

Statistical Comparative Study of the Gamma Dose Rate and Associated Risk Assessment in Rural and Urban Areas of Durg District, Chhattisgarh, India

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Abstract—The gamma dose rates in rural and urban areas of Durg were compared. The statistical study was made to compare the outdoor and indoor gamma dose rates for the rural and urban areas. The lifetime effective doses for the rural and urban areas were found to be from 64.4 ± 2.6 to 105.4 ± 4.2 and from 82.2 ± 3.3 to 92.9 ± 3.7 mSv, respectively. The excess lifetime cancer risk ranging from 5.2×10^{-3} to 5.3×10^{-3} was found in several rural areas. The maximum values of the indoor gamma dose rate observed in the rural and urban areas are 253 ± 10 and 224 ± 9 nSv/h, respectively, which is higher than the typical range (10–200 nSv/h) reported by UNSCEAR. The measured gamma dose rate for terrestrial is compared to the reported values of radiation near uranium mines in India and in the world. The effective organ dose is higher than the recommended limit of 1.0 mSv/year.

Keywords: gamma dose rate, indoor and outdoor gamma dose rate, annual effective dose equivalent, excess lifetime cancer risk, organ dose

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INTRODUCTION

More than 65% of Indian population lives in rural areas [1]. Natural radiation is present everywhere on the earth and is not escapable. The natural and anthropogenic radiation sources always affect the mankind [2]. The natural sources release 87% of the radiation dose that was received by the mankind [2]. Naturally occurring primordial radionuclides mainly include ^{238}U , ^{235}U , and ^{232}Th series, ^{40}K , and ^{226}Ra [3, 4]. The health effect due to exposure to radionuclides and inhalation by human beings within the indoor environment is a major public concern worldwide [4]. The background radiation comes from cosmic and terrestrial sources [5]. The United Nations Scientific Commission on Effects of Atomic Radiation (UNSCEAR) reported cosmic radiation dose at the sea level of 32 nSv/h and external terrestrial radiation dose of 59 nSv/h with the average annual dose rate of 0.07 mSv/year [6, 7]. According to the UNSCEAR report, the population weighted average AEDE (annual effective dose equivalent) due to cosmic rays and terrestrial gamma radiation is 0.87 mSv [6, 7]. The rural and urban natural background radiation comes

from cosmos, food, air, building materials, industrial activities, and the human body itself [8]. Terrestrial radiation makes a higher contribution to the total background radiation as compared to cosmic radiation [9]. The risk arising due to gamma dose was studied for the indoor and outdoor environment [10–17]. The main aim of this study is to compare the gamma dose rates in rural and urban areas of Durg district and assess the cancer risk in Durg areas. Here we make the first estimation of the equivalent dose for different organs of the human body for this region. This study will serve as baseline data for future gamma radiation effect in rural and urban areas of the Durg district, Chhattisgarh region.

EXPERIMENTAL

Selection of the measurement sites. The study location is a famous district of Chhattisgarh as the world largest steel plant is situated here. The Durg district of Chhattisgarh is one of the most densely populated districts of India. It is located in the southern part of the prosperous Chhattisgarh plain between $21^{\circ}04'$ and $21^{\circ}37'N$ and $81^{\circ}16'$ and $81^{\circ}40'E$ [18] with the average

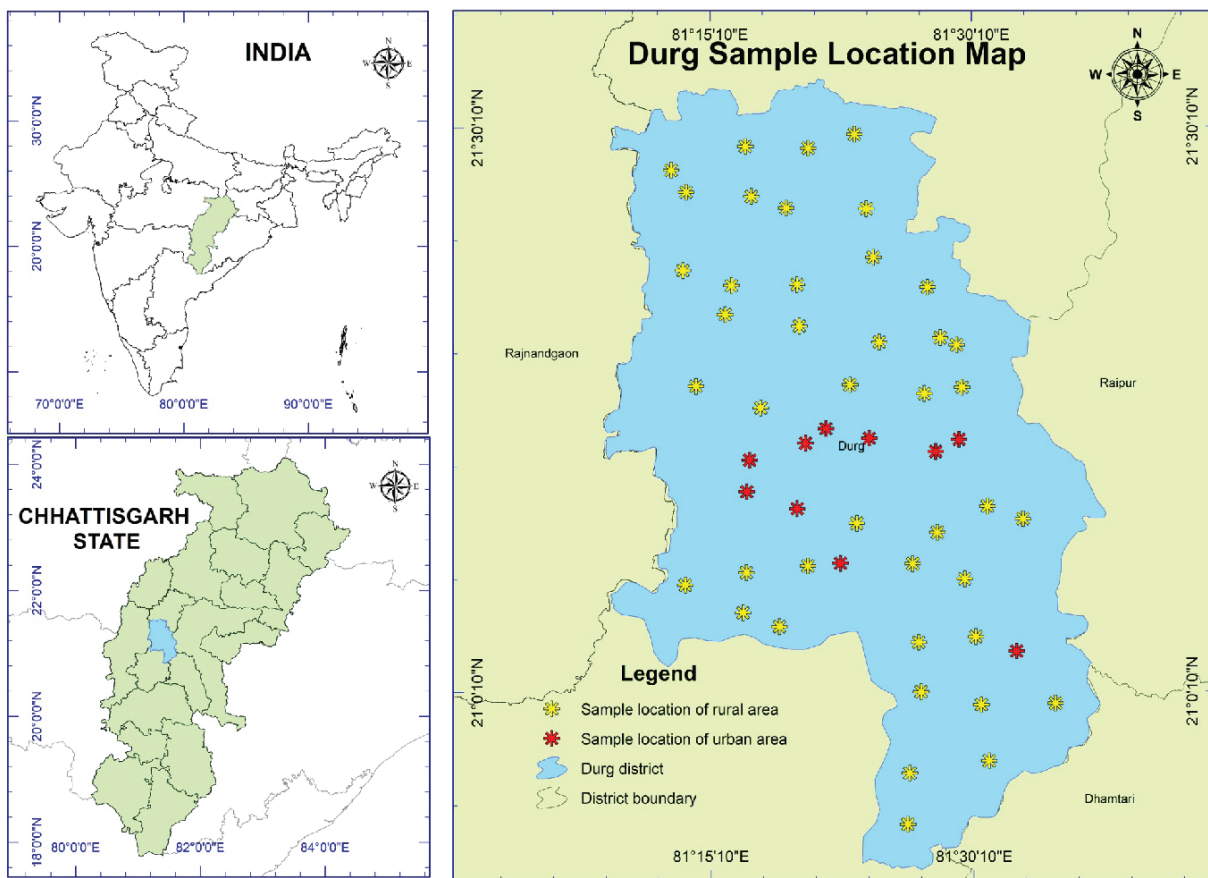


Fig. 1. (Color online) Grid map of study areas of Durg district, Chhattisgarh, India.

elevation of 317 m (1040 ft) above sea level. The total area of Durg district is 223836 ha; it is located in the central part of Chhattisgarh. It is situated on the east bank of Shivnath River and is endowed with industrial and cultural competence, social harmony, and resources [18]. This district does not involve the forest part. The gamma dose rates were measured in 42 locations of rural and 10 locations of urban areas of Durg district, Chhattisgarh, India, where the total population is 184931 (rural population: 70378; urban population: 114553). The male population is about 51%, and the female population is 49% [1]. All the study areas are shown in Fig. 1. The study location has been selected by 6 km² grids as per guidelines of the Board of Research in Nuclear Sciences, Department of Atomic Energy.

