from space is 32.00 nGy/h at sea level, according to the UNSCEAR [5, 15]. Radiation exposure to the human occurs within as well as outside of the body [16]. Radiation interactions harm cells, resulting in cell death and alterations that have major health consequences (effects that can cause cancer and are hereditary in nature, malfunctioning organs and tissues, etc.) [5]. The principal cause of radiation's long-term impacts on the body's organs and tissues is DNA damage to the nucleus. The alterations in genes caused by radiation exposure are reflected in a variety of illnesses and cancer [5]. When the dose to the tissue increases, more cells become susceptible to damage, increasing the risk of stochastic consequences. As a result, it's important to monitor the outdoor γ-dose rate that individuals are exposed to. In an effort to close this gap, the current study assessed the in-situ background γ-dose rate in outdoor settings in the Karnal, Kaithal, and Kurukshetra districts of Haryana. Public radiation exposure was evaluated by estimating Annual Effective Dose and its potential to cause cancer by estimating Excess lifetime cancer risk. Few studies are available related to seasonal impacts on radiation level. Seasonal variations on outdoor γ-dose rate were studied to see changes in radiation level owing to different seasons.

Study area

Karnal

The district is located on the western bank of the Yamuna River, which divides Uttar Pradesh from Haryana. It is lied in the north latitudes 29°25′05″ and 29°59′20″ and the east longitudes 76°27′40″ and 77°13′08″ (Fig. 1). Its elevation above sea level is around 240 m. The district has one of the highest densities of population in the whole state. The area features a substantial network of western Yamuna canals and is a component of the Indus-Ganges plain (Upper Yamuna Basin) [17]. The district's climate is distinguished by the dryness of the air, an extremely hot summer, and a chilly winter. Four seasons can be used to categorise the entire year. Late November marks the beginning of the cold season, which lasts until the middle of March. The hot season follows it, and it lasts until the end of June, when the southwest monsoon starts to move across the area. It rains in the southwest from July through September. October to December is considered the postmonsoon season. The district typically receives 582 mm of precipitation per year, which is measured across 32 rainy days [17]. The southwest monsoon, which lasts from July to September each year, is responsible for around 82.39% of the annual rainfall. The wettest month of the year is August, which has an average of nine rainy days and 221.5 mm of precipitation. The region is a part of the huge Indo-Gangetic plain and resembles an alluvial plain with no obvious topographical characteristics. The terrain has a generally southerly slope [17]. The ground descends southwestward towards the district's northwest. There are various topographical depressions in the region, with Daha, south of Karnal, being the most notable one.

Kaithal

With a total size of 2317 square kilometers, Kaithal is the northeastern district of Haryana State. It is situated between latitudes 29°31′ and 30°12′ north and longitudes 76°10′ and 76°42′ east (Fig. 1). Kurukshetra, Karnal, and Jind districts of Haryana are its neighbours in the northeast, eastern, western & southernly. The area typically receives 511 mm of precipitation per year. The southwest monsoon, which contributes around 85% of the annual rainfall, starts moving in the final week of June and ends at the end of September [18]. The rainiest months are July and August. After western disturbances and thunderstorms, the remaining 15% of rainfall occurs during the non-monsoon season. Physiographically, the area is distinguished by different characteristics such as upland plain and alluvial bed (flood plain) of rivers Ghaggar and Markanda. With a little slope to the southwest, the terrain is nearly flat overall [18]. The Ghaggar and Markanada rivers serve as the district's primary drainage systems. The district's geological formations are unconsolidated alluvial deposits from the Quaternary period. Sand, silt, and clay along with kankar can be found in the alluvial deposits [18].

