



Natural radioactivity levels and associated radiation hazards in soil samples of Chikkamagaluru district, Karnataka, India

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Abstract

The ²²⁶Ra, ²³²Th and ⁴⁰K activities were investigated in soil samples of Chikkamagaluru district, Karnataka, using γ -ray spectrometry. The average activity of ²²⁶Ra, ²³²Th and ⁴⁰K were found to vary from 15.2 ± 0.6 to 58 ± 1.2 Bq kg⁻¹, 14 ± 0.6 to 86.2 ± 1.7 Bq kg⁻¹, and 224.5 ± 5.5 to 1650 ± 20.3 Bq kg⁻¹ with a mean value of 36.93 ± 1.0 , 51.6 ± 1.3 and 566.97 ± 11.0 Bq kg⁻¹. The average activity concentrations are slightly higher than world average value. The average annual effective dose is more than the Indian average value of 0.084 mSv y⁻¹. The average values of all the radiological hazards are less than the criterion limit.

Keywords Natural radionuclides · Dose rate · Radiation hazards · Annual effective dose · Chikkamagaluru

Introduction

Environmental radiation exposure may arise from natural and artificial sources. A significant portion of the background radiation mainly comes from natural radionuclides in the soil [1]. Radioactivity and radiation existed long before life evolved on the earth. Radionuclides are the sources of natural radioactivity and are continuously releasing the radiation during their nuclear decay. Therefore, we live in an ocean of natural radioactivity. Ionizing radiation (α , β and γ) resulting from radionuclides in the earth crust and the interaction of cosmic rays with the earth atmosphere, are the two most significant radiation sources [2]. The study of natural radioactivity in the atmosphere is significant since the primordial radionuclides and their daughter products found in the earth crust are the primary source of radiation exposure to man [2]. Soil is considered to be the main source

of natural primordial radionuclides to other environmental matrices, like water, air, sediments and other biological systems [3]. Natural radioactivity concentration assessment in soil is important because people can receive exposure from soil via multiple pathways, for example it is used as a building material [4–6]. Radionuclides and natural radioactivity also act as good biochemical and geochemical tracers in the atmosphere. The interaction of primordial radionuclides with the environmental system, like physical and chemical constituents represents a prime factor in their mobility and environmental speciation [7–9]. Understanding of the radionuclides distribution, availability and their mobility as well as changes caused by the variation in environmental conditions, is essential for soil rehabilitation. Soil is formed by weathering of rocks in the earth crust, and it contains mineral components, water and vapor, the air filled pores, organic matter and organisms [10]. The natural radioactivity in soil primarily comes from ²³⁸U, ²³⁵U, ²³²Th series and natural ⁴⁰K. Artificial radionuclides can also be present from fallout of weapons testing and from nuclear accidents such as Chernobyl, Fukushima [10]. The radiological implication of these radionuclides is due to the gamma ray exposure of the body and irradiation of lung tissue from inhalation of radon and its progeny. The radionuclides such as ²³⁸U, ²²⁶Ra, ²³²Th, and ⁴⁰K present in soil are distributed non uniformly, hence the understanding of their distribution is very important for radiation safety [2, 7, 10–13]. These radionuclides and their decay series are major sources of natural radiation

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exposure to human beings and a threat to our health [11]. The determination of the quantity of change in background radiation over time as a result of any radioactive release from factories (like thermal power station, nuclear mining activity), open-air nuclear weapon testing conducted in the past, and nuclear accidents necessitates the measurement of radioactivity in soil. As a result, determining the external gamma dose rate is critical in determining whether or not precautionary measures are required when the dose exceeds the prescribed level [14]. There have been many radiological surveys to determine the background radionuclides levels in soil samples and their radiological hazards [1, 3–10, 12, 15, 16]. The objective of the present work is to estimate the distribution of radioactive nuclides in the soil and estimation of AED to the publics of the study area.

