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Measurement of Seasonal Variation of Outdoor Gamma Radiation Dose Rate Level and Assessment of Consequent Health Hazards in Panchkula, Haryana, India

N. Tanwer[a], P. Anand[a,*], N. Batra[a], K. Kant[b], Y. P. Gautam[c], and S. K. Sahoo[d]

[a] *Department of Chemistry, Aggarwal College, Ballabgarh, 121004 India*
[b] *Department of Physics, Aggarwal College, Ballabgarh, 121004 India*
[c] *NAPS, Narora, 203389 India*
[d] *Health Physics Division, Bhabha Atomic Research Centre, Mumbai, 400085 India*
**e-mail: poonam.anand10@gmail.com*

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Abstract—A systematic measurement of outdoor gamma radiations in Panchkula district of Haryana, India, was done using a radiation monitor based on Geiger–Muller technique. The gamma dose rate was found to be in the range from 70.0 ± 3.5 to 168.0 ± 8.4 nSv/h. The annual effective dose (AED) due to the outdoor gamma radiation in Panchkula district was computed to range from 0.086 ± 0.004 to 0.206 ± 0.010 mSv/year. The value of excess lifetime cancer risk (ELCR) was found to be in the range from 0.322×10^{-3} to 0.773×10^{-3}.

Keywords: annual effective dose, excess lifetime cancer risk, gamma radiation level, seasonal variation

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INTRODUCTION

Natural radiations are an unavoidable part of environment. There is no place on the Earth which is devoid of background radiations. All living beings inhabiting the Earth get exposure due to these radiations at all the times. The sources of their exposure are cosmic rays that come from outer space and from sun's surface, cosmogenic radionuclides, i.e., radioactive nuclei that are produced by interaction with cosmic rays (e.g., ^{3}H, ^{7}Be, and ^{14}C), and primordial terrestrial that occur in the Earth's crust, building materials, air, water, and even in human body itself [1]. Some of the exposures are fairly consistent and uniform for all the individuals everywhere, while other exposures show variation largely depending on location and geo-environmental conditions such as composition of soil, rock, and Earth's crust of the region. The annual exposure due to the natural background radiation is 2.4 mSv, which accounts for 85% of the total radiation exposure dose (2.8 mSv) [2]. The exposure due to cosmic radiations increases with latitude and altitude, which makes the polar and mountain inhabitants as well as aircrew and frequent air travelers more prone to receive higher radiation exposure due to cosmic rays [3]. The worldwide average contribution of cosmic rays to the annual effective dose (excluding cosmogenic radionuclides that account for 0.01 mSv) is 16% of the total annual exposure of the population due to natural background radiation (about 0.38 mSv) [4]. The terrestrial radiations including radiations from radon and its progenies make up more than 60% of the total natural background radiations. The annual exposure due to terrestrial radiations and radon (including its progenies) is 0.48 and 1.15 mSv, respectively [5]. The terrestrial radionuclides include ^{238}U, ^{232}Th series, and ^{40}K, and their relative contributions to the radiation level is 25, 40, and 35%, respectively. The contribution from anthropogenic activities like nuclear tests, accidents, and power production, whose fission product is ^{137}Cs, is negligible. By far, the highest contribution to radiation exposure comes from the natural background radiation.

The human body gets exposure due to radiations by two pathways: external and internal exposure [6]. The radiation interaction causes damage in cells, resulting in cell death and modifications, which lead to malfunctioning of organs and tissues and end with stochastic health effects (cancerous and hereditary effects) [5]. The damage to DNA of the nucleus is the main initiating step by which radiation causes long-term effects to the organs and tissues of the body. The mutation caused by radiation interaction with the genes is reflected in several disorders and cancer [5]. As the dose to the tissue increases, gradually more and more cells become prone to damage and probability of stochastic effects increases.

