



# Gamma radiation dose rate distribution in the Anand, Bharuch, Vadodara, and Narmada districts of Gujarat, India

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## Abstract

Radiation is present everywhere in the earth, and human beings are continuously exposed to gamma radiation. The health consequences of environmental radiation exposure are a serious societal issue. The purpose of this study was to analyse outdoor radiation in four districts of Gujarat, India: Anand, Bharuch, Narmada, and Vadodara during summer and winter seasons. This study illustrated the influence of lithology of areas on gamma radiation dose values. Summer and winter seasons are the primary factors that alter the causes directly or indirectly; therefore, the influence of season fluctuation on radiation dose rate was investigated. The annual dose rate and mean gamma radiation dose rate values from four districts were found to be greater than the global population weight average value. The mean value of gamma radiation dose rate from 439 locations in the summer and winter seasons was 136.23 nSv/h and 141.58 nSv/h, respectively. According to a paired differences sample study, the significance value between outdoor gamma dose rate in summer and winter seasons was 0.05 indicating that seasons have a significant impact on gamma radiation dose rate. The impact of various types of lithology on gamma radiation dose was studied in all 439 places, and the statistical analysis revealed that there was no significant association between lithology and gamma radiation dose rate in the summer season, but a relationship between lithology and gamma dose rate was observed in the winter season.

**Keywords** Gamma radiation · Lithology · Outdoor radiation · Seasonal variation

## Introduction

Gamma radiation is abundant everywhere on the planet, and it is considerably more prevalent inside homes than outdoors. Outdoor gamma dose rate is more important in understanding the radiation distribution scenario of a place. Natural environmental radioactivity and corresponding

background radiation depends on the geological and geographical conditions. This radiation comes from the soils, rocks, and lithosphere of the surrounded areas (Almayahi et al. 2012). People are constantly exposed to background radiation from both natural and artificial sources. Naturally occurring radioactive elements are found in almost all compartments of the environment (Cooper 2005). The common long-lived radioactive elements such as thorium and uranium are slowly producing other radioactive elements, such as Ra, which further undergo radioactive decay. Most building materials made from rocks, soil, and other natural sources consist significant levels of naturally occurring radioactive nuclides (Yu et al. 1992; Jindal et al. 2018a). Natural radiation existed since the earth's creation, and is impossible to avoid (Gusain et al. 2012). The soil and rocks rich with  $U^{238}$  lead to high release of radon gas, which is considered the largest source of radiation exposure (UNSCEAR 2000). Since natural radiation is the main source of the population's external exposure, it is crucial to assess the gamma radiation dose rate coming from these sources. Numerous national and international studies have been published to

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estimate the levels of background gamma radiation on the earth and determine the population's exposure to radiation (Gusain et al. 2012; Harikrishnan et al. 2018; Jindal et al. 2018a, 2021; Jindal and Sar 2020b; Guarino et al. 2022). Gamma radiation measurements and its distribution are crucial for identifying any variations in activity over time based on radioactive emission. Gamma rays can enter into the body and destroy cells, as well as pose a stochastic health risk depending on the likelihood of causing genetic damage and cancer. Radiation may injure cells or pass through them without causing any harm as the human body is capable to repair the cells through self-repair mechanism. However, there is certain possibility of permanent damage to the cells in case of high dose or long-time span exposure (Jindal and Sar 2020a; Jindal et al. 2021).

The current study aims to quantify the natural gamma radiation dose rate in Gujarat State of India from a few districts, namely Anand, Bharuch, Narmada, and Vadodara district so as to create a baseline database on the levels of gamma radiation and the concentration of natural radionuclides in the vicinity of the research locations. So, such research would be useful in determining the radioactive influence on the surroundings and the local population. This study also includes investigation of the spatial distribution, geological, and seasonal impact on gamma radiation dose rate. This study will also give ideas for policymakers regarding control and prevention of gamma radiation exposure for these regions.

## Study area

### Geology and geography of study area

The Indian peninsula's western shore is where Gujarat State is located. The study areas are shown in Fig. 1 which includes Anand, Vadodara, Narmada, and Bharuch districts of Gujarat. The Anand District is located between latitudes of 22° 06' and 22° 43' in the north and longitudes of 72° 20' and 73° 12' in the east. The population and covered area of the district are 2.09 million and 2941 km<sup>2</sup> (Anand District Administration 2022). The Mahisagar district borders Anand district on the north, the Gulf of Cambay (Khambhat) on the south, the Panchmahals on the east, Vadodara district on the south-east, and Kheda district on the west. The area's diverse lithology, structure, and denudational as well as depositional processes have combined to produce the current physiographic configuration. According to geomorphology, the region can be largely divided into three types: piedmont plain, alluvial plain, and coastal plains, which is known as Bhag (Yadav 2013). The area of the Vadodara District is 7546 km<sup>2</sup> where the total population is 4.17 million (Nandkeolyar and Sandhya Kiran 2019). The Panchmahal district to the north, the Anand and

Kheda districts to the west, the Bharuch and Narmada districts to the south, and the Chhota Udaipur district to the east, all encircle the district. The district is traversed by the Mahi River. The geology of the Vadodara district is notable for its complete lack of Palaeozoic rocks and the development of just the highest Mesozoic rocks. The rocks in the Vadodara district range in age from Proterozoic to recent (Gupte 2012). Vadodara is to the north, Surat is to the south, the Gulf of Khambhat is to the east, and Bharuch is situated at 21.712°N 72.993°E. Both the geology and the terrain are diverse in the Bharuch district. The entire region is made up of four different topographic units, including a mountainous area with high relief, a piedmont zone, an alluvial plain, and a coastline area. A complex hydrogeological pattern is produced by the district's geology, which includes significant coastal salt effect in certain regions. Semi-consolidated Cretaceous, hard rock, and tertiary formations, as well as unconsolidated alluvial deposits, produce multi-aquifer systems in throughout the region (CGWB 2014; Patel et al. 2022).

Similarly, Bharuch, the landscape of the Narmada district is diverse which is situated at 21.8757° N, 73.5594° E. Bharuch and Narmada districts covered the area of 5246 and 2755 km<sup>2</sup>, respectively. Population of Bharuch and Narmada districts are 15.5 and 0.59 million, respectively (Bharuch District Administration 2022; Narmada District Administration 2022). Narmada district can be divided into four topographic units, including drainage, the mountainous area with high relief, the Piedmont zone, and alluvial plain, according to the study reported by Central Groundwater Board. Basaltic rocks from the Cretaceous dominate the landscape, with no notable minerals. There is a small patch of exposed Mesozoic formations in Tilakwada Tehsil (CGWB 2014). In study area, ten types of geology and lithology of the study locations are grouped which are shown in Table 1.