Geology of Durg district. The study area is a part of Chhattisgarh basin that consists of argillaceous and calcareous sediments represented by mainly shale and limestone [19, 20]. The Durg district is covered by four different lithological units, namely, Chandi limestone,

Tarenga formation, Gunderdehi formation, and Chandi sandstone [19, 20]. About 80% of the study area is covered by Chandi limestone, and the remaining part of the study area is covered by Tarenga formation, Gunderdehi formation, and Chandi sandstone. The soil of the study area consists of clay loam, gravelly clay loam, gravelly sandy clay loam, gravelly sandy loam, and sandy clay loam [19, 20].

Measurement of the gamma dose rate. A Polimaster PM-1405 survey meter based on Geiger–Muller technique was used for measuring the indoor and outdoor gamma dose rate levels for rural and urban areas of Durg district. All the readings were recorded in nSv/h. This survey meter records the terrestrial as well as the cosmic radiation. This apparatus was placed at a height of 1 m above the ground surface. The energy range for gamma radiation measurement of this device is 0.05–3 MeV, and the detection range for dose rate is from 0.01 μ Sv/h to 100 mSv/h [16, 21]. The GPS (GARMIN OREGON-650) coordination device was

used for determining the latitude (N) and longitude (E) of all the study areas. The radiation map of indoor and outdoor gamma dose rate was prepared using Arc GIS 9.3 software.

Statistical analysis of the relationship between outdoor and indoor gamma dose rates. The Statistical Package for the Social Sciences (SPSS), version 21, was used to facilitate the analysis. The paired sample *t*-test was conducted to determine the relationship between the outdoor and indoor gamma dose rates for the rural and urban areas of Durg district based on the hypotheses formulated below.

Hypothesis for the correlation study of an urban area: $H_{o(cu)}$ = there is no relationship between the outdoor and indoor gamma dose rates for an urban area; $H_{a(cu)}$ = there is a relationship between the outdoor and indoor gamma dose rates for an urban area

Hypothesis for the correlation study of a rural area: $H_{o(cr)}$ = there is no relationship between the outdoor and indoor gamma dose rates for a rural area; $H_{a(cr)}$ = there is a relationship between the outdoor and indoor gamma dose rates for a rural area.

Paired difference study for the urban area: $H_{o(pdu)}$ = there is no significant difference between the outdoor and indoor gamma dose rates for an urban area; $H_{a(pdu)}$ = there is a significant difference between the outdoor and indoor gamma dose rates for an urban area.

Paired difference study for the rural area: $H_{o(pdr)}$ = there is no significant difference between the outdoor and indoor gamma dose rates for a rural area; $H_{a(pdr)}$ = there is a significant difference between the outdoor and indoor gamma dose rates for a rural area.

Calculation of the annual effective dose equivalent (AEDE). Indoor and outdoor gamma dose rates were used for calculating the indoor and outdoor annual effective dose equivalent (AEDE). The ionizing radiations affecting human beings are evaluated based on AEDE [22]. The annual effective dose equivalent was calculated using the following equation:

$$\text{AEDE}(\text{indoor/outdoor}) = D(\text{indoor/outdoor}) \times T \times \text{conversion coefficient} \times \text{occupancy factor}, \quad (1)$$

where $D(\text{indoor})$ is the indoor absorbed gamma dose rate (nGy/h), $D(\text{outdoor})$ is the outdoor absorbed gamma dose rate (nGy/h), and T is the time conversion factor (hour into a year, 1 year = 8760 h).

The dose conversion coefficient reported by UNSCEAR for an adult is 0.7, and the occupancy factor for indoor and outdoor is 0.8 and 0.2, respectively [6]. The conversion coefficient is higher for children and infants by approximately 10 and 30%, respectively [6]. Thus, Eq. (1) for an adult becomes

$$P = \text{AEDE}(\text{indoor}) = D(\text{indoor}) \times 8760 \times 0.7 \times 0.8, \quad (2)$$

$$Q = \text{AEDE}(\text{outdoor}) = D(\text{outdoor}) \times 8760 \times 0.7 \times 0.2. \quad (3)$$

For children:

$$R = \text{AEDE}(\text{indoor}) = D(\text{indoor}) \times 8760 \times 0.8 \times 0.8, \quad (4)$$

$$S = \text{AEDE}(\text{outdoor}) = D(\text{outdoor}) \times 8760 \times 0.8 \times 0.2. \quad (5)$$

For infants:

$$T = \text{AEDE}(\text{indoor}) = D(\text{indoor}) \times 8760 \times 0.9 \times 0.8, \quad (6)$$

$$U = \text{AEDE}(\text{outdoor}) = D(\text{outdoor}) \times 8760 \times 0.9 \times 0.2. \quad (7)$$

The AEDE indoor and outdoor values for rural and urban areas were calculated using the Eqs. (2)–(7). The total annual effective dose equivalent was calculated by summation of the indoor and outdoor AEDE values:

$$\text{Total AEDE} = \text{AEDE}(\text{indoor}) + \text{AEDE}(\text{outdoor}). \quad (8)$$

Calculation of cosmic radiation. The cosmic radiation was calculated using the elevation above the sea level. The measured outdoor gamma dose rate involved the terrestrial radiation and cosmic radiation. The terrestrial radiation level was estimated by subtracting the cosmic radiation level from the outdoor gamma dose rate. Equation (9) was used for calculating the cosmic radiation level [6, 23]:

$$E(a) = E(0)[0.21e^{-1.649a} + 0.79e^{0.4528a}], \quad (9)$$

where $E(a)$ is the effective dose rate, a is the altitude above sea level (km), and $E(0)$ is the cosmic radiation at the sea level.

Risk Assessment

Lifetime effective dose. The total annual effective dose equivalent and duration of life were used for calculating the lifetime effective dose:

$$\text{Lifetime Effective Dose} = [52(P + Q) + 16(R + S) + 2(T + U)], \quad (10)$$