The level of radiation exposure to human varies geographically, depending upon the activity of radionuclides, which, in turn, depends on the soil types and geological formation of the area. Therefore, at some places the high content of natural radionuclides in the soil causes heavy external exposure due to natural radiation; such regions are known as high background area. The range of annual effective dose in typical circumstances may vary from 1 to 10 mSv. In the previous study, some areas were found to have higher level of natural radioactivity like Kerala (India), Ramsar (Iran), Campina (Italy), etc. [7, 8]. The United Nations Scientific Commission on the Effects of Atomic Radiation (UNSCEAR) has reported the radiation dose rate of 32 nSv/h due to cosmic radiations at mean sea level, and the population weight average of outdoor terrestrial radiation dose rate was 59 nSv/h [5, 9]. The annual effective dose due to terrestrial as well as cosmic gamma radiation is 0.87 mSv/year collectively [5, 9]. However, the variation in terrestrial gamma radiation dose rate is higher as compared to cosmic radiations, and the former one also contributes more to the total background radiation level [10]. Therefore, it becomes necessary to evaluate the outdoor gamma radiation level to which people are exposed and keep them under observation on regular basis. In recent years, various studies have been conducted to evaluate the gamma radiation dose rate and the factors affecting its level in the environment [10–15]. In our previous study of Panipat district, gamma radiation level was observed to vary seasonally. So, in continuation of our previous research work, this study focuses on measurement of the variation in the outdoor gamma radiation level, consequent radiation dose received by the inhabitants, and associated lifetime cancer risk due to outdoor gamma radiation exposure in Panchkula district of Haryana. We have evaluated the seasonal variation and consequential health hazards due to gamma radiation dose rate in the proposed district. This study of the proposed area is the first of its kind and will generate the baseline data of outdoor radiation dose rate that, in case of a radiation accident in future, can be used as a standard in remedial actions for environmental decontamination of the area. This study envisages the comparison of results with national and international reported data available in the literature.

STUDY AREA

Panchkula was chosen as the area of the study. It lies in the northern region of Haryana between 30°26’ and 30°55’ N and between 76°46’ and 77°10’ E with an area of 898 km^2 (Fig. 1). It shares boundaries with two states, namely, Himachal in the north and northeast and Punjab in the south, and one district, namely, Ambala in the west. Panchkula has Siwalik Hills in north and northeast of district, while its south and southwest have alluvial plains. There are rolling plains having an altitude of 500 m between Siwalik Hills and alluvial plains. The main draining river is Ghaggar and its tributaries. A small northwestern part of the district is drained by Sirsa Nadi, which is the tributary of Sutlej River. Panchkula is endowed with good surface as well as groundwater resources. The major portion of groundwater is used for irrigation purpose. The percentage of gross irrigated area to total cropped area is 91.6%, and the average annual rainfall is about 1057 mm [16]. Out of the total annual rainfall, 86% is contributed by the southwest monsoon in the period of June to September and 14%, by nonmonsoon rains. The physiography of district is divided mainly into three groups, namely, Siwalik Hills, Kandi Belts, and Alluvial Plains. Siwalik Hills are characterized by the broad table and topography with very sharp slopes. Numerous ephemeral streams are originated; they come down to the outer slopes of the Siwalik Hills, spreading much of gravel boulders and pebbles throughout the region. The soil types vary from loamy sands to fine sandy loams (except in depressions), well-drained, non-saline, non-alkali, non-calcareous, and mostly base-saturated; they are classified as loamy skeletal typic, lithyhic, and eurtrochrepts/udorthents. These soils are found in the Siwalik range, while in Yamuna Plains, water-logged soils with loam to clay-loam texture showing the effect of glazing are classified as aeric/typic haplaquepts [16]. The dose rate measured for different places of Panchkula is shown in Fig. 1.

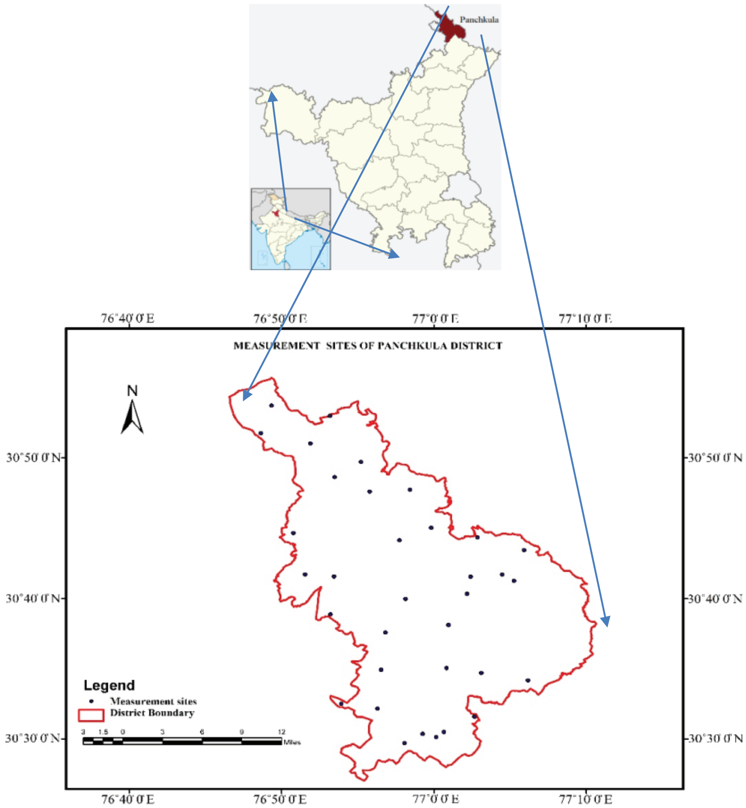

Fig. 1. Enlarged view of measurement sites of Panchkula district.

