Title Page

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Assessment of Ambient Gamma Dose Rate around the Atomic Power Station and its Health Effects in West UP, India

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Abstract

In this study an attempt has been made to estimate the exposure of natural radiation due to ambient gamma dose by using RedEye-G gamma survey meter measured at 1m height from the ground surface at 150 locations in the 18 villages situated within 5 km radius around the Narora Atomic Power Station, Bulandshahr, (U. P.) India. The average outdoor gamma dose rate varied from 1.31 to 2.72 mSv/y with an average value of 1.94 ± 0.25 mSv/y. The total annual effective dose ranged 0.93 to 1.79 mSv/y with an average value of 1.32 ± 0.16 mSv/y. The estimated mean of AED values is higher than the values prescribed by UNSCEAR and ICRP both. The result suggested that the measured gamma dose rates in the studied villages were requires a further investigation. The Excess Lifetime Cancer Risk, reduction coefficient and the dose received by various organs such as the kidneys, lungs, bone marrow, ovaries, liver and testes was evaluated. The calculation shows that the highest dose received by testes was 0.21 mSv/y and lowest dose received by liver was 0.09 mSv/y.

Keywords: Gamma Radiation; Annual Effective Dose; Dosimeter; Health Effect; Excess Lifetime Cancer Risk.

1. Introduction

The natural radiation is omnipresent in varying magnitude in the environment over the earth as well as into the space [1, 2]. It originates from various natural sources, such as the Earth's crust, Cosmic rays from space and radioactive isotopes present in the environment, depending on the geological formations and geographical locations [3, 4]. The human beings are continuously exposed by the natural radiation since primordial age by both terrestrial and cosmic ones, popularly known as Naturally Occurring Radioactive Materials (NORMs) [5]. Due to heavy industrialization and various economic activities, to meet up the energy requirement, a number of coal and nuclear power plants have been set up at the various locations in India. Hence, a new radiation contributing category immerged, named as manmade radiation or Technology Enhanced Natural Radioactive Materials (TENROMs) [6].

The terrestrial Radiation emitted by naturally occurring radioactive materials present in the Earth's crust, such as uranium, thorium, and potassium [6]. These radioactive elements decay over time and release radiation in the form of alpha-beta particles, and gamma rays, whereas the cosmic radiation originates from the surface of Sun, cosmogenic radionuclides, and other celestial sources [7, 8]. It consists mainly of high-energy charged particles, such as protons and alpha particles that travel through space and reaches to the Earth's atmosphere via penetrating the atmosphere thus, contributing to natural radiation exposure. The main elements responsible for this gamma radiation exposure are ^{238}U, ^{235}U, ^{232}Th series, ^{40}K and ^{226}Ra. The contributions made by terrestrial radionuclides including ^{238}U, ^{232}Th series, and ^{40}K to the radiation level are 25%, 40% and 35%, respectively [9]. The two isotopes of radon namely radon (^{222}Rn) and thoron (^{220}Rn) are the radioactive gaseous emitted by ^{238}U and ^{232}Th. The radon, thoron and their progeny are mainly responsible for the more than half of the dose received by natural radiation [5, 10-13]. The concern with the Radon gas is primarily related to its radioactive decay products, particularly solid radioactive particles called radon progeny or radon daughters. These particles can become lodged in the lungs and emit radiation, increasing the risk of lung cancer. The alpha particles emitted during the decay of radon progeny can cause damage to the cells in the lung tissue, potentially leading to cancer over time. Radon exposure is a leading cause of lung cancer, especially among the non-smokers [2, 14].

These radionuclides can contaminant the environment. Radioactive elements released from the Earth's crust can enter and contaminate the air, water, food, and soil. The extent of the environmental impact depends upon factors such as the concentration of radioactive elements, their mobility and the exposure pathways for organisms that can have harmful effects on health of human beings. These emitted gamma radiations can enters in to the body or may came in to the touch of skin of the residents and can pose health risks like lung cancer if exposure occurs at high levels or for prolonged periods [12]. The exposure pathway is crucial because it determines how living organisms come into contact with these radioactive substances, like, inhalation of radioactive particles in the air or consumption of contaminated food can lead to internal exposure in human beings. Living organisms can be adversely affected by exposure to radiation. High doses of radiation can damage cells and tissues, leading to genetic mutations, cancer, and other health problems. It can also disrupt ecosystems by impacting different species in the food chain. Acute exposure to intense gamma radiation can cause radiation sickness, damage to organs, radiation burns, and even death. Long-term exposure to lower levels increases the risk of cancer and other health issues. It can cause harm to the cell structure, change in DNA or death of a tissue or organs that embarked to the different kinds of cancers like leukaemia, lymphomas and CNS tumours etc [7, 15].

According to the UNSCEAR, the estimated annual effective dose received by human beings is 2.4 mSv, out of which 87% is due to terrestrial and cosmic radiation and the remaining 13% is due to manmade radiation [12]. The world average outdoor terrestrial gamma radiation dose rates and cosmic radiation dose rates are 59 nSv/h and 32 nSv/h respectively at the sea level. The worldwide average of annual effective dose due to total cosmogenic radiation at the sea level is 0.39 mSv and for average terrestrial radiation dose due to outdoor and indoor is 0.07 mSv/y and 0.41 mSv/y making a total external terrestrial radiation is 0.48 mSv. The average worldwide value with a total of AED (annual effective dose) due to cosmic and terrestrial is 0.87 mSv/y as stated by UNSEAR [12, 16].

Many researchers have worked out over the estimation of natural gamma radiation in the various parts of India and all over the world and calculated various parameters. Table 1 and 2 shows the work done by various researchers in different parts of World and India respectively [6, 8, 14, 17-34]. The average outdoor gamma dose rate in India and World reported as 39 nSv/h and 41 nSv/h respectively [35]. In India the minimum value of annual effective dose in indoor, outdoor and total was found 0.06 mSv/y at Narmada and Bharuch districts of Gujrat, 0.039 mSv/y at Churu, Rajsthan and 0.3 mSv/y at Uttara Kannada, Karnataka while the maximum value of total annual effective dose reported 2.38 mSv/y at Hasan district of Karnataka, 1.707 mSv/y at Udhampur district of Jammu and Kashmir and 2.90 mSv/y at Uttara Kannada district of Karnataka as indoor, outdoor and total maximum value [17, 21, 22, 29, 30].

Table 1: Environmental gamma dose rate range and annual effective dose range due to natural radionuclide sources for selected countries and for this study [UNSCEAR 2008]

Table 2: Shows the different parameters reported by different researchers in the different parts of India

It's important to note that the hazards effects of natural radiation are typically considered in the context of long-term exposure to high levels of radiation. It also helps to the scientific community for the understanding the environmental impacts, and conducting geological studies. The natural background radiation levels experienced by most individuals in their day-to-day lives are generally within safe limits and do not pose significant health risks but some regions are belongs to High Background Radiation Areas (HBRAs). Some of the low back ground areas have become region of keen interest to the researchers for the measurement of natural gamma radiation. The study of natural gamma radiation is crucial because it helps in understanding and assessing the potential hazardous effects of radiation on human health and the environment. By quantifying natural gamma radiation levels, scientists and regulatory bodies can establish guidelines and safety limits to protect individuals from excessive radiation exposure, geologists can analyze the composition, structure, and stratigraphy of the Earth's crust, aiding in mineral exploration and understanding geological processes [11, 36].

2. Study Area and Measurement

The Narora Atomic Power Station (NAPS) is situated on the bank of the river Ganga in the Bulandshahr District of Uttar Pradesh, India. Its GPS coordinates are 28.1573° N and 78.4097° E [37]. NAPS has an installed power generation capacity of 440 MW as shown in figure 1. The study was carried out in 18 villages situated within a 5 km radius circle around NAPS as the center. These villages were selected as they fall in the vicinity of the nuclear power station. Out of them some villages are belongs to Bulandshahr district and some are to the Budaun district of Uttar Pradesh. The soil in some villages is sandy due to their proximity to the river Ganga, while others have loamy soil as they are in the Ganga-Yamuna Doab region. Tube wells and canals are used for irrigation purposes in the fields. There are around 35000 people living in the studied area [38]. The GPS-Coordinates each of the selected locations taken by GARMIN GPS-62S, which is a satellite connected, easy to use passive device. Figure 2 shows the images of RedEye-G gamma survey meter and GARMIN GPS-62S.

Figure 1: Locations of the studied area around NAPS, Narora, Bulandshahr

Figure 2: Images of the instruments RedEye-G and GARMIN-GPS-62S

The Outdoor gamma dose rate measurements were conducted at 150 locations using a pocket-sized GM tube-based gamma dosimeter known as "RedEye-G". This dosimeter, manufactured by Thermo Scientific, can detect gamma rays in the energy range of 45 keV to 3 MeV. The dose rate measurement range is 50 μR/h to 10 R/h. The recorded dose rates in μR/h were converted into absorbed dose rates (μSv/h) using the conversion factor (1 μR/h = 0.01 μSv/h). Additionally, the absorbed dose rates were converted into equivalent effective dose rates for adults using a conversion factor of 0.7 [39]. The measured indoor and outdoor gamma dose rates with the location code with the coordinates and height from sea level, annual effective dose, reduction coefficient and excess lifetime cancer risk are tabulated in table 3.