## Materials and method

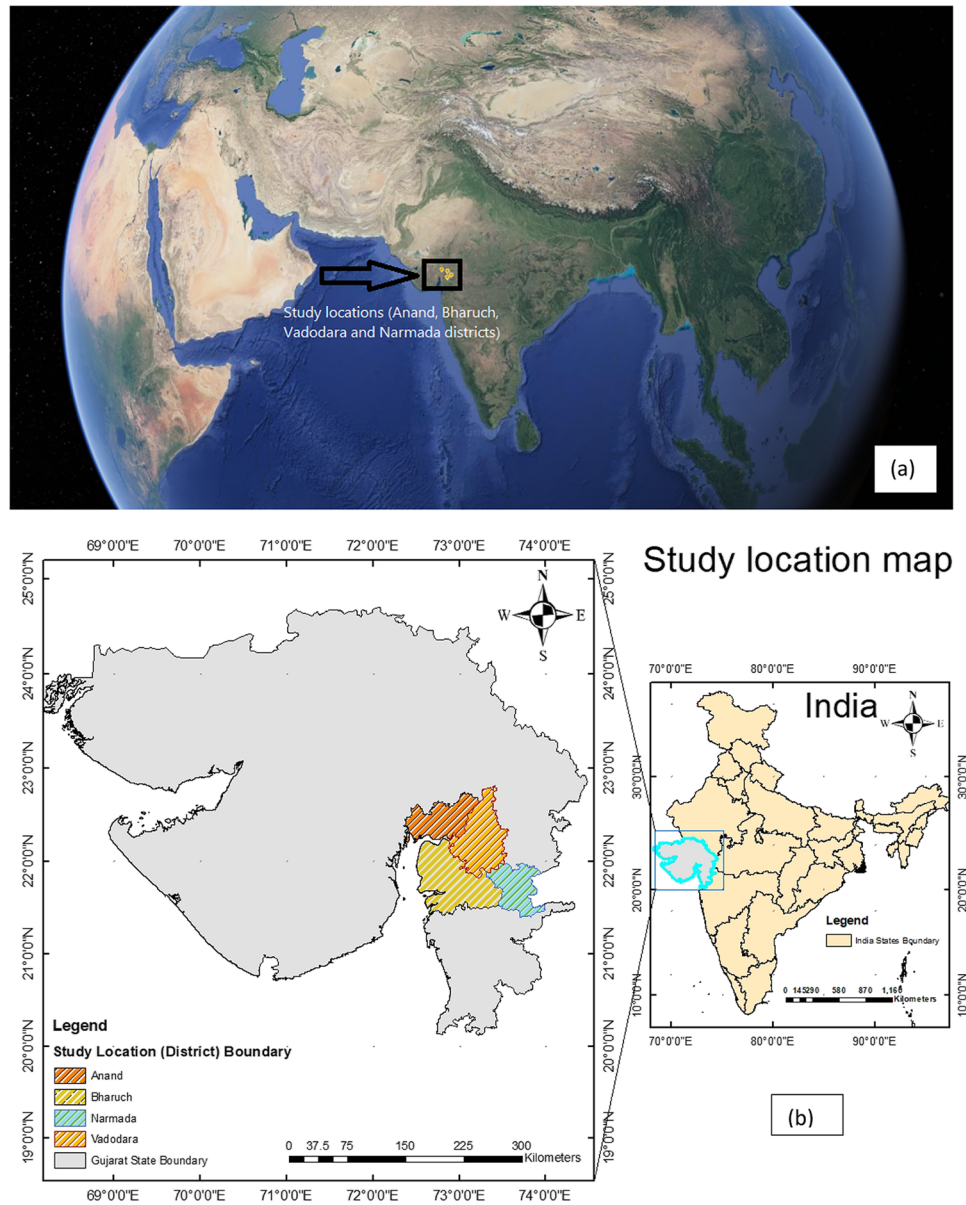
### Selection of measurement sites

Environmental gamma radiation dose rates were measured from a total of 439 sampling locations in Anand, Vadodara, Bharuch, and Narmada districts during summer and winter seasons. Based on feasibility and systematic approach, sampling areas were divided into 6 × 6 km<sup>2</sup> grids which are shown in Fig. 2. Gamma radiation dose was measured from each grid.

### Quantitative and qualitative assessment

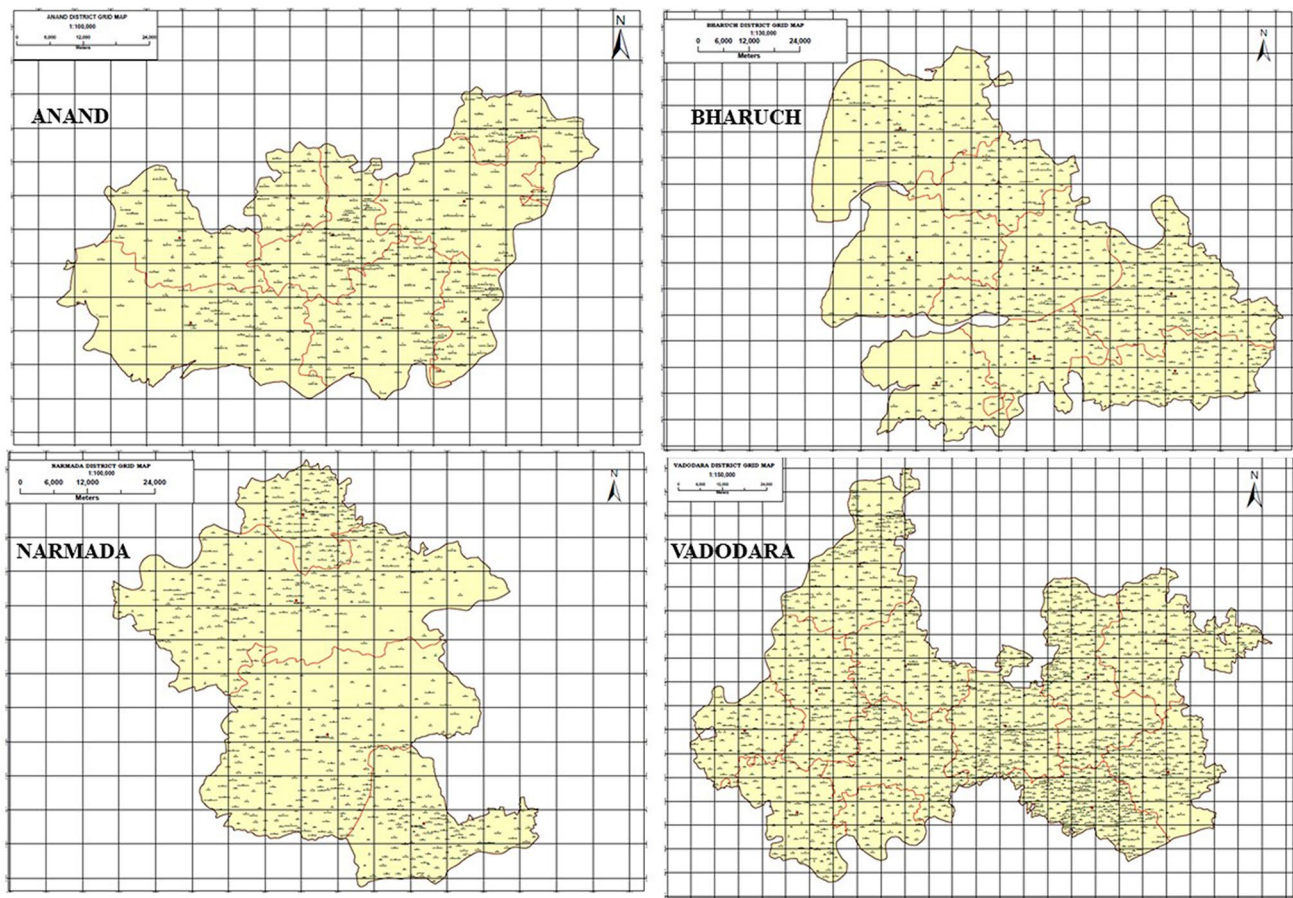
This study involves both quantity and quality approaches. For quantitative assessment, the study carried out in total of 439 locations involving 82, 125, 144, and 88 locations