EXPERIMENTAL

Methodology

A systematic measurement of the gamma dose rate was done by dividing the district into grids with a size of 6 × 6 km^2. A total of 35 locations were investigated in the winter and summer seasons, and GPS coordinates were recorded using Garmin 78S. The outdoor gamma dose rate was measured using a handheld Polimaster PM 1405 radiation monitor. This instrument is based on Geiger–Muller technique and measures the terrestrial as well as cosmic radiation dose rate. Five measurements were done at a location by holding the monitor 1 m above the ground, and the mean dose rate was taken to get concordant dose rate. The energy range of the monitor to measure gamma radiation is 0.05–3.0 MeV, and its detection range for gamma dose rate is from 0.01 μSv/h to 100 mSv/h. It has dose equivalent measurement accuracy of ±(20 + K/H)%, where H is the dose rate in μSv/h and K is the coefficient equal to 1.0 μSv/h. The locations were pointed in Panchkula map using Arc GIS10.7 software.

Calculation of Annual Effective Dose (AED)

The annual effective dose due to outdoor gamma radiations was calculated. The effect due to ionizing radiation on human beings was evaluated using the annual effective dose [Eq. (1):

$$\text{AED [mSv/year]} = D\ \text{[nSv/h]} \times T \times \text{(conversion coefficient)} \times \text{(occupancy factor)}, \quad (1)$$

where D is the outdoor gamma dose rate in nSv/h, T is the time conversion factor, which was taken as 8760 (365 days × 24 h), the conversion coefficient was taken as 0.7 Sv/Gy, and the occupancy factor for outdoor exposure was taken as 0.2 [5].

Calculation of Excess Lifetime Cancer Risk (ELCR)

The cancer risk estimates the potential carcinogenic effects involving the cancer incidence in population for specific lifetime. The excess lifetime cancer risk was calculated using Eq. (2):

Table 1. Gamma radiation dose rate, annual effective dose, and excess lifetime cancer risk in winter and summer seasons of Panchkula district of Haryana