Table 3: Gamma Dose Rate in the unit of μR/h, Annual Effective Dose Rate in mSv/y, Hieght from Sea Level (m) for each location, Reduction Coefficient and Excess Lifetime Cancer Risk

3. Calculations

3.1 Estimation of Annual Effective Dose (AED)

The effective dose is a measure to check the biological impact of radiation over the human body. The annual effective dose (AED) resulting from indoor and outdoor gamma-dose rate calculated by using formula [25, 40]. However, the calculated AED values are reported in the units of mSv/y for the sake of convenience.

$$\mathbf{AED_{indoor}\ (\mu Sv/y) = Indoor\ gamma\ dose\ rate\ (\mu R/h) \times T \times OF_{indoor} \times Conversion\ Factor} \quad \text{.....(1)}$$

$$\mathbf{AED_{Outdoor}\ (\mu Sv/y) = Outdoor\ gamma\ dose\ rate\ (\mu R/h) \times T \times OF_{outdoor} \times Conversion\ Factor} \quad \text{.....(2)}$$

Where T (hour) is time of exposure duration per year i.e. (24 hours × 365.25 days = 8766 h/y), OF_{indoor} and $OF_{outdoor}$ are the indoor and outdoor occupancy factors (0.8) and (0.2) respectively and f is conversion coefficient (0.7 for adults) reported by UNSCEAR to convert absorbed dose in the air to the effective dose [12].

Equation (1) and (2) are used for the calculation of AED indoor and outdoor respectively. Total AED is calculated by adding indoor and outdoor AED values.

$$\mathbf{AED_{total} = AED_{indoor} + AED_{outdoor}} \quad \text{.........(3)}$$

3.2 Lifetime Effective Dose

The lifetime effective dose estimated by using the total annual effective dose and the duration of life as

$$\mathbf{Lifetime\ Effective\ Dose\ (mSv/y) = AED_{total} \times duration\ of\ life} \quad \text{......(4)}$$

Where the total annual effective dose taken from calculated values by using Eq. (3) and duration of life taken as 70 years [41].

3.3 Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk gives an approximation idea about the danger level due to the ambient gamma dose rate hence it is estimated by using the formula [42].

3.4 ELCR (mSv/y) = Lifetime Effective Dose × RF …….(5)

Where lifetime effective dose is calculated by using Eq. (4) and RF is the risk factor 0.057 is employee as per ICRP recommendations [43].

3.5 The effective dose rate (Dorgan) to different body organs and tissues

The effective dose rate to an organ is calculated by using

Organ Dose (mSv/y) = AED (mSv/y) × O × F …....(6)

Where AED is the outdoor annual effective dose rate, O is the occupancy factor is 0.8 and F is the conversion factor for particular organ from injection. The effective dose rates are calculated with the F values for lungs, ovaries, bone marrow, testes, kidneys,liver and whole body being 0.64, 0.58, 0.69, 0.82, 0.62, 0.46 and 0.68, respectively, as recommended by ICRP [43, 44].

4. Results

4.1 Gamma dose rate and annual effective dose

The indoor and outdoor gamma dose rate measured ranged as 15.00 µR/h to 31.00 µR/h and 15.00 µR/h to 24.00 µR/h with the average (SD) 22.17 (2.87) µR/h and 18.89 (1.94) µR/h respectively. The indoor and outdoor annual gamma dose rate estimated varied as 1.31 mSv/y to 2.72 mSv/y and 1.31 mSv/y to 2.10 mSv/y with the average (SD) 1.94 (0.25) mSv/y and 1.66 (0.17) mSv/y respectively as given in table 3 and figure 3, 4 and 5 reflects the indoor, outdoor and total gamma dose at each of the location and the frequency curve with the cumulative frequency curve. The GM (GSD) for the indoor, outdoor and total annual gamma dose rate is 1.92 (1.14), 1.64 (1.1), and 3.58 (1.11) respectively in the unit of mSv/y.

Figure 3: Frequency Curve with cumulative curve and Column graph for the Indoor Gamma Dose Rate (mSv/y) for each location of the studied area

Figure 4: Frequency Curve with cumulative curve and Column graph for the outdoor Gamma Dose Rate (mSv/y) for each location of the studied area

Figure 5: Frequency Curve with cumulative curve and Column graph for the Total Gamma Dose Rate (mSv/y) for each location of the studied area

The indoor and outdoor annual effective dose estimated ranged as 0.74 mSv/y to 1.52 mSv/y and 0.18 mSv/y to 0.29 mSv/y with the average (SD) 1.09 (0.14) mSv/y and 0.23 (0.02) mSv/y respectively. The minimum and maximum total annual effective dose rate had 0.93 mSv/y and 1.79 mSv/y with an average (SD) of 1.32 (0.16) mSv/y as tabulated in table 4. The variation is shown with the line curve in figure 6 for the indoor, outdoor and total annual effective dose. The GM (GSD) for the indoor, outdoor and total annual effective dose rate is 1.07(1.14), 0.23(1.11), and 1.31(1.12) respectively in the unit of mSv/y.

Table 4: Statistics of the Gamma Dose Rate, Lifetime Effective Dose and Annual Effective Dose in the unit of mSv/y

Figure 6: Variation of the Indoor, Outdoor and Total Gamma Dose Rate (mSv/y) for each location of the studied area as Line Curve

The reduction coefficient (Indoor gamma dose rate/outdoor gamma dose rate) varies as 0.92 to 1.67 with an average (SD) 1.17 (0.13). The total lifetime dose rate varied as 190.22 to 325.22 with an average (SD) 251.99 (26.13) in the unit of mSv/y as submitted in the table 3 and in the figure 7 with the bar graph.

Figure 7: Variation in the Reduction Coefficient for each location of the studied area in the form of Bar Graph

4.2 Excess lifetime cancer risk

The table 3 shows the excess lifetime cancer risk ranges as 0.01×10^{-3} to 0.17×10^{-3} with an arithmetic mean ± SD $0.75 \times 10^{-3} \pm 0.09$, whereas the worldwide mean value of ELCR is given by 0.29×10^{-3} reported by Taskin et al [41]. Figure 8 shows the variation in the ELCR is shown. Radiological hazards were evaluated by estimating the excess lifetime cancer risks caused by external exposure. The calculated excess lifetime cancer risk values indicate that the chance of contracting cancer for residents of the study area is low, i.e. the chances of contracting cancer due to the evaluated radiological exposures are not significantly high.

Figure 8: Variation in the ELCR for each location of the studied area in the form of Bar Graph

4.3 Organ Dose

The dose received by bone marrow, kidneys, liver, lungs, ovaries and testicles and whole body has given in table 5. The lowest dose received by liver and highest doses received by testicles is 0.43 and 1.47 mSv/y respectively. The Box-Whisker graph shows the minimum, maximum, and means variation in the dose received by various orgrns figure 9.

Figure 9: Box-Whisker Graph Showing the Organ Dose received by different Organs

Table 5: Statistics of the Reduction Coefficient, Excess Lifetime Cancer Risk and Organ Dose received by Bone Marrow, Kidneys, Liver, Lungs, Ovaries, Testicles and Whole Body

5. Discussion

The annual effective dose rate received by residents in the study area is greater than the average value reported 1.0 mSv/y and 0.48 mSv/y by ICRP and UNSCEAR [12, 43]. The outdoor annual effective dose reported by as 0.11 mSv/y [34].

These results indicate that the estimated doses to the different organs examined are all below the international tolerable limits on dose to the body organs of 1.0 mSv annually. The world and Indian average gamma dose rate has mean value of 59 nGy/h and 89 nGy/h. The worldwide average annual effective dose is 0.41 mSv, of which 0.07 mSv/y is from outdoor exposure and 0.34 mSv/y is from indoor exposure.

The average value of ELCR is found well below than the worldwide average of 0.29×10^{-3}. This suggests that further investigation and monitoring are necessary to fully understand the extent of the gamma radiation exposure in the area and assess potential health risks accurately.

UNSCEAR and Nambi, et al., reported the average value of reduction coefficient 1.4 and 1.8 for world and India and the average value is well within the limit [12, 45].

The calculated effective dose from the present exposure rate to the adult organs investigated is insignificant. This means that the level of radiation exposure experienced by the residents is not considered to pose a substantial risk to their health, specifically in terms of cancer development.

Overall, these findings suggest that the radiological hazards in the study area are not a significant cause for concern when it comes to cancer risks. However, it's essential to continue monitoring and assessing radiation levels periodically to ensure the ongoing safety of the residents.

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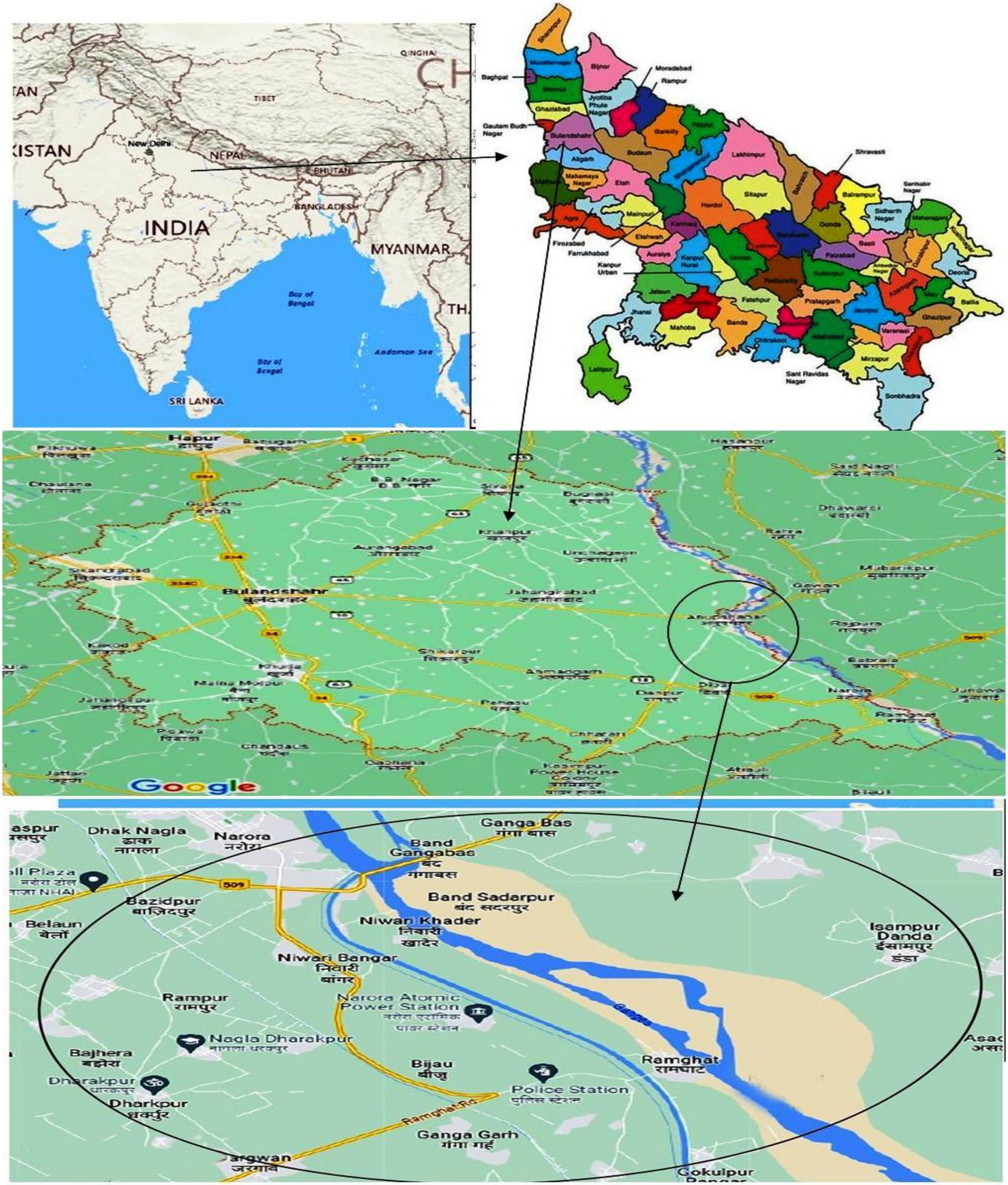