**Fig. 1** Map of study locations. **a** Aerial view of locations. **b** Districts geographical view



**Table 1** Geology and lithology groups of study locations

Types	Lithology
1	Alluvium, blown sand, miliolite sand
2	Alluvium, blown sand, miliolite sand, shale, marls and sandstone, limestone, gypsiferous pyritous
3	Alluvium, blown sand, miliolite sand, basalts (Deccan traps)
4	Alluvium, blown sand, miliolite sand, shale, marls and sandstone, limestone, gypsiferous pyritous and carbonaceous shale
5	Alluvium, blown sand, miliolitic sand, Basalt andesite and trachytic flows
6	Alluvium, blown sand, miliolitic sand, Basalt andesite and trachytic flows, Phyllites with mangeniferous horizon, mica-shale
7	Basalts (Deccan traps)
8	Limestones and Sandstones (Bagh group) and Basalt (Deccan traps)
9	Limestones and Sandstones (Bagh group) and Quaternary alluvium
10	Shale, marls and sandstone, limestone, gypsiferous pyritous and carbonaceous shale, Basalt andesite and trachytic flows



**Fig. 2** Depicting grid maps of sampling locations

from Anand, Vadodara, Bharuch, and Narmada districts, respectively. All measurements were performed in summer and winter seasons. For qualitative approach, the gamma radiation dose rate from each place was measured three times to minimise the error and deviation. The constant reading with particular equipment's error has been taken for consideration.

### Measurement of gamma radiation

Gamma-Scout device (Germany made) was used to quantify the dose rates of gamma radiation. The device is based on Geiger-Muller technique and it is capable to detect gamma radiation as well as alpha and beta radiation. It measures both cosmic and terrestrial radiation. Value of gamma radiation dose rate was recorded in nSv/h. For the measurement, the device was placed at 1 m above the ground. The detection range of gamma radiation dose rate measurement is 0.1 to 1000  $\mu$ Sv/h. The latitude and longitude of the study locations were detected using a GPS (GPS map 70 s) coordinated device.

### Annual effective dose (AED)

Using the relative gamma radiation dose rates, the AED values from the study locations were determined. AED is used to analyse the biological consequences of radiation on people (NRC 2006; Jindal et al. 2018b). AED was calculated using Eq. (1) (UNSCEAR 2000):

$$\text{AED} = D \times \text{Conversion coefficient} \times T \times \text{Occupancy factor} \quad (1)$$

where  $D$  = measured gamma radiation dose rate (nSv/h),  $T$  = time conversion factor (8760 h/year). UNSCEAR (2000) reported dose conversion coefficient for an adult to be 0.7, and a higher conversion coefficient of about 0.8 and 0.9 for children and infants, respectively. The value of the occupancy factor reported by UNSCEAR for outdoor was 0.2.

### Statistical analysis

The analysis of information about seasonal variability and the effects of lithology and geology as well as climatic

conditions on the gamma radiation dose rate were performed using the Statistical Package for the Social Sciences (SPSS) version 23. In this study, the effect of season on the gamma radiation dose rate in the study region was estimated using the paired *t*-test, paired sample test, correlation, box plot, control chart, min, max, median, standard deviation, range, skewness, and kurtosis.

## Results and discussion

### Gamma radiation

The examination of outdoor gamma dose rates in four districts of Gujarat, namely Anand, Bharuch, Vadodara, and Narmada has been performed in this study. According to UNSCEAR (2000), the indoor/outdoor gamma dose rate ratio is 1.4. Very few studies were reported on the seasonal change of outdoor gamma radiation levels during last few decades (Al-Ghorabie 2005; Negi et al. 2009; Mrdakovic

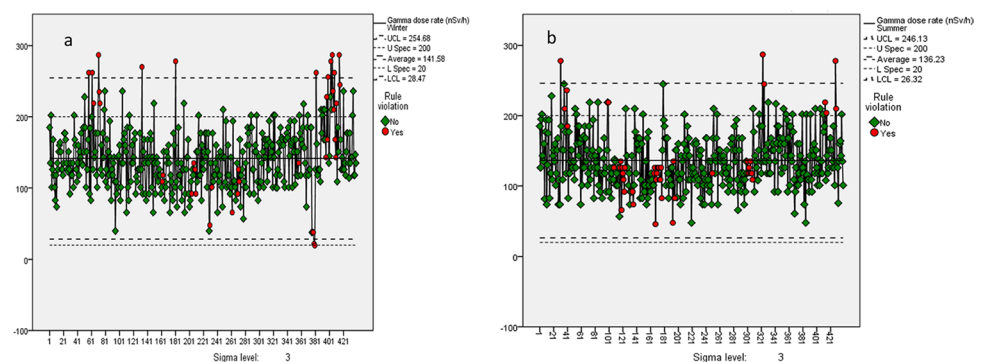
et al. 2012; Dhawal et al. 2013; Karunakara et al. 2014; Jindal et al. 2021). Even after these published studies, estimating the outdoor gamma radiation dose rate in seasons based on a single season remains uncertain. Therefore, the outdoor gamma radiation dose rate in both seasons is included in this study. Table 2 displays the average, minimum, maximum, standard deviation, and median values of outdoor gamma radiation dose rate. Outdoor gamma radiation dose rate in Anand, Bharuch, Vadodara, and Narmada districts in summer ranged between 74 and 278 nSv/h, 46 and 245 nSv/h, 48 and 287 nSv/h, and 66 and 210 nSv/h, respectively. During the winter season, the gamma radiation dose rate values in Anand, Bharuch, Vadodara, and Narmada districts ranged between 74 and 287 nSv/h, 40 and 278 nSv/h, 19 and 287 nSv/h, and 40 and 210 nSv/h, respectively. The mean value of the outdoor gamma radiation dose rate was somewhat lower in the summer season compared to the winter season; Anand (summer = 149 nSv/h, winter = 150 nSv/h), Bharuch (summer = 125 nSv/h, winter = 131 nSv/h), Vadodara (summer = 147 nSv/h, winter = 158 nSv/h), and Narmada (summer = 128, winter = 128 nSv/h); which is similar as reported in Balod, Chhattisgarh; At-Taif City; Al-Hada Village; and Ash-Shafa Village from the region of Kingdom of Saudi Arabia and three locations from Norway (Al Ghorabie 2005; Mrdakovic et al. 2012; Jindal et al. 2021).