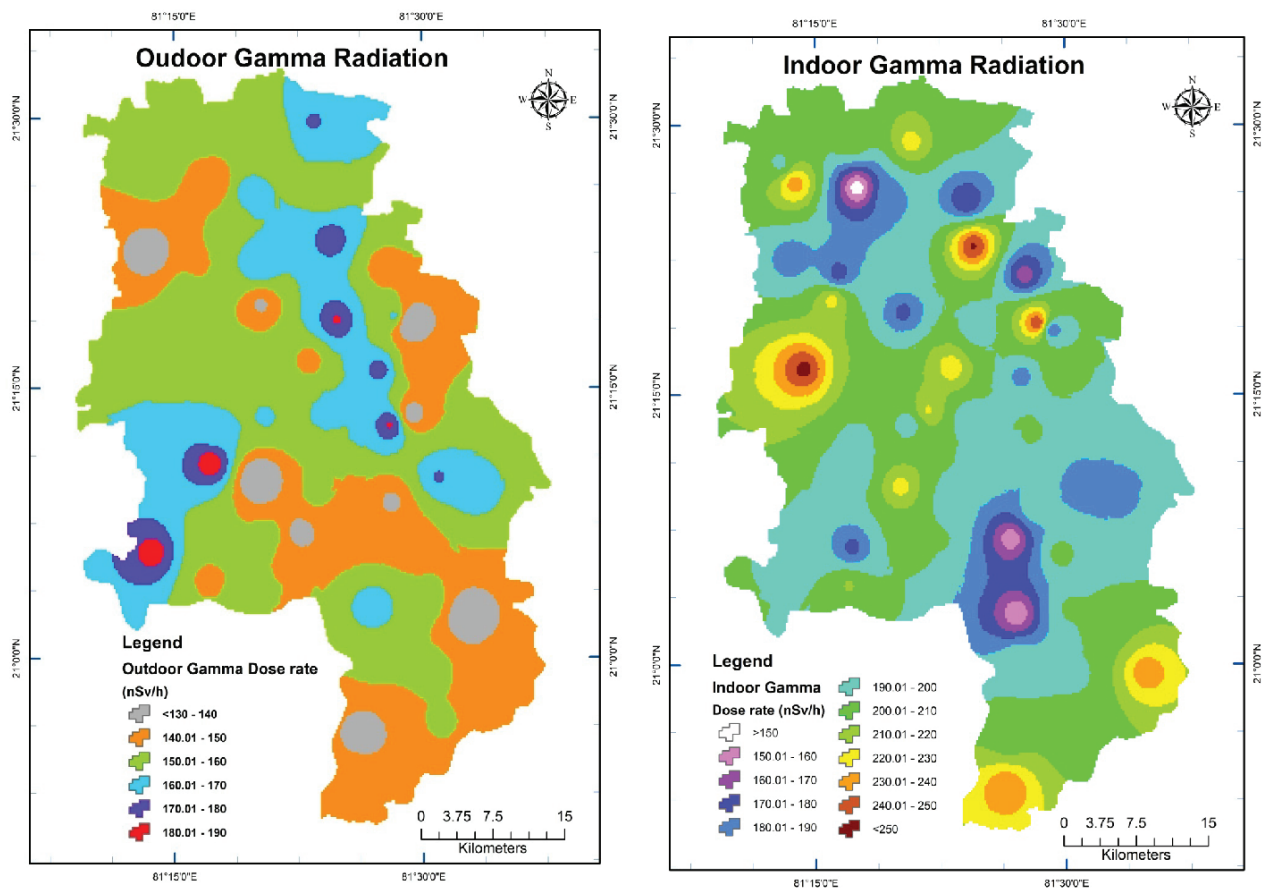


Fig. 2. (Color online) Radiation map for outdoor and indoor gamma dose rate of Durg district, Chhattisgarh, India.

where the quantities P , Q , R , S , T , and U were calculated by Eqs. (2)–(7), and the duration of life was taken as 70 years (adult: 52 years, children: 16 years; infants: 2 years) [10, 16].

Calculation of excess lifetime cancer risk (ELCR). Low levels of gamma rays cause a stochastic health risk, which can be probably used for the assessment of cancer induction and genetic damage. Cancer risk estimates the potential carcinogenic effects involving the probability of cancer incidence in population for a specific lifetime. The value of lifetime effective dose and risk factor was used for calculating the excess lifetime cancer risk. The value of the risk factor used by ICRP 60 for the public is 0.05 [10, 16]. The cancer risk was calculated only for those areas where the lifetime effective dose exceeded 100 mSv [21, 24]:

$$ELCR = \text{Lifetime Effective Dose} \times \text{Risk factor}, \quad (11)$$

Calculation of the effective dose for different organs and tissues of human body (D_{organ}). The value

of AEDE was used for calculating the effective dose for different organs and tissues of the human body. The value of conversion factor of the organ dose from the air dose for bone marrow, kidneys, liver, lungs, ovaries, testes, and whole body are 0.69, 0.62, 0.46, 0.64, 0.58, 0.82, and 0.68 respectively [25, 26].

$$D_{\text{organ}} = \text{AEDE} \times \text{Conversion factor}, \quad (12)$$

RESULTS AND DISCUSSION

Data on the radiation level (indoor and outdoor gamma dose rate, AEDE, and lifetime effective dose values) for 42 rural and 10 urban areas of Durg district of Chhattisgarh are presented in Table 1. The radiation maps for the indoor and outdoor gamma dose rate are shown in Fig. 2. In this study, the indoor and outdoor gamma dose rate levels at rural areas range from 145 ± 6 to 253 ± 10 and from 117 ± 5 to 185 ± 7 nSv/h, respectively. For urban areas, the indoor and outdoor gamma dose rates levels range from 191 ± 8 to $224 \pm$

Table 1. Indoor and outdoor gamma dose rates and AEDE (annual effective dose equivalent) values for rural (DV points) and urban (DU points) areas of Durg district of Chhattisgarh