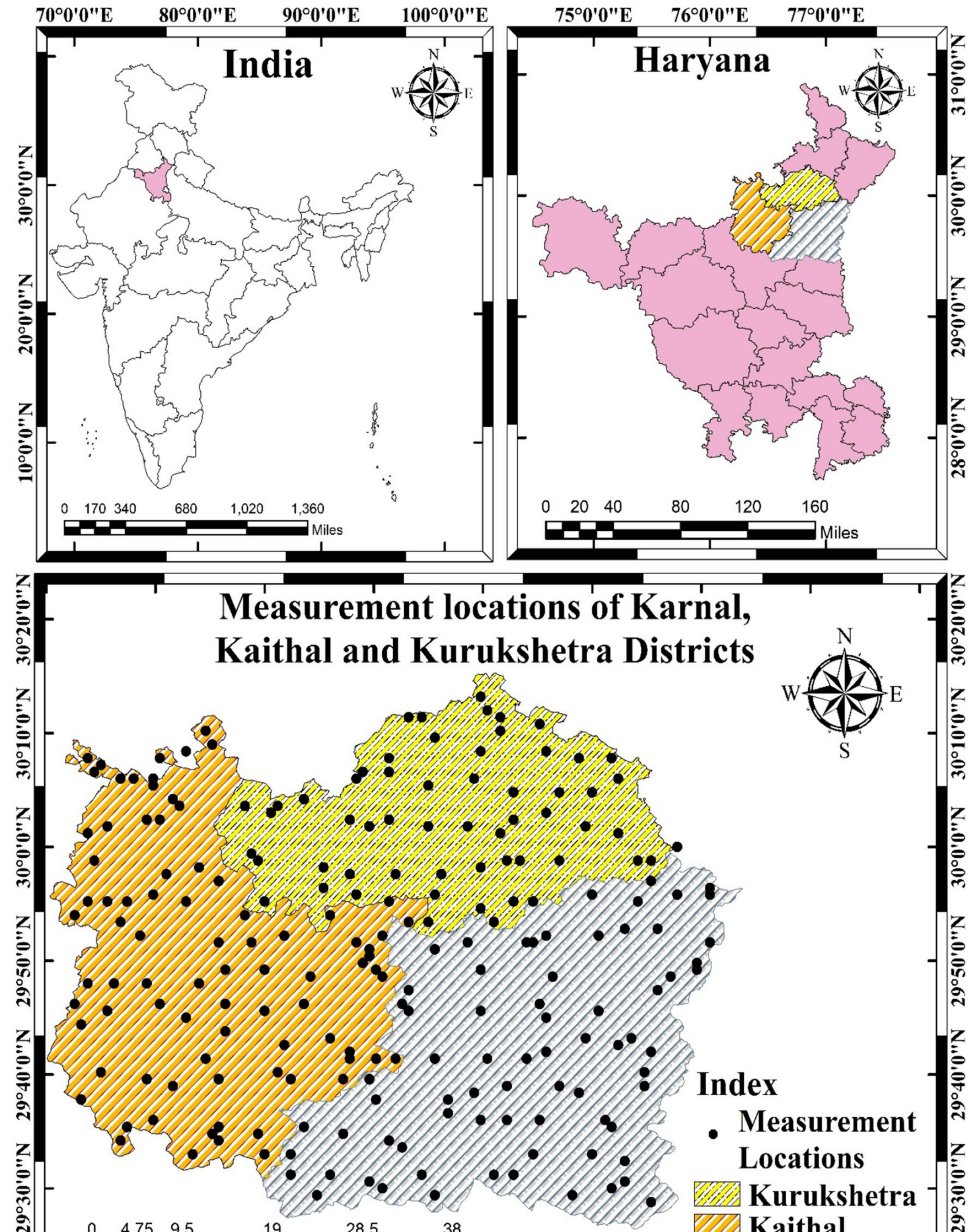

Fig. 1 Map of studied districts and measurement locations

Kurukshetra

Kurukshetra district is located in the northeastern region of the Haryana State and is bordered by the longitudes of 76°26′27″ and 77°07′57″ in the east and latitude 29°53′00″ and 30°15′02″ in the north (Fig. 1). Apart from the monsoon season, when humid air of oceanic origin makes its way into the region, Kurukshetra's climate is primarily dry with extremely hot summers and frigid winters. The district typically receives 582 mm of rainfall each year, which is dispersed unevenly around the region. The southwest monsoon, which contributes to roughly 81% of the annual rainfall, begins to enter in around the final week of June and ends at the end of September [19]. Rainfall is highest in July and August. Rest in the midst of western disturbances and thunderstorms, 19% of rainfall is recorded during the non-monsoon season. Rainfall in the district tends to rise from the southwest to the northeast [19]. The region is an almost completely flat alluvial plain devoid of any obvious topographical characteristics. The extensive Indo-Gangetic alluvial plains include it. The plain's typical altitude ranges from 274 to 241 m above mean sea level. The district is covered with Quaternary geological formations, including Recent alluvial deposits from the massive Indus alluvial plains [19].

Material and methods

Measurement of γ-dose rate

Grids of 6 × 6 km^2 have been employed to organize the whole region for a comprehensive inspection of the γ-dose rate. Each grid was tested for outdoor γ-dose rate. The measurement was done by holding the one meter above the earth surface and in open area (away from building or plant or any other potential influencer) [20]. 5 measurements were recorded, and the average dose rate was calculated to get a reliable dosage rate. The time difference between subsequent reading was 5–6 min. Measurement was taken two times (one in postmonsoon (Oct, 2018) and another one in premonsoon (May, 2019) season) at a place on clear day. 214 locations were sampled in three districts in the postmonsoon and premonsoon season individually. Using a GPS MAP (Model Garmin eTrex 20, USA) and ArcGIS 10.3 software, the places' coordinates were recorded and placed on the district map respectively (Fig. 1). A radiation monitor model PM-1405 (Polimaster, Belarus) that measures both terrestrial and cosmic γ-radiation dose rates in nSv/h was used to assess the outdoor γ-radiation exposure. The energy range of the monitor for monitoring γ-radiation is 0.05–3.0 MeV, and the measurement range is 0.01 μSv/h–100 mSv/h. It has a dosage equivalent measuring accuracy of ± (20 + K/H) %, where H is the radiation rate in μSv/h and K is the coefficient which is 1.0 μSv/h.The five measurements were taken at a location with the radiation meter held one meter above the ground, and the average dose rate was calculated to get a reliable dosage rate [20]. The annual effective dosage and excess lifetime cancer risk were both calculated using the reported γ-dose rate. ArcGIS software used the IDW (Inverse Distance Weighted) approach to interpolate the γ-dose rate to understander the pattern of distribution [21].

Annual effective dose (AED)

To assess the impact of γ-rays on people, the annual effective dose of γ-radiation from the environment was calculated. Equation (1) was used to calculate the AED [5, 22]:

$$\mathrm{AED(mSv/y)} = (\mathrm{GDR\ (nSv/h)} \times \mathrm{T\ (h/y\ )} \times \mathrm{CC\ (Sv/Gy\ )}) \quad (1)$$

Here, GDR is the outdoor gamma dose rate in nSv/h, where T is the outside occupancy time in hours per year, which was estimated to be 1753.2 h/y (365.5 d × 24 h × 0.2) [23], and CC is the coefficient of conversion, which was used to be 0.70 Sv/Gy [5].

The UNSCEAR recommends these values for converting the absorbed radiation into the effective dose received by adults (the conversion coefficient) and then spending time outside (occupancy factor) [5].

