Journal of Radioanalytical and Nuclear Chemistry (2018) 317:387–395
https://doi.org/10.1007/s10967-018-5846-9

Risk assessment from gamma dose rate in Balod District of Chhattisgarh, India

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Received: 2 February 2018 / Published online: 3 April 2018

Abstract

People are generally exposed to the natural radiation that presents inside and outside the houses. This investigation has been carried out gamma dose rate of 52 areas of Balod district, Chhattisgarh India. The values of outdoor and indoor gamma dose rates observed were 103.0 ± 3.1 to 201.0 ± 6.0 and 132.0 ± 4.0 to 260.0 ± 7.8 nSv/h, respectively. Indoor to outdoor gamma dose ratio was found to be 1.37. Total average annual effective dose value found to be slightly higher than the world population weighted average. Excess lifetime cancer risk was found to be 5.0×10^{-3} to 5.2×10^{-3} for a few places.

Keywords Gamma dose rate · Indoor and outdoor gamma dose rate · Annual Effective Dose Equivalent (AEDE) · Excess Lifetime Cancer Risk (ELCR)

Introduction

Radiation is emitted due to spontaneous transformation of an unstable nucleus. Radiation dose released from natural sources is higher than that of anthropogenic sources, which were received by mankind. Therefore exposure due to natural radiation has special significance [1, 2]. Naturally radioactivity arises from primordial radioactive materials that mainly consisting uranium (^{238}U, ^{235}U), thorium (^{232}Th), potassium (^{40}K) and ^{226}Ra [3–5]. The artificial radioactivity is due to various human-artificial activities [6–8]. Naturally background radiation is due to cosmic and terrestrial sources [9–11]. The variation in the value of terrestrial radiation is generally greater than the cosmic rays [12]. Cosmic radiation comes from the sun and galaxies through the earth's atmosphere. The worldwide annual average cosmic radiation dose at sea level is 0.39 mSv/y [1, 13]. Terrestrial radiation comes from the radioactive nuclides present in the Earth's crust, from the atmosphere and from building materials (derived from rocks and soils) [14]. Average annual outdoor terrestrial radiation dose is 0.07 mSv/y and for indoor 0.41 mSv/y [1, 13]. The health impact due to an exposure to radionuclides, inhalation by human beings within the indoor environment is a major public concern worldwide [15, 16]. Avoiding natural radionuclides is not possible since as it is present since the formation of the earth [17]. Few researchers studied the risk assessment of the gamma radiation dose rate for outdoor and indoor environment [3–5, 14, 18–21]. The main objective of this study is to determine the risk arises from the gamma dose rate for Balod District. The result of this study will serve as baseline data for future gamma radiation effect in Chhattisgarh region.

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Table 1 Outdoor and indoor gamma dose rate and AEDE values for Balod District of Chhattisgarh