Geology of study area

The Chikkamagaluru district lies between 12° 54' and 13° 53' North latitude and between 75° 04' and 76° 21' East longitude. The district is divided into three sections: Southern Malnad, Central Semi-Malnad, and South-Eastern Malnad region. Red loamy and sandy soil are the most common forms of soil in the study area. Hilly region soil, mixed red and black soil can also be found in small areas in the central and north-eastern parts, respectively [17]. The black soil is found around Baba Budan Giri hills whereas Red and Gravel soil are found in southern part of the district. Lithostratigraphy of Chikkamagaluru district belongs to the Baba budan group-Mulainagiri formation with phyllites and rare ultramafic sill. The Baba budan group represents a typical mafic platformal association with quartz pebble conglomerate at the base followed by bands of basalt and orthoquartzite, ending with strong development of banded iron formation, there are rare carbonate rocks within this lower sequence. Rock falling within this basal group are comparatively more metamorphosed than the rock types falling within the overlying Chitradurga group. The major rock types are Santaveri formation-Meta basalts, gabbros, layered basic complexes, siliceous phyllites and schists, cross bedded quartzites, ultramafic schists, basal conglomerate, charnokite, gneisses and unclassified crystalline slates, phyllites etc. The Chikkamagaluru district has seven taluks covered by schist followed by gneissic rock formation in the southern part of the district. Weathered, fractured, and jointed schist and gneiss serves as potential auriferous in the area. The district is rich in iron, magnetite, and granite deposits. The present study area is not associated with any high natural radionuclide content. The radionuclides activity concentration variation is mainly depending on geological and mineralogical composition of the study area. The geological map of the study area is shown in Fig. 1.

Materials and methods

Sample collection and preparation

The soil samples were collected from different locations of the study area. The places, which were free from surface runoff during heavy rain, were carefully selected. An area of approximately 0.5 m² was cleared of vegetation and roots. About 2 kg soil was collected at each spot. Finally, the samples were mixed thoroughly and extraneous materials like plants, debris, big pieces of stones and pebbles were removed [10, 12, 18]. Composite samples of a 1 kg were taken and sealed in a polythene bag. These samples were transferred to a porcelain dish and oven dried overnight at 110 °C. The samples were powdered by using a mortar and pestle and sieved through 150 µm sieve, weighted and sealed in a 300 ml plastic container and kept for a month before counting by gamma spectrometry to ensure that the radioactive equilibrium was reached between ²²⁶Ra, ²²²Rn and its progeny.

Radioactivity measurements

The activity concentration of ²²⁶Ra, ²³²Th, and ⁴⁰K, in different soil samples at few places of Kadur, Birur and Tarikere taluks of Chikkamagaluru district were determined by γ -ray spectrometer (HPGe). The detector used is *n*-type 42% relative efficiency closed end coaxial detector (model GR 4021, Canberra USA). It measures 6.1 cm in diameter and 5.2 cm in length. The energy resolution (FWHM) of the detector is 2.01 keV at 1.33 MeV. The detector was enclosed in a 10 cm thick graded lead shield (Model 747, Canberra, USA) to reduce the background. The Canberra, DSA-1000 (which consists of HV bias supply, ADC and 16 K MCA) and GENIE-2000 software were used for data acquisition and analyses. The detector efficiency calibration was performed using the IAEA quality assurance reference materials: RG U-238, RG Th-232, RG K-1 and SOIL-6. The standard material and samples were taken in containers of same size and type so that detection geometry remained the same. Samples were counted for 60,000 s long enough to reduce the counting error. The ²²⁶Ra activity was evaluated from the weighed mean of the activities of three photo peaks of ²¹⁴Pb (609.3, 1129.3 and 1764.5 keV) after applying Compton corrections. In the case of ²³²Th one photo peak of ²²⁸Ac (911.2 keV) and two photo peaks of ²⁰⁸Tl (583.1 and 2614.5 keV) were used in the same way. The activity of ⁴⁰K was derived from its 1460.8 keV gamma line. The activity of radionuclide was estimated by the following equation [10, 12, 18].

$$\text{Activity (Bq kg}^{-1}\text{)} = \frac{(S \pm \sigma) \times 100 \times 1000 \times 100}{\epsilon w A} \quad (1)$$