Excess lifetime cancer risk (ELCR)

The cancer risk assessment determines the possible carcinogenic implications according to the probability of cancer incidence in a population during a certain lifespan. In order to calculate lifetime excess lifetime cancer risk, the following Eq. (2) was employed [5]:

$$\mathrm{ELCR} = (\mathrm{AED\ (mSv/y)} \times \mathrm{ALD(y)} \times \mathrm{RF(1/Sv\ )}) \quad (2)$$

Here, AED is used as annual effective dose, ALD is the mean age in India, which as of 2011 was 65.80 years [24], and RF is used as the risk factor, which as per the International Commission on Radiation Protection was 0.057 Sv^{-1} [25].

Statistical analysis

The data were statistically analyzed by using Microsoft Excel and Origin 2019b software. The statistical parameter such as mean, median, minimum, maximum, and histogram was performed by Microsoft Excel. Statistical test including Shapiro–Wilk test for normality testing, Kruskal–Wallis test for checking the hypothesis of the difference between radiation level of different districts, Mann–Whitney test to check the significant impact of seasons on radiation level was performed using Origin 2019b [26].

Result and discussion

The outdoor γ-dose rate in Karnal ($n = 76$), Kaithal ($n = 77$), and Kurukshetra ($n = 61$) varied from 91 ± 5–190 ± 10 nSv/h, 79 ± 4–175 ± 9 nSv/h, to 89 ± 4–137 ± 7 nSv/h in postmonsoon while it was 70 ± 4–174 ± 9, 82 ± 4–267 ± 13, and 77 ± 4–196 ± 10 in premonsoon season respectively. The mean and median values of outdoor γ-dose rate in Karnal ($n = 76$), Kaithal ($n = 77$), and Kurukshetra ($n = 61$) were estimated 121.63 ± 6.08 nSv/h and 118.00 ± 5.90 nSv/h, 109.09 ± 5.45 nSv/h and 106.00 ± 5.30 nSv/h, 114.82 ± 5.75 nSv/h, and 117.00 ± 5.85 nSv/h in postmonsoon season while 111.37 ± 5.56 and 109 ± 5.45, 134.48 ± 6.72 and 126 ± 6.30, 104.3 ± 5.22 and 100 ± 5.00 in premonsoon season respectively. The detailed description of statistical parameters of outdoor γ-dose rate and their corresponding AED and ELCR in both seasons is shown in Table 1. The mean value of outdoor γ-dose rate level in all studied districts for both seasons was higher than the mean value of outdoor γ-dose rate reported for India i.e., 88 nGy/h (reported average terrestrial outdoor radiation for India i.e., 56 nGy/h + average cosmic component throughout the world i.e., 32nGy/h = 88 nGy/h), and worldwide reported mean value i.e., 91 nGy/h (59 nGy/h + 32nGy/h = 91 nGy/h) [5, 27, 28]. 8 locations in premonsoon of Karnal, 8 locations in postmonsoon, 1 location in premonsoon of Kaithal, and 13 locations of premonsoon of Kurukshetra, γ-dose rate was less than the reported mean dose for India i.e., 88 nGy/h. 10 locations in premonsoon of Karnal, 11 locations in postmonsoon, 1 location in premonsoon of Kaithal, and 1 location in postmonsoon and 16 locations of premonsoon of Kurukshetra, γ-dose rate was less than the reported mean dose for world i.e., 91 nGy/h. The mean value of γ-dose rate was maximum in the case of Kaithal and minimum in the case of Kurukshetra. The decreasing order of mean values for studied districts was Kaithal > Karnal > Kurukshetra. However, except at two spots in Kaithal during premonsoon, all measurement sites were observed to have outdoor γ-dose rate within the typical range of 20–190 nSv/h, suggested by UNSCEAR, 2000 as shown in Figs. 2, 3, 4 [5]. Except for the case of the premonsoon of Kurukshetra, the outdoor γ-dose rate at the majority of locations was observed to lie in the range of 101–150 nSv/h (Figs. 2, 3, 4). The radiation profile of northern parts of India has a high radiation. Unconsolidated dunes and river sands, which are all byproducts of the disintegration of Himalayan rocks and are moved by river systems, are together referred to as gangetic alluvium [14]. The geology of the investigated all three districts, which is characterized by gangetic alluvium of quaternary age (detailed in study area) and has been found to contain greater natural radioactivity, may be accountable for the higher value of outdoor γ-dose rate [13, 14, 29]. Although U and Th together make up the majority of natural radiation, potassium is the dominant source of ambient radiation in the regions [14]. The mean value of outdoor γ-dose rate was higher than the median value in all districts except for postmonsoon season of Kurukshetra indicating the positive skewed