S. no.	Area code	Name of area	GPS coordinates		Population [23]	Outdoor gamma dose rate (nSv/h)	Indoor gamma dose rate (nSv/h)	Indoor/outdoor gamma dose rate	Outdoor annual effective dose equivalent (mSv/y)	Indoor annual effective dose equivalent (mSv/y)	Total annual effective dose equivalent (mSv/y)	Lifetime effective dose (mSv)
			Latitude (N)	Longitude (E)								
1	B-1	Parsada	21°01.350′	81°18.230′	1476	133.0 ± 4.0	194.0 ± 5.8	1.46	0.16	0.95	1.11	78.0
2	B-2	Tiloda	21°00.222′	81°23.279′	1805	142.0 ± 4.3	198.0 ± 5.9	1.39	0.17	0.97	1.15	80.2
3	B-3	Joratarai	20°55.688′	81°22.747′	1401	154.0 ± 4.6	211.0 ± 6.3	1.37	0.19	1.04	1.22	85.7
4	B-4	Rewagahan	20°53.175′	81°04.300′	1126	163.0 ± 4.9	184.0 ± 5.5	1.13	0.20	0.90	1.10	77.2
5	B-5	Limora	20°54.096′	81°17.413′	561	126.0 ± 3.8	165.0 ± 5.0	1.31	0.15	0.81	0.96	67.5
6	B-6	Rehchi	20°55.059′	81°14.503′	633	146.0 ± 4.4	178.0 ± 5.3	1.22	0.18	0.87	1.05	73.7
7	B-7	Borgahan	20°56.255′	81°12.046′	1499	160.0 ± 4.8	201.0 ± 6.0	1.26	0.20	0.99	1.18	82.8
8	B-8	Suregaon	20°54.897′	81°08.116′	1665	140.0 ± 4.2	181.0 ± 5.4	1.29	0.17	0.89	1.06	74.2
9	B-9	Pinkapar	20°57.858′	81°08.036′	647	170.0 ± 5.1	157.0 ± 4.7	0.92	0.21	0.77	0.98	68.5
10	B-10	Rauna	20°58.558′	81°15.201′	1218	147.0 ± 4.4	185.0 ± 5.6	1.26	0.18	0.91	1.09	76.2
11	B-11	Saloni	21°00.421′	81°14.912′	1127	145.0 ± 4.4	198.0 ± 5.9	1.37	0.18	0.97	1.15	80.4
12	B-12	Khursuni	21°01.978′	81°10.107′	1830	159.0 ± 4.8	232.0 ± 7.0	1.46	0.19	1.14	1.33	93.3
13	B-13	Jewartala	20°59.183′	81°06.010′	1049	107.0 ± 3.2	174.0 ± 5.2	1.63	0.13	0.85	0.98	68.9
14	B-14	Marri	20°54.916′	81°02.277′	1673	126.0 ± 3.8	175.0 ± 5.3	1.39	0.15	0.86	1.01	70.9
15	B-15	Sanjari	20°51.633′	81°00.811′	2832	103.0 ± 3.1	132.0 ± 4.0	1.28	0.13	0.65	0.77	54.2
16	B-16	Kotera	20°49.743′	81°01.198′	2222	127.0 ± 3.8	180.0 ± 5.4	1.42	0.16	0.88	1.04	72.7
17	B-17	Kharthuli	20°48.455′	81°07.564′	593	133.0 ± 4.0	182.0 ± 5.5	1.37	0.16	0.89	1.06	73.9
18	B-18	Mudkhusra	20°51.381′	81°08.107′	655	120.0 ± 3.6	185.0 ± 5.6	1.54	0.15	0.91	1.05	73.8
19	B-19	Borri	20°51.070′	81°10.999′	895	115.0 ± 3.5	221.0 ± 6.6	1.92	0.14	1.08	1.23	85.8
20	B-20	Sakaraj	20°48.367′	81°12.232′	1723	119.0 ± 3.6	200.0 ± 6.0	1.68	0.15	0.98	1.13	78.9
21	B-21	Aroud	20°48.465′	81°15.226′	1485	147.0 ± 4.4	174.0 ± 5.2	1.18	0.18	0.85	1.03	72.4
22	B-22	Pairi	20°50.587′	81°15.461′	2609	135.0 ± 4.1	198.0 ± 5.9	1.47	0.17	0.97	1.14	79.6
23	B-23	Khuteri	20°55.284′	81°17.612′	1160	139.0 ± 4.2	192.0 ± 5.8	1.38	0.17	0.94	1.11	77.9
24	B-24	Dania	20°51.561′	81°18.271′	662	130.0 ± 3.9	232.0 ± 7.0	1.78	0.16	1.14	1.30	90.8
25	B-25	Gundardehi	20°56.740′	81°17.414′	8614	179.0 ± 5.4	189.0 ± 5.7	1.06	0.22	0.93	1.15	80.3
26	B-26	Khapri	20°52.023′	81°19.775′	759	125.0 ± 3.8	196.0 ± 5.9	1.57	0.15	0.96	1.11	78.0
27	B-27	Mahud	20°49.731′	81°18.875′	1516	127.0 ± 3.8	213.0 ± 6.4	1.68	0.16	1.04	1.20	84.1
28	B-28	Belodi	20°48.033′	81°21.444′	2220	126.0 ± 3.8	221.0 ± 6.6	1.75	0.15	1.08	1.24	86.7
29	B-29	Bohara	20°48.959′	81°28.315′	1011	165.0 ± 5.0	260.0 ± 7.8	1.58	0.20	1.28	1.48	103.5
30	B-30	Dadhari	20°45.767′	81°25.788′	1582	135.0 ± 4.1	179.0 ± 5.4	1.33	0.17	0.88	1.04	73.1
31	B-31	Kochera	20°43.370′	81°24.690′	1637	153.0 ± 4.6	209.0 ± 6.3	1.37	0.19	1.03	1.21	84.9
32	B-32	Bagdai	20°43.185′	81°21.481′	1204	158.0 ± 4.7	177.0 ± 5.3	1.12	0.19	0.87	1.06	74.3
33	B-33	Nipani	20°45.443′	81°20.718′	2555	154.0 ± 4.6	193.0 ± 5.8	1.25	0.19	0.95	1.14	79.5

Table 1 (continued)