Figure 1: Locations of the studied area around NAPS, Narora, Bulandshahr

Figure 2: Images of the instruments RedEye-G and GARMIN-GPS-62S

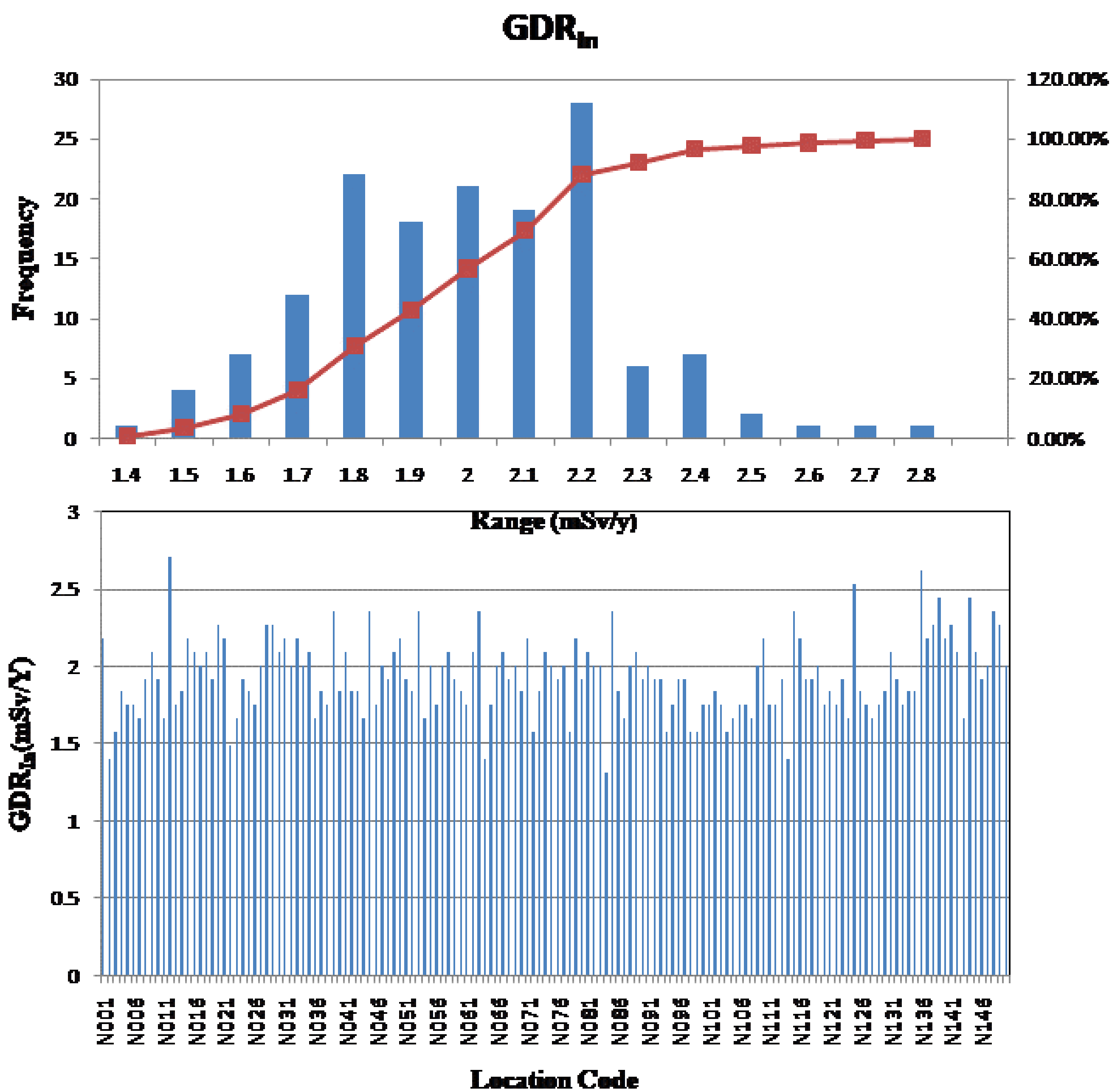


Figure 3: Frequency Curve with cumulative curve and Column graph for the Indoor Gamma Dose Rate (mSv/y) for each location of the studied area

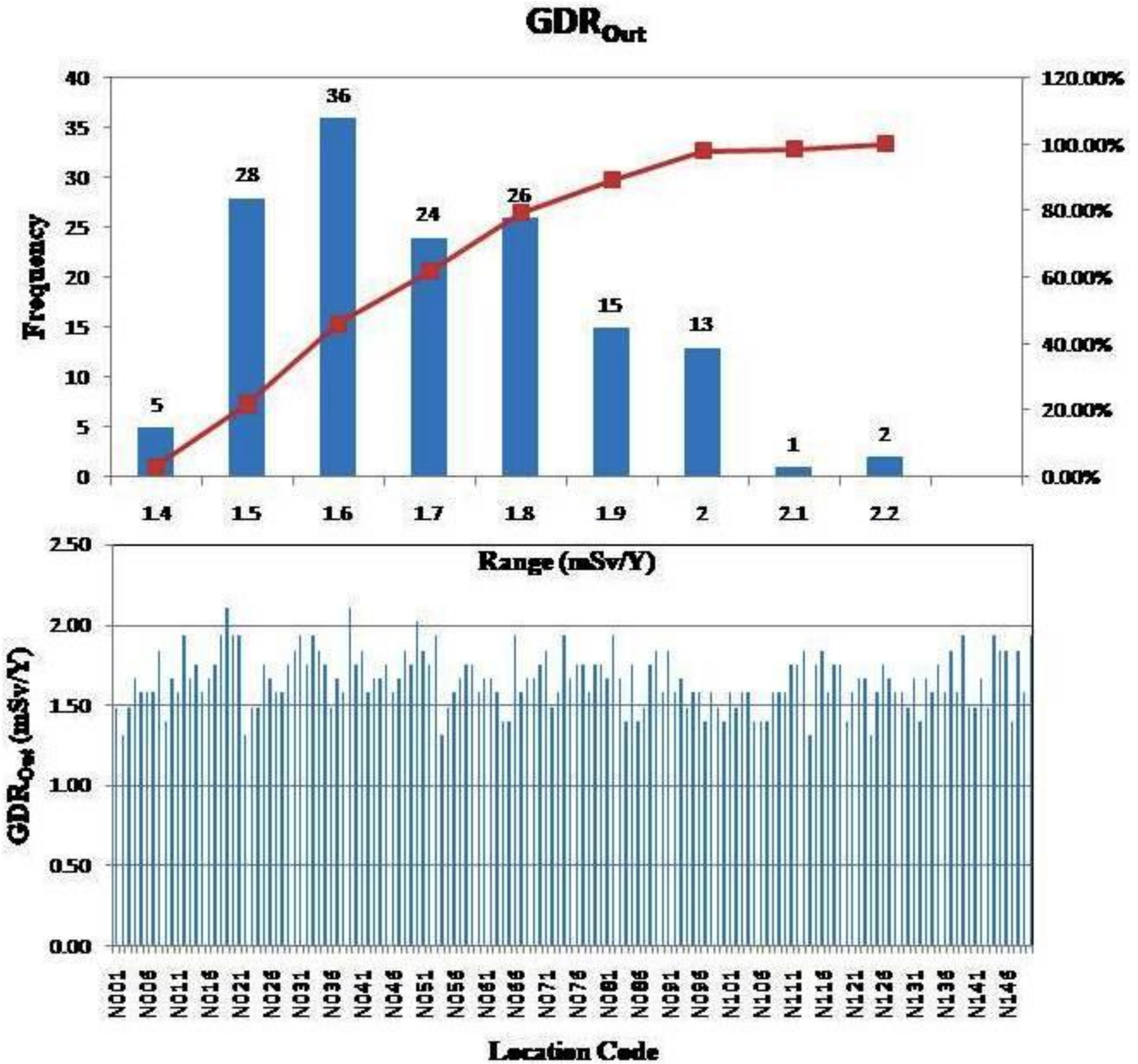
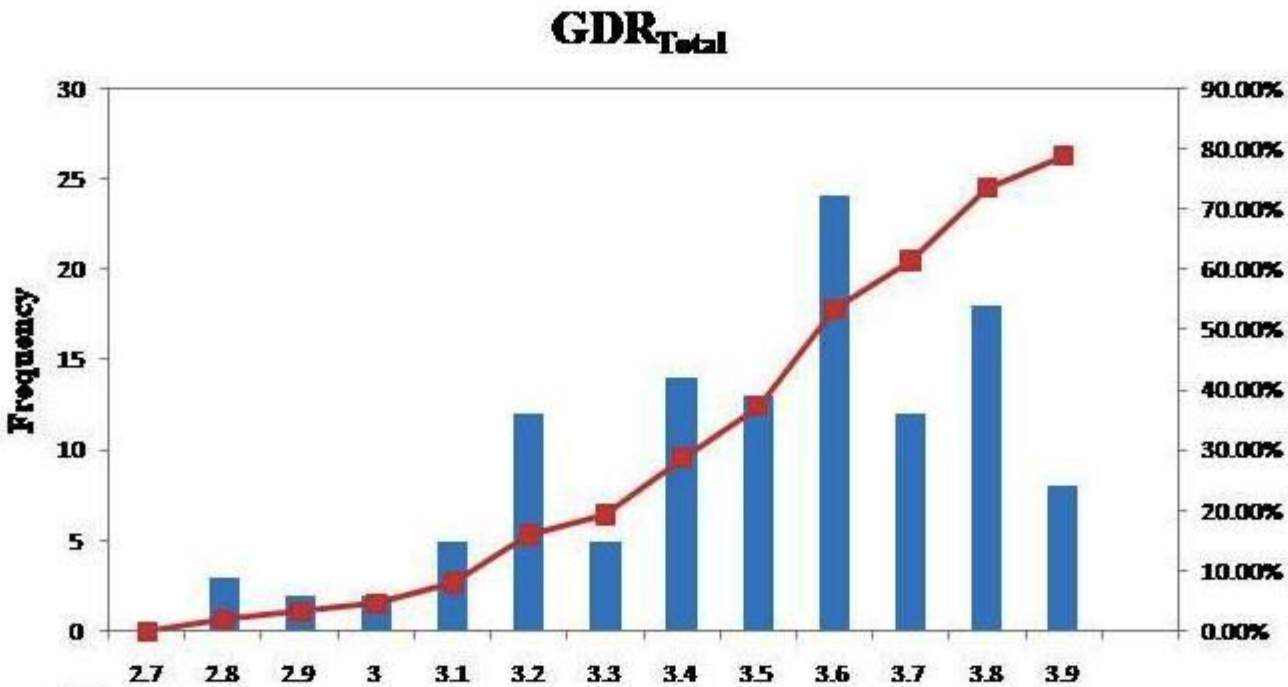


