

An Investigation of Indoor Terrestrial Gamma Radiation and Its Health Hazard in the Garhwal Foothills

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Abstract

This study assesses indoor gamma radiation from naturally occurring radioactive substances. It was carried out to measure the gamma radiation dose rate indoors in the Dehradun district. The Dehradun district is situated in the foothills of the Garhwal Himalaya. The study deals with the estimation of possible radiological health risk to the resident community from long-term exposure in enclosed areas. The ATOMTEX portable gamma survey meter was used to measure the gamma dose rate at 25 different locations. The level of indoor gamma dose rate ranges from 0.09 $\mu\text{Sv/h}$ to 0.21 $\mu\text{Sv/h}$, with an average of $0.15 \pm 0.02 \mu\text{Sv/h}$. The estimated values of Annual Effective Dose Equivalent in the context of indoor exposure were found to be between 0.44 and 1.03 mSv/y, with a mean of 0.78 mSv/y. The value is below the population-weighted average of 0.80 mSv/y for indoors, as reported by United Nations Scientific Committee on the Effects of Atomic Radiation. The increased levels of indoor radiation stem primarily from the natural radionuclides within local building materials, which include Uranium-238, Thorium-232, and Potassium-40 within the building materials. The Lifetime Effective Dose was between 28.69 mSv and 66.96 mSv, whereas the Excess Lifetime Cancer Risk of ranged from 1.43×10^{-3} to 3.34×10^{-3} with an average of 2.53×10^{-3} was found in more than an acceptable limit of 0.29×10^{-3} . Such observations underscore the importance of systematic radiological follow-up, community education, and remedial interventions.

Categories: Environmental and Sustainable Engineering

Keywords: annual effective dose equivalent (aede), garhwal himalaya, excess lifetime cancer risk (elcr), lifetime effective dose (led), gamma radiation

Introduction

Natural radiation has existed since the formation of the Earth and is ubiquitous in the environment of all living organisms [1]. Of all the natural ionizing radiations, gamma radiation is said to be the most penetrating and can be the most biologically important. The gamma photons have no mass or charge, as is the case with alpha and beta particles, and therefore, they can penetrate through building materials, walls, and human bodies. Due to this deep penetration, low-intensity gamma radiation is also a source of considerable long-term human exposure [2]. Due to the rapid urbanization processes and the dynamic lifestyle pattern, the importance of research into indoor gamma radiation has grown. Humans spend 80-90% of their time indoors, namely at home, in hostels, offices, classrooms, and other covered areas [3]. This long period of indoor inhabitancy implies that even mild sources of natural radioactivity in the walls and

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construction materials may eventually become a significant Annual Effective Dose. Thus, the area of the indoor gamma dose evaluation has become a very important aspect of the environmental radiation research [4]. The source of indoor gamma radiation is mainly due to Naturally Occurring Radioactive Materials that are found in common construction materials. The measurable quantities of the radionuclides Uranium (^{238}U), Thorium (^{232}Th), and Potassium (^{40}K) are found in substances such as cement, concrete, granite, marble, bricks, ceramic tiles, plaster of Paris, and locally quarried stones [5]. These radionuclides decay and continuously emit gamma photons.

In the foothills of the Himalaya, the Dehradun district is geologically diverse, accompanied by the tectonic nature. The area has rock structures, including limestone, dolomite, quartzite, shale, and sandstone, most of which have uranium- and thorium-bearing minerals naturally [6]. As more and more urban developments take place, high amounts of constructed material (mostly locally procured) are utilized in the region. This poses a risk of high content of gamma radiation within the indoors, and thus, scientific evaluation becomes crucial. The Himalayan foothills are largely underexplored regarding indoor exposures to gamma radiation in spite of this geological significance [7]. International institutions like UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) and ICRP (International Commission on Radiological Protection) insist on the necessity to check the natural radiation levels at home [2,8]. Though these natural radiation levels are normally low, in the event of chronic exposure over long periods, the likelihood of stochastic health effects, such as cancer, genetic mutations, and genetic syndromes, may be elevated. Indoor gamma radiation, therefore, is not merely an issue of environmental monitoring but also a public health concern.

The area is situated in the foothills of the Garhwal Himalayas, and the MBT passes through this region, which can contribute to terrestrial radiation. In the absence of reasonable base values, exposure levels cannot be compared against international safety levels, nor can the risk of potential harm to people due to living, studying, and working in the area be assessed [9]. Measuring indoor gamma dose levels is also crucial for assessing whether local building materials contribute significantly to radiological exposure. The current research is focused only on indoor gamma dose rate measurement in the common places around the Dehradun district. The measurement of the absorbed dose rate ($\mu\text{Sv/h}$) indoors is done systematically with the help of a portable gamma survey meter (ATOMTEX AT6130C). The received values are employed to assess the annual effective dose equivalent (AEDE) and Excess Lifetime Cancer Risk (ELCR) to examine health consequences after a period of time [10]. The purpose of this research is to set the baseline data of indoor gamma radiation in the Doon Valley. The results will provide future recommendations on safe building materials, better ventilation practices, and radiation-conscious urban planning in geologically very sensitive and fast-developing regions of Uttarakhand.