S. no.	Area code	Name of area	GPS coordinates		Population [23]	Outdoor gamma dose rate (nSv/h)	Indoor gamma dose rate (nSv/h)	Indoor/outdoor gamma dose rate	Outdoor annual effective dose equivalent (mSv/y)	Indoor annual effective dose equivalent (mSv/y)	Total annual effective dose equivalent (mSv/y)	Lifetime effective dose (mSv)
			Latitude (N)	Longitude (E)								
34	B-34	Piparchhedi	20°45.650′	81°19.445′	1802	201.0 ± 6.0	181.0 ± 5.4	0.90	0.25	0.89	1.13	79.4
35	B-35	Tekapar	20°46.088′	81°14.979′	414	165.0 ± 5.0	176.0 ± 5.3	1.07	0.20	0.86	1.07	74.6
36	B-36	Parekibhat	20°45.098′	81°14.767′	1087	157.0 ± 4.7	198.0 ± 5.9	1.26	0.19	0.97	1.16	81.5
37	B-37	Belmand	20°44.714′	81°15.979′	1830	129.0 ± 3.9	188.0 ± 5.6	1.46	0.16	0.92	1.08	75.6
38	B-38	Jhalmala	20°42.971′	81°14.313′	2734	147.0 ± 4.4	199.0 ± 6.0	1.35	0.18	0.98	1.16	81.0
39	B-39	Chiri Gori	20°42.608′	81°17.356′	1066	120.0 ± 3.6	176.0 ± 5.3	1.47	0.15	0.86	1.01	70.7
40	B-40	Deur Tarai	20°42.384′	81°12.551′	583	188.0 ± 5.6	245.0 ± 7.4	1.30	0.23	1.20	1.43	100.3
41	B-41	Miri Tola (Purur)	20°39.555′	81°29.323′	2489	123.0 ± 3.7	150.0 ± 4.5	1.22	0.15	0.74	0.89	62.1
42	B-42	Mokha	20°39.774′	81°24.348′	1811	129.0 ± 3.9	167.0 ± 5.0	1.29	0.16	0.82	0.98	68.4
43	B-43	Ruputola	20°36.229′	81°20.841′	141	112.0 ± 3.4	165.0 ± 5.0	1.47	0.14	0.81	0.95	66.3
44	B-44	Parregura	20°40.267′	81°18.515′	746	169.0 ± 5.1	249.0 ± 7.5	1.47	0.21	1.22	1.43	100.0
45	B-45	Jamruwa	20°40.958′	81°16.535′	1727	168.0 ± 5.0	186.0 ± 5.6	1.11	0.21	0.91	1.12	78.3
46	B-46	Slhetola	20°40.075′	81°16.495′	394	123.0 ± 3.7	183.0 ± 5.5	1.49	0.15	0.90	1.05	73.4
47	B-47	Godpal	20°36.406′	81°15.627′	470	157.0 ± 4.7	201.0 ± 6.0	1.28	0.19	0.99	1.18	82.5
48	B-48	Marram Kheda	20°35.826′	81°15.782′	217	194.0 ± 5.8	255.0 ± 7.7	1.31	0.24	1.25	1.49	104.2
49	B-49	Pandel	20°36.894′	81°09.933′	805	165.0 ± 5.0	256.0 ± 7.7	1.55	0.20	1.26	1.46	102.1
50	B-50	Gujra	20°40.191′	81°07.650′	1617	154.0 ± 4.6	187.0 ± 5.6	1.21	0.19	0.92	1.11	77.4
51	B-51	Kusumkasa	20°38.492′	81°04.816′	4457	135.0 ± 4.1	196.0 ± 5.9	1.45	0.17	0.96	1.13	78.9
52	B-52	Sikaritola	20°39.491′	81°05.131′	730	124.0 ± 3.7	198.0 ± 5.9	1.60	0.15	0.97	1.12	78.6