The exact permissible or threshold value of outdoor gamma radiation dose rate is not available, only prediction of possibility is reported based on epidemic data which is highly uncertain. UNSCEAR (2000) reported the world populated weight average value of radiation dose is  $84 \text{ nGy h}^{-1}$  and national averages to be in the range 20 to 200 nSv/h. In the present study, out of 439 locations under study, gamma radiation dose rate values from 34 locations in summer and 47 locations in winter exceeded the dose rate of 200 nSv/h. The control charts of gamma radiation dose rate for summer and winter seasons are shown in Fig. 3 which shows the data between range 20 to 200 nSv/h and deviation of data from this range. High radiation dose rate data was obtained in winter season in all districts except Bharuch district. The number of sample locations along with their percentage

**Table 2** Statistical overview of gamma radiation dose rate data from Anand, Bharuch, Vadodara, and Narmada districts of Gujarat State, India

Seasons	Statistical parameters	Gamma radiation dose (nSv/h)			
		Anand	Bharuch	Vadodara	Narmada
	Number of samples	82	144	125	88
Summer	Average	149	125	147	128
	Min	74	46	48	66
	Max	278	245	287	210
	Std. deviation	43	37	42	32
	Median	143	118	143	126
Winter	Average	150	131	158	128
	Min	74	40	19	40
	Max	287	278	287	210
	Std. deviation	43	39	50	37
	Median	139	126	160	126

**Fig. 3** Control charts for gamma radiation dose rate (nSv/h). **a** Summer. **b** Winter



where gamma radiation dose rate was higher than the 200 nSv/h is shown in Table 3.

**AED**

Annual effective dose equivalent values for gamma radiation dose rate during summer and winter seasons are given in Table 4. In summer season, the values of AED for Anand, Vadodara, Bharuch, and Narmada districts were found to be 0.09–0.35 mSv/year, 0.06–0.30 mSv/year, 0.08–0.26 mSv/year, and 0.06–0.35 mSv/year, respectively, while in winter, the values were in the range of 0.09–0.35 mSv/year, 0.05–0.34 mSv/year, 0.05–0.26 mSv/year, and 0.02–0.35 mSv/year, respectively. The average values in Anand, Vadodara, Bharuch, and Narmada districts in summer were 0.18 mSv/year, 0.15 mSv/year, 0.16 mSv/year, and 0.18 mSv/year, respectively, and in winter 0.18 mSv/year, 0.16 mSv/year, 0.16 mSv/year, and 0.19 mSv/year, respectively. However, UNSCEAR has reported the worldwide annual average cosmic radiation dose

at sea level to be 0.078 mSv/year (with 0.2 occupancy factor of 0.39 mSv/year) and the world populated weighted annual average value of outdoor terrestrial radiation dose was 0.07 mSv/year (UNSCEAR 2000). According to this analysis, all districts’ AED values were slightly higher than the aforementioned global average (0.148 mSv/year). The present study being the first of its kind in these regions, the results will provide as essential background information for the area.

**Spatial distribution of gamma radiation**

GIS-based spatial analysis is proving to be a potent technique and an excellent instrument for generating the desired results for the spatial distribution of different environmental components (Burrough and McDonnell 1998; Jasrotia and Kumar 2014). It also aids in the analysis of air quality trends and other types of natural radiation. Numerous research were undertaken utilising remote sensing and GIS techniques to map the spatial distribution of the gamma radiation dose rate in districts level to understand the distribution pattern study within various types of geographical setup (Gnanachandrasamy et al. 2018). Using Arc GIS 10.8 software, geographic analysis was carried out for the current study. These samples were plotted according to their GPS-based coordinates, and GIS interpolation techniques were used to create the contours. The representation of the summer and winter gamma radiation dose rate spatial distribution maps for all four districts Anand, Vadodara, Bharuch, and Narmada are given in Figs. 4, 5, 6, and 7, respectively. No definite trend was observed in the districts under study.

**Statistical analysis of data**

The mean value of gamma radiation dose rate from 439 spots in the summer season was 136.23 nSv/h with a standard deviation of 39.86; however, the gamma dose rate in the winter season was a little higher, at 141.58 nSv/h with a standard deviation of 44.57 (Table 5).

The correlation and paired study were carried out by using the hypotheses.

Correlation:  $H_{o(r1)}$  and  $H_{a(r1)}$ .  $H_{o(r1)}$ : there is no relationship between the gamma radiation dose rate in the summer and winter seasons;  $H_{a(r1)}$ : there is a relationship between the gamma radiation dose rate in the summer and winter seasons. Paired test:  $H_{o(d1)}$  = the season has no considerable influence on the gamma radiation dose rate;  $H_{a(d1)}$  = the season has a considerable influence on the gamma radiation dose rate.

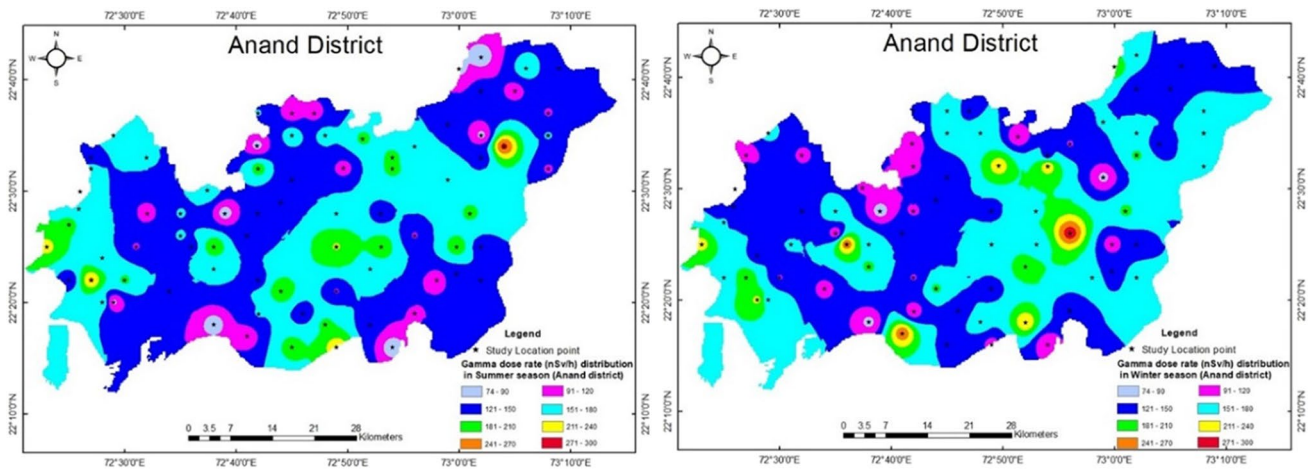
Based on the statistical analysis of gamma radiation dose rate data from the summer and winter seasons (Table 6), the significance value for paired sample