Study area

The current research was done in the Dehradun district of Uttarakhand, located at the foothills of the Garhwal Himalayas, with a latitude of $30^{\circ}19'\text{N}$ - $30^{\circ}24'\text{N}$ and a longitude of $77^{\circ}52'\text{E}$ - $78^{\circ}04'\text{E}$ at high altitudes of 400-950 meters above mean sea level. The climate in the area is humid subtropical, with clear seasonal variations, and the average precipitation is about 2000 mm per annum. Dehradun is a rapidly developing urban area in northern India. Residential, commercial, and institutional buildings are rapidly developing. The materials used in these constructions are mostly locally available, including limestone, sandstone, shale, and concrete, which could have a variety of radioactive minerals. Due to the fact that people spend more than 80% of their time in indoor environments, it is important to study indoor gamma radiation in this area to determine the environmental radiation exposure and associated health risks.

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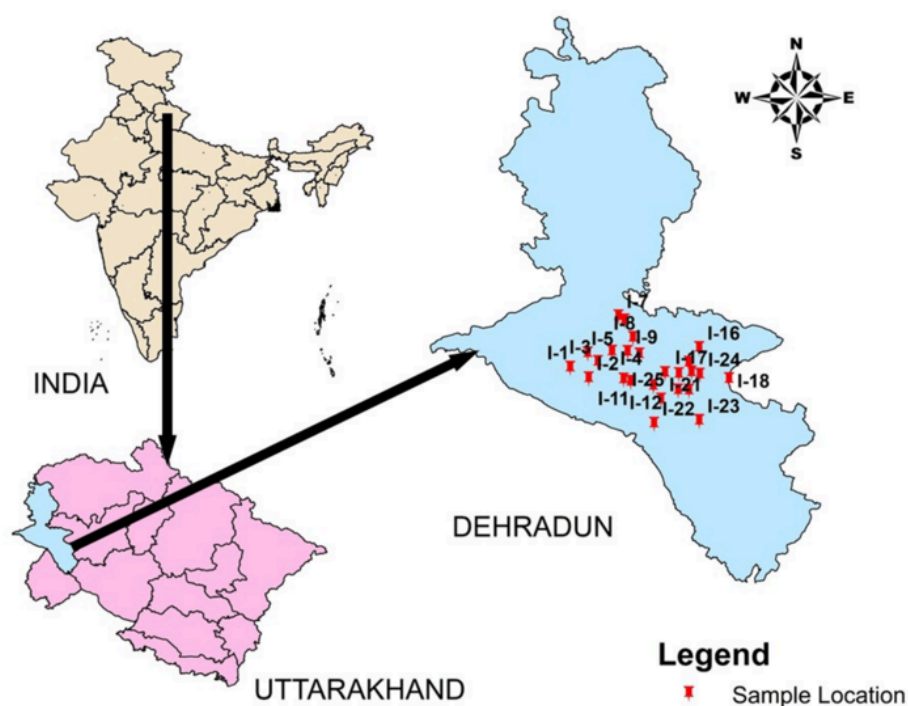


FIGURE 1: Map of study area Dehradun district, Uttarakhand (Made by ArcMap 10.8)

Geologically, Dehradun is located within the outer and lesser Himalayan ranges and has a broad range of geological formations, some as old as the Precambrian and as recent as the Quaternary [11]. The northern part of the district is composed of limestone, dolomite, quartzite, and shale of the Krol and Blaini formations of the Lesser Himalaya. Such formations frequently contain minerals of uranium, thorium, and potassium, which are sources of natural background radiation [12]. The Neogene to Quaternary period has resulted in the deposition of the southern part of Dehradun, which is formed of the Siwalik Group, including sandstone, clay, siltstone, and conglomerates. The center of this, referred to as the Doon Valley, is comprised of unconsolidated Quaternary sediments formed by erosion of the Lesser Himalayan rocks and carried by local rivers such as the Tons, Rispana, and Bindal [13]. These geological differences affect the natural radionuclide distribution, and thus the degree of indoor gamma radiation varies, since most of the building materials utilized during construction are products of these local rock units.