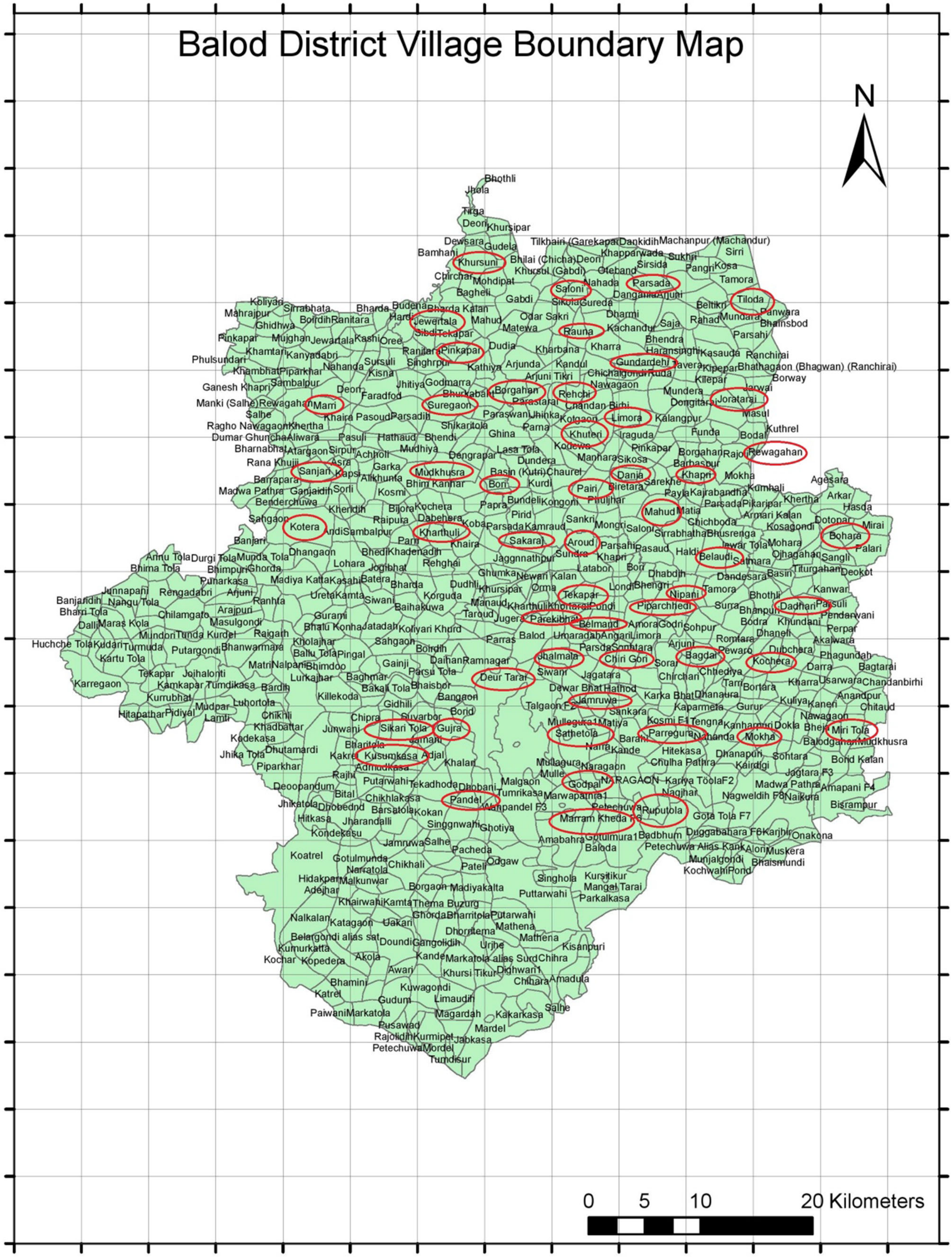

Fig. 1 Grid map of study areas Balod District, Chhattisgarh India

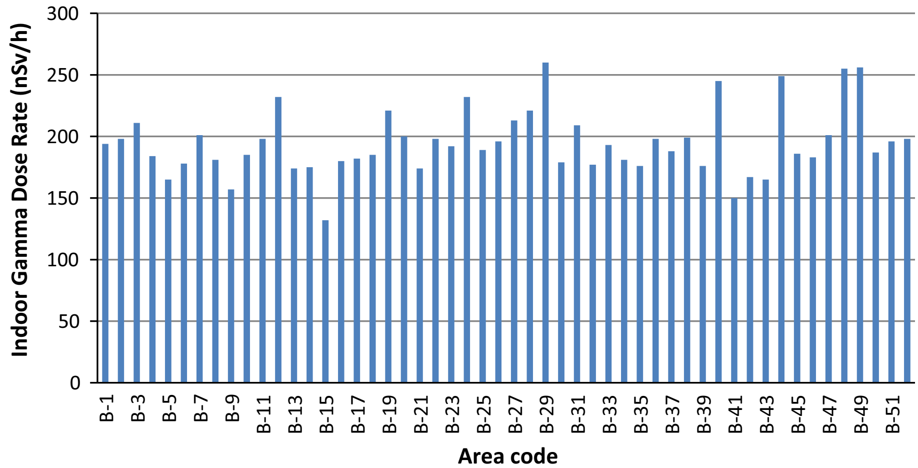

Fig. 2 Indoor gamma dose rate from Balod District Chhattisgarh

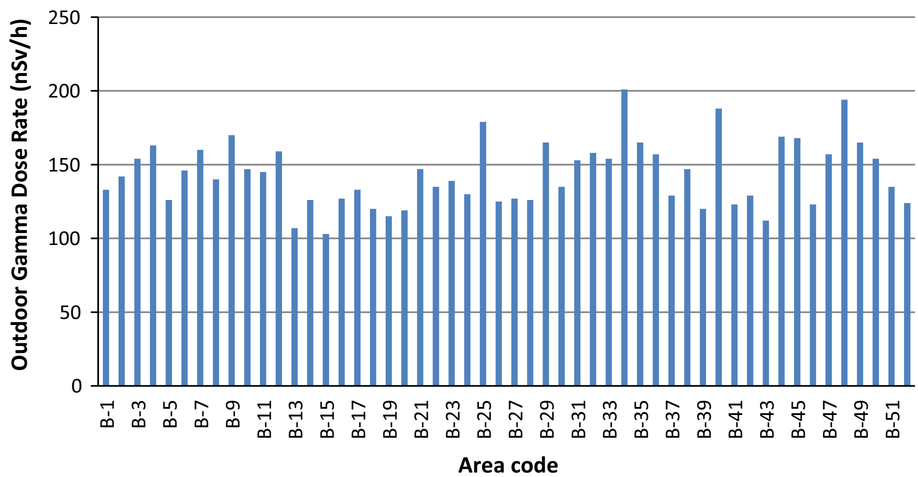

Fig. 3 Outdoor gamma dose rate from Balod District Chhattisgarh

Material and methodology

Selection of the measurement sites

Balod city is situated on the bank of Tandula River, which has District Headquarter from 1st January 2012. This District is situated on an average 324 meters (1063 feet) above sea level. The total areas of District Balod which situated in Chhattisgarh centre is 352,700 ha, where 74,911 ha covered by forest and remain are part of the land. This District is endowed with natural resources like water, forest and mineral resources [22]. Outdoor and Indoor gamma dose rates were measured in 52 study locations from Balod District, Chhattisgarh India, where total population is 78,764 [23]; that is mentioned in Table 1. All study locations are shown in Fig. 1. Six square kilometre grid have been taken as per Board of Research in Nuclear Sciences, Department of Atomic Energy.