**Table 3** Samples exceeding gamma radiation dose rate 200 nSv/h in each district

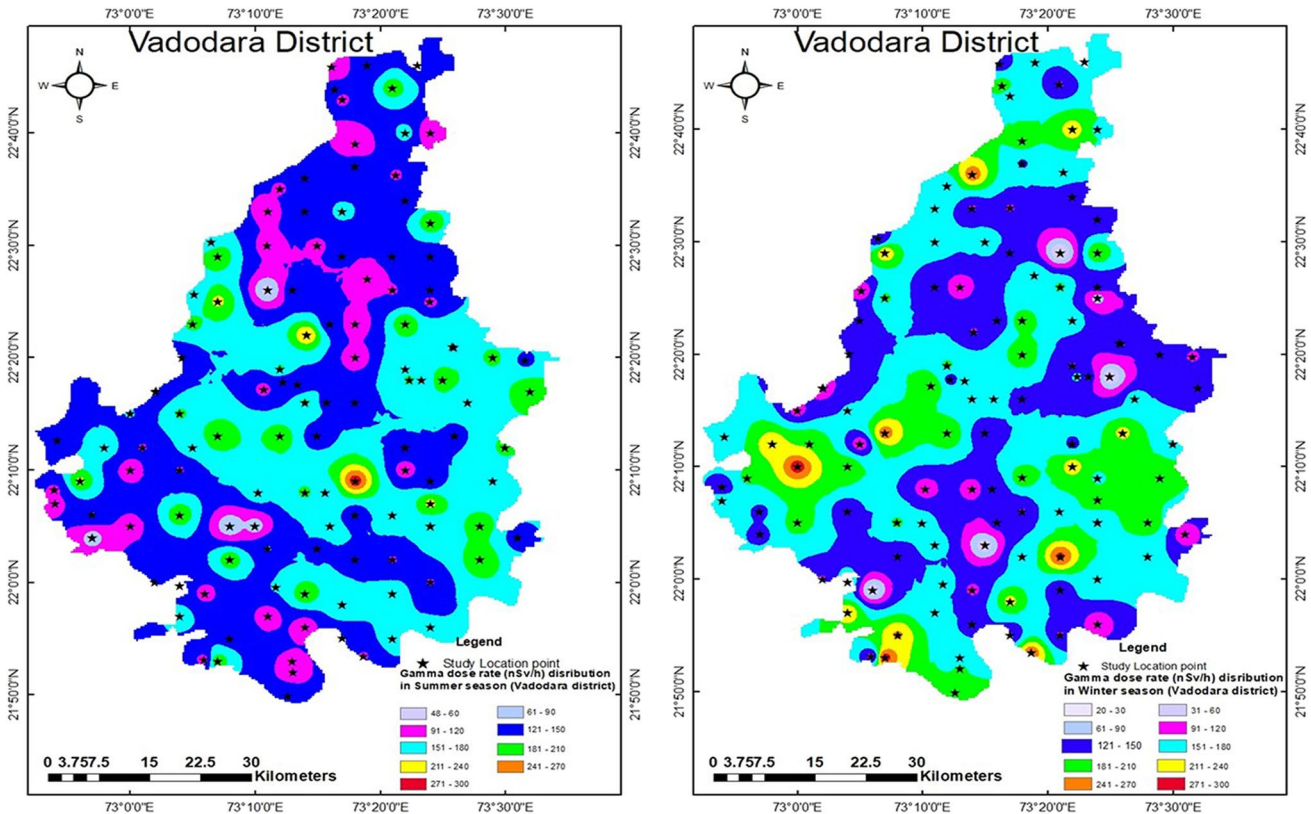
Name of districts (locations)	Gamma radiation dose rate (nSv/h)			
	Number of samples exceeding 200 nSv/h		% of samples exceeding 200 nSv/h	
	Summer	Winter	Summer	Winter
Anand	9	12	11	14
Bharuch	8	7	6	5
Vadodara	14	25	11	20
Narmada	3	3	3	3

**Table 4** Annual effective gamma radiation dose values for Anand, Vadodara, Bharuch, and Narmada districts in summer and winter seasons

Season	Statistical parameters	Annual effective radiation dose (mSv/year)			
		Anand	Bharuch	Vadodara	Narmada
Summer	Average	0.18	0.15	0.16	0.18
	Min	0.09	0.06	0.08	0.06
	Max	0.34	0.30	0.26	0.35
	Std. deviation	0.05	0.05	0.04	0.05
	Median	0.18	0.14	0.15	0.18
Winter	Average	0.18	0.16	0.16	0.19
	Min	0.09	0.05	0.05	0.02
	Max	0.35	0.34	0.26	0.35
	Std. deviation	0.05	0.05	0.05	0.06
	Median	0.17	0.15	0.15	0.20



**Fig. 4** Gamma radiation dose rate distribution during summer and winter across Anand district



**Fig. 5** Gamma radiation dose rate distribution during summer and winter across Vadodara district

correlation between gamma radiation dose rate in the summer and winter seasons was 0.06, which was greater than the 0.05, indicating that the null hypothesis for the study is accepted, revealing that the relationship between gamma radiation dose rate in the summer and winter seasons is not significant. This is also reflected in the correlation value,

which is only 0.09; so, monitoring of gamma radiation dose rate is required in both summer and winter.

The significance value of the paired sample *t*-test between outdoor gamma radiation dose rate in summer and winter seasons was 0.05 (Table 7), implying that the null hypothesis for the study is rejected, indicating that seasons have a substantial influence on gamma radiation dose rate. Similar studies