Table 1 The mean, minimum, maximum, and median of outdoor GDR, AED, and ELCR

Districts	Parameters	Mean	Min	Max	Median
Karnal	GDR (PSM)(nSv/h)	121.63 ± 6.08	91 ± 5	190 ± 10	118 ± 5.90
	GDR (PRM)(nSv/h)	111.37 ± 5.56	70 ± 4	174 ± 9	109 ± 5.45
	AED (PSM)(mSv/y)	0.149 ± 0.007	0.112 ± 0.006	0.233 ± 0.012	0.145 ± 0.007
	AED (PRM)(mSv/y)	0.137 ± 0.007	0.086 ± 0.004	0.213 ± 0.011	0.134 ± 0.007
	ELCR $\times 10^{-3}$ (PSM)	0.559×10^{-3}	0.419×10^{-3}	0.874×10^{-3}	0.543×10^{-3}
	ELCR $\times 10^{-3}$ (PRM)	0.512×10^{-3}	0.322×10^{-3}	0.8×10^{-3}	0.501×10^{-3}
Kaithal	GDR (PSM)(nSv/h)	109.09 ± 5.45	79 ± 4	175 ± 9	106 ± 5.30
	GDR (PRM)(nSv/h)	134.48 ± 6.72	82 ± 4	267 ± 13	126 ± 6.30
	AED (PSM)(mSv/y)	0.134 ± 0.007	0.097 ± 0.005	0.215 ± 0.011	0.13 ± 0.007
	AED (PRM)(mSv/y)	0.165 ± 0.008	0.101 ± 0.005	0.327 ± 0.016	0.155 ± 0.008
	ELCR $\times 10^{-3}$ (PSM)	0.502×10^{-3}	0.363×10^{-3}	0.805×10^{-3}	0.488×10^{-3}
	ELCR $\times 10^{-3}$ (PRM)	0.619×10^{-3}	0.377×10^{-3}	1.228×10^{-3}	0.58×10^{-3}
Kurukshetra	GDR (PSM)(nSv/h)	114.82 ± 5.74	89 ± 4	137 ± 7	117 ± 5.85
	GDR (PRM)(nSv/h)	104.3 ± 5.22	77 ± 4	196 ± 10	100 ± 5.00
	AED (PSM)(mSv/y)	0.141 ± 0.007	0.109 ± 0.005	0.168 ± 0.008	0.143 ± 0.007
	AED (PRM)(mSv/y)	0.128 ± 0.006	0.094 ± 0.005	0.240 ± 0.012	0.123 ± 0.006
	ELCR $\times 10^{-3}$ (PSM)	0.528×10^{-3}	0.409×10^{-3}	0.63×10^{-3}	0.538×10^{-3}
	ELCR $\times 10^{-3}$ (PRM)	0.48×10^{-3}	0.354×10^{-3}	0.902×10^{-3}	0.460×10^{-3}

PSM postmonsoon, *PRM* premonsoon

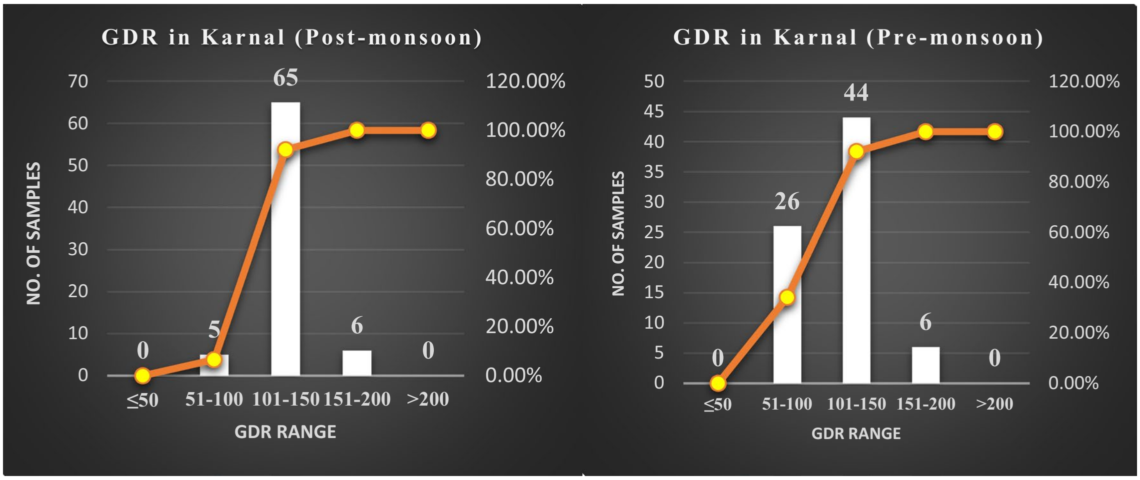

Fig. 2 Frequency distribution in different range of outdoor GDR Karnal district in both seasons

Fig. 3 Frequency distribution in a different ranges of outdoor GDR Karnal district in both seasons

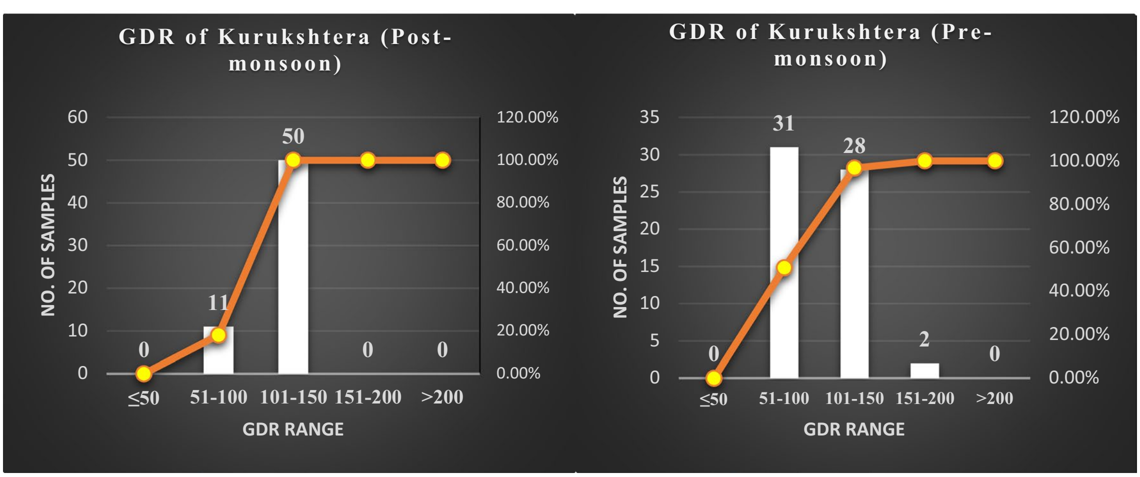

Fig. 4 Frequency distribution in a different range of outdoor GDR Karnal district in both seasons

nature of data. The outdoor γ-dose rate data was negatively skewed for postmonsoon season of Kurukshetra. The data distribution was checked using the Shapiro–Wilk test, detailed in Table 2.