Gamma dose rate measurement

Outdoor and Indoor gamma dose rates were measured by using Geiger–Muller based dosimeter (Polimaster PM-1405) for study locations. Reading was recorded in nSv/h. This apparatus record both the cosmic and the terrestrial radiation at 1 m height above the ground surface. The energy range of this device for gamma radiation is 0.05–3 MeV and measurement range for dose rate is 0.01 μSv/h to 100 mSv/h [20]. The Latitude (N) and Longitude (E) of all study locations were determined by the GPS (GARMIN OREGON-650) coordination device.

Calculation of Annual Effective Dose Equivalent (AEDE)

Annual effective dose equivalent (AEDE) value of outdoor and indoor from study locations were calculated by using outdoor and indoor gamma dose rates respectively. The biological effects on humans due to radiations are

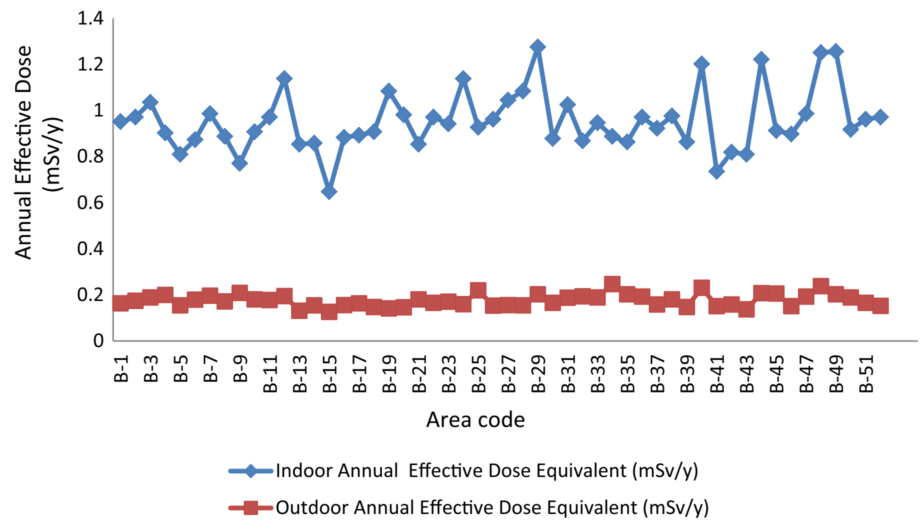

Fig. 4 Indoor and outdoor annual effective dose equivalent values from Balod District Chhattisgarh

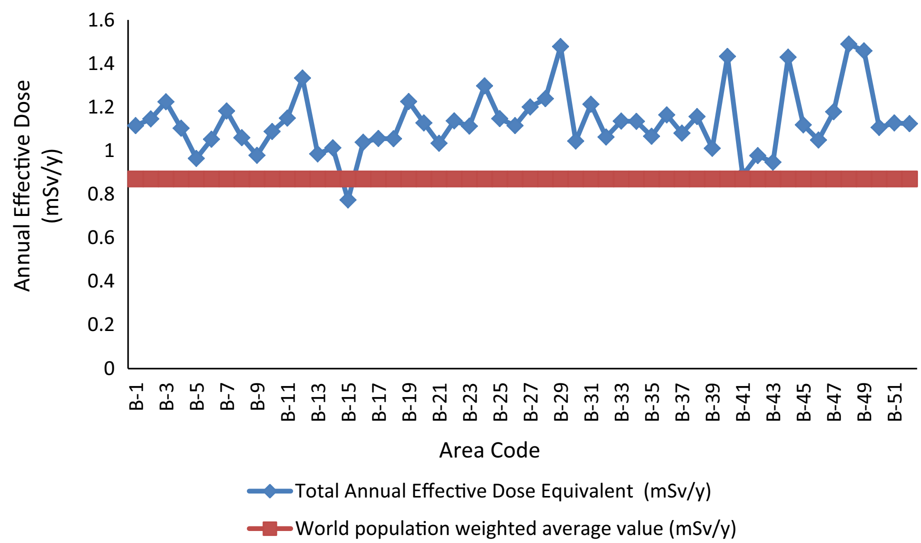

Fig. 5 Values of total annual effective dose equivalent and their comparison with world population weighed average value

evaluated on the basis of AEDE [24]. AEDE was estimated by using the following equation:

$$\begin{aligned}\mathrm{AEDE(indoor/outdoor)} &= D(\mathrm{indoor/outdoor}) \times \text{conversion coefficient} \times T \\ &\quad \times \text{occupancy factor}\end{aligned} \tag{1}$$

where: D(indoor) = Absorbed gamma dose rate in indoor (nGy/h), D(outdoor) = Absorbed gamma dose rate in outdoor (nGy/h), T = Time (h).