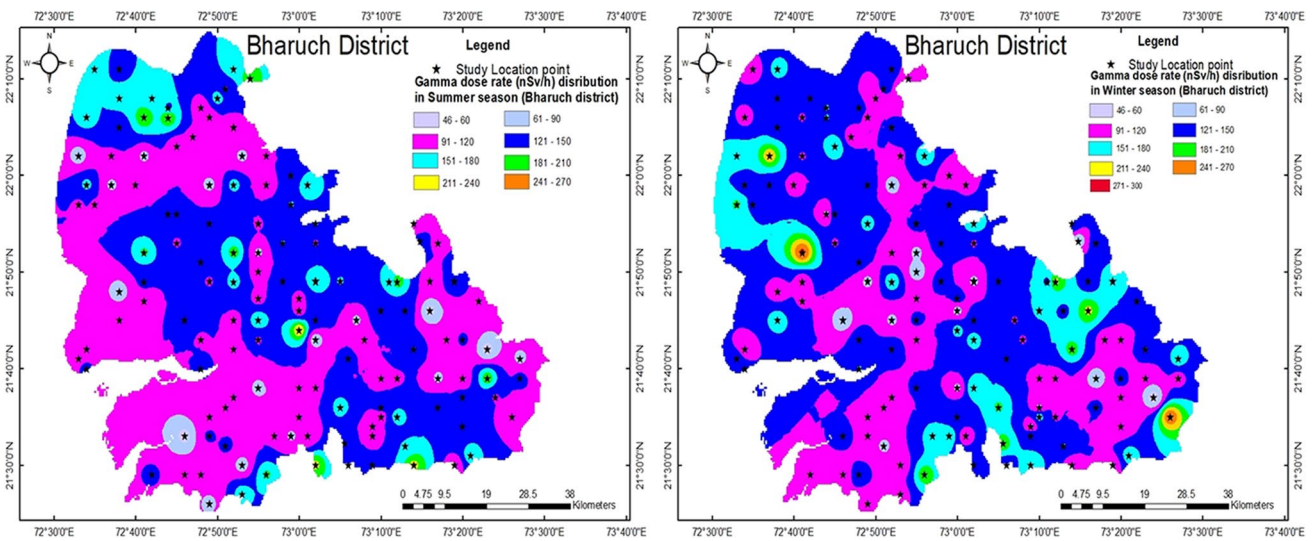


Fig. 6 Gamma radiation dose rate distribution during summer and winter across Bharuch district

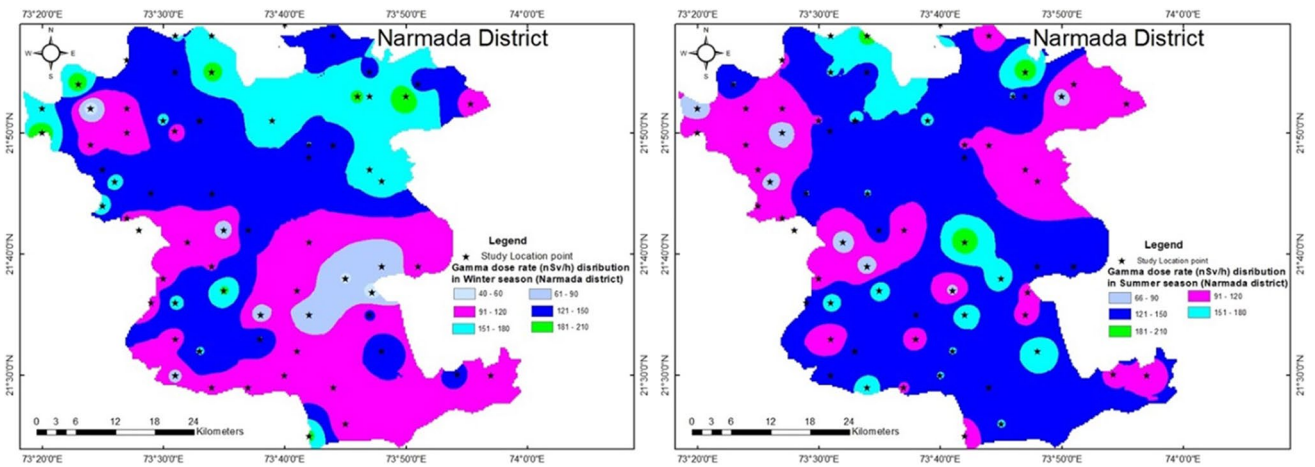


Fig. 7 Gamma radiation dose rate distribution during summer and winter across Narmada district

were reported by various researchers (Jindal et al. 2021). This test also demonstrated the importance of seasonal monitoring. One of the main elements for natural background gamma radiation dose rate is the lithology of the research areas. Ten types of lithology are available in all studied 439 locations with percentage coverage being Alluvium, blown sand, miliolite sand (54.4%); Alluvium, blown sand, miliolite sand, shale, marls and sandstone, limestone, gypsiferous pyritous

and carbonaceous shale, Basalt andesite and trachytic flows (6.2%); Alluvium, blown sand, miliolite sand, basalts (Deccan traps) (1.8%); Alluvium, blown sand, miliolite sand, shale, marls and sandstone, limestone, gypsiferous pyritous and carbonaceous shale (2.7%); Alluvium, blown sand, miliolitic sand, Basalt andesite and trachytic flows (6.4%); Alluvium, blown sand, miliolitic sand, Basalt andesite and trachytic flows, Phylites with manganiferous horizon, mica-schist and quartzite,

Table 5 Statistics of gamma radiation dose rate in summer and winter seasons

	Mean	N	Std. deviation	Std. error mean
Gamma radiation dose rate (nSv/h) summer	136.23	439	39.86	1.90
Gamma radiation dose rate (nSv/h) winter	141.58	439	44.57	2.13



**Table 6** Paired samples correlations between gamma radiation dose rate in summer and winter seasons

		<i>N</i>	Correlation	Sig
Pair 1	Gamma radiation dose rate (nSv/h) summer and winter	439	0.09	0.06

**Table 7** Paired samples test of gamma radiation dose rate between summer and winter seasons

	Paired differences	<i>t</i>	df	Sig. (2-tailed)					
					Mean	Std. deviation	Std. error mean	95% confidence interval of the difference	
								Lower	Upper
Pair 1	Gamma radiation dose rate (nSv/h) summer–winter	– 5.35	57.07	2.72	– 10.71	0.00	– 1.97	438	0.05

limestone, nodular marls and sandstone, quartzite with intercalated phyllites and basal conglomerates, granitoids and pegmatites (4.6%); Basalts (Deccan traps) (9.8%); Limestones and Sandstones (Bagh group) and Basalt (Deccan traps) (7.7%); Limestones and Sandstones (Bagh group) and Quaternary alluvium (2.5%) and; shale, marls and sandstone, limestone, gypsiferous pyritous and carbonaceous shale, Basalt andesite and trachytic flows (3.9%).

Hypotheses study was performed to find the relationship and difference with lithology and gamma radiation dose rate in summer and winter seasons which are as:

Correlation: paired 2:  $H_{o(r2)}$ : there is no relationship between the gamma radiation dose rates in the summer with lithology;  $H_{a(r2)}$ : there is a relationship between the gamma radiation dose rates in the summer with lithology. Paired 3:  $H_{o(r3)}$ : there is no relationship between

the gamma radiation dose rates in the winter with lithology;  $H_{a(r3)}$ : there is a relationship between the gamma radiation dose rates in the winter with lithology.

Differences: paired 2:  $H_{o(d2)}$ =the lithology had no considerable influence on the gamma radiation dose rate in summer season;  $H_{a(d2)}$ =the lithology had a considerable influence on the gamma radiation dose rate in summer season. Paired 3:  $H_{o(d3)}$ =the lithology had no considerable influence on the gamma radiation dose rate in winter season;  $H_{a(d3)}$ =the lithology had a considerable influence on the gamma radiation dose rate in winter season.