Materials And Methods

The indoor gamma radiation was measured at 25 different sites within the Dehradun district, and they were intended to represent different types of buildings like residential houses, classrooms, laboratories, and offices. The sites were chosen in such a way as to represent various construction materials, ages, and ventilation conditions (Figure 7). The gamma survey meter was mounted 1.5 meters above floor height, which is the breathing height of an average adult, and was placed at least 1 meter from walls or large furniture to reduce backscatter. Each site was measured three times after 60 seconds and averaged to get the final value. Measurements were taken under normal occupancy situations to indicate real exposure situations [14]. Other parameters that were observed during the reading included environmental parameters like temperature, humidity, type of ventilation, and building material. A portable Gamma Survey Meter (Model AT6130C) produced by ATOMTEX in Belarus was used to measure the gamma dose rates in the indoor

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environments [15] (Figure 2). This instrument has an NaI(Tl) scintillation detector that has the capability of detecting the gamma radiation with energies that lies between 50 keV and 3 MeV. The instrument was also calibrated with the standard Cesium-137 (^{137}Cs) source according to ISO 4037 standards to ensure accuracy prior to use.

Formula used and data analysis

The measured indoor gamma dose rates ($\mu\text{Sv/h}$) were converted to AEDE, Lifetime Effective Dose (LED), and ELCR with the help of standard equations suggested by UNSCEAR and ICRP [2,8].

Formula of AEDE

Indoor gamma radiation dose rate was utilized to calculate the AEDE values for the selected research locations. AEDE is used to assess the biological consequences of radiation on people [16]. The following equation was used to estimate AEDE [2].

$$AEDE(mSv/y) = DoseRate(\mu Sv/h) \times 8760 \times 0.8 \times 0.7$$

Where:

AEDE = Annual Effective Dose Equivalent (mSv/y)

Dose rate = indoor dose rate ($\mu\text{Sv/h}$)

CF = conversion factor (0.7 Sv/Gy)

T = time (8760 h/year)

OF = occupancy factor (0.8 in the case of indoor exposure)

Lifetime Effective dose (LED)

Total AEDE values and life expectancy, or 70 years, were used to compute the lifetime effective dosage [8].

$$LED(mSv) = AEDE \times L$$

Where: L = 70 years (average human lifespan)

LED stands for the total dose over a 70-year lifespan [2].

Excess Lifetime Cancer Risk (ELCR)

The assessment of the Excess Lifetime Cancer Risk was based on the LED and a risk factor of 0.05 per Sievert ICRP [8,17].

$$ELCR = Lifetime \times Riskfactor$$

Results And Discussion

Indoor gamma radiation

Table 1 shows the results of the Dehradun district of Uttarakhand indoor gamma radiation rates, AEDE, and lifetime effective dose. This study revealed that the ranges of values for the indoor gamma radiation rate were $0.09 \pm 15\%$ to $0.21 \pm 15\% \mu\text{Sv/h}$. The arithmetic average of indoor gamma dose rate across 25 survey locations was $0.15 \mu\text{Sv/h}$. The standard deviation of $0.029 \mu\text{Sv/h}$ indicates a relatively uniform distribution of gamma radiation exposure in the study location. The maximum value of the gamma dose rate ($0.21 \mu\text{Sv/h}$) was observed at I-8 (Dunga). The indoor gamma radiation was relatively higher in several sites, namely I-1, I-3, I-7, I-8, I-9, I-15, I-21, I-24, and I-25, shown in Table 1. Some sites having values greater than $0.18 \mu\text{Sv/h}$ suggest that it is most likely caused by the geological formation in the area or by the presence of dense construction material. This implies that local geology and structural features contribute significantly to

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the increase in levels of indoor gamma radiation. Overall, the gamma dose rates that are observed inside the study area (0.09-0.21 $\mu\text{Sv/h}$) are higher than the 0.084 $\mu\text{Sv/h}$ world population-weighted average indoor gamma absorbed dose rate reported by UNSCEAR (2008) [9]. The distribution of indoor gamma dose rate is depicted in Figure 2.

S. no.	Area code	Latitude (°N)	Longitude (°E)	Gamma dose rate (μSv/h)	Error	Indoor AEDE (mSv/y)	LED (mSv)	ELCR (×10 ⁻³)
1	I-1	30.3674	77.8371	0.19	±15%	0.93	65.3	3.27
2	I-2	30.3473	77.8721	0.16	±15%	0.78	55	2.75
3	I-3	30.3784	77.8895	0.18	±15%	0.88	61.8	3.09
4	I-4	30.3978	77.9165	0.13	±15%	0.64	44.7	2.23
5	I-5	30.3945	77.8702	0.17	±15%	0.83	58.4	2.92
6	I-6	30.4569	77.9405	0.15	±15%	0.74	51.5	2.58
7	I-7	30.4646	77.9286	0.18	±15%	0.88	61.8	3.09
8	I-8	30.4237	77.9561	0.21	±15%	1.03	72.11	3.61
9	I-9	30.3973	77.9458	0.19	±15%	0.93	65.3	3.27
10	I-10	30.3927	77.9682	0.16	±15%	0.78	55	2.75
11	I-11	30.3405	77.9517	0.15	±15%	0.74	51.5	2.58
12	I-12	30.3327	77.9946	0.12	±15%	0.59	41.2	2.06
13	I-13	30.3573	78.0167	0.16	±15%	0.78	55	2.75
14	I-14	30.3552	78.043	0.12	±15%	0.59	41.2	2.06
15	I-15	30.3767	78.0614	0.18	±15%	0.88	61.8	3.09
16	I-16	30.4045	78.0815	0.13	±15%	0.64	44.7	2.23
17	I-17	30.3586	78.0669	0.09	±15%	0.44	30.9	1.55
18	I-18	30.3455	78.1379	0.17	±15%	0.83	58.4	2.92
19	I-19	30.3241	78.0621	0.16	±15%	0.78	55	2.75
20	I-20	30.3243	78.0414	0.17	±15%	0.83	58.4	2.92
21	I-21	30.3071	78.0093	0.18	±15%	0.88	61.8	3.09
22	I-22	30.2614	77.9959	0.11	±15%	0.54	37.8	1.89
23	I-23	30.2667	78.0816	0.15	±15%	0.74	51.5	2.58