Figure 4: Frequency Curve with cumulative curve and Column graph for the Outdoor Gamma Dose Rate (mSv/y) for each location of the studied area



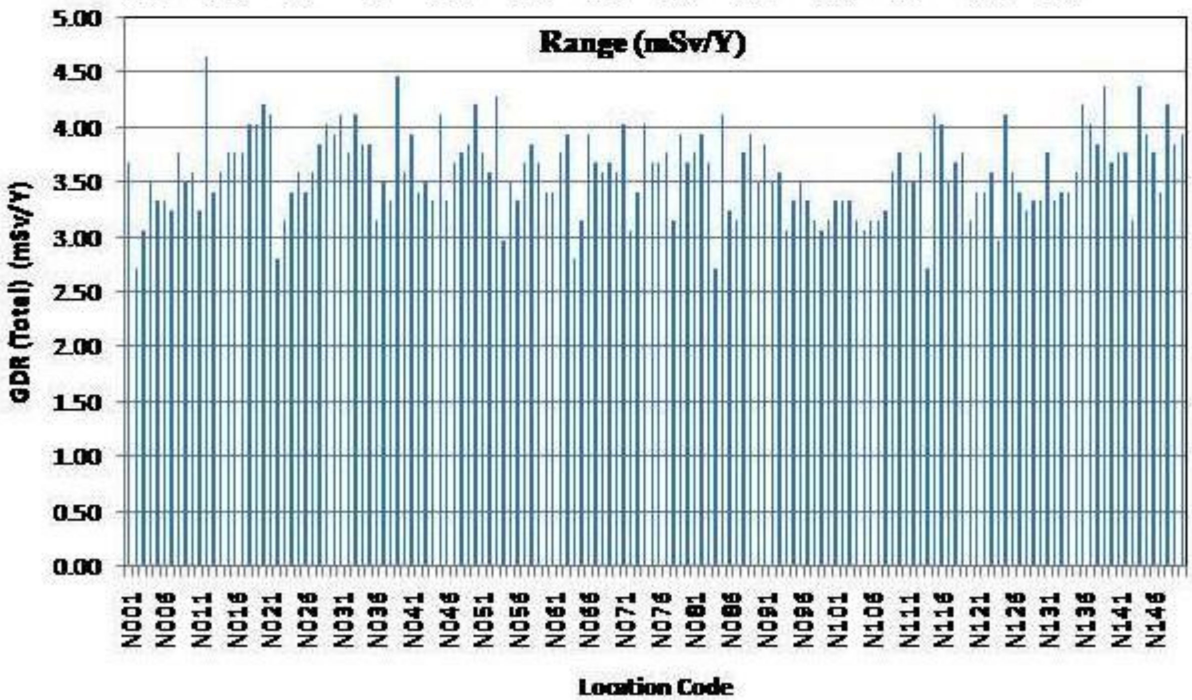


Figure 5: Frequency Curve with cumulative curve and Column graph for the Total Gamma Dose Rate (mSv/y) for each location of the studied area

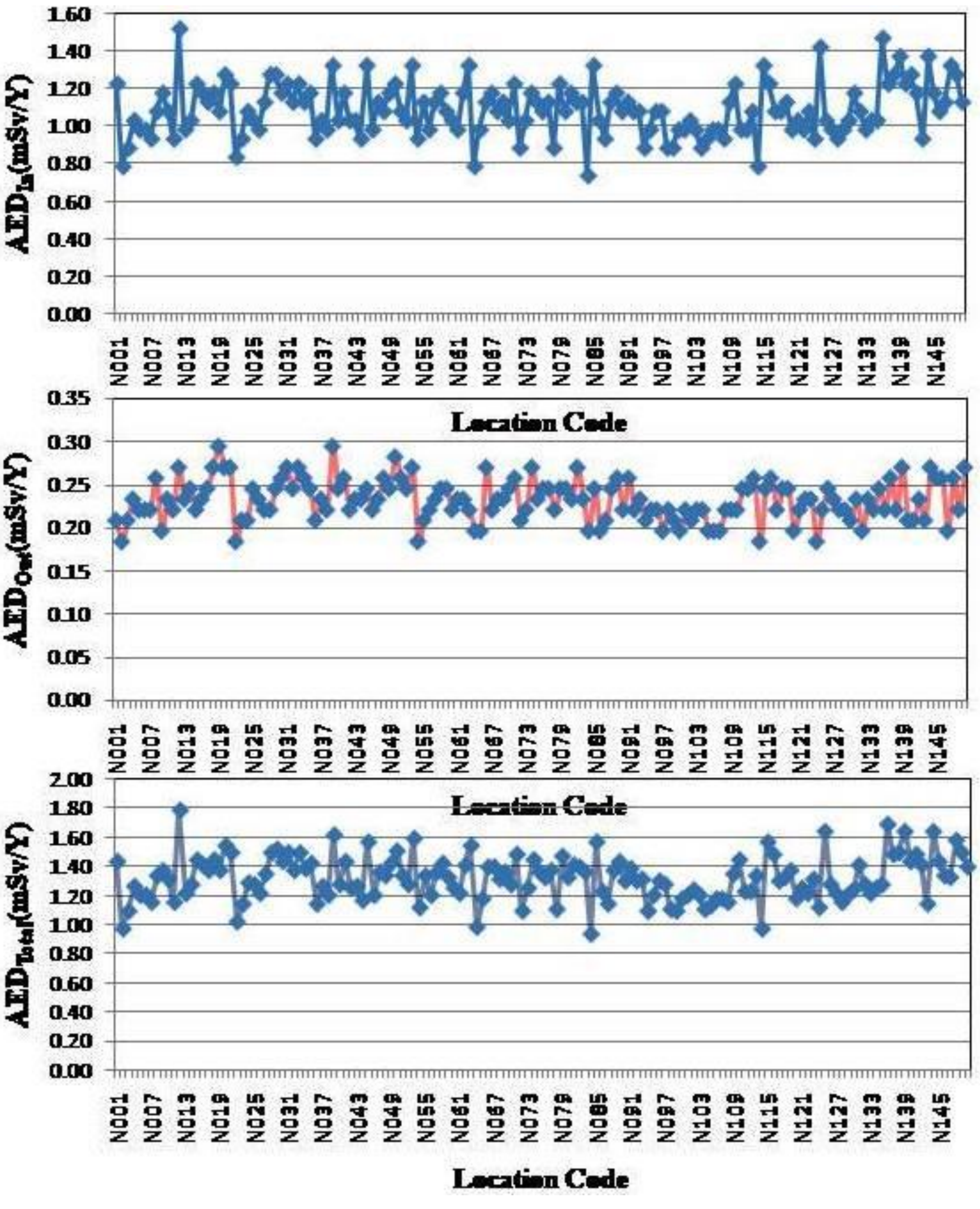


Figure 6: Variation of the Indoor, Outdoor and Total Gamma Dose Rate (mSv/y) for each location of the studied area as Line Curve