Area Code	Rural area name	Total population [1]	GPS coordinates		Indoor gamma dose rate, nSv/h	Outdoor gamma dose rate, nSv/h	Indoor/outdoor gamma dose rate	Indoor annual effective dose equivalent, mSv/year (for adult)	Outdoor annual effective dose equivalent, mSv/year (for adult)	Total annual effective dose equivalent, mSv/year (for adult)	Lifetime effective dose, mSv
			Latitude (N)	Longitude (E)							
DV-1	Purai	4064	21°06.875'	81°20.727'	208 ± 8	155 ± 6	1.34	1.02 ± 0.04	0.19 ± 0.01	1.21 ± 0.05	88.2 ± 3.5
DV-2	Dundera	1092	21°09.137'	81°23.520'	192 ± 8	153 ± 6	1.25	0.94 ± 0.04	0.19 ± 0.01	1.13 ± 0.05	82.3 ± 3.3
DV-3	Karsa	1353	21°08.649'	81°28.131'	196 ± 8	137 ± 6	1.43	0.96 ± 0.04	0.17 ± 0.01	1.13 ± 0.05	82.3 ± 3.3
DV-4	Dhaur	688	21°06.986'	81°26.710'	153 ± 6	144 ± 6	1.06	0.75 ± 0.03	0.18 ± 0.01	0.93 ± 0.04	67.6 ± 2.7
DV-5	Loharsi	2061	21°06.175'	81°29.694'	204 ± 8	142 ± 6	1.44	1.00 ± 0.04	0.17 ± 0.01	1.17 ± 0.05	85.6 ± 3.4
DV-6	Matang	1220	21°02.810'	81°27.046'	151 ± 6	170 ± 7	0.89	0.74 ± 0.03	0.21 ± 0.01	0.95 ± 0.04	69.2 ± 2.8
DV-7	Nawagaon	1064	21°03.102'	81°30.311'	202 ± 8	158 ± 6	1.28	0.99 ± 0.04	0.19 ± 0.01	1.18 ± 0.05	86.3 ± 3.5
DV-8	Bhansuli (Kesra)	2480	20°59.550'	81°34.851'	237 ± 10	143 ± 6	1.66	1.16 ± 0.05	0.18 ± 0.01	1.34 ± 0.05	97.5 ± 3.9
DV-9	SirsaKhurd	6211	21°15.276'	81°18.045'	205 ± 8	156 ± 6	1.31	1.01 ± 0.04	0.19 ± 0.01	1.20 ± 0.05	87.2 ± 3.5
DV-10	Anjora	2287	21°16.437'	81°14.331'	253 ± 10	160 ± 6	1.58	1.24 ± 0.05	0.20 ± 0.01	1.44 ± 0.06	104.7 ± 4.2
DV-11	Bhanpuri	1424	21°06.532'	81°17.211'	177 ± 7	152 ± 6	1.16	0.87 ± 0.03	0.19 ± 0.01	1.05 ± 0.04	76.8 ± 3.1
DV-12	Anda	4169	21°04.393'	81°17.012'	211 ± 8	147 ± 6	1.44	1.04 ± 0.04	0.18 ± 0.01	1.22 ± 0.05	88.6 ± 3.5
DV-13	Risama	2849	21°03.657'	81°19.089'	202 ± 8	151 ± 6	1.34	0.99 ± 0.04	0.19 ± 0.01	1.18 ± 0.05	85.7 ± 3.4
DV-14	Belodi	1214	21°00.182'	81°27.176'	198 ± 8	154 ± 6	1.29	0.97 ± 0.04	0.19 ± 0.01	1.16 ± 0.05	84.5 ± 3.4
DV-15	Borid	1854	20°59.481'	81°30.612'	198 ± 8	154 ± 6	1.29	0.97 ± 0.04	0.19 ± 0.01	1.16 ± 0.05	84.5 ± 3.4
DV-16	Ausar	996	20°56.506'	81°31.060'	202 ± 8	151 ± 6	1.34	0.99 ± 0.04	0.19 ± 0.01	1.18 ± 0.05	85.7 ± 3.4
DV-17	Auri	1630	20°55.862'	81°26.515'	205 ± 8	134 ± 5	1.53	1.01 ± 0.04	0.16 ± 0.01	1.17 ± 0.05	85.2 ± 3.4
DV-18	Gatapar	841	20°53.145'	81°26.407'	240 ± 10	145 ± 6	1.66	1.18 ± 0.05	0.18 ± 0.01	1.36 ± 0.05	98.7 ± 4.0
DV-19	Khedamara	2512	21°16.500'	81°23.157'	226 ± 9	145 ± 6	1.56	1.11 ± 0.04	0.18 ± 0.01	1.29 ± 0.05	93.7 ± 3.8
DV-20	Semariya	998	21°18.761'	81°24.830'	192 ± 8	181 ± 7	1.06	0.94 ± 0.04	0.22 ± 0.01	1.16 ± 0.05	84.8 ± 3.4
DV-21	Achhoti	2596	21°18.984'	81°28.313'	249 ± 10.0	162 ± 7	1.54	1.22 ± 0.05	0.20 ± 0.01	1.42 ± 0.06	103.5 ± 4.1
DV-22	Borsi	1668	21°18.597'	81°29.260'	183 ± 7	117 ± 5	1.56	0.90 ± 0.04	0.14 ± 0.01	1.04 ± 0.04	75.9 ± 3.0
DV-23	Murra	1037	21°16.346'	81°29.559'	207 ± 8	144 ± 6	1.44	1.02 ± 0.04	0.18 ± 0.01	1.19 ± 0.05	86.9 ± 3.5
DV-24	Nandaauri	1281	21°16.017'	81°27.404'	186 ± 7	175 ± 7	1.06	0.91 ± 0.04	0.21 ± 0.01	1.13 ± 0.05	82.1 ± 3.3
DV-25	Amlidih	1467	21°10.026'	81°30.996'	186 ± 7	171 ± 7	1.09	0.91 ± 0.04	0.21 ± 0.01	1.12 ± 0.04	81.8 ± 3.3
DV-26	Kapsi	878	21°09.362'	81°33.027'	188 ± 8	166 ± 7	1.13	0.92 ± 0.04	0.20 ± 0.01	1.13 ± 0.05	82.0 ± 3.3
DV-27	Changori	2374	21°05.864'	81°13.714'	198 ± 8	185 ± 7	1.07	0.97 ± 0.04	0.23 ± 0.01	1.20 ± 0.05	87.3 ± 3.5
DV-28	Raweldih	1914	21°19.620'	81°20.264'	177 ± 7	138 ± 6	1.28	0.87 ± 0.03	0.17 ± 0.01	1.04 ± 0.04	75.6 ± 3.0

Table 1. (Contd.).

Area Code	Rural area name	Total population [1]	GPS coordinates		Indoor gamma dose rate, nSv/h	Outdoor gamma dose rate, nSv/h	Indoor/outdoor gamma dose rate	Indoor annual effective dose equivalent, mSv/year (for adult)	Outdoor annual effective dose equivalent, mSv/year (for adult)	Total annual effective dose equivalent, mSv/year (for adult)	Lifetime effective dose, mSv
			Latitude (N)	Longitude (E)							
DV-30	ParsadaaKhurd	575	21°21.782'	81°16.381'	175 ± 7	148 ± 6	1.18	0.86 ± 0.03	0.18 ± 0.01	1.04 ± 0.04	75.8 ± 3.0
DV-31	Funda	695	21°20.239'	81°16.007'	223 ± 9	159 ± 6	1.4	1.09 ± 0.04	0.19 ± 0.01	1.29 ± 0.05	93.9 ± 3.8
DV-32	Arsi	1244	21°22.576'	81°13.597'	184 ± 7	129 ± 5	1.43	0.90 ± 0.04	0.16 ± 0.01	1.06 ± 0.04	77.3 ± 3.1
DV-33	Hiretara	957	21°26.744'	81°13.793'	236 ± 9	153 ± 6	1.54	1.16 ± 0.05	0.19 ± 0.01	1.35 ± 0.05	98.0 ± 3.9
DV-34	Paraskol	1011	21°27.907'	81°12.925'	198 ± 8	152 ± 6	1.30	0.97 ± 0.04	0.19 ± 0.01	1.16 ± 0.05	84.4 ± 3.4
DV-35	Kutaha	413	21°29.168'	81°17.191'	210 ± 8.4	153 ± 6	1.37	1.03 ± 0.04	0.19 ± 0.01	1.22 ± 0.05	88.7 ± 3.6
DV-36	Khapri	1609	21°26.505'	81°17.528'	145 ± 6	141 ± 6	1.03	0.71 ± 0.03	0.17 ± 0.01	0.88 ± 0.04	64.4 ± 2.6
DV-37	Pandora	1255	21°25.901'	81°19.520'	187 ± 8	165 ± 7	1.13	0.92 ± 0.04	0.20 ± 0.01	1.12 ± 0.04	81.6 ± 3.3
DV-38	Rahtadah	778	21°29.073'	81°20.788'	224 ± 9	154 ± 6	1.45	1.10 ± 0.04	0.19 ± 0.01	1.29 ± 0.05	93.8 ± 3.8
DV-39	Dargaon	2782	21°29.798'	81°23.432'	205 ± 8	171 ± 7	1.20	1.01 ± 0.04	0.21 ± 0.01	1.22 ± 0.05	88.6 ± 3.5
DV-40	Hardi	1066	21°25.844'	81°24.110'	170 ± 7	154 ± 6	1.10	0.83 ± 0.03	0.19 ± 0.01	1.02 ± 0.04	74.5 ± 3.0
DV-41	Pitaura	1605	21°23.263'	81°24.501'	251 ± 10	176 ± 7	1.43	1.23 ± 0.05	0.22 ± 0.01	1.45 ± 0.06	105.4 ± 4.2
DV-42	MalpuriKhurd	810	21°21.673'	81°27.608'	165 ± 7	145 ± 6	1.14	0.81 ± 0.03	0.18 ± 0.01	0.99 ± 0.04	71.9 ± 2.9
DU-1	Utai	8752	21°07.020'	81°22.581'	201 ± 8	135 ± 5	1.49	0.99 ± 0.04	0.17 ± 0.01	1.15 ± 0.05	83.9 ± 3.4
DU-2	Patan	10133	21°02.322'	81°32.632'	207 ± 8	124 ± 5	1.67	1.02 ± 0.04	0.15 ± 0.01	1.17 ± 0.05	85.1 ± 3.4
DU-3	Sikola	6599	21°12.506'	81°17.404'	196 ± 8	165 ± 7	1.19	0.96 ± 0.04	0.20 ± 0.01	1.16 ± 0.05	84.8 ± 3.4
DU-4	Kohka	6814	21°13.397'	81°20.597'	195 ± 8	162 ± 7	1.20	0.96 ± 0.04	0.20 ± 0.01	1.16 ± 0.05	84.2 ± 3.4
DU-5	Hathkhoj	16828	21°13.654'	81°24.253'	191 ± 8	164 ± 7	1.16	0.94 ± 0.04	0.20 ± 0.01	1.14 ± 0.05	82.9 ± 3.3
DU-6	Urla	6292	21°13.579'	81°29.379'	197 ± 8	132 ± 5	1.49	0.97 ± 0.04	0.16 ± 0.01	1.13 ± 0.05	82.2 ± 3.3
DU-7	Deobaloda	6824	21°12.940'	81°28.044'	202 ± 8	181 ± 7	1.12	0.99 ± 0.04	0.22 ± 0.01	1.21 ± 0.05	88.4 ± 3.5
DU-8	Risali	26341	21°09.922'	81°20.116'	224 ± 9	115 ± 5	1.95	1.10 ± 0.04	0.14 ± 0.01	1.24 ± 0.05	90.3 ± 3.6
DU-9	Kasaridih	4337	21°10.825'	81°17.236'	191 ± 8	189 ± 8	1.01	0.94 ± 0.04	0.23 ± 0.01	1.17 ± 0.05	85.2 ± 3.4
DU-10	Jamul	21633	21°14.171'	81°21.771'	221 ± 7	156 ± 5	1.42	1.08 ± 0.03	0.19 ± 0.01	1.28 ± 0.04	92.9 ± 3.7