The normality of outdoor γ-dose rate for postmonsoon and premonsoon data of Karnal was tested at a 5% level of significance and estimated *p*-values were 3.16×10^{-4} and 8.61×10^{-5} respectively, hence rejecting the null hypothesis and inferred that the sample was not taken out from normally distributed population.

The *p*-value of outdoor γ-dose rate for postmonsoon and premonsoon in the case of Kaithal was 0.00461 and 9.85×10^{-8} and in the case of Kurukshetra was 0.029 and 2.38×10^{-6} respectively, indicating the rejection of the null hypothesis. Hence it was inferred that outdoor γ-dose rate data for both seasons for Kaithal and Kurukshetra was not normally distributed. No district data was observed to follow normal distribution which indicated the inapplicability of the parametric test. significance difference between outdoor γ-dose rate for all three districts was tested using the Kruskal–Wallis test at a 95% level of confidence. The estimated *p*-value was 3.93×10^{-17} which inferred to reject the null hypothesis. It means that the samples were significantly different from each other and hence did not come from the same population.

Interpolation maps for outdoor γ-dose rate

According to Burrough and McDonnell (1998) and Jasrotia and Kumar (2014), GIS-based spatial analysis is proven to be a powerful approach and an ideal tool for producing the required outcomes for the geographical distribution of various environmental factors [30, 31]. Also, it helps with the analysis of trends in water, air, and soil quality and other kinds of natural radiation. In several studies, the spatial representation of the γ-radiation dose rate was mapped using remote sensing and GIS techniques to understand the distribution pattern within different types of geographical setups [32–34]. For the present study, geographic analysis was performed using ArcGIS 10.8 software. The samples were plotted using GPS-based coordinates, and the distribution was made using GIS interpolation techniques. IDW method was employed to interpolate the data from point date to continuous distribution map. The spatial distribution of Outdoor γ-dose rate for both seasons in all three districts is shown in Figs. 5, 6, 7. In the studied districts, no discernible trend was seen.

The outdoor γ-dose rate level in studied districts was compared with previous studies conducted in India and across the world. Some studies focused on outdoor γ-dose rate conducted in India and around the world are given in the Table 3. The outdoor γ-dose rate was reported as maximum in the case of Kaithal and minimum in the case of Karnal. The outdoor γ-dose rate in Karnal and Kurukshetra was somewhat equal reported γ- dose rate in Bhilai, Chhattisgarh; Durg, Chhattisgarh, India and Panchkula, Haryana, India; Enugu urban areas, Enugu state, Nigeria. The γ-dose rate in Kaithal was somewhat similar to Balod, Chhattisgarh; Anand, Bharuch, Vadodara, and Narmada, Gujarat, India. Ranges of γ-dose rate in the studied district were somewhat higher than the γ-dose rate reported along the bank of Alaknanda and Gange river, India; Kuwait; Thailand; Algiers Province, Algeria but somewhat lesser than γ-dose rate reported in Kanniyakumari district Ramanathapuram, Virudhunagar, Tirunelveli, and Thoothukudi districts of Tamilnadu, India; Dornogobi Province, southeastern Mongolia. The details of outdoor γ-dose rate with mean value in different states and across the world are given in Table 3.

Seasonal variability in outdoor γ-dose rate

The seasonal variation in outdoor γ-dose rate was evaluated by measuring the γ-dose rate in postmonsoon and premonsoon seasons. The mean value of outdoor γ-dose rate for the postmonsoon season in Karnal and Kurukshetra was higher than premonsoon. This might be a result of radionuclides like ^{214}Pb and ^{214}Bi that are carried to the ground surface by the scavenging action of rain throughout the post-monsoon period [45–48]. Precipitation greatly increases the ground surface γ-dose rate intensity. Precipitation included radionuclides including ^{7}Be, ^{212}Pb, and ^{210}Pb [47]. Melintescu et al. (2018) claim that precipitation has the most impact on ambient γ-dose, increasing its levels [49]. But the trend in the case of Kaithal was opposite. The mean outdoor γ- dose

Table 2 Normality test parameters of GDR data

Districts	DF	Standard deviation	SE of mean	Statistic	*p*-value	Decision at level (5%)
Karnal (PSM)	76	19.30	2.21	0.92858	3.61E-04	Reject normality
Karnal (PRM)	76	22.51	2.58	0.91467	8.16E-05	Reject normality
Kaithal (PSM)	77	17.74	2.02	0.95055	0.00461	Reject normality
Kaithal (PRM)	77	29.66	3.38	0.83768	9.85E-08	Reject normality
Kurukshetra (PSM)	61	12.00	1.53	0.95654	0.02984	Reject normality
Kurukshetra (PRM)	61	21.22	2.72	0.84868	2.38E-06	Reject normality