Sample no.	Gamma radiation level, nSv/h		AED, mSv/year		Excess lifetime cancer risk (ELCR)	
	winter	summer	winter	summer	winter	summer
1	113 ± 6	81 ± 4	0.139 ± 0.007	0.099 ± 0.005	0.520×10^{-3}	0.373×10^{-3}
2	93 ± 5	81 ± 4	0.114 ± 0.006	0.099 ± 0.005	0.428×10^{-3}	0.373×10^{-3}
3	88 ± 4	80 ± 4	0.108 ± 0.005	0.098 ± 0.005	0.405×10^{-3}	0.368×10^{-3}
4	97 ± 5	79 ± 4	0.119 ± 0.006	0.097 ± 0.005	0.446×10^{-3}	0.363×10^{-3}
5	101 ± 5	86 ± 4	0.124 ± 0.006	0.105 ± 0.005	0.465×10^{-3}	0.396×10^{-3}
6	98 ± 5	72 ± 4	0.120 ± 0.006	0.088 ± 0.004	0.451×10^{-3}	0.331×10^{-3}
7	95 ± 5	79 ± 4	0.117 ± 0.006	0.097 ± 0.005	0.437×10^{-3}	0.363×10^{-3}
8	81 ± 4	85 ± 4	0.099 ± 0.005	0.104 ± 0.005	0.373×10^{-3}	0.391×10^{-3}
9	112 ± 6	86 ± 4	0.137 ± 0.007	0.105 ± 0.005	0.515×10^{-3}	0.396×10^{-3}
10	99 ± 5	70 ± 4	0.121 ± 0.006	0.086 ± 0.004	0.455×10^{-3}	0.322×10^{-3}
11	89 ± 4	83 ± 4	0.109 ± 0.005	0.102 ± 0.005	0.409×10^{-3}	0.382×10^{-3}
12	109 ± 5	89 ± 4	0.134 ± 0.007	0.109 ± 0.005	0.501×10^{-3}	0.409×10^{-3}
13	114 ± 6	84 ± 4	0.140 ± 0.007	0.103 ± 0.005	0.524×10^{-3}	0.386×10^{-3}
14	96 ± 5	92 ± 5	0.118 ± 0.006	0.113 ± 0.006	0.442×10^{-3}	0.423×10^{-3}
15	88 ± 4	87 ± 4	0.108 ± 0.005	0.107 ± 0.005	0.405×10^{-3}	0.400×10^{-3}
16	101 ± 5	88 ± 4	0.124 ± 0.006	0.108 ± 0.005	0.465×10^{-3}	0.405×10^{-3}
17	106 ± 5	96 ± 5	0.130 ± 0.006	0.118 ± 0.006	0.488×10^{-3}	0.442×10^{-3}
18	168 ± 8	120 ± 6	0.206 ± 0.010	0.147 ± 0.007	0.773×10^{-3}	0.552×10^{-3}
19	125 ± 6	99 ±	0.153 ± 0.008	0.121 ± 0.006	0.575×10^{-3}	0.455×10^{-3}
20	114 ± 6	98 ± 5	0.140 ± 0.007	0.120 ± 0.006	0.524×10^{-3}	0.451×10^{-3}
21	112 ± 6	95 ± 5	0.137 ± 0.007	0.117 ± 0.006	0.515×10^{-3}	0.437×10^{-3}
22	116 ± 6	98 ± 5	0.142 ± 0.007	0.120 ± 0.006	0.534×10^{-3}	0.451×10^{-3}
23	102 ± 5	83 ± 4	0.125 ± 0.006	0.102 ± 0.005	0.469×10^{-3}	0.382×10^{-3}
24	105 ± 5	83 ± 4	0.129 ± 0.006	0.102 ± 0.005	0.483×10^{-3}	0.382×10^{-3}
25	96 ± 5	82 ± 4	0.118 ± 0.006	0.101 ± 0.005	0.442×10^{-3}	0.377×10^{-3}
26	92 ± 5	85 ± 4	0.113 ± 0.006	0.104 ± 0.005	0.423×10^{-3}	0.391×10^{-3}
27	98 ± 5	91 ± 5	0.120 ± 0.006	0.112 ± 0.006	0.451×10^{-3}	0.419×10^{-3}
28	115 ± 6	74 ± 4	0.141 ± 0.007	0.091 ± 0.005	0.529×10^{-3}	0.340×10^{-3}
29	103 ± 5	93± 5	0.126 ± 0.006	0.114 ± 0.006	0.474×10^{-3}	0.428×10^{-3}
30	102 ± 5	92 ± 5	0.125 ± 0.006	0.113 ± 0.006	0.469×10^{-3}	0.423×10^{-3}
31	116 ± 6	98 ± 5	0.142 ± 0.007	0.120 ± 0.006	0.534×10^{-3}	0.451×10^{-3}
32	112 ± 6	89 ± 4	0.137 ± 0.007	0.109 ± 0.005	0.515×10^{-3}	0.409×10^{-3}
33	97 ± 5	94 ± 5	0.119 ± 0.006	0.115 ± 0.006	0.446×10^{-3}	0.432×10^{-3}
34	123 ± 6	95 ± 5	0.151 ± 0.008	0.117 ± 0.006	0.566×10^{-3}	0.437×10^{-3}
35	118 ± 6	92 ± 5	0.145 ± 0.007	0.113 ± 0.006	0.543×10^{-3}	0.423×10^{-3}
Average	106 ± 5	88 ± 4	0.129 ± 0.006	0.108 ± 0.005	0.483×10^{-3}	0.405×10^{-3}
Minimum	81 ± 4	70 ± 4	0.099±0.005	0.086 ± 0.004	0.373×10^{-3}	0.322×10^{-3}
Maximum	168 ± 8	120 ± 6	0.206±0.010	0.147 ± 0.007	0.773×10^{-3}	0.552×10^{-3}

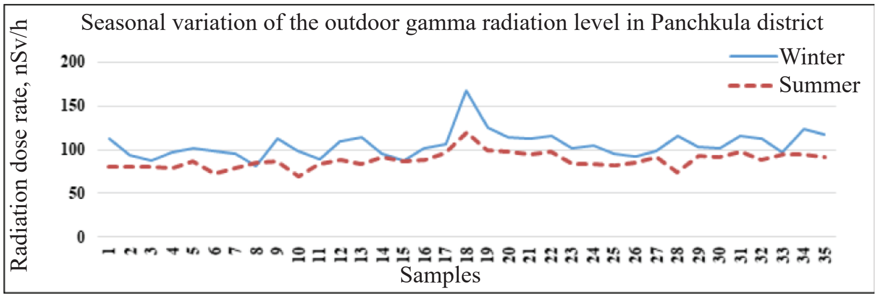

Fig. 2. Line graph showing seasonal variation of the outdoor gamma radiation level in the winter and summer seasons.

$$\text{ELCR} = \text{AED} \times \text{ALD} \times \text{RF}, \quad (2)$$

where AED is the annual effective dose, ALD is the average life duration which was taken as 65.8 years, and RF is the risk factor; its value suggested ICRP is 0.057 [17].