The value of occupancy factor reported by UNSCEAR for indoor and outdoor was 0.8 and 0.2, respectively; and the conversion coefficient for an adult was reported 0.7 [1]. The values are about 10 and 30% higher for children and infants [1].

Therefore above formula become as:

$$\mathrm{AEDE(indoor)} = \mathrm{D(indoor)} \times 0.7 \times 8760 \times 0.8 \tag{2}$$

$$\mathrm{AEDE(outdoor)} = \mathrm{D(outdoor)} \times 0.7 \times 8760 \times 0.2 \tag{3}$$

Equation (2) and (3) were used for calculation of AEDE indoor and outdoor respectively. Total AEDE was calculated by adding indoor and outdoor AEDE values.

$$\text{Total AEDE} = \mathrm{AEDE(indoor)} + \mathrm{AEDE(outdoor)} \tag{4}$$

Risk assessment

Lifetime effective dose

Lifetime effective dose calculated by total AEDE values and duration of life.

$$\text{Lifetime effective dose} = \text{Total AEDE} \times \text{duration of life} \tag{5}$$

Table 2 Statistical data of gamma dose rates for Balod District of Chhattisgarh and their comparison with world population weighted average

	Outdoor gamma dose rate (nSv/h)	Indoor gamma dose rate (nSv/h)	Indoor/outdoor gamma dose rate	Outdoor annual effective dose equivalent (mSv/y)	Indoor annual effective dose equivalent (mSv/y)	Total annual effective dose equivalent (mSv/y)	Reference
Minimum value	103.0 ± 3.1	132.0 ± 4.0	0.90	0.13	0.65	0.77	Present study
Maximum value	201.0 ± 6.0	260.0 ± 7.8	1.92	0.25	1.28	1.49	
Arithmetic Average	143.6 ± 4.3	194.7 ± 5.8	1.37	0.18	0.95	1.13	
Geometric mean	142.0 ± 4.3	192.9 ± 5.8	1.36	0.17	0.95	1.12	
World population weighted average	59[a]	84[a]	1.40	0.07[a]	0.41[a]	0.87[b]	UNSCEAR [1]

[a]Not include cosmic radiation (cosmic radiation at sea level 31 nSv/h), [b]Terrestrial and cosmic includes

Table 3 Values of Excess Lifetime Cancer Risk (ELCR)

Area code	Name of area	Excess lifetime cancer risk (ELCR)
B-29	Bohara	5.2×10^{-3}
B-40	Deur Tarai	5.0×10^{-3}
B-44	Parregura	5.0×10^{-3}
B-48	Marram Kheda	5.2×10^{-3}
B-49	Pandel	5.1×10^{-3}

where total AEDE value calculated by Eq. (4) and take duration of life 70 year [3, 20].

Calculation of Excess Lifetime Cancer Risk (ELCR)

Excess lifetime cancer risk was calculated by using lifetime effective dose (from Eq. (5)) and risk factor. For public, value of risk factor was 0.05 used by ICRP 60 [3, 20]. The value of cancer risk calculated only for those locations where lifetime effective dose crosses the 100 mSv [25].

$$\text{ELCR} = \text{Lifetime effective dose} \times \text{risk factor} \quad (6)$$

Results and discussion

Results of outdoor gamma dose rate, indoor gamma dose rate, AEDE and lifetime effective dose from Balod District of Chhattisgarh are presented in Table 1. In the present investigation, the value of outdoor and indoor gamma dose rate range was found to be extending from 103.0 ± 3.1 to 201.0 ± 6.0 and 132.0 ± 4.0 to 260.0 ± 7.8 nSv/h, respectively. The values of the Indoor and outdoor gamma dose rate are shown in Figs. 2 and 3. Arithmetic average values for outdoor and indoor gamma dose rate was 143.6 ± 4.3 and 194.7 ± 5.8 nSv/h. The maximum value

Table 4 Values of Excess lifetime cancer risk from gamma dose rate in different location (country/city) of world

S. no.	Location (country/city)	Excess life time cancer risk (ELCR) due to gamma dose rate	Reference
1	Jhelum valley Northwest Himalayas, Pakistan	0.352×10^{-3} to 2.377×10^{-3}	[11]
2	Alaknanda and Ganges rivers, India	0.375×10^{-3} to 0.662×10^{-3}	[14]
3	Warri city, Nigeria	0.61×10^{-3}	[19]
4	Alapuzha, Kerala	0.17×10^{-3} to 0.42×10^{-3}	[20]
5	Kirklareli, Turkey	0.10×10^{-3} to 1.2×10^{-3}	[3]
6	Artvin Province, Turkey	0.19×10^{-3} to 2.16×10^{-3}	[4]
7	Okposi Okwu and Uburu salt lakes, Ebonyi State	1.007×10^{-3} and 1.173×10^{-3}	[5]
8	Akoko region, Ondo State, Nigeria	0.307×10^{-3} to 0.736×10^{-3}	[21]
9	Balod area	5.0×10^{-3} to 5.2×10^{-3}	Present study

of indoor gamma dose rate was observed 260.0 nSv/h in Bohara area; however UNSCEAR reported gamma dose rate varies from 20 to 200 nSv/h. In this study indoor gamma dose rate from area code B-3, B-7, B-12, B-19, B-24, B-27, B-28, B-29, B-31, B-40, B-44, B-47, B-48 and B-49 were found to be more than 200 nSv/h.