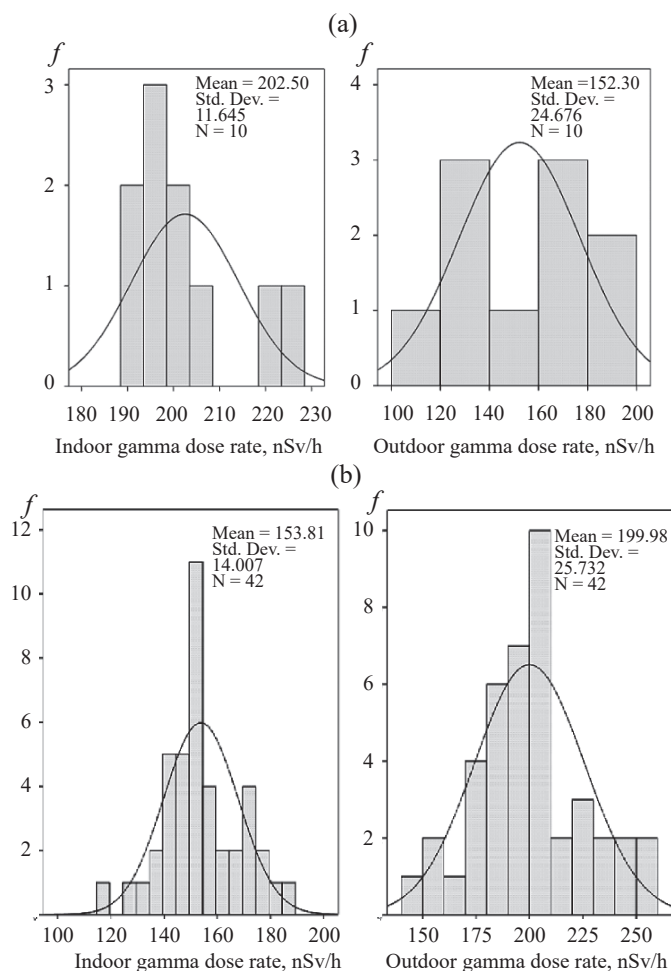


Fig. 3. Gamma dose rate histograms for (a) urban and (b) rural area. (f) Frequency.

9 and from 115 ± 5 to 189 ± 8 nSv/h, respectively. Histograms for the gamma dose rate for urban and rural areas are shown in Fig. 3. The arithmetic and geometric mean values of the indoor gamma dose rate for rural areas (200 ± 8 and 198 ± 8 nSv/h) are insignificantly lower compared to urban areas (203 ± 6 and 202 ± 6 nSv/h). The arithmetic and geometric mean values of the outdoor gamma dose rate for rural areas (154 ± 6 and 153 ± 6 nSv/h) are insignificantly higher than those for the urban areas (152 ± 5 and 151 ± 5 nSv/h). The maximum value of the indoor gamma dose rate, 253 ± 10 nSv/h, was found in Anjora (Dhaba Anjora) rural area; UNSCEAR reported gamma dose rates varied from 20 to 200 nSv/h. Our results show that the indoor gamma dose rates for the rural area points DV-1, DV-5, DV-7–DV-10, DV-12, DV-13, DV-16–DV-19, DV-21, DV-23, DV-29, DV-31, DV-33, DV-35, DV-38, DV-39, and DV-41 and from urban area points DU-1, DU-2,

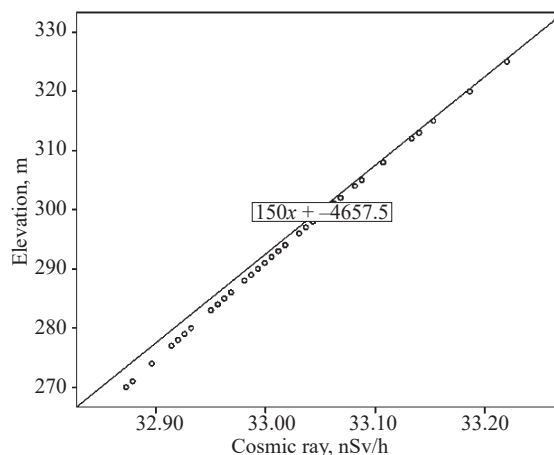


Fig. 4. Plot of the dose rate from cosmic rays vs. elevation above sea level.

DU-7, DU-8, DU-10 exceed 200 nSv/h. The elevation in the study area varies from 270 to 325 m above MSL (mean sea level). The variation of the cosmic radiation with the elevation in this range is shown in Fig. 4. The cosmic radiation level throughout the study area varies from 32.87 to 33.32 nSv/h.