RESULTS AND DISCUSSION

The results of measurement of outdoor gamma radiation dose rate at 35 locations of Panchkula district for both the seasons, i.e., winter and summer, are given in Table 1. This quantity ranges from 81 ± 4 to 168 ± 8 nSv/h with an average of 106 ± 5 nSv/h in the winter season and from 70.0 ± 3.5 to 120 ± 6 nSv/h with an average of 88 ± 4 nSv/h in the summer season.

The outdoor gamma radiation dose rate at all the locations for both seasons was within the typical range of radiation level, from 20 to 200 nSv/h as reported by UNSCEAR. At 60% locations in the winter season and 49% locations in summer the season, the gamma dose rate level was higher than its mean value. Only at one sampling location, namely, sample 18 in the summer season, the outdoor gamma radiation dose rate was higher than 100 nSv/h as presented in supporting information. On the other hand, in the winter season, out of 35 sampling sites, 21 locations were observed to have outdoor radiation dose rate higher than 100 nSv/h (Fig. 1 of supporting information). The slightly higher level of the outdoor gamma dose rate in the study area was attributed to the geology of the area, dominated by gangetic alluvium of quaternary age, which has been reported to have higher natural radioactivity [18, 19]. The results of this study lie between the results of other studies conducted in different regions of India. The similar studies were conducted to measure the outdoor gamma radiation dose rate in India, namely, in Kashmir, Jammu, Ladakh, Shimoga (Karnataka), Durg (Chhattisgarh), and also coastal regions of district of Kerala and along the rivers Alaknanda and Gange [12]. The gamma dose rate for the above-mentioned districts was reported to be in the range 92.0–181.7, 72.4–157.5, 79.9–367.6, (87.0 ± 1.7))–(324 ± 17), (117 ± 5)–(185 ± 7), 210–1340, and (81.3 ± 2.3)–(144 ± 6) nSv/h, respectively [12–14, 20, 21]. In statistical analysis, it was found that the data of gamma radiation level are positively skewed (the mean value is greater than the median value) in both seasons (Fig. 2 of the supporting information), which indicates that the radiation levels at some locations were relatively on the higher side.

Seasonal Variation

Seasonally, the outdoor gamma radiation dose rate was observed to vary greatly. In the winter season, the outdoor radiation dose rate at many sites is higher than that observed in the summer season (Fig. 2). The majority of sampling locations in the winter season show the outdoor gamma radiation dose rate higher than 100 nSv/h, whereas in the summer season these values were lower than 100 nSv/h. The similar trend of the seasonal variation of outdoor radiation level was also observed in Panipat district [18]. Possibly, this may be due the precipitation of radionuclides such as ^{214}Pb and ^{214}Bi, which are brought down to the ground surface with the scavenging effect of rains in the winter season (post-monsoon period) [22]. Precipitation elevates the gamma dose rate intensity at the ground surface significantly [23–25]. Various radionuclides such as ^{7}Be, ^{212}Pb, and ^{210}Pb were observed in the precipitation [23]. Therefore, this might be the probable reason for the elevation of