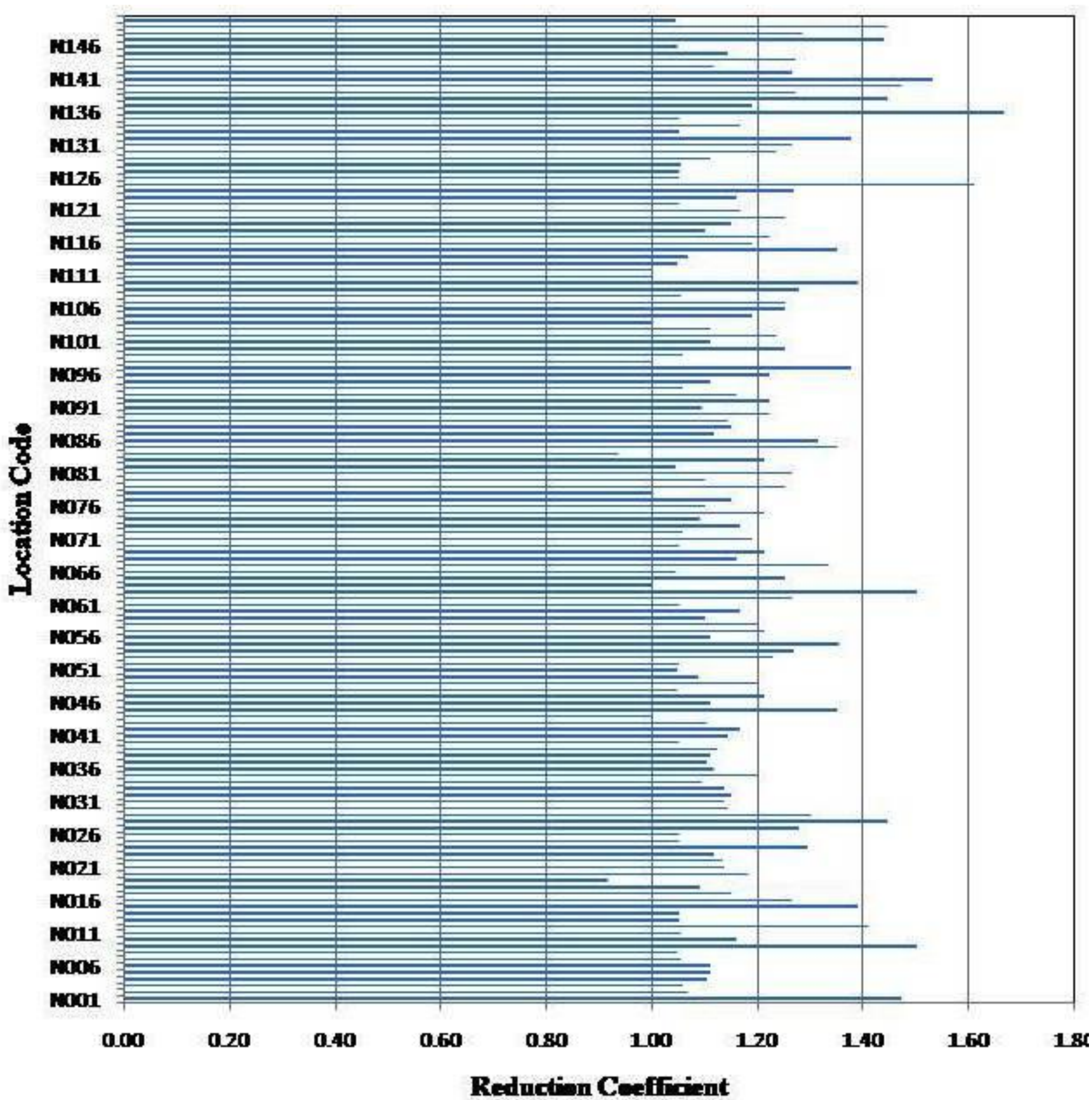


Figure 7: Variation in the Reduction Coefficient for each location of the studied area in the form of Bar Graph

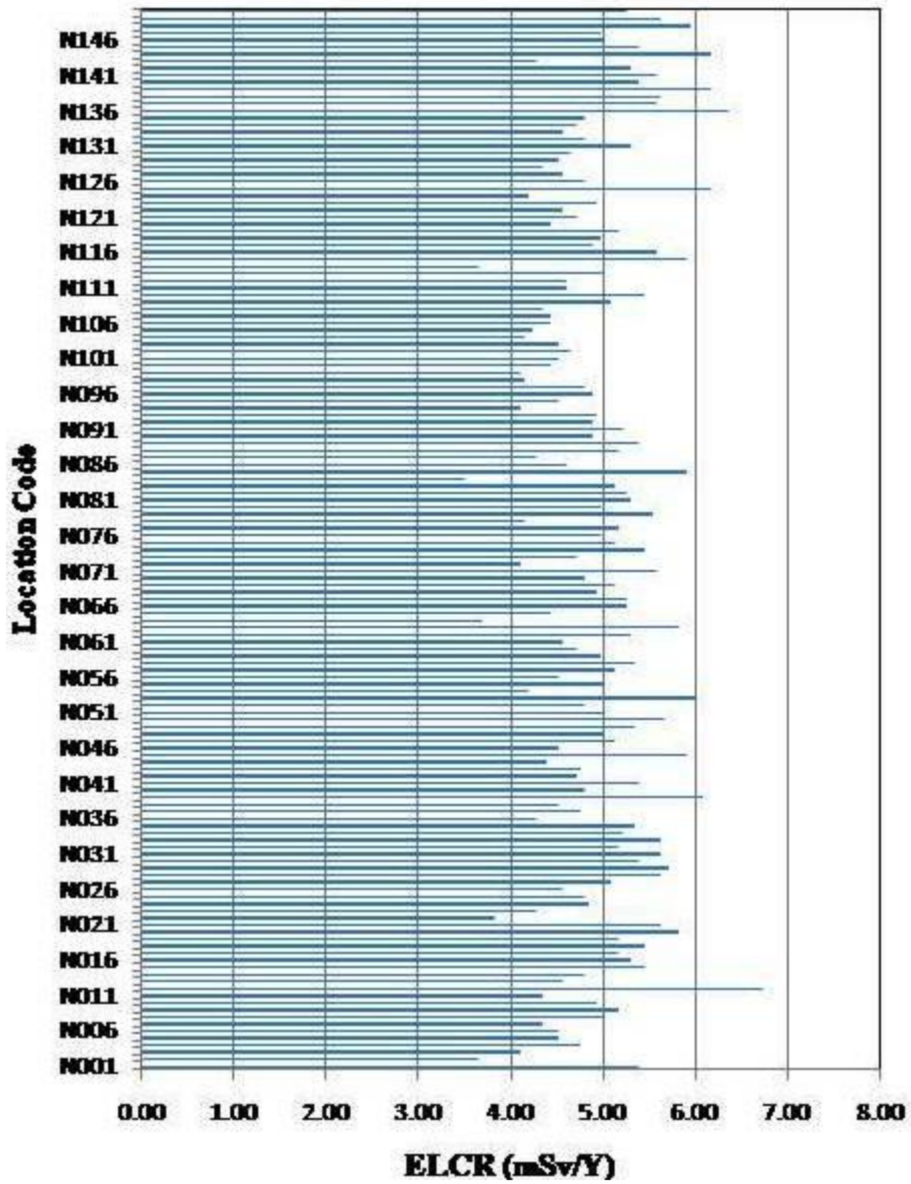


Figure 8: Variation in the ELCR for each location of the studied area in the form of Bar Graph

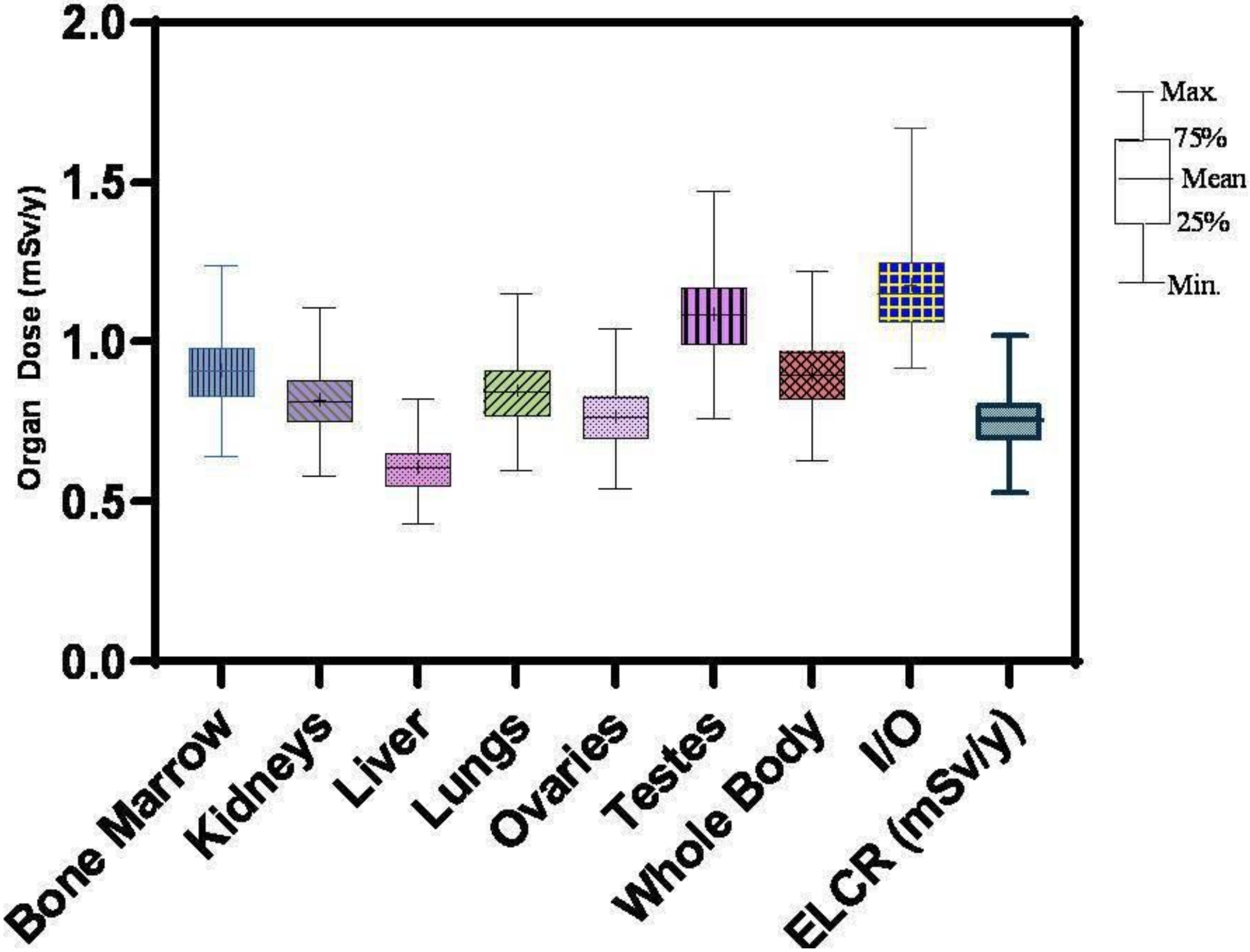


Figure 9: Box-Whisker Graph Showing the Organ Dose received by different Organs

Table 1: Environmental gamma dose rate range and annual effective dose range due to natural radionuclide sources for selected countries and for this study [UNSCEAR 2008]