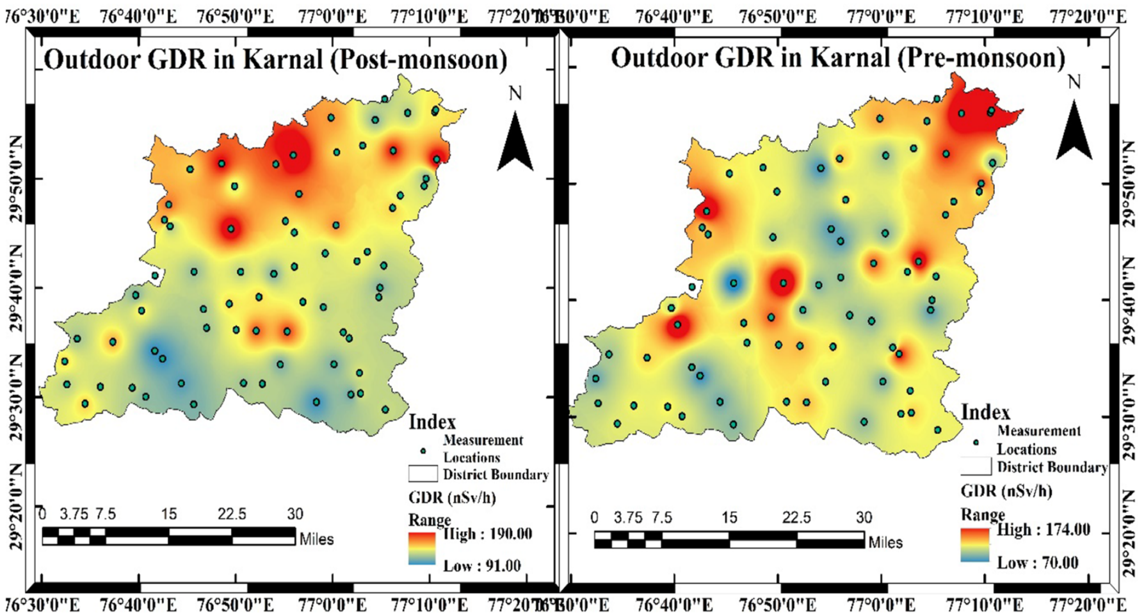

Fig. 5 Interpolation map of outdoor GDR in Karnal district in postmonsoon and premonsoon season

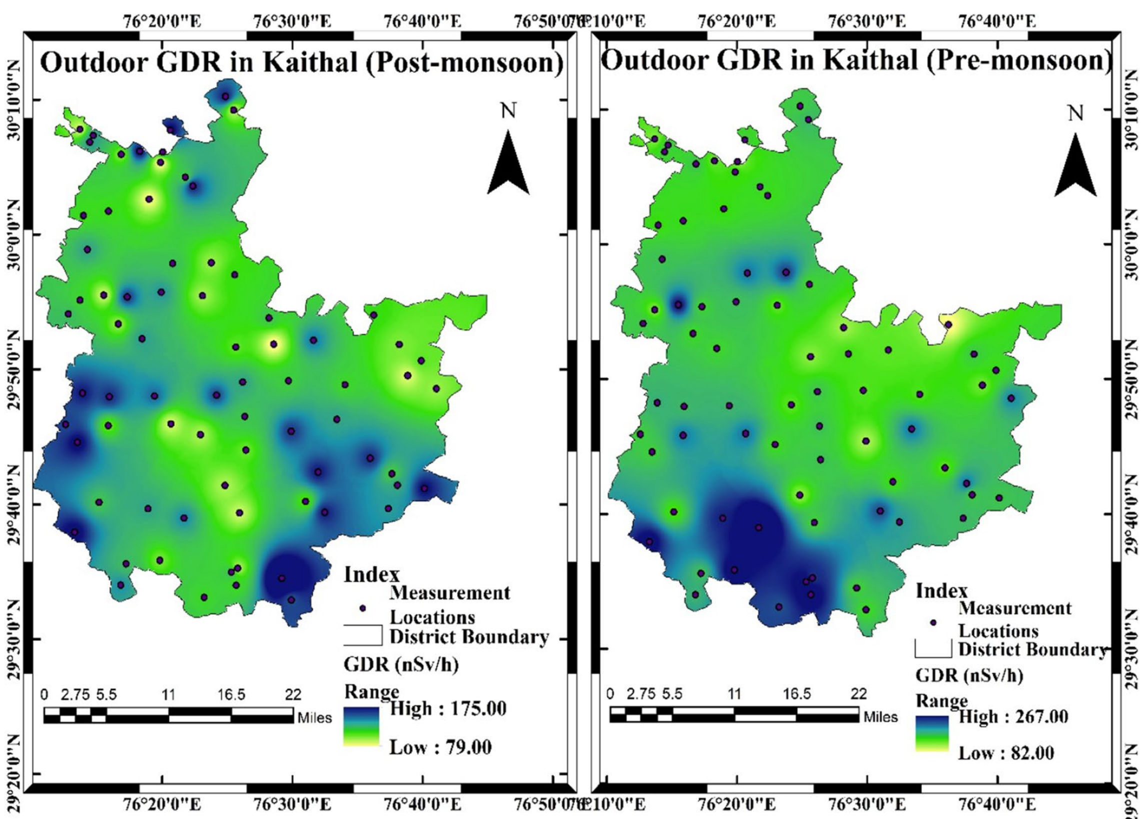

Fig. 6 Interpolation map of outdoor GDR in Kaithal district in postmonsoon and premonsoon season

rate level for premonsoon in Kaithal was higher as compared to postmonsoon. Guagliardi et al. (2016) observed a similar tendency in which regions with higher radioactivity readings in the summer tend to have much lower values in the winter, suggesting that soil moisture plays a significant role in influencing field measurements [50]. In fact, at that time, more