Tarenga formations are dominantly constituted by silt and very fine mudstone with minor calcareous, cherty, and dolomitic beds [19]. The terrestrial gamma dose rate in the area of Tarenga formation varies from 108.1 to 138.1 nSv/h. Gunderdehi formation consists mainly of calcareous purple to grey shale including sandstone and siltstone [19]. The radiation level in this lithology varied from 100.8 to 111.9 nSv/h. Chandi formation contains dolomite and stromatolitic limestone. It generally exists in two forms: Chandi limestone and Chandi sandstone [19, 20]. The gamma radiation level for Chandi limestone varies from 81.9 to 152.1 nSv/h, and for Chandi sandstone, from 99 to 156 nSv/h.

Annual effective dose equivalent (AEDE). The indoor and outdoor annual effective dose equivalents for an adult with standard error bars for rural and urban areas are shown in Fig. 5. The indoor and outdoor AEDE values for rural areas range from 0.71 ± 0.03 to 1.24 ± 0.05 and from 0.14 ± 0.01 to 0.23 ± 0.01 mSv/year, respectively, and for urban areas, from 0.94 ± 0.04 to 1.10 ± 0.04 and from 0.14 ± 0.01 to 0.23 ± 0.01 mSv/year, respectively. The indoor AEDE values was found to be higher than the outdoor AEDE values for all the study areas, both rural and urban, due to higher occupancy factor in the inside (people spend more time inside). The arithmetic mean value of total AEDE for rural, 1.17 ± 0.05 mSv/year, is

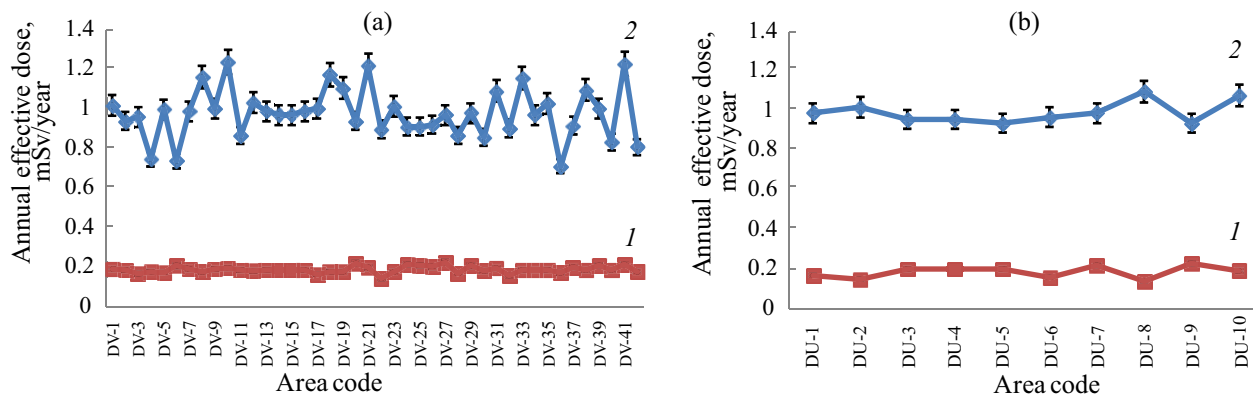


Fig. 5. (1) Outdoor and (2) indoor annual effective dose equivalents with standard error bars for (a) rural and (b) urban areas of Durg district, Chhattisgarh, India.

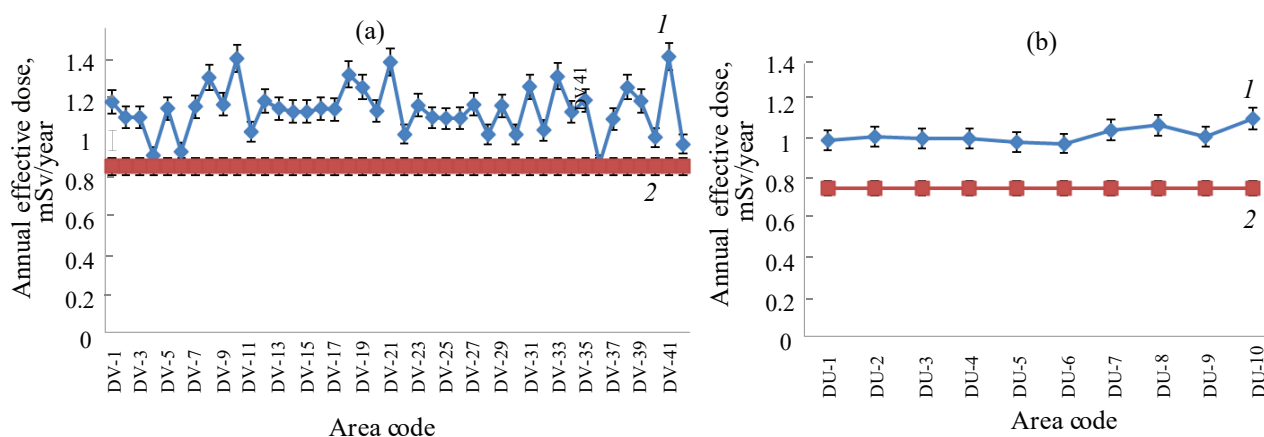


Fig. 6. (1) Total annual effective dose equivalents with standard error bars for (a) rural and (b) urban area of Durg district and their comparison with (2) world population weighted average value.

virtually equal to that for urban, 1.18 ± 0.05 mSv/year. The world population weighted average reported for AEDE is 0.87 mSv/year (UNSCEAR 2000).

Figure 6 shows the total annual effective dose equivalents with standard error bars for the rural and urban areas of Durg district in comparison with the world population weighted average value. As can be seen, the AEDE values of for rural and urban from Durg district are slightly higher than the world average value. The data presented in this study can serve as useful baseline data for Durg region.

Hypothesis test. As from Table 2, the mean outdoor and indoor gamma dose rate is 152.3 and 202.5 nSv/h, respectively. The standard deviation is 24.7 and 11.6 for ten urban area observations. The significance value for the paired sample correlation between the outdoor and indoor gamma dose rates for the urban area is 0.092,

which is greater than 0.05. Thus, the null hypothesis should be selected, namely, the hypothesis that there is no relationship between the outdoor and indoor gamma dose rates for the urban area. The correlation between the outdoor and indoor gamma dose rates for the urban area is negative. The significance value of the paired sample *t*-test between the outdoor and indoor gamma dose rates for the urban area is 0.001, which is less than 0.05 and allows the null hypothesis for this case to be rejected. Namely, there is a significant difference between the outdoor and indoor gamma dose rates for the urban area. The mean for the outdoor and indoor gamma dose rates is 153.8 and 200 nSv/h, with the standard deviation of 14.0 and 25.7, respectively, for 42 rural area observations. The significance value for the paired sample correlation for the rural area is 0.394, which is also greater than 0.05. Thus, in this case also the null hypothesis should be selected, i.e.,

Table 2. Statistical data of pair *t*-test for the gamma dose rate from urban and rural areas of Durg district, Chhattisgarh