Country	Range of Dose rate ($\mu Sv.h^{-1}$)	Mean Gamma Dose rate ($\mu Sv.h^{-1}$)	Range of annual effective dose (mSv)
Libyan Arab Jamahiriya	0.048 - 0.054	0.051	0.059 - 0.066
Mauritius	0.08 - 0.126	0.098	0.098 - 0.155
Tanzania (United Rep. of)	0.098 - 0.121	0.104	0.120 - 0.148
Canada	0.031- 0.075	0.054	0.038 - 0.092
Mexico	0.023 - 0.184	0.088	0.028 - 0.226
Costa Rica	0.035 - 0.147	0.066	0.043 - 0.180
Odisha, India	0.251 - 0.879	0.449	0.308 - 1.078
Cuba	0.038 - 0.196	0.055	0.047 - 0.240
Azerbaijan	0.075 - 0.205	0.140	0.092 - 0.251
China	0.011 - 0.523	0.815	0.013 - 0.641
Indonesia	0.045 - 0.102	0.0675	0.055 - 0.125
Korea	0.018 - 0.200	0.079	0.022 - 0.245
Turkey	0.032 - 0.094	0.065	0.039 - 0.115
Denmark	0.056 - 0.101	0.066	0.069 - 0.124
Finland	0.077 - 0.171	0.103	0.094 - 0.209
Lithuania	0.079 - 0.115	0.095	0.097 - 0.141
Sweden	0.040 - 0.630	0.097	0.049 - 0.773
Belgium	0.045 - 0.102	0.076	0.055 - 0.125
Ireland	0.035 - 0.143	0.065	0.043 - 0.175
Italy	0.057 - 0.243	0.112	0.069 - 0.298
Spain	0.050 - 0.129	0.085	0.061 - 0.158
Switzerland	0.053 - 0.155	0.081	0.065 - 0.190
Bulgaria	0.075 - 0.140	0.100	0.092 - 0.172
Czech Republic	0.040 - 0.285	0.100	0.049 - 0.349
Poland	0.051 - 0.126	0.080	0.063 - 0.155
Romania	0.052 - 0.163	0.092	0.065 - 0.199
Albania	0.077 - 0.103	0.094	0.094 - 0.126
Croatia	0.070 - 0.140	0.115	0.086 - 0.172
New Zealand	0.034 - 0.122	0.076	0.042 - 0.149
This study			

Table 1: Shows the different parameters reported by different researchers in the different parts of India

References	Location	Gamma Dose Rate		AED		ELCR	I/O
		Outdoor	Indoor	Outdoor	Total		
1.	Reasi, Jammu and Kashmir	0.06 ± 0.03 - 0.18 ± 0.06 μSv/h	0.11 ± 0.03 to 0.20 ± 0.04 μSv/h	105 ± 53 - 315 ± 105 μSv/y			0.9 to 2.5
2.	Udhampur, Jammu and Kashmir	60 - 400 nGy/h	97 - 210 nGy/h	256 to 1707 μSv/y	670 to 2603 μSvy		0.34 to 2.08
3.	Amritsar, Punjab	0.06–0.25 μSv/h	0.05–0.23 μSv/h	105 to 438 μSv/y	455 to 2050 μSv/y		0.45 to 1.62
4.	Panchkula, Haryana	70.0 ± 3.5 to 168 ± 8 nSv/h		0.086 ± 0.004 to 0.206 ± 0.010 mSv/ y		0.322×10^{-3} to 0.773×10^{-3}	
5.	Nagaur, Rajsthan	66 ± 2.1 to163 ± 6.8 nSv/h		0.081 ± 0.0026 to 0.2 ± 0.0083 mSv/y		$0.304 \pm 0.0097 x10^{-3}$ to $0.75 \pm 0.0292 x10^{-3}$	
6.	Jhajjar, Sonipat and Rohtak, Haryana	85 ± 2.97 to 184 ± 8.76 nSv/h		0.104 ± 0.003 to 0.225 ± 0.011 mSv/y		$(0.391 \pm 0.014$ to $0.846 \pm 0.04) \times 10^{-6}$	
7.	Churu, Rajsthan	32.00 to 231.00 nSv/h		0.039 to 0.283 mSv/y		0.147×10^{-3} to 1.063×10^{-3}	
	Jhunjhunu, Rajsthan	75.00 to 188.00 nSv/h		0.092 to 0.231 mSv/y		0.345×10^{-3} to 0.865×10^{-3}	
8.	Anand, Gujrat	74 to 287 nSv/h		0.09–0.35 mSv/y			
	Bharuch, Gujrat	40 to 278 nSv/h		0.05–0.34 mSv/ y			
	Vadodara, Gujrat	19 to 287 nSv/h		0.05–0.26 mSv/y			
	Narmada, Gujrat	40 to 210 nSv/h		0.02–0.35 mSv/y			
9.	Balod, Chattisgarh	103.0 ± 3.1 – 201.0 ± 6.0 nSv/h	132.0 ± 4.0 to 260.0 ± 7.8 nSv/h	0.13 - 0.25 mSv/y	0.77 to 1.49 mSv/y	5.0×10^{-3} to 5.2×10^{-3}	0.90–1.92
10.	Bhilai, Chattisgarh	108 ± 3 to 172±5 nSv/h	146 ± 4 to 233 ± 7 nSv/hr	0.13 ± 0.004 to 0.21 ± 0.006 mSv/y	0.86 ± 0.03 to 1.29 ± 0.04 mSv/y		0.6 to 2.3
11.	Durg, Chattisgarh	81.9 ± 3.3 to 156.0 ± 6.2 nSv/h	145 ± 6 to 253 ± 10 nSv/h	0.14 ± 0.01 to 0.23 ± 0.01 mSv/y	0.88 ± 0.04 to 1.45 ± 0.06 mSv/y	5.17×10^{-3} to 5.27×10^{-3}	0.89 to 1.95
12.	Kabirdham, Chattisgarh	101 ± 5 to 172 ± 9 nSv/h	165 ± 27 to 192 ± 37 nSv/h	0.12 ± 0.01 to 0.23 ± 0.01 mSv/y	1.17 ± 0.06 to 0.94 ± 0.05 mSv/y		1.04 to 1.64
13.	Dasarlapally, Nalgonda, Telangana	1536 to 2796 μGy/y	1716 to 2728 μGy/y		1.22 to 1.86 mSv/y		0.92 to 1.54
14.	Meghavath Thanda, Nalgonda, Telangana	1850 to 2310 μGy/y	1690 to 2240 μGy/y		1.27 to 1.66 mSv/y		1.00 to 1.27
15.	Uttara Kannada, Karnataka	44.6 to 220.1 nGy/h	57.4 to 242.5 nGy/h	0.06 to 0.27 mSv/y	0.3 to 1.38 mSv/y		1.00 to 1.88
16.	Hassan, Karnataka	78.3 to 461nGy/h	87 to 487 nGy/h	0.09to 0.51 mSv/y	0.67 to 2.90 mSv/y		1.44 to 8.89
17.	Shimoga, Karnataka	87 ± 1.72 to 323.64±16.6 nGy/h	114.05 ± 2.11 to 332.6 ± 3.99 nGy/h	0.106 to 0.393 mSv/y	0.952 to 1.737 mSv/y		
18.	Bellary, Karnataka	78.3 to 191.3 nGy/h	143.55 to 256.65 nGy/h	0.71 to 1.26 mSv/y	0.85 to 1.37 mSv/y		

Table 3: Gamma Dose Rate in the unit of μR/h, Annual Effective Dose Rate in mSv/y, Hieght from Sea Level (m) for each location, Reduction Coefficient and Excess Lifetime Cancer Risk