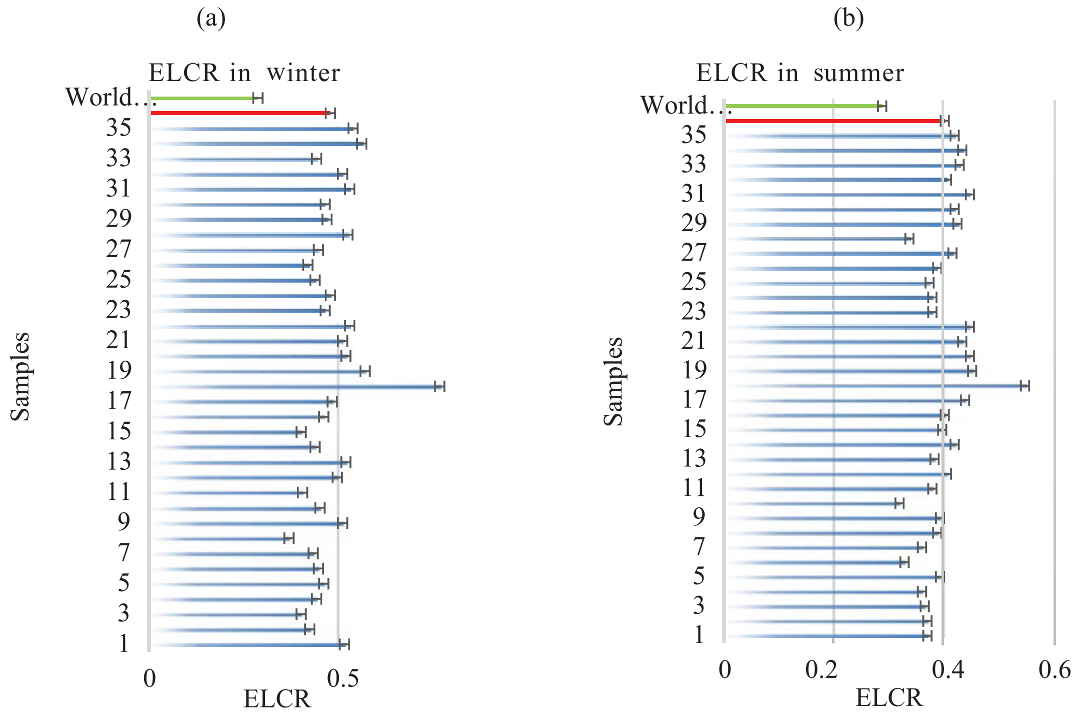

Fig. 3. Excess lifetime cancer risk due to outdoor gamma dose rate in the (a) winter and (b) summer season.

the outdoor radiation dose rate in the winter season as compared to the summer season.

Annual Effective Dose and Excess Lifetime Cancer Risk

The annual effective dose (AED) due to outdoor gamma radiations ranges from 0.099 ± 0.005 to 0.206 ± 0.010 and from 0.086 ± 0.004 to 0.147 ± 0.007 mSv/year with an average of 0.129 ± 0.006 and 0.108 ± 0.005 mSv/year in the winter and summer seasons, respectively (Table 1). The average annual effective dose due to outdoor gamma radiation was higher in the winter season as compared to the summer season. This was attributed to higher gamma radiation level in winter as compared to the summer season. The AED at all locations in both seasons was somewhat higher than the worldwide average value of 0.07 mSv/year as shown in Fig. 3 of supporting information [5]. The possibility for such behavior may be attributed to the natural geology and rocks of the region. The higher terrestrial outdoor radiation level is due to the radionuclides present in parental rocks, which increases the background radiation level in the area. The district is dominated by gangetic alluvium of quaternary age, which has been reported to have higher natural radioactivity [12, 19]. Previous investigations of the groundwater contamination due to U in alluvial plains of the neighbouring district showed high U content [26]. The sediments in these plain regions were transported from nearby areas of Siwalik, granite and metamorphic rocks [27, 28]. The geology of Siwalik regions has been explored by AMDER (Atomic Minerals Directorate for Exploration and Research) due to U mineralization. The U mineralization of Siwalik region can be assumed to be one of the causes of the relatively high gamma radiation level and consequent annual effective dose. The excess lifetime cancer risk was computed and observed to range from 0.373×10^{-3} to 0.773×10^{-3} in winter (Fig. 3a) and from 0.322×10^{-3} to 0.552×10^{-3} in summer (Fig. 3b).

The average value of ELCR in both seasons was higher than the worldwide average value of 0.29×10^{-3} [29]. Although the values of AED and ELCR at the studied locations of Panchkula district were higher than the reported worldwide average values, all the values are well below the background radiation level of 2.4 mSv/year. The AED values due to gamma radiation dose rate at all locations in both seasons are well below the permissible value of AED of 1.0 mSv/year as per ICRP [30]. Therefore, it can be suggested that the radiation level measured in the studied area does not pose any serious health hazard. In this regard, it should be taken into consideration that the number of researchers, as per one school of thought, suggested that the exposure to low level of radiation might be good for human health by accelerating the DNA damage repair mechanism, reducing the genetic instability, and enhancing the overall immune response that leads to the cellular protection from low level of radiation [31–34]. The low levels of radiation (less than 100 mSv) were reported to have some curative effects in different ailments like prevention of tumor growth, wound healing, reduced inflammation of lymph glands, relief from arthritis, and treatment of various infections [35–40]. Therefore, it seems important to explore further and conduct epidemiological surveys of the studied area for establishing the fact of possible health effect on sizeable segment of population.