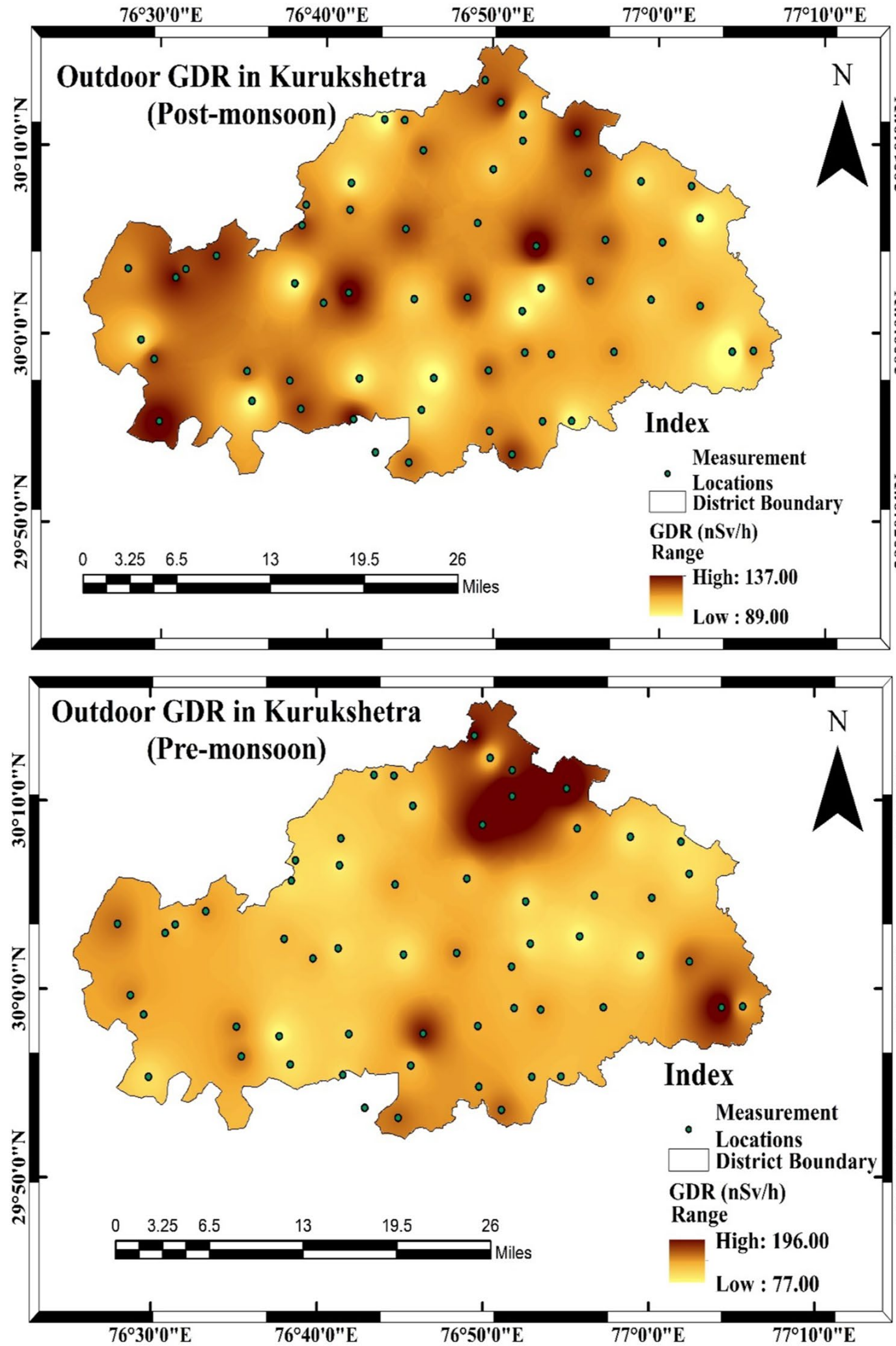

Fig. 7 Interpolation map of outdoor GDR in Kurukshetra district in postmonsoon and premonsoon seasons

frequent rainfall and cooler temperatures encourage a higher moisture availability in the soil, which alters the behavior of the soil with regard to γ-ray measurement. This may encourage the leaching of some elements, including radionuclides, but it is more likely to create a physical barrier that prevents the detection of γ-rays. Statistical difference between outdoor γ-dose rate for postmonsoon and premonsoon season was analysed. As data was not normally distributed. Therefore, a non-parametric Wilcoxson signed rank test was applied to see the significant difference between the seasonal measurement of all three districts. The estimated *p*-value at a 5% level of significance for postmonsoon and premonsoon of Karnal district was 3.87×10^{-4}, indicating that there was a significant difference between outdoor γ-dose rate for post and premonsoon seasons in Karnal district. Similarly, the estimated *p*-value for the difference between outdoor γ-dose

Table 3 Range and the mean value of outdoor GDR in some places of India and the world

S. No	Ranges of γ-dose rate (nSv/h)	Mean GDR (nSv/h)	Locations	References
National studies				
1	81.33–144	100.83	Along Alaknanda and Gange river, India	[29]
2	108–172	136.8	Bhilai, Chhattisgarh	[35]
3	103–201	143.6	Balod, Chhattisgarh	[36]
4	117–185	154	Durg, Chhattisgarh, India	[37]
5	103–271	146.5	Balod, Chhattisgarh	[38]
6	58–3880	276	Kanniyakumari district	[39]
7	85–216	135.5	Panipat District, Haryana	[13]
8	35–335	89	Ramanathapuram, Virudhunagar, Tirunelveli, and Thoothukudi districts of Tamilnadu, India	[40]
9	70–168	97	Panchkula, Haryana, India	[10]
10	74–287	149.5	Anand, Gujarat, India	[27]
11	40–278	128	Bharuch, Gujarat, India	[27]
12	19–287	152.5	Vadodara, Gujarat, India	[27]
13	40–210	128	Narmada, Gujarat, India	[27]
International studies				
1	14–279 nGy/h	–	Mountainous locations in the western region of Saudi Arabia	[41]
2	31–59	46.5	Kuwait	[42]
3	45–450 nGy/h	–	Dornogobi Province, southeastern Mongolia	[43]
4	77–180	124.92	Enugu urban areas, Enugu state, Nigeria	[4]
5	8–141	41	Thailand	[44]
6	14.3–114.3	47.70	Algiers Province, Algeria	[23]

rate for post and premonsoon in Kaithal and Kurukshetra was 1.156×10^{-9} and 1.431×10^{-4} respectively indicating the outdoor γ-dose rate distribution for both seasons in Kaithal and Kurukshetra was significantly different at 95% level of confidence.