SPSS software was used for statistical analysis by converting the lithology string data to numeric data. The correlation analysis (Table 8) indicated that the pair 2 gamma radiation dose rate in summer with lithology followed the null hypothesis, while pair 3 indicated that the analysis

**Table 8** Paired samples correlation for gamma radiation dose rate in summer and winter with lithology of the study locations

		<i>N</i>	Correlation	Sig
Pair 2	Gamma radiation dose rate (nSv/h) summer and lithology	439	– 0.08	0.08
Pair 3	Gamma radiation dose rate (nSv/h) winter and lithology	439	– 0.13	0.00

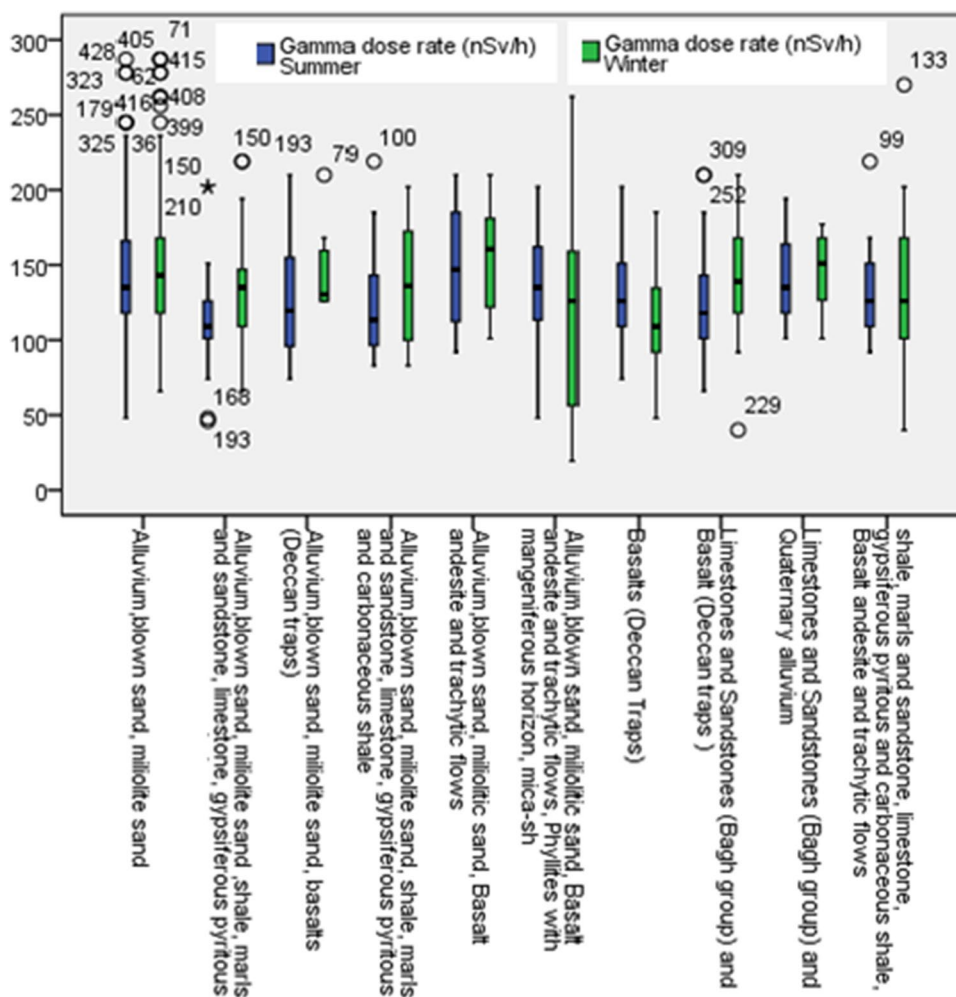
**Table 9** Paired samples test for gamma radiation dose rate with lithology of the areas in summer and winter seasons

	Paired differences	<i>t</i>	df	Sig. (2-tailed)					
					Mean	Std. deviation	Std. error mean	95% confidence interval of the difference	
								Lower	Upper
Pair 2	Gamma radiation dose rate (nSv/h) summer–lithology	132.88	40.23	1.92	129.11	136.66	69.21	438	0.00
Pair 3	Gamma radiation dose rate (nSv/h) winter–lithology	138.24	45.08	2.15	134.01	142.46	64.25	438	0.00

**Table 10** Statistical analysis of gamma radiation dose rate with lithology of the areas

	Alluvium, blown sand, miliolite sand	Alluvium, blown sand, miliolite sand, shale, marls and sandstone, limestone, gypsiferous pyritous	Alluvium, blown sand, miliolite sand, basalts (Deccan traps)	Alluvium, blown sand, miliolite sand, shale, marls and sandstone, limestone, gypsiferous pyritous and carbonaceous shale	Alluvium, blown sand, miliolite sand, andesite and trachytic flows	Alluvium, blown sand, miliolite sand, basalt andesite and trachytic flows, phyllites with manganiferous horizon, mica-shale	Basalts (Deccan traps)	Limestones and sandstones (Bagh group) and basalt (Deccan traps)	Limestones and sandstones (Bagh group) and quaternary alluvium	Shale, marls and sandstone, limestone, gypsiferous pyritous and carbonaceous shale, basalt andesite and trachytic flows	
Gamma radiation dose rate (nSV/h) summer	Min	48	46	74	83	92	74	66	101	92	
	Max	287	202	210	219	210	202	210	194	219	
	Mean	141.05	115.41	128.13	125.25	147.96	135.5	128.95	143.55	134.88	
	Median	135	109	119.5	113.5	147	135	126	135	126	
	Std. deviation	41.92	36.05	45.75	42.73	38.63	42.14	29.32	34.63	33.73	
	Skewness	0.7	0.56	0.78	1.27	0.04	-0.13	0.14	0.82	0.22	0.8
	Kurtosis	0.71	1.37	0.01	0.75	-1.35	-0.12	-0.32	0.85	-1.17	0.91
	Range	239	156	136	136	118	154	128	144	93	127
	Min	66	66	126	83	101	19	48	40	101	40
	Max	287	219	210	202	210	262	185	210	177	270
Gamma radiation dose rate (nSV/h) winter	Mean	147.5	133.26	146	138.75	156.11	122.97	112.49	143.47	137.29	
	Median	143	135	130.5	136	160.5	126	109	151	126	
	Std. deviation	44.78	38.5	30.06	40.88	33.78	69.99	32.77	36.79	54.71	
	Skewness	0.91	0.57	1.68	0.07	-0.02	0.21	0.41	-0.27	-0.5	0.59
	Kurtosis	0.87	0.51	2.52	-1.52	-1.17	-0.48	-0.16	0.56	-1.06	0.91
	Range	221	153	84	119	109	243	137	170	76	230

**Fig. 8** Box plot of gamma radiation dose rate based on lithology in summer and winter seasons



followed the alternative hypothesis in some way. There was no significant relationship between lithology and gamma radiation dose rate in the summer season, however, statistical study indicates that there was a significant relationship between lithology and gamma radiation dose rate in the winter season.