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24	I-24	30.3543	78.0826	0.18	±15%	0.88	61.8	3.09
25	I-25	30.3451	77.9382	0.19	±15%	0.93	65.3	3.27
Maximum				0.21	±15%	1.03	72.11	3.61
Minimum				0.09	±15%	0.44	30.91	1.55
Arithmetic mean				0.15	±15%	0.78	55.67	2.73
Standard deviation				0.03	±15%	0.14	9.96	0.5

TABLE 1: Indoor readings with GPS location of sites of Dehradun district**How to cite this article:**

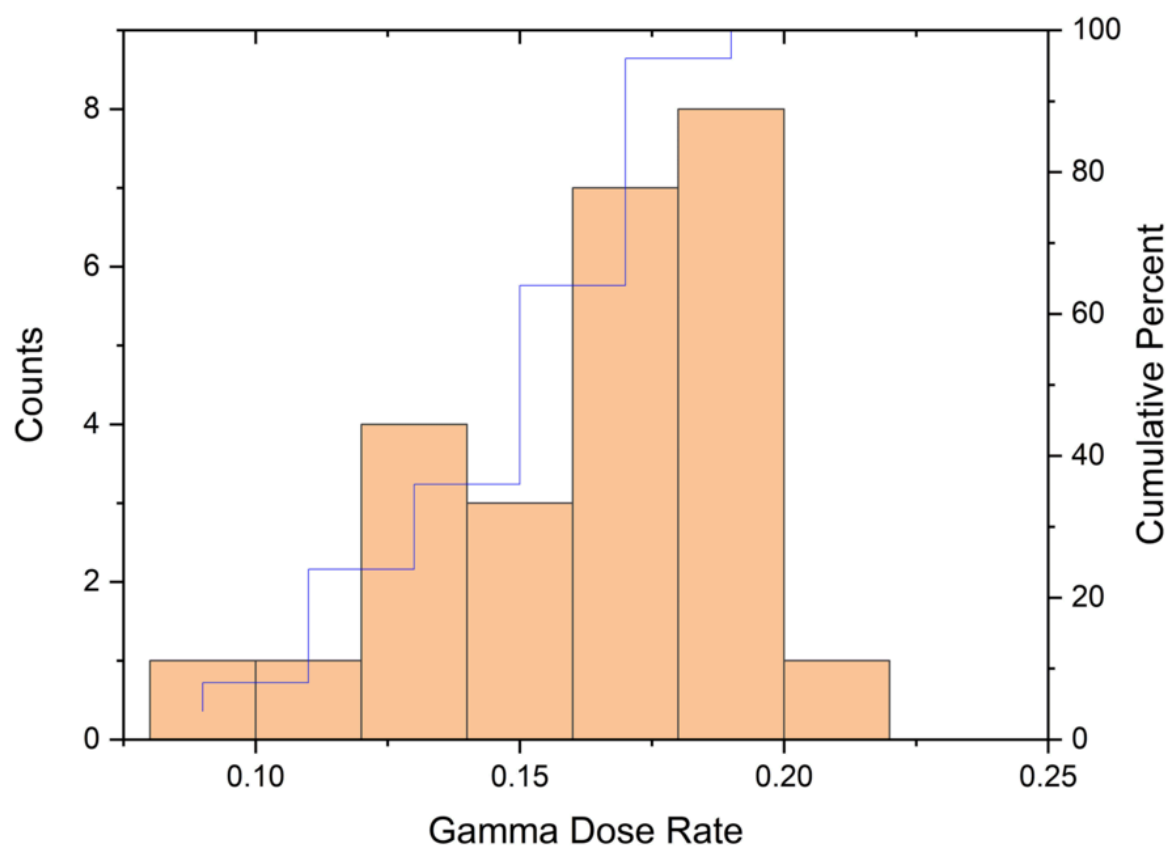


FIGURE 2: Distribution graph of gamma dose rate from the indoor environment

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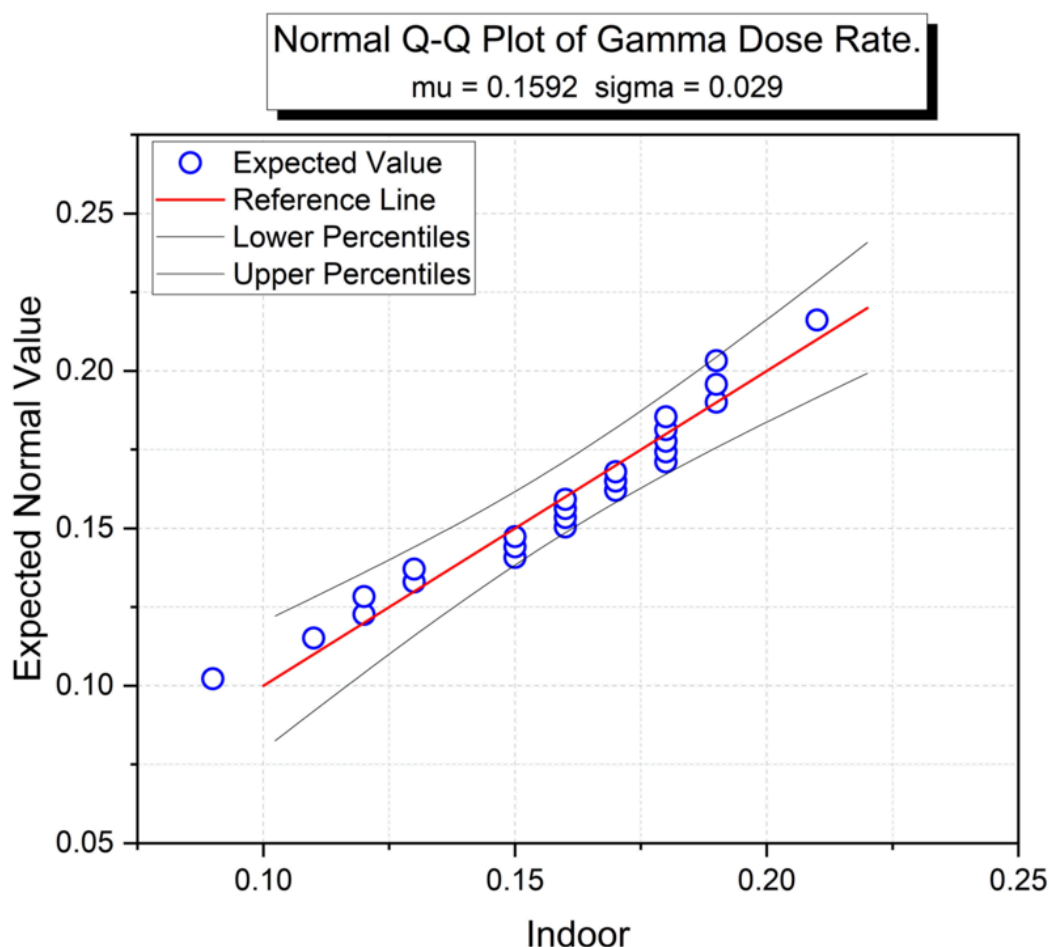


FIGURE 3: Q-Q plot for measured gamma dose rate in indoor environment of Dehradun

The level of indoor gamma radiation was regularly above the average values in the world due to a mix of geogenic, constructional, and environmental factors: Dehradun is in the foothill system of the Himalayas and has formations that contain uranium, thorium, and potassium-bearing minerals [18]. Certain rocks like granite, gneiss, shale, and monazite-bearing sediments are known to have significant contributions to gamma emissions [19]. Radionuclides are common in indoor environments, where they contribute to elevated gamma levels. Materials that contain trace amounts of ^{40}K , ^{238}U , and ^{232}Th include cement, bricks, gypsum, ceramics, plaster, and aggregate mixes. It is possible that buildings built using dense concrete blocks or baked-clay bricks add to the intensity of gamma emissions, which results in the continuously high values of indoor gamma found in this study [20]. Indoor environments that are poorly ventilated result in a buildup of radon and its progeny, which accumulate on the indoor surfaces and contribute slightly to indoor gamma levels. Though the gamma dose contribution due to radon decay is less than the alpha exposure, it can still lead to noticeable increments in the indoor gamma rate [21]. Figure 3 shows the normal Q-Q plot of indoor gamma dose rate. Most of the data points are close to the reference line, and the remaining points are within the confidence boundaries, indicating that the results exhibit approximately normal statistical behavior. A small deviation may be due to the impact of local geological variation.