AED and ELCR

The AED values were computed based on the γ-dose rate measured. A detailed description of the statistical parameters of AED and ELCR for both seasons is given in Table 1. The AED value was observed to vary between 0.112 ± 0.006–0.233 ± 0.012 mSv/y during postmonsoon and 0.086 ± 0.004–0.213 ± 0.011 mSv/y during premonsoon of Karnal district. The postmonsoon and premonsoon AED in Kaithal and Kurukshetra was estimated to range between 0.097 ± 0.005–0.215 ± 0.011 mSv/y, 0.101 ± 0.005–0.327 ± 0.016 mSv/y and 0.109 ± 0.005–0.168 ± 0.008 mSv/y and 0.094 ± 0.005–0.240 ± 0.012 mSv/y. The mean value of AED (Table 1) in postmonsoon of Karnal, premonsoon of Kaithal locations is higher than the worldwide mean value of AED of 0.148 mSv/y (0.07 mSv/y + (0.39 mSv/y *0.2)) while in rest districts it is lower than world average value [5, 27]. In Karnal, 42% Locations in postmonsoon and 21% location in premonsoon, the AED value was higher than reported average value of AED by UNSCEAR [5]. In case of Kaithal 26% Locations in postmonsoon and 65% locations in premonsoon, the AED value was higher than reported average value of AED. Similarly, in Karnal, 36% Locations in postmonsoon and 11% location in premonsoon, the AED value was higher than reported average value of AED. This confirms that background γ- radiation levels in Karnal, Kaithal, and Kurukshetra are relatively high, which is a sign of a radiation-contaminated environment. However, the AED value is less than the value reported in High background areas of India and the world. The calculated AED values fell within the 0.3–0.6 mSv/y range reported worldwide [5]. Moreover, the current levels are below the 1.0 mSv/y suggested permissible limits for exposure to the general population [5, 25]. The ranges of ELCR during both seasons in all studied districts are given in Table 1. The mean value of ELCR during both seasons in all three districts is higher than the worldwide reported mean value of ELCR of 0.29×10^{-3}[51]. The mean number of anticipated cancer cases in Karnal, Kaithal, and Kurukshetra for post and premonsoon season were 55, 51; 50, 61; and 52, 48 per hundred thousand people respectively. The highest anticipated cancer cases were in Kaithal and the lowest was in Kurukshetra. The probability of cancer cases in the three districts is in decreasing order as Kaithal > Karnal > Kurukshetra.

Despite the fact that radiation hormesis is supported by a considerable amount of empirical evidence and statistically significant epidemiological investigations [52]. There are reports of several epidemiological studies that show that exposure to Low levels of radiation (less than 100 mSv/y) has reportedly had a good impact on health [53]. The database of about 700,000 shipyard employees included nearly 108,000 nuclear workers with exposure of around 20 years in the investigation of nuclear shipyard workers, which is perhaps the greatest proof that exposure to low levels of ionizing radiation is safe. To examine the mortality rates owing to various causes, data from three study groups i.e., 33,352 non-nuclear workers (NNW), 10,462 nuclear workers with dose equivalents (DE) under 5 mSv, and 28,542 nuclear workers with DEs more than 5 mSv was gathered. According to the gathered data, it was observed that nuclear employees expire from all causes at a lower rate than non-nuclear workers. Compared to employees who weren't exposed, exposed workers' overall mortality rate was just 76% [54].

Therefore, an epidemiological survey needs to be done to get a clear idea about the actual effect due to the radiation in the study region.

Conclusion

The comprehensive measurement of outdoor γ-dose rate at 214 locations of three districts (Karnal, Kaithal, and Kurukshetra) during postmonsoon and premonsoon seasons was employed to estimate seasonal impacts on outdoor γ-dose rate and health risks to the exposed population. The mean value of outdoor γ-dose rate in all three districts was higher than the average reported value of India i.e., 88 nGy/h, and the world i.e., 91 nGy/h. This may be attributed to the geology of the studied districts which is characterized by gangetic alluvium of quaternary age (detailed in study area) and has been found to contain greater natural radioactivity, may be accountable for the higher value of outdoor γ-dose rate in the study area. The outdoor γ-dose rate in all three districts during post and premonsoon season were within the suggested range of 20–190 nSv/h, given by UNSCEAR, 2000 except at two locations of Kaithal during pre-monsoon season. The mean value of radiation level in postmonsoon season was higher than premonsoon in the case of Karnal and Kurukshetra but the trend was opposite in the case of Kaithal. The normality of γ-radiation data was rejected for both seasons in all three districts which were tested by Shapiro–Wilk test. Kruskal–Walslis test confirmed the significant difference between the radiation level of the three districts. The season had significant impacts on outdoor γ-radiation levels, tested using the Mann–Whitney test. At various locations in both season the AED value was higher than reported mean value of AED i.e., 0.148 mSv/y throughout the world. ELCR in all three districts during each season was higher than the worldwide reported mean of ELCR i.e., 0.29×10^{-3}. Some studies reported the hormetic effects of low levels of radiation. Therefore, a health survey is required to get the actual status of people's health and its correlation with the radiation level of the area.

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