Annual Effective Dose Equivalent (AEDE)

Annual Effective Dose Equivalent values for outdoor and indoor are shown in Fig. 4. The value of outdoor and indoor AEDE was found to be in the range from 0.13 to 0.25 and 0.65 to 1.28 mSv/y, respectively. In this study Indoor AEDE value found to be higher than the outdoor AEDE because people spend more time inside as compare to outside. Arithmetic average value of indoor AEDE was found to be 0.95 mSv/y and arithmetic average value of outdoor annual dose was found to be 0.18 mSv/y. Total AEDE was found to be 1.13 mSv/y; however the world population weighted average value reported for AEDE was 0.87 mSv/y [1]. The values of total AEDE and their comparison with world population weighed average value are shown in Fig. 5. This study indicates the values of AEDE from Balod District to be slightly higher than the above mentioned world average. The data reported in this study will seem as useful baseline data for this region.

Indoor and outdoor gamma dose rate ratio

The range of indoor to outdoor gamma dose ratios was found to be 0.90–1.92, with an arithmetic average value 1.37. This ratio value is slightly lower than the world population weighted average 1.4 [1]. Only in two study location (B-9 and B-34) indoor gamma dose rate values recorded lower than the outdoor gamma dose rate.

Overall Statistical data of gamma dose rates for Balod District of Chhattisgarh and their comparison with world population weighted average are shown in Table 2.

Excess Lifetime Cancer Risk (ELCR)

The probability of the incidence of cancer and the potentially carcinogenic effects of gamma dose rates during a specific lifetime is evaluated by ELCR [19]. In this study calculated ELCR values with their location are shown in Table 3. The values of ELCR from gamma dose rate in different locations (country/city) of the world are shown in Table 4. The highest value of ELCR found to be 5.2×10^{-3} in Marram Kheda. Present study showed that the ELCR range varies from 5.0×10^{-3} to 5.2×10^{-3}; which are higher than the reported values from Jhelum valley Northwest Himalayas, Pakistan; Ondo State, Nigeria; Alapuzha Kerala; Ebonyi State and Turkey [3–5, 14, 18–21]. Previous study was also reported high uranium in water sample from Deur Tarai [26] and in this area ELCR found to be 5.0×10^{-3} due gamma dose rate.

Conclusions

The mean value (arithmetic and geometric) of AEDE for Balod district was slightly higher than the world population weighted average value. The maximum value of AEDE was found to be 1.49 mSv/y in Marram Kheda area. Lifetime effective dose was varies from 54.2 to 104.2 mSv. Only in five area lifetime effective dose more than the 100 mSv. ELCR values were found to be 5.2×10^{-3}, 5.0×10^{-3}, 5.0×10^{-3}, 5.2×10^{-3} and 5.1×10^{-3} in areas Bohara, Deur Tarai, Parregura, Marram Kheda and Pandel, respectively. The population of five areas of Balod district: Bohra, Deor Tarai, Paraguara, Marram Kheda and Pandel was 1011, 583, 746, 217 and 805, respectively; where the ELCR was calculated. This study will be helpful for a preventive measure towards cancer risk. As per Indian scenario we generally lives in concrete structure. So here all most all indoor data were effective the radiation. It seems that our data represent the authentic proof for indoor to outdoor ratios values.

Acknowledgements We are thankful to the Board of Research in Nuclear Sciences (BRNS), Department of Atomic Energy, Government of India for funding the project 36(4)/14/90/2014-BRNS. The authors are also thankful to Bhilai Institute of Technology for providing the facilities.

References

1. UNSCEAR (United Nation Scientific Committee on the effect of Atomic Radiations) (2000) Ionizing radiation. Sources and biological effects report to the general assembly with scientific annexes. New York, United Nations
2. Sulekha RN, Kajori P, Hiroaki K, Sengupta D (2015) Measurement of environmental external gamma radiation dose rate outside the dwellings of southern coastal Odisha, eastern India. Curr Sci 109(3):600
3. Taskin H, Karavus M, Ay P, Topuzoglu HS, Karahan G (2009) Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. J Environ Radioact 100:49–53
4. Kobya Y, Taskın H, Yesilkanat CM, Cevik U (2015) Evaluation of Outdoor Gamma Dose Rate and Cancer Risk in Artvin Province, Turkey. Hum Ecol Risk Assess 21(8):2077–2085
5. Avwiri GO, Nwaka BU, Ononugbo CP (2016) Radiological health risk due to gamma dose rates around Okposi Okwu and Uburu Salt Lakes, Ebonyi state. Int J Emerg Res Manag Technol 5(9):18–30
6. Tripathi RM, Sahoo SK, Mohapatra S, Patra AC, Lenka P, Dubey JS, Jha VN, Puranik VD (2012) An Assessment of the Radiological scenario around uranium mines in Singhbhum East district, Jharkhand, India. Radiat Protect Dosim 150(4):458–464. https://doi.org/10.1093/rpd/ncr431