Sample Code	Coordinates		Height from sea level (m)	Gamma Dose Rate μR/h		AED (mSv/y)			I/O	ELCR $\times 10^{-4}$
	Lattitude	Longitude		Indoor	Outdoor	Indoor	Outdoor	Total		
N001	28.123483°	78.380917°	209	25.0	17.0	1.23	0.21	1.44	1.47	0.82
N002	28.123433°	78.381430°	208	16.0	15.0	0.79	0.18	0.97	1.07	0.55
N003	28.123467°	78.380917°	209	18.0	17.0	0.88	0.21	1.09	1.06	0.62
N004	28.123550°	78.381017°	209	21.0	19.0	1.03	0.23	1.26	1.11	0.72
N005	28.123217°	78.381433°	210	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N006	28.123350°	78.381283°	210	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N007	28.124467°	78.380050°	209	19.0	18.0	0.93	0.22	1.15	1.06	0.66
N008	28.124467°	78.380067°	209	22.0	21.0	1.08	0.26	1.34	1.05	0.76
N009	28.124450°	78.380067°	209	24.0	16.0	1.18	0.20	1.37	1.50	0.78
N010	28.124150°	78.379950°	210	22.0	19.0	1.08	0.23	1.31	1.16	0.75
N011	28.124733°	78.380750°	209	19.0	18.0	0.93	0.22	1.15	1.06	0.66
N012	28.167533°	78.393450°	207	31.0	22.0	1.52	0.27	1.79	1.41	1.02
N013	28.167350°	78.394467°	207	20.0	19.0	0.98	0.23	1.21	1.05	0.69
N014	28.167117°	78.394250°	209	21.0	20.0	1.03	0.25	1.28	1.05	0.73
N015	28.166467°	78.393333°	209	25.0	18.0	1.23	0.22	1.45	1.39	0.83
N016	28.166300°	78.393533°	210	24.0	19.0	1.18	0.23	1.41	1.26	0.80
N017	28.166433°	78.393567°	210	23.0	20.0	1.13	0.25	1.37	1.15	0.78
N018	28.166733°	78.393600°	210	24.0	22.0	1.18	0.27	1.45	1.09	0.83
N019	28.166533°	78.393400°	209	22.0	24.0	1.08	0.29	1.37	0.92	0.78
N020	28.173683°	78.387550°	208	26.0	22.0	1.28	0.27	1.55	1.18	0.88
N021	28.173350°	78.385800°	208	25.0	22.0	1.23	0.27	1.50	1.14	0.85
N022	28.173300°	78.386633°	208	17.0	15.0	0.83	0.18	1.02	1.13	0.58
N023	28.173333°	78.386483°	209	19.0	17.0	0.93	0.21	1.14	1.12	0.65
N024	28.173333°	78.386500°	209	22.0	17.0	1.08	0.21	1.29	1.29	0.73
N025	28.173500°	78.386667°	207	21.0	20.0	1.03	0.25	1.28	1.05	0.73
N026	28.165033°	78.363350°	213	20.0	19.0	0.98	0.23	1.21	1.05	0.69
N027	28.165150°	78.363500°	212	23.0	18.0	1.13	0.22	1.35	1.28	0.77
N028	28.165300°	78.363850°	212	26.0	18.0	1.28	0.22	1.50	1.44	0.85

N029	28.166533°	78.364567°	215	26.0	20.0	1.28	0.25	1.52	1.30	0.87
N030	28.165400°	78.364133°	213	24.0	21.0	1.18	0.26	1.44	1.14	0.82
N031	28.165333°	78.364083°	212	25.0	22.0	1.23	0.27	1.50	1.14	0.85
N032	28.166167°	78.363950°	214	23.0	20.0	1.13	0.25	1.37	1.15	0.78
N033	28.166433°	78.363867°	214	25.0	22.0	1.23	0.27	1.50	1.14	0.85
N034	28.165300°	78.363133°	213	23.0	21.0	1.13	0.26	1.39	1.10	0.79
N035	28.166000°	78.363933°	214	24.0	20.0	1.18	0.25	1.42	1.20	0.81
N036	28.142083°	78.370867°	213	19.0	17.0	0.93	0.21	1.14	1.12	0.65
N037	28.141867°	78.370867°	213	21.0	19.0	1.03	0.23	1.26	1.11	0.72
N038	28.140667°	78.370217°	211	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N039	28.140350°	78.370300°	211	27.0	24.0	1.33	0.29	1.62	1.13	0.92
N040	28.141083°	78.370850°	210	21.0	20.0	1.03	0.25	1.28	1.05	0.73
N041	28.141367°	78.371217°	211	24.0	21.0	1.18	0.26	1.44	1.14	0.82
N042	28.141067°	78.371733°	210	21.0	18.0	1.03	0.22	1.25	1.17	0.71
N043	28.141417°	78.371600°	210	21.0	19.0	1.03	0.23	1.26	1.11	0.72
N044	28.154983°	78.361467°	210	19.0	19.0	0.93	0.23	1.17	1.00	0.66
N045	28.155150°	78.360367°	210	27.0	20.0	1.33	0.25	1.57	1.35	0.90
N046	28.155117°	78.360500°	210	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N047	28.155467°	78.360117°	210	23.0	19.0	1.13	0.23	1.36	1.21	0.78
N048	28.156617°	78.358917°	211	22.0	21.0	1.08	0.26	1.34	1.05	0.76
N049	28.156650°	78.358933°	211	24.0	20.0	1.18	0.25	1.42	1.20	0.81
N050	28.156567°	78.358367°	210	25.0	23.0	1.23	0.28	1.51	1.09	0.86
N051	28.156817°	78.358000°	210	22.0	21.0	1.08	0.26	1.34	1.05	0.76
N052	28.156833°	78.356667°	212	21.0	20.0	1.03	0.25	1.28	1.05	0.73
N053	28.113333°	78.402883°	203	27.0	22.0	1.33	0.27	1.60	1.23	0.91
N054	28.113317°	78.402833°	204	19.0	15.0	0.93	0.18	1.12	1.27	0.64
N055	28.111483°	78.405700°	206	23.0	17.0	1.13	0.21	1.34	1.35	0.76
N056	28.111417°	78.405083°	206	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N057	28.111383°	78.405183°	206	23.0	19.0	1.13	0.23	1.36	1.21	0.78
N058	28.111383°	78.405167°	206	24.0	20.0	1.18	0.25	1.42	1.20	0.81
N059	28.111383°	78.405883°	205	22.0	20.0	1.08	0.25	1.33	1.10	0.76
N060	28.111117°	78.405967°	206	21.0	18.0	1.03	0.22	1.25	1.17	0.71
N061	28.111100°	78.405917°	206	20.0	19.0	0.98	0.23	1.21	1.05	0.69
N062	28.111017°	78.404067°	207	24.0	19.0	1.18	0.23	1.41	1.26	0.80

N063	28.127000°	78.410883°	210	27.0	18.0	1.33	0.22	1.55	1.50	0.88
N064	28.127221°	78.410970°	208	16.0	16.0	0.79	0.20	0.98	1.00	0.56
N065	28.127417°	78.411000°	212	20.0	16.0	0.98	0.20	1.18	1.25	0.67
N066	28.129217°	78.412900°	208	23.0	22.0	1.13	0.27	1.40	1.05	0.80
N067	28.129383°	78.412967°	207	24.0	18.0	1.18	0.22	1.40	1.33	0.80
N068	28.128883°	78.412883°	209	22.0	19.0	1.08	0.23	1.31	1.16	0.75
N069	28.128267°	78.412600°	208	23.0	19.0	1.13	0.23	1.36	1.21	0.78
N070	28.127783°	78.412733°	208	21.0	20.0	1.03	0.25	1.28	1.05	0.73
N071	28.133033°	78.405867°	209	25.0	21.0	1.23	0.26	1.48	1.19	0.85
N072	28.132700°	78.405850°	210	18.0	17.0	0.88	0.21	1.09	1.06	0.62
N073	28.132717°	78.406683°	210	21.0	18.0	1.03	0.22	1.25	1.17	0.71
N074	28.117467°	78.405467°	210	24.0	22.0	1.18	0.27	1.45	1.09	0.83
N075	28.111910°	78.405590°	208	23.0	19.0	1.13	0.23	1.36	1.21	0.78
N076	28.112400°	78.405467°	204	22.0	20.0	1.08	0.25	1.33	1.10	0.76
N077	28.112333°	78.405667°	204	23.0	20.0	1.13	0.25	1.37	1.15	0.78
N078	28.134217°	78.419883°	211	18.0	18.0	0.88	0.22	1.10	1.00	0.63
N079	28.134150°	78.419783°	208	25.0	20.0	1.23	0.25	1.47	1.25	0.84
N080	28.135067°	78.420200°	211	22.0	20.0	1.08	0.25	1.33	1.10	0.76
N081	28.135267°	78.421833°	208	24.0	19.0	1.18	0.23	1.41	1.26	0.80
N082	28.134350°	78.419617°	207	23.0	22.0	1.13	0.27	1.40	1.05	0.80
N083	28.133167°	78.419117°	210	23.0	19.0	1.13	0.23	1.36	1.21	0.78
N084	28.147683°	78.436283°	201	15.0	16.0	0.74	0.20	0.93	0.94	0.53
N085	28.147450°	78.436400°	201	27.0	20.0	1.33	0.25	1.57	1.35	0.90
N086	28.147117°	78.435333°	204	21.0	16.0	1.03	0.20	1.23	1.31	0.70
N087	28.147000°	78.434533°	205	19.0	17.0	0.93	0.21	1.14	1.12	0.65
N088	28.147700°	78.434050°	204	23.0	20.0	1.13	0.25	1.37	1.15	0.78
N089	28.148283°	78.434150°	205	24.0	21.0	1.18	0.26	1.44	1.14	0.82
N090	28.149000°	78.434467°	207	22.0	18.0	1.08	0.22	1.30	1.22	0.74
N091	28.149350°	78.434133°	210	23.0	21.0	1.13	0.26	1.39	1.10	0.79
N092	28.149283°	78.433583°	212	22.0	18.0	1.08	0.22	1.30	1.22	0.74
N093	28.192933°	78.445083°	202	22.0	19.0	1.08	0.23	1.31	1.16	0.75
N094	28.193250°	78.445350°	201	18.0	17.0	0.88	0.21	1.09	1.06	0.62
N095	28.194350°	78.444550°	202	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N096	28.194352°	78.444554°	202	22.0	18.0	1.08	0.22	1.30	1.22	0.74