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Annual effective dose equivalent

The measured values for the indoor environments ranged from 0.44 to 1.03 mSv/y, with an arithmetic averages of 0.78 mSv/y. The highest indoor gamma dose rate of 0.21 μ Sv/h was observed at site I-8 (Dunga). Most of the values lying around the standard global indoor average level indicate the indoor median and mode of AEDE ($\approx$ 1 mSv/y), as shown in Figure 4. The AEDE value has a negative skewness of -0.66, indicating a slightly negatively skewed pattern, but the positive kurtosis (0.145) implies a flatter-than-normal (platykurtic) distribution. This combination indicates that there are few sites that have a relatively higher AEDE values than the rest. Geologically enriched regions, building materials with naturally occurring radionuclides, and a deficiency of indoor ventilation favor the occurrence of high indoor doses [22].

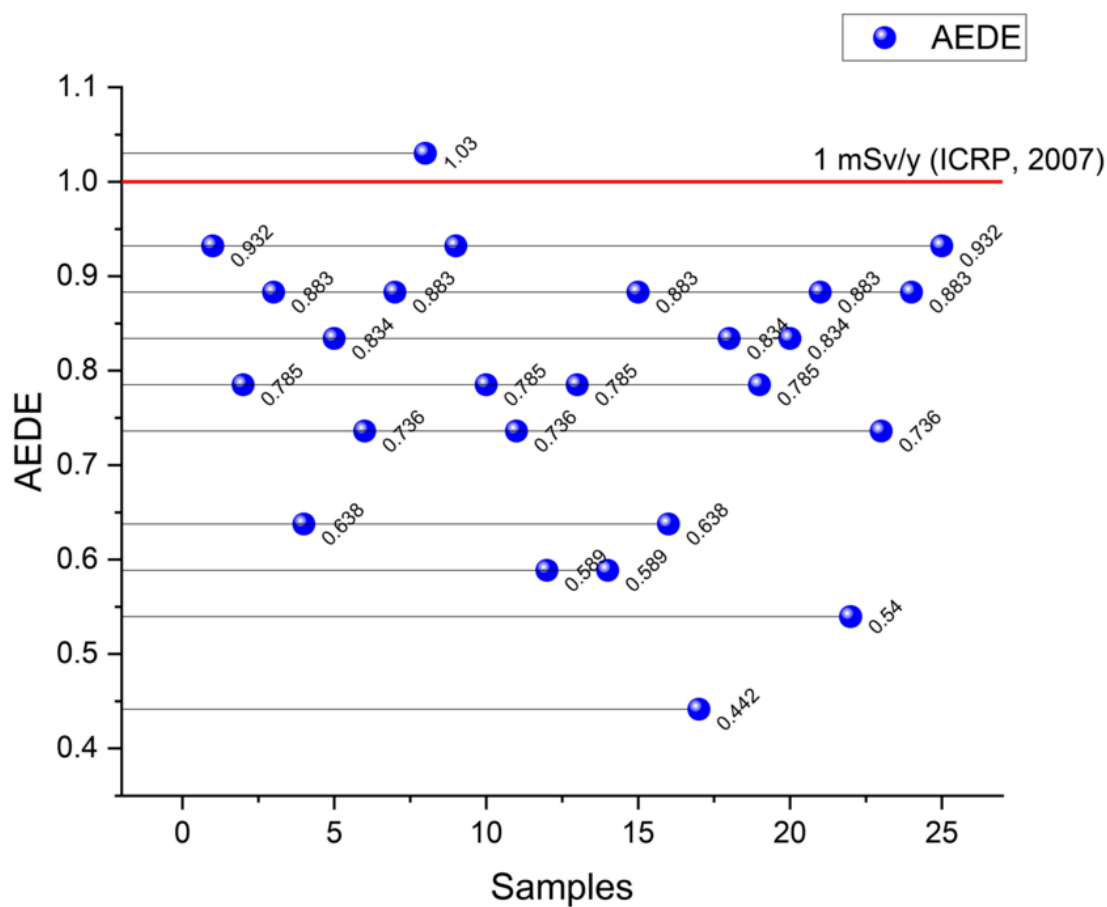


FIGURE 4: Estimated annual effective dose equivalent from selected locations

Lifetime Effective Dose (LED)

LED is used to describe the radiation that individuals are exposed to over an average lifespan of 70 years. The range of the LED values that have been obtained during this study is between 30.9 mSv and 72.1 mSv; its mean is 54.6 mSv. Figure 5 shows the calculated LED values from all selected locations. The mentioned values are less than the $\sim$ 100 mSv level, which is usually linked to a noticeable increase in stochastic risk, but small doses add to the total risk to the population, so the individuals in Dehradun are generally safe from negative health impacts of indoor gamma radiation [8].

The greater values of LED were found more in the old stone houses or those buildings that are not well ventilated, where the exposure is maintained over a long period. This finding implies that indoor radiation levels are not high, although continuous long-term exposure in confined areas can have a minor cumulative effect in increasing long-term dose levels [16].