Paired sample statistics for urban area															
Pair 1	Indoor gamma dose rate	Outdoor gamma dose rate	mean	N	standard deviation	standard error of mean	correlation	significance	paired differences			<i>t</i>	<i>df</i>	Significance (2-tailed)	
									standard deviation	standard error of mean	95% confidence interval of the difference				
									lower	upper					
			202.5	10	11.6	3.7	-0.56	0.092	32.7	10.3	26.8	73.6	4.86	9	0.001
			152.3	10	24.7	7.8									

Paired sample statistics for rural area

Pair 1	Indoor gamma dose rate	Outdoor gamma dose rate	mean	N	standard deviation	standard error of mean	correlation	significance	paired differences			<i>t</i>	<i>df</i>	Significance (2-tailed)	
									standard deviation	standard error of mean	95% confidence interval of the difference				
									lower	upper					
			200	42	25.7	4.0	0.135	0.394	27.6	4.26	37.6	54.8	10.85	41	0.000
			153.8	42	14.0	2.2									

Table 3. Statistical data on gamma dose rate for Durg district of Chhattisgarh and comparison between rural and urban values

	Indoor gamma dose rate, nSv/h		Outdoor gamma dose rate, nSv/h		Indoor/outdoor gamma dose rate		Indoor annual effective dose equivalent, mSv/year (for adult)		Outdoor annual effective dose equivalent, mSv/year (for adult)		Total annual effective dose equivalent, mSv/year (for adult)		Lifetime effective dose, mS	
	rural	urban	rural	urban	rural	urban	rural	urban	rural	urban	rural	urban	rural	urban
Minimum value	145 ± 6	191 ± 8	117 ± 5	115 ± 5	1.01	1.01	0.71 ± 0.03	0.94 ± 0.04	0.14 ± 0.01	0.14 ± 0.01	0.88 ± 0.04	1.13 ± 0.05	64.4 ± 2.6	82.2 ± 3.3
Maximum value	253 ± 10	224 ± 9	185 ± 7	189 ± 8	1.95	1.66	1.24 ± 0.05	1.10 ± 0.04	0.23 ± 0.01	0.23 ± 0.01	1.45 ± 0.06	1.24 ± 0.05	105.4 ± 4.2	92.9 ± 3.7
Arithmetic mean	200 ± 8	203 ± 8	154 ± 6	152.3 ± 6	1.41	1.31	0.98 ± 0.04	1.00 ± 0.04	0.19 ± 0.01	0.19 ± 0.01	1.17 ± 0.05	1.18 ± 0.05	85.2 ± 3.4	86.0 ± 3.4
Geometric mean	198 ± 8	202 ± 8	153 ± 6	151 ± 6	1.39	1.29	0.97 ± 0.04	0.99 ± 0.04	0.19 ± 0.01	0.18 ± 0.01	1.16 ± 0.05	1.18 ± 0.05	84.7 ± 3.4	85.9 ± 3.4
World population weighted average [6, 7]	84 ^a		59 ^a		1.40		0.41 ^a		0.07 ^a		0.87 ^b		-	

^a Cosmic radiation not included (cosmic radiation at sea level 31 nSv/h); ^b terrestrial + cosmic radiation.

Table 4. Reported values of the excess lifetime cancer risk from gamma dose rate in different areas (country/city) of the world

Location (country/city)	Excess lifetime cancer risk (ELCR) due to gamma dose rate	References
Kirklareli, Turkey	0.10×10^{-3} to 1.2×10^{-3}	[10]
Alaknanda and Ganges rivers, India	0.375×10^{-3} to 0.662×10^{-3}	[13]
Alapuzha, Kerala	0.17×10^{-3} to 0.42×10^{-3}	[16]
Akoko region, Ondo State, Nigeria	0.307×10^{-3} to 0.736×10^{-3}	[17]
Artvin Province, Turkey	0.19×10^{-3} to 2.16×10^{-3}	[11]
Jhelum valley, Northwest Himalayas, Pakistan	0.352×10^{-3} to 2.377×10^{-3}	[5]
Okposi Okwu and Uburu salt lakes, Ebonyi State	1.007×10^{-3} and 1.173×10^{-3}	[12]
Warri city, Nigeria	0.61×10^{-3}	[15]
Balod district, India	5.0×10^{-3} to 5.2×10^{-3}	[21]
Anjora (Dhaba Anjora)	5.24×10^{-3}	This work
Acchoti	5.17×10^{-3}	
Pitaura	5.27×10^{-3}	

Table 5. Reported values of the outdoor gamma dose rate near uranium mines area (country/city) of the world in comparison with the data for Durg district

Location (country/city)	Outdoor gamma dose rate, nSv/h		References
	range	mean (AM/GM)	
Gobi village, Yadgiri district, Karnataka	45-320	97	[9]
Bagjata, Singhbhum district, Jharkhand	33.4-222.3	116.2	[27]
Turamdih, Jharkhand	56.4-214.6	97.85	[27]
Jaduguda, Jharkhand	53.1-113.5	90.0	[27, 31]
Narwapahar, Jharkhand	87-220	128 ± 18.5	[29]
Village around uranium mine, Jaduguda	75-150	130	[31]
Mailuu Suu, Kyrgyzstan	–	137 ± 10	[30]
Sikar district, Rajasthan	83-110	99.2	[28]
Rural area, Durg	83.9 ± 3.4 to 152.1 ± 6.1	120.8 ± 4.8	This work
Urban area, Durg	81.9 ± 3.3 to 156.0 ± 6.2	119.3 ± 4.8	

the hypothesis that there is no relationship between the outdoor and indoor gamma dose rates for the rural area. The correlation between the outdoor and indoor gamma dose rates for the rural area is very weak (0.135). The significance value of the paired sample t-test for the rural area is 0.000, which is less than 0.05 and allows the null hypothesis for this case to be rejected. Namely, the difference between outdoor and indoor gamma dose rates is significant for the rural area also.

Indoor and outdoor gamma dose rate ratio. The indoor and outdoor gamma dose rate ratio for the rural and urban areas ranges from 0.89 to 1.66 and from 1.01 to 1.95, respectively, with an arithmetical mean of 1.31 and 1.41. The arithmetic mean value of the indoor to outdoor ratio for the rural area is slightly lower than the world population weighted average of 1.4 [6], and for

the urban area this ratio is slightly higher. Only one rural study area (DV-06) of Durg district has the indoor to outdoor ratio lower than 1.00 (the indoor gamma dose rate is lower than the outdoor gamma dose rate).

The overall statistical data for the gamma dose rates for the rural and urban areas from the Durg district of Chhattisgarh are given in Table 3 in comparison with the world population weighted average.