7. Sadegh H, Naghizadeh BA, Hadi S, Manouchehr B, Sahar Z, Soheila R (2012) Investigation of natural effective gamma dose rates case study: Ardebil Province in Iran. Iran J Environ Health Sci Eng. https://doi.org/10.1186/1735-2746-9-1
8. Ononugbo CP, Avwiri GO, Ogan CA (2016) Natural radioactivity measurement and evaluation of radiological hazards in sediment of Imo River, in rivers state, Nigeria by gamma ray spectrometry. J Appl Phys 8(3):75–83
9. Tripathi RM, Sahoo SK, Jha VN, Rajesh Kumar, Shukla AK, Puraniki VD, Kushwaha HS (2011) Radiation dose to members of public residing around uranium mining complex, Jadguda, Jharkhand, India. Radiat Protect Dosim 147(4):565–572. https://doi.org/10.1093/rpd/ncq496
10. Ahmed RK (2012) Measurement the average gamma rate radiation for some regions in Baghdad city. J Kufa-Phys 4(1):48–55
11. Muhammad R, Ur RS, Muhammad B, Wajid A, Iftikhar A, Lone AK, Ahmed MK (2014) Evaluation of excess life time cancer risk from gamma dose rates in Jhelum valley. J Radiat Res Appl Sci 7:29–35. https://doi.org/10.1016/j.jrras.2013.11.005
12. Karunakara N, Yashodhara I, Kumara K, Sudeep, Tripathi RM, Menon SN, Kadam S, Chougaonkar MP (2014) Assessment of ambient gamma dose rate around a prospective uranium mining area of South India-A comparative study of dose by direct methods and soil radioactivity measurements. Results Phys 4:20–27. https://doi.org/10.1016/j.rinp.2014.02.001
13. UNSCEAR (United Nation Scientific Committee on the effect of Atomic Radiations) (1993) Sources and effects of ionizing radiation. UNSCEAR, New York
14. Prerna S, Kumar MP, Prasad MK (2014) Terrestrial gamma radiation dose measurement and health hazard along river Alaknanda and Ganges in India. J Radiat Res Appl Sci 7(4):595–600
15. Bagher TM, Ehsan K, Zahra S (2012) Assessment of gamma-dose rate in city of Kermanshah. J Educ Health Promot 1:1–4. https://doi.org/10.4103/2277-9531.100159
16. Ononugbo CP, Avwiri GO, Tutumeni G (2015) Estimation of indoor and outdoor effective doses from gamma dose rates of residential buildings in Emelogu village in Rivers State, Nigeria. Int Res J Pure Appl Phys 3(2):18–27
17. Jwanbot DI, Izam MM, Nyam GG, Yusuf M (2014) Indoor and outdoor gamma dose rate exposure levels in major commercial building materials distribution outlets in Jos, plateau State-Nigeria. Asian Rev Environ Earth Sci 1(1):5–7
18. Mahmoud PA, Mahdi A, Iraj N, Majid A (2014) Annual effective dose from environmental gamma radiation in Bushehr city. J Environ Health Sci Eng. https://doi.org/10.1186/2052-336X-12-4
19. Ezekiel AO (2017) Assessment of excess lifetime cancer risk from gamma radiation levels in Effurun and Warri city of Delta state, Nigeria. J Taibah Univ Sci 11:367–380. https://doi.org/10.1016/j.jtusci.2016.03.007
20. Monica S, Prasad Visnu AK, Soniya SR, Jojo PJ (2017) Ambient gamma levels in the in seaside regions of Alapuzha district, Kerala. Int J Pure Appl Phys 13:179–187
21. Asere AM, Ajayi IR (2017) Estimation of outdoor gamma dose rates and lifetime cancer risk in Akoko Region, Ondo state, Southwestern Nigeria. J Environ Sci Toxicol Food Technol 11(5):49–52. https://doi.org/10.9790/2402-1105024952
22. Balod District Administration. Government of Chhattisgarh. http://balod.gov.in/en
23. Census Data, Meta Data (2011) Ministry of Home Affair, Government of India. http://www.censusindia.gov.in
24. NRC (National Research Council) (2006) Health risk from exposure to low levels of ionizing radiation: BEIR VII PHASE 2. The National Academies Press, Washington, DC
25. Radiation Risk in Perspective (2016) Position statement of the Heath Physics Society
26. Sar SK, Diwan V, Biswas S, Singh S, Sahu M, Jindal MK, Arora A (2017) Study of uranium level in groundwater of Balod District of Chhattisgarh State, India and assessment of health risk. Hum Ecol Risk Assess. https://doi.org/10.1080/10807039.2017.1397498