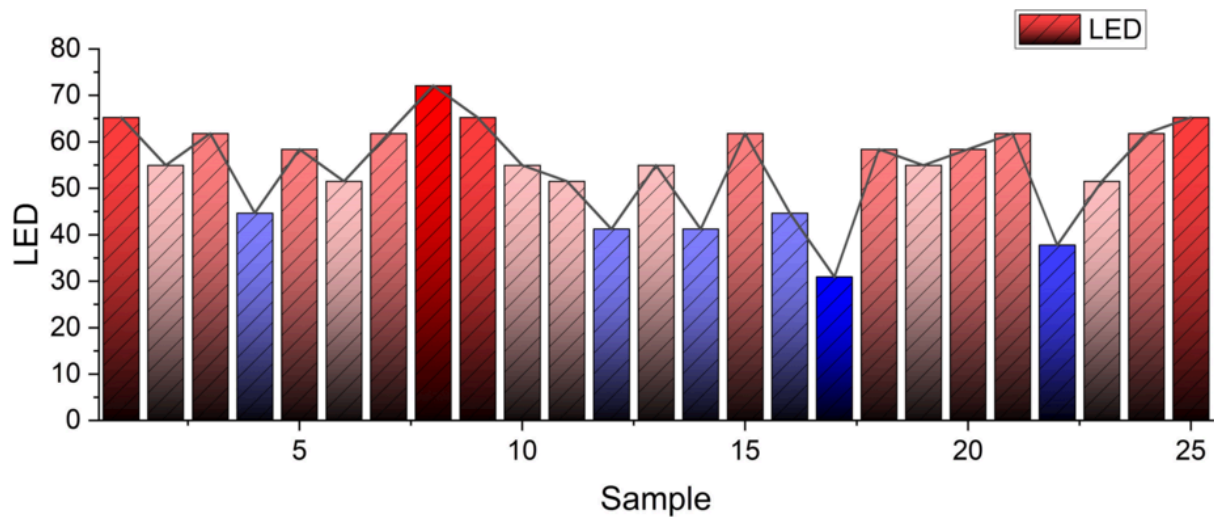


FIGURE 5: Bar graph for measured LED from selected locations

LED, Lifetime Effective Dose

Excess Lifetime Cancer Risk (ELCR)

According to Ezekiel (2017), ELCR estimates the chances of developing cancer over lifetime exposure to gamma radiation [23]. The values obtained after calculation of ELCR were in the range of 1.55×10^{-3} to 3.61×10^{-3} with the mean being 2.73×10^{-3} . This is equivalent to a predicted 2.73 per 1000 individuals over a lifetime of exposure, which is somewhat greater than the world-acceptable value of 0.29×10^{-3} of natural surroundings radiation [2]. Figure 6 shows the spatial distribution of ELCR by the contour mapping.

The statistical results of the indoor ELCR values show a distribution with a standard deviation of 0.54×10^{-3} . The skewness has a value of -0.66, meaning that the distribution is slightly skewed to the left; a positive value of kurtosis (0.145) indicates a platykurtic distribution (flatter than a normal curve). Maximum ELCR values were observed at sites I-8, I-7, and I-9; this is in agreement with the fact that they recorded the highest values of indoor gamma dose rates and subsequent levels of AEDE.