Excess lifetime cancer risk (ELCR). The possibility of the incidence of cancer and the potentially carcinogenic effects from gamma dose rates during a particular lifetime are evaluated by excess lifetime cancer risk (ELCR) [14, 21]. The ELCR values from the gamma dose rate for different areas (country/city) of the world are given in Table 4. The lifetime effective dose values exceed 100 in a few study areas. The maximum

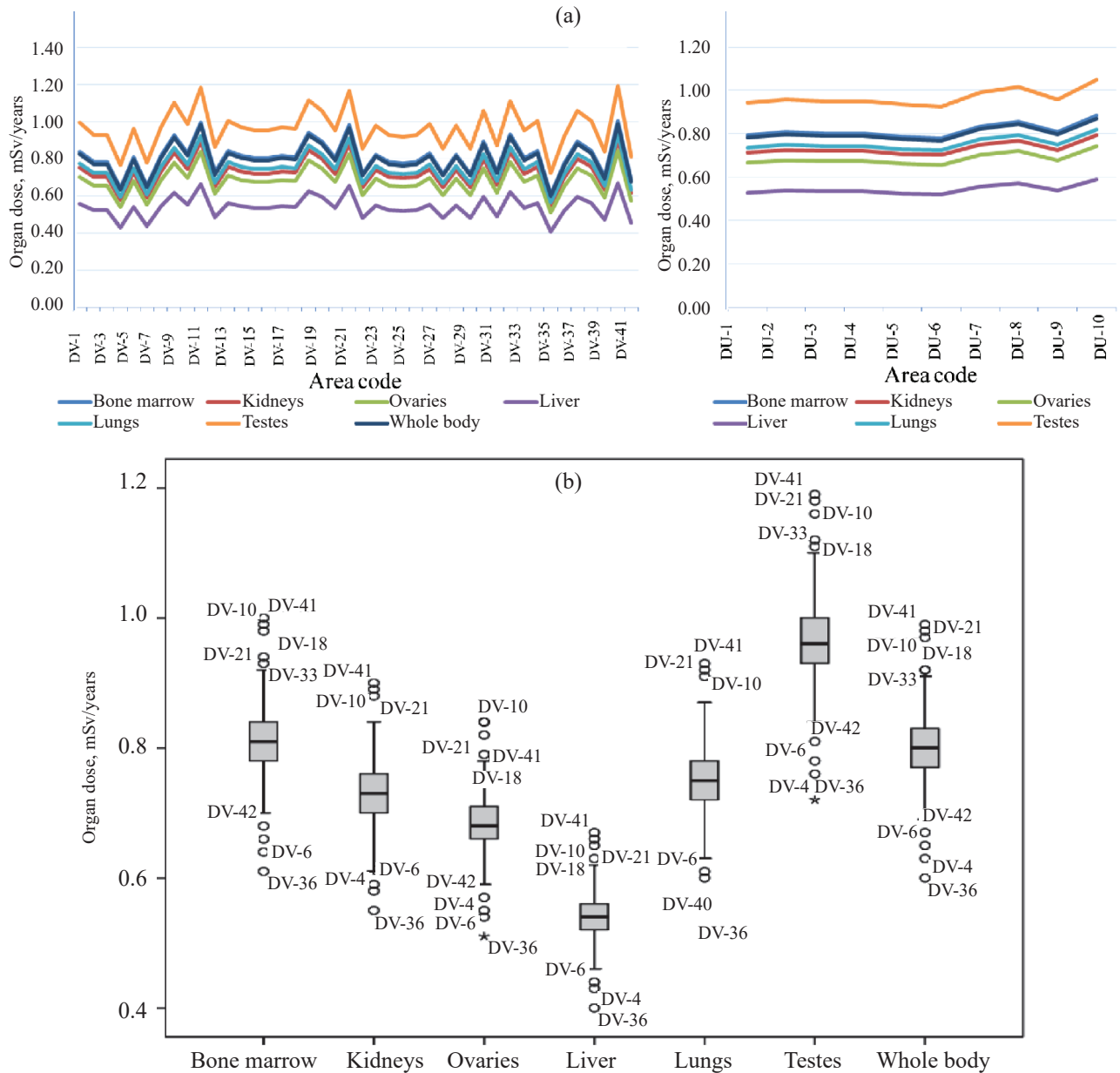


Fig. 7. (a) Comparison of effective dose values for different organ of the body for rural (DV points) and urban (DU points) areas of Durg district and (b) Box plot for organ dose values.

value of ELCR is 5.27×10^{-3} in Pitaura area. In this study, ELCR ranges from 5.17×10^{-3} to 5.27×10^{-3} , exceeding the reported values for Turkey; Jhelum valley Northwest Himalayas, Pakistan; Alappuzha Kerala Ondo State, Nigeria; and Ebonyi State [10–17]. High uranium content of a water sample from Auri area (DV-17) was reported [32]; however, in this place the lifetime effective dose due to gamma radiation was found to be 85.2 ± 3.4 mSv, which is less than 100 mSv.

Effective dose for different body organs (D_{organ}).

The calculated average values of D_{organ} for bone marrow,

kidneys, liver, lungs, ovaries, testes, and whole body were 0.81, 0.81, 0.68, 0.54, 0.73, 0.75, and 0.96 mSv/y, respectively. The variation of D_{organ} for different body organs and tissues and their Box plot are shown in Fig. 7. The effective dose for testes due to radiation was found to be higher than the tolerable limit of 1.00 mSv/years [15] in areas DV-8, DV-10, DV-12, DV-18, DV-19, DV-21, DV-31, DV-33, DV-38, DV-39, DV-41, DU-8, and DU-10. Only one area, DV-41, is characterized by a high effective organ dose for bone marrow.

The reported values of the outdoor terrestrial gamma

dose rate (cosmic ray dose rate subtracted from the outdoor gamma dose rate) near uranium mines in India and other countries are compared with the urban and rural areas of Durg district in Table 5. As can be seen, the mean value of terrestrial radiation for the rural and urban areas of Durg district is higher than the values for the Gobi village, Yadgiri district, Karnataka; Bagjata, Singhbhum district, Jharkhand; Turamdih, Jharkhand; few areas of Jaduguda, Jharkhand; Sikar district, Rajasthan, and lower than the values for Narwapahar, Jharkhand; Mailuu Suu, Kyrgyzstan, and few villages around uranium mine, Jaduguda [9, 27–31].

CONCLUSIONS

The arithmetic and geometric mean values of the annual effective dose equivalent for rural and urban areas of Durg district are slightly higher than the world population weighted average. The maximum AEDE value and lifetime effective dose were found to be 1.45 ± 0.06 mSv/year and 105 ± 4 mSv in Pitaura (rural area). In 7% of rural areas from Durg district, the lifetime effective dose exceeds 100 mSv, whereas for the urban areas this value is not exceeded. The contribution of cosmic radiation (32.87 to 33.22 nSv/h) is lower than that of the terrestrial radiation (81.9 to 156.0 nSv/h). The arithmetic mean value of indoor gamma dose rate for the urban areas is slightly higher than that for the rural areas. In Anjora (Dhaba Anjora), Acchoti, and Pitaura areas, ELCR values were found to be 5.24×10^{-3} , 5.17×10^{-3} , and 5.27×10^{-3} , respectively. The rural population of these three areas of Durg district is 2287, 2596 and 1605, respectively. This study will be helpful for making preventive measures toward cancer risk in the region. Rural and urban houses in Durg district are made of concrete, and almost everywhere the indoor gamma dose rate is higher than the outdoor value, except one location. The strongest radiation effect is exerted on testes, whereas the other parts are not affected. The paired sample *t*-test shows that there is no relationship between the outdoor and indoor gamma dose rates for rural and urban areas. The difference between the outdoor and indoor gamma dose rates is significant. The radiation level obtained in this study is higher than in some areas near uranium mines. The radiation map of the gamma dose rate is reported for this region the first time.

CONFLICT OF INTEREST

The authors state that they have no conflict of interest.

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