CONCLUSION

Study was carried out in Panchkula district (the hilliest district of Haryana) to measure the outdoor gamma radiation dose rate, seasonal variation, and consequent health hazards associated with their exposure. The gamma dose rate at all the measurement sites for both seasons was within the typical range from 20 to 200 nSv/h as reported by UNSCEAR. The average value of the gamma dose rate in the winter season was higher than in summer, which may be due to the precipitation of suspended radionuclides such as ^{214}Pb and ^{214}Bi from air with rains in the winter season. The annual effective dose and excess lifetime cancer risk due to outdoor gamma radiation for both seasons was higher than the worldwide average values, which can be attributed to the geology of the region. However, the AED due to outdoor radiation dose rate in both seasons was much below the permissible value of 1.0 mSv/year as per ICRP. Thus, it can be concluded that the outdoor radiation dose rate in the district studied does not cause serious health hazards to the exposed population of the area.

SUPPLEMENTARY INFORMATION

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. National Council on Radiation Protection and Measurements (NCRP), Bethesda, MD Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection: NCRP Report no. 126, 1997.
2. Kapdan, E., Altinsoy, N., Karahan, G., and Yuksel, A., *J. Radioanal. Nucl. Chem.,* 2018, vol. 318, p. 1033. https://doi.org/10.1007/s10967-018-6060-5
3. Gabdo, H.T., Ramli, A.T., Sanusi, M.S., Saleh, M.A., and Garba, N.N., *J. Radioanal. Nucl. Chem.,* 2014, vol. 299, p. 1793. https://doi.org/10.1007/s10967-014-2928-1
4. Jeelani, G., Hassan, W., Saleem, M., Sahu, S.K., Pandit, G.G., and Lone, S.A., *J. Radioanal. Nucl. Chem.,* 2021. https://doi.org/10.1007/s10967-021-07647-6
5. *Sources and Effects of Ionizing Radiation,* New York: United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), 2000.
6. Solehah, A.R. and Samat, S.B., *J. Radioanal. Nucl. Chem.,* 2018, vol. 315, p. 127. https://doi.org/10.1007/s10967-017-5654-7
7. Licínio, M. V., Freitas, A.C., Evangelista, H., Costa-Gonçalves, A., Miranda, M., and Alencar, A.S., *J. Environ. Radioact.,* 2013, vol. 126, p. 32. https://doi.org/10.1016/j.jenvrad.2013.07.012
8. *Sources and Effects of Ionizing Radiation: UNSCEAR Report to the General Assembly, with Scientific Annexes,* New York: United Nations, 1994.
9. *Sources and Effects of Ionizing Radiation: UNSCEAR Report to General Assembly, with Scientific Annexes,*

New York: United Nations, 1993.