N097	28.194333°	78.444500°	202	22.0	16.0	1.08	0.20	1.28	1.38	0.73
N098	28.194667°	78.444500°	200	18.0	18.0	0.88	0.22	1.10	1.00	0.63
N099	28.192833°	78.445000°	202	18.0	17.0	0.88	0.21	1.09	1.06	0.62
N100	28.205017°	78.433233°	202	20.0	16.0	0.98	0.20	1.18	1.25	0.67
N101	28.205400°	78.433233°	202	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N102	28.206133°	78.432067°	203	21.0	17.0	1.03	0.21	1.24	1.24	0.71
N103	28.206283°	78.431767°	203	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N104	28.204800°	78.431950°	203	18.0	18.0	0.88	0.22	1.10	1.00	0.63
N105	28.204750°	78.433283°	202	19.0	16.0	0.93	0.20	1.13	1.19	0.64
N106	28.204667°	78.433167°	202	20.0	16.0	0.98	0.20	1.18	1.25	0.67
N107	28.204833°	78.432167°	202	20.0	16.0	0.98	0.20	1.18	1.25	0.67
N108	28.215250°	78.423317°	202	19.0	18.0	0.93	0.22	1.15	1.06	0.66
N109	28.214367°	78.423200°	201	23.0	18.0	1.13	0.22	1.35	1.28	0.77
N110	28.214317°	78.423467°	202	25.0	18.0	1.23	0.22	1.45	1.39	0.83
N111	28.215617°	78.423267°	202	20.0	20.0	0.98	0.25	1.23	1.00	0.70
N112	28.215500°	78.423167°	202	20.0	20.0	0.98	0.25	1.23	1.00	0.70
N113	28.215667°	78.423167°	202	22.0	21.0	1.08	0.26	1.34	1.05	0.76
N114	28.221517°	78.409133°	203	16.0	15.0	0.79	0.18	0.97	1.07	0.55
N115	28.224600°	78.405167°	201	27.0	20.0	1.33	0.25	1.57	1.35	0.90
N116	28.225050°	78.412917°	201	25.0	21.0	1.23	0.26	1.48	1.19	0.85
N117	28.225083°	78.412217°	201	22.0	18.0	1.08	0.22	1.30	1.22	0.74
N118	28.224700°	78.412183°	202	22.0	20.0	1.08	0.25	1.33	1.10	0.76
N119	28.220717°	78.409167°	202	23.0	20.0	1.13	0.25	1.37	1.15	0.78
N120	28.215983°	78.407983°	203	20.0	16.0	0.98	0.20	1.18	1.25	0.67
N121	28.216550°	78.408667°	202	21.0	18.0	1.03	0.22	1.25	1.17	0.71
N122	28.216650°	78.407950°	203	20.0	19.0	0.98	0.23	1.21	1.05	0.69
N123	28.216283°	78.407833°	202	22.0	19.0	1.08	0.23	1.31	1.16	0.75
N124	28.130050°	78.370767°	209	19.0	15.0	0.93	0.18	1.12	1.27	0.64
N125	28.129980°	78.371020°	210	29.0	18.0	1.42	0.22	1.64	1.61	0.94
N126	28.149967°	78.377650°	209	21.0	20.0	1.03	0.25	1.28	1.05	0.73
N127	28.150733°	78.377500°	210	20.0	19.0	0.98	0.23	1.21	1.05	0.69
N128	28.150717°	78.377433°	210	19.0	18.0	0.93	0.22	1.15	1.06	0.66
N129	28.150717°	78.377433°	210	20.0	18.0	0.98	0.22	1.20	1.11	0.69
N130	28.150867°	78.376967°	210	21.0	17.0	1.03	0.21	1.24	1.24	0.71

N131	28.150950°	78.376983°	210	24.0	19.0	1.18	0.23	1.41	1.26	0.80
N132	28.151100°	78.377250°	210	22.0	16.0	1.08	0.20	1.28	1.38	0.73
N133	28.151017°	78.377150°	210	20.0	19.0	0.98	0.23	1.21	1.05	0.69
N134	28.151017°	78.377067°	210	21.0	18.0	1.03	0.22	1.25	1.17	0.71
N135	28.151450°	78.386200°	210	21.0	20.0	1.03	0.25	1.28	1.05	0.73
N136	28.152333°	78.389717°	208	30.0	18.0	1.47	0.22	1.69	1.67	0.97
N137	28.153083°	78.389750°	208	25.0	21.0	1.23	0.26	1.48	1.19	0.85
N138	28.153133°	78.388683°	210	26.0	18.0	1.28	0.22	1.50	1.44	0.85
N139	28.152767°	78.388650°	211	28.0	22.0	1.37	0.27	1.64	1.27	0.94
N140	28.151800°	78.388650°	209	25.0	17.0	1.23	0.21	1.44	1.47	0.82
N141	28.151800°	78.386167°	208	26.0	17.0	1.28	0.21	1.48	1.53	0.85
N142	28.151817°	78.386733°	210	24.0	19.0	1.18	0.23	1.41	1.26	0.80
N143	28.181967°	78.371550°	213	19.0	17.0	0.93	0.21	1.14	1.12	0.65
N144	28.182033°	78.371817°	214	28.0	22.0	1.37	0.27	1.64	1.27	0.94
N145	28.182150°	78.371617°	214	24.0	21.0	1.18	0.26	1.44	1.14	0.82
N146	28.181917°	78.371267°	213	22.0	21.0	1.08	0.26	1.34	1.05	0.76
N147	28.181633°	78.371017°	211	23.0	16.0	1.13	0.20	1.33	1.44	0.76
N148	28.181933°	78.371367°	213	27.0	21.0	1.33	0.26	1.58	1.29	0.90
N149	28.181650°	78.371467°	212	26.0	18.0	1.28	0.22	1.50	1.44	0.85
N150	28.181800°	78.371933°	213	23.0	22.0	1.13	0.27	1.40	1.05	0.80
Minimum			200.00	15.00	15.00	0.74	0.18	0.93	0.92	0.05
Maximum			215.00	31.00	24.00	1.52	0.29	1.79	1.67	0.10
Average			207.77	22.17	18.89	1.09	0.23	1.32	1.18	0.08
Sd			3.84	2.87	1.94	0.14	0.02	0.16	0.14	0.01
GM				21.99	18.79	1.08	0.23	1.31	1.17	0.07
Skewness				0.29	0.15	0.29	0.15	0.17	1.03	0.17

Table 4: Statistics of the Reduction Coefficient, Excess Lifetime Cancer Risk and Organ Dose received by Bone Marrow, Kidneys, Liver, Lungs, Ovaries, Testicles and Whole Body

Data	Organ Dose (mSv/y)							I/O	ELCR×10^{-3}
	Bone Marrow	Kidneys	Liver	Lungs	Ovaries	Testes	Whole Body		
Number of Samples	150	150	150	150	150	150	150	150	150
Minimum	0.64	0.58	0.43	0.6	0.54	0.76	0.63	0.92	0.01
Maximum	1.24	1.11	0.82	1.15	1.04	1.47	1.22	1.67	0.17
Range	0.6	0.53	0.39	0.55	0.5	0.71	0.59	0.75	0.16
Median	0.91	0.815	0.605	0.845	0.765	1.085	0.895	1.15	0.075
Mean	0.9105	0.8187	0.6075	0.8455	0.7656	1.086	0.8977	1.178	0.07564
Std. Deviation	0.1069	0.09613	0.07146	0.09958	0.09053	0.1268	0.1059	0.1358	0.01311
Std. Error of Mean	0.008731	0.007849	0.00584	0.008131	0.007392	0.01036	0.008648	0.01108	0.00105
Geometric mean	0.9043	0.8131	0.6033	0.8397	0.7603	1.078	0.8915	1.171	0.0743
Geometric SD factor	1.126	1.126	1.126	1.126	1.127	1.125	1.126	1.117	1.239
25% Percentile	0.83	0.75	0.55	0.77	0.7	0.99	0.82	1.06	0.07
75% Percentile	0.98	0.88	0.65	0.91	0.83	1.17	0.97	1.25	0.08
10% Percentile	0.781	0.701	0.521	0.721	0.651	0.931	0.771	1.05	0.06
90% Percentile	1.039	0.939	0.69	0.969	0.879	1.239	1.029	1.38	0.09
Skewness	0.1627	0.1667	0.1701	0.1647	0.1499	0.1596	0.1706	1.042	1.634
Kurtosis	0.1152	0.07873	0.04666	0.06291	0.0499	0.09452	0.09145	1.111	19.99

Table 5: Statistics of the Gamma Dose Rate, Lifetime Effective Dose and Annual Effective Dose in the unit of mSv/y

Data	GDR(mSv/y)			Lifetime Effective Dose (mSv/y)			AED (mSv/y)		
	Indoor	Outdoor	Total	Indoor	Outdoor	Total	Indoor	Outdoor	Total
Number of values	150	150	150	150	150	150	150	150	150
Minimum	1.31	1.31	2.72	92.04	92.04	190.2	0.74	0.18	0.93
Maximum	2.72	2.1	4.65	190.2	147.3	325.2	1.52	0.29	1.79
Range	1.41	0.79	1.93	98.18	55.23	135	0.78	0.11	0.86
Median	1.93	1.67	3.59	135	116.6	251.6	1.08	0.23	1.32
Mean	1.944	1.656	3.6	136.1	115.9	252	1.089	0.2324	1.32
Std. Deviation	0.252	0.1702	0.3724	17.64	11.9	26.13	0.1423	0.02421	0.1557
Std. Error of Mean	0.021	0.0139	0.03041	1.44	0.9716	2.133	0.01162	0.00198	0.01271
Geometric mean	1.928	1.648	3.581	134.9	115.3	250.6	1.079	0.2311	1.311
Geometric SD factor	1.139	1.109	1.11	1.139	1.108	1.111	1.14	1.11	1.126
25% Percentile	1.75	1.58	3.33	122.7	110.5	233.2	0.98	0.22	1.2
75% Percentile	2.1	1.75	3.86	147.3	122.7	270	1.18	0.25	1.42
10% Percentile	1.67	1.4	3.16	116.6	98.18	220.9	0.93	0.2	1.131
90% Percentile	2.28	1.93	4.12	159.5	135	288.4	1.28	0.27	1.509
Skewness	0.292	0.1243	0.03679	0.2928	0.1527	0.02887	0.2878	0.1146	0.1563
Kurtosis	0.218	-0.3336	-0.1065	0.2037	-0.3601	-0.1143	0.09447	-0.601	0.04373