The paired difference test was used to determine the statistical difference in gamma radiation dose rate in the summer and winter seasons along with the lithology of the studied areas. The paired sample *t*-test significance values for gamma radiation dose rate in summer and winter seasons with lithology were zero (Table 9), implying that the null hypothesis for the study is accepted, demonstrating that lithology has no significant impact on gamma radiation dose rate.

Table 10 shows the statistical results of gamma radiation dose rate for summer and winter, as well as the box plot in Fig. 8 for summer and winter based on lithology of study area. It was observed that the measured gamma radiation dose rates from summer and winter are found in a very wide

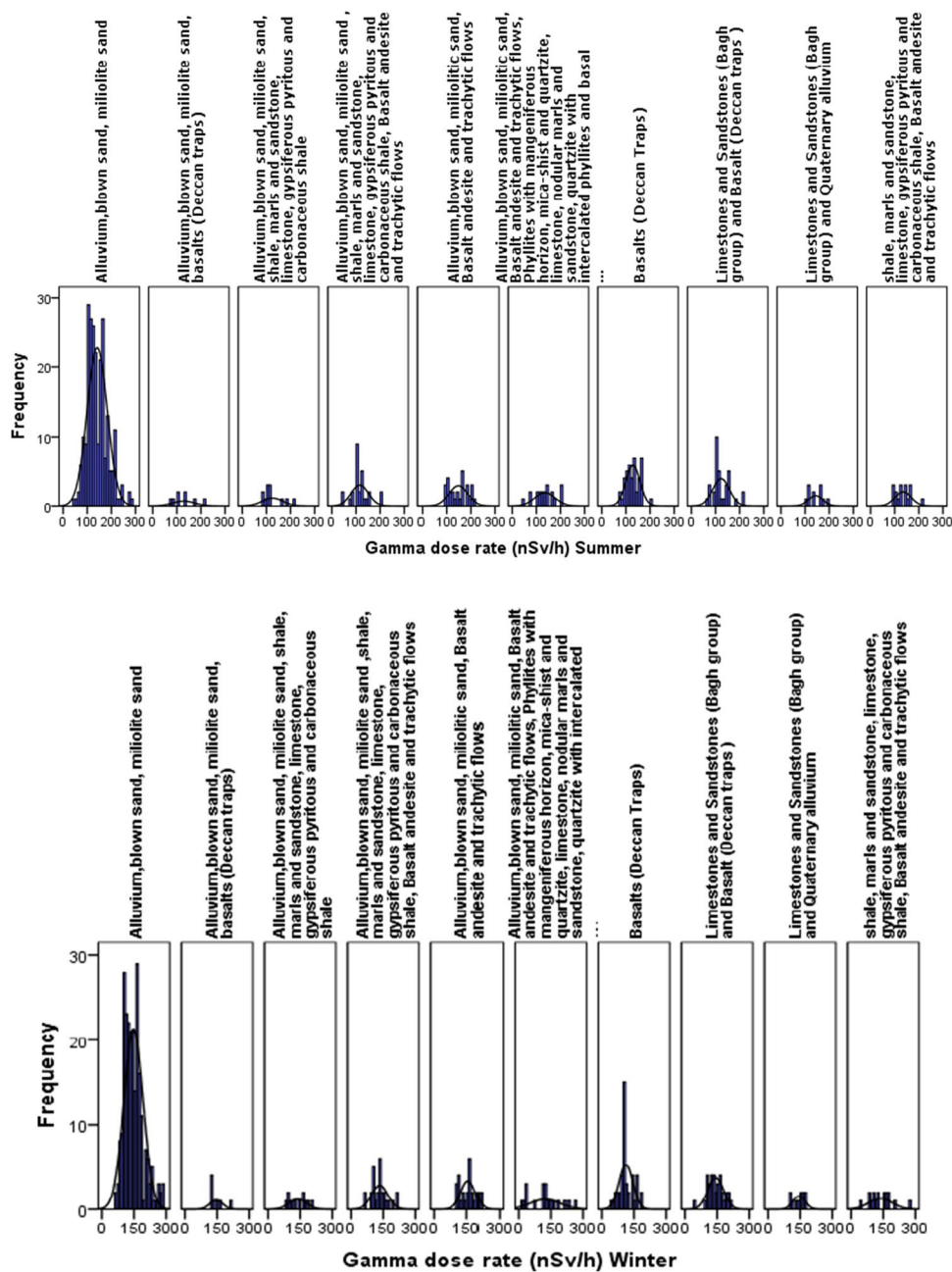
range. The variation observed in all districts may be due to several types of geological and lithological variations.

From this study, it was observed that area comprising (Alluvium, blown sand, miliolite sand) of lithology are showing high frequency of gamma radiation dose rate in the study area. Figure 9 represents frequency distribution of gamma radiation dose rate in both seasons on the basis of lithology. From the figure, it is also observed that basaltic rocks are also responsible for high gamma radiation dose rate. Some researchers also have studied gamma radiation dose rate on the basis of lithological formation (Adabanija et al. 2020).

**Conclusion**

Gamma radiation dose levels were monitored in four districts of Gujarat, India: Anand, Bharuch, Vadodara, and Narmada. Many radionuclides emit gamma radiation; some have short half-lives, while others have very long

**Fig. 9** Frequency of gamma radiation dose rate (nSv/h) based on lithology in summer and winter seasons



half-lives. It is constantly decaying and emitting gamma radiation into the environment. The findings from this investigation showed that the mean value of the outdoor gamma radiation dose rate was slightly lower in the summer than in the winter. The mean values of gamma radiation dose rate in Anand, Bharuch, Vadodara, and Narmada districts in the summer season were 149, 125, 147, and 128 nSv/h, respectively, while in winter, the values were 150, 131, 158, and 128 nSv/h, respectively. The results demonstrated that the gamma radiation dose rate exceeded the value of 200 nSv/h by 8 and 11% in the summer and

winter seasons, respectively. The geographical spatial distribution of gamma radiation dose rate for all four districts can be useful for other radionuclides studies. Annual effective dose values were found to be greater than the world average value reported by UNSCEAR. There was no significant relationship between lithology and gamma radiation dose rate in the summer season, while a significant relationship between lithology and gamma radiation dose rate was observed in the winter season. The significant relationship between lithology and gamma radiation dose rate may be attributed to the exposure of lithology of the

area and leaching of the radioactive materials during the rains occurring just before winter season than in summer. According to statistical analysis, the variations in gamma radiation dose rate with lithology in the summer and winter seasons also support the notion that the radiation dose is higher in the winter season. The study will be useful in comprehending and averting risk that arises in future from radiation or radionuclides in these areas.

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**Author contribution** Project inception and management was done by PPS and DC. DC, PPS, and DP contributed to the experimental design and collection of samples. Data analysis was done by DC, PPS, DP, and MKJ. The first draft of the manuscript was written by DP and MKJ, and all authors commented on previous versions of the manuscript and modified the manuscript. All authors read and approved the final manuscript.

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**Data availability** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Conflict of interest** The authors declare no competing interests.

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