10. Jindal, M.K., Sar, S.K., Baghel, T., and Wadhwa, D.S., *J. Geol. Soc. India,* 2021, vol. 97, p. 85. https://doi.org/10.1007/s12594-021-1629-y
11. Kumar, J.M., Kumar, S.S., Arun, A., Shweta, S., Megha, S., and Vijita, D., *Res. J. Chem. Environ.,* 2018, vol. 22, p. 22.
12. Sharma, P., Kumar Meher, P., and Prasad Mishra, K., *J. Radiat. Res. Appl. Sci.,* 2014, vol. 7, p. 595. https://doi.org/10.1016/j.jrras.2014.09.011
13. Jindal, M.K., and Sar, S.K., *J. Radioanal. Nucl. Chem.,* 2020, vol. 325, p. 121. https://doi.org/10.1007/s10967-020-07205-6
14. Kaur, M., Kumar, A., Mehra, R., and Mishra, R., *Nucl. Technol. Radiat. Prot.,* 2018, vol. 33, p. 106. https://doi.org/10.2298/NTRP1801106K
15. Kobya, Y., Taşkın, H., Yeşilkanat, C.M., and Çevik, U., *Hum. Ecol. Risk Assess.,* 2015, vol. 21, p. 2077. https://doi.org/10.1080/10807039.2015.1017876
16. Ground Water Information Booklet Panchkula District, Haryana, North Western Region, Chandigarh: Central Ground Water Board (CGWB), 2013.
17. International Commission on Radiological Protection (ICRP) Publication 103, Ann. ICRP, 2007, 37(2–4)-F.
18. Tanwer, N., Anand, P., Batra, N., Kant, K., Gautam, Y.P., and Sahoo, S.K., *J. Radioanal. Nucl. Chem.,* 2021. https://doi.org/10.1007/s10967-021-07960-0
19. Sankaran, A.V., Jayaswal, B., Nambi, K.S.V., and Sunata, C.M., *U, Th and K Distributions Inferred from Regional geology Gnd the Terrestrial Radiation Profiles in India,* Bombay: Bhabha Atomic Research Centre, 1986.
20. Rangaswamy, D.R., Srinivasa, E., Srilatha, M.C., and Sannappa, J., *Radiat. Prot. Environ.,* 2015, vol. 38, p. 154. https://doi.org/10.4103/0972-0464.176152
21. Monica, S., Visnu Prasad, A., Soniya, S., and Jojo, P., *Radiat. Prot. Environ.,* 2016, vol. 39, p. 38. https://doi.org/10.4103/0972-0464.185180
22. Mercier, J.F., Tracy, B.L., d'Amours, R., Chagnon, F., Hoffman, I., Korpach, E.P., Johnson, S., and Ungar, R.K., *J. Environ. Radioact.,* 2009, vol. 100, p. 527. https://doi.org/10.1016/j.jenvrad.2009.03.002
23. Fujinami, N., *Environ. Int.,* 1996, vol. 22, p. 181. https://doi.org/10.1016/S0160-4120(96)00106-7
24. Greenfield, M.B., Domondon, A.T., Tsuchiya, S., and Tomiyama, M., *J. Appl. Phys.,* 2003, vol. 93, p. 5733. https://doi.org/10.1063/1.1563313
25. Paatero, J., *Radiat. Prot. Dosim.,* 2000, vol. 87, p. 273. https://doi.org/10.1093/oxfordjournals.rpd.a033008
26. Rishi, M.S., Keesari, T., Sharma, D.A., Pant, D., and Sinha, U.K., *J. Radioanal. Nucl. Chem.,* 2017, vol. 311, p. 1937. https://doi.org/10.1007/s10967-017-5178-1
27. Pant, D., Keesari, T., Sharma, D., Rishi, M., Singh, G., Jaryal, A., Sinha, U.K., Dash, A., and Tripathi, R.M., *J. Radioanal. Nucl. Chem.,* 2017, vol. 313, p. 635. https://doi.org/10.1007/s10967-017-5284-0
28. Tanwer, N., Khyalia, P., Deswal, M., and Laura, J., *Rasayan J. Chem.,* 2022. vol. 15, p. 343. https://doi.org/10.31788/RJC.2022.1516608
29. Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hidiroglu, S., and Karahan, G., *J. Environ. Radioact.,* 2009, vol. 100, p. 49. https://doi.org/10.1016/j.jenvrad.2008.10.012
30. *Age-Dependent Doses to Members of the Public from Intake of Radionuclides, part 5: Compilation of lngestion and Inhalation Dose Coefficients: ICRP Publication 72,* Oxford: Pergamon, 1996.
31. Cuttler, J.M., *Dose-Response,* 2013, vol. 11, p. 432. https://doi.org/10.2203/dose-response.13-008.Cuttler
32. Feinendegen, L.E., *Radiat. Prot. Dosim.,* 2003, vol. 104, p. 337. https://doi.org/10.1093/oxfordjournals.rpd.a006197
33. Feinendegen, L.E., Pollycove, M., and Neumenn, R.D., *Dose-Response,* 2012, vol. 557. https://doi.org/10.2203/dose-response.09-035.Feinendegen
34. Pandey, B.N., Sarma, H.D., Shukla, D., and Mishra, K.P., *Int. J. Low Radiat.,* 2006, vol. 2, p. 111. https://doi.org/10.1504/IJLR.2006.007901
35. Mishra, K.P., Ahmed, M., and Hill, R.P., *Int. J. Radiat. Biol.,* 2008, vol. 84, p. 441. https://doi.org/10.1080/09553000802061293
36. Murphy, B.Y.J.B., Morton, J.J., *J. Exper. Med.,* 1915, https://doi.org/10.1084/jem.29.1.25
37. Calabrese, E.J., *Wound Repair Regen.,* 2013, vol. 21, p. 180. https://doi.org/10.1111/j.1524-475X.2012.00842.x
38. Calabrese, E.J. and Calabrese, V., *Int. J. Radiat. Biol.,* 2013, vol. 89, p. 287. https://doi.org/10.3109/09553002.2013.752595
39. Rodel, F., Frey, B., Gaipl, U., Keilholz, L., Fournier, C., Manda, K., Schollnberger, H., Hildebrandt, G., and Rodel, C., *Curr. Med. Chem.,* 2012, vol. 19, p. 1741. https://doi.org/10.2174/092986712800099866
40. Calabrese, E.J. and Dhawan, G., *Dose-Response,* 2012, vol. 10, p. 626. https://doi.org/10.2203/dose-response.12-016.Calabrese