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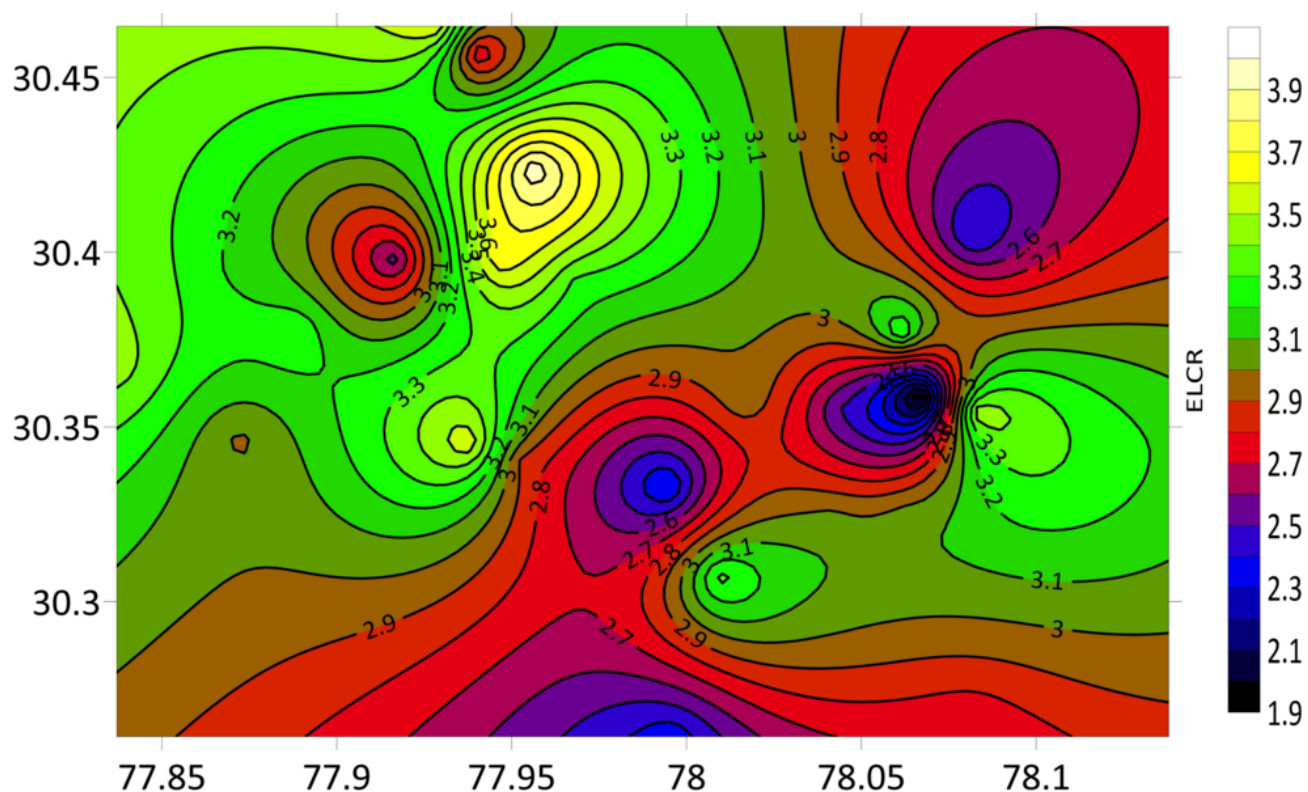


FIGURE 6: Contour map of ELCR of indoor level from study area

ELCR, Excess Lifetime Cancer Risk

The slightly higher ELCR values in the Dehradun district can be essentially linked to the occurrence of naturally occurring radionuclides, the geology of the Himalayan foothills, building materials with higher radioactivity, and insufficient indoor ventilation, which favors the buildup of decay products [24].

Worldwide indoor gamma radiation range

Global activities of indoor gamma radiation vary considerably with local geology, building material, and natural radionuclide content in soil and construction materials. Among the surveyed areas, indoor gamma dose is highest in the Kerala region of India (~1060 nGy/h), which is a high background radiation area due to monazite-rich coastal sands [25]. Moderate ranges are also observed in other parts of Asia (Hong Kong, 220 nGy/h) [26], Pakistan (131 nGy/h) [27], and Iran (115 nGy/h) due to soil type/brick/concrete materials [28]. Some European and Asian countries, like Poland (80 nGy/h) [29] and China (90 nGy/h) [30], have lower levels of indoor gamma radiation. The global variations indicate that the gamma radiation measurements indoors can be substantially affected by the geology of an area and the construction materials used.

Conclusions

The study presents a descriptive analysis of the indoor gamma radiation level in the Dehradun district of Uttarakhand using the ATOMTEX AT6130C portable gamma survey meter. The indoor gamma dose rates in this study (0.09–0.21 $\mu\text{Sv/h}$) are higher than the world population-weighted indoor gamma dose rate of 0.084 $\mu\text{Sv/h}$ as reported by UNSCEAR (2000). It is also found in the study that geological conditions, construction materials, and patterns of ventilation influence the level of indoor radiation. Constructions composed of limestone and dolomite were associated with higher radiation levels because natural radionuclides such as uranium, thorium, and potassium are present in them, compared to those

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constructed with bricks and cement. The values of AEDE, LED, and ELCR were determined to be within the safety limits as suggested by the ICRP (2007). These findings strongly suggest that indoor gamma radiation in Dehradun is not a major health hazard to the population.

The results also affirm that geological differences in the indoor radiation of the district are significant, as the index is higher in areas underlain by Himalayan limestone compared to areas that have Siwalik sandstone. Overall, this study concludes that the gamma radiation profile of Dehradun is safe and stable as far as the indoor environment is concerned. Its findings are consistent with other national and international studies and offer an adequate scientific interpretation of radiation exposure in the Doon Valley.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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Acquisition, analysis, or interpretation of data: Rohit S. Sajwan, Priyanshu Raj, Veena Joshi, Taufiq Ahamad

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Supervision: Rohit S. Sajwan, Veena Joshi

Critical review of the manuscript for important intellectual content: Priyanshu Raj, Veena Joshi, Taufiq Ahamad

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

Data Availability Statements

The datasets (and/or code) supporting this study are available from the corresponding author upon reasonable request. All data generated or analyzed during this study are included in this published article and/or its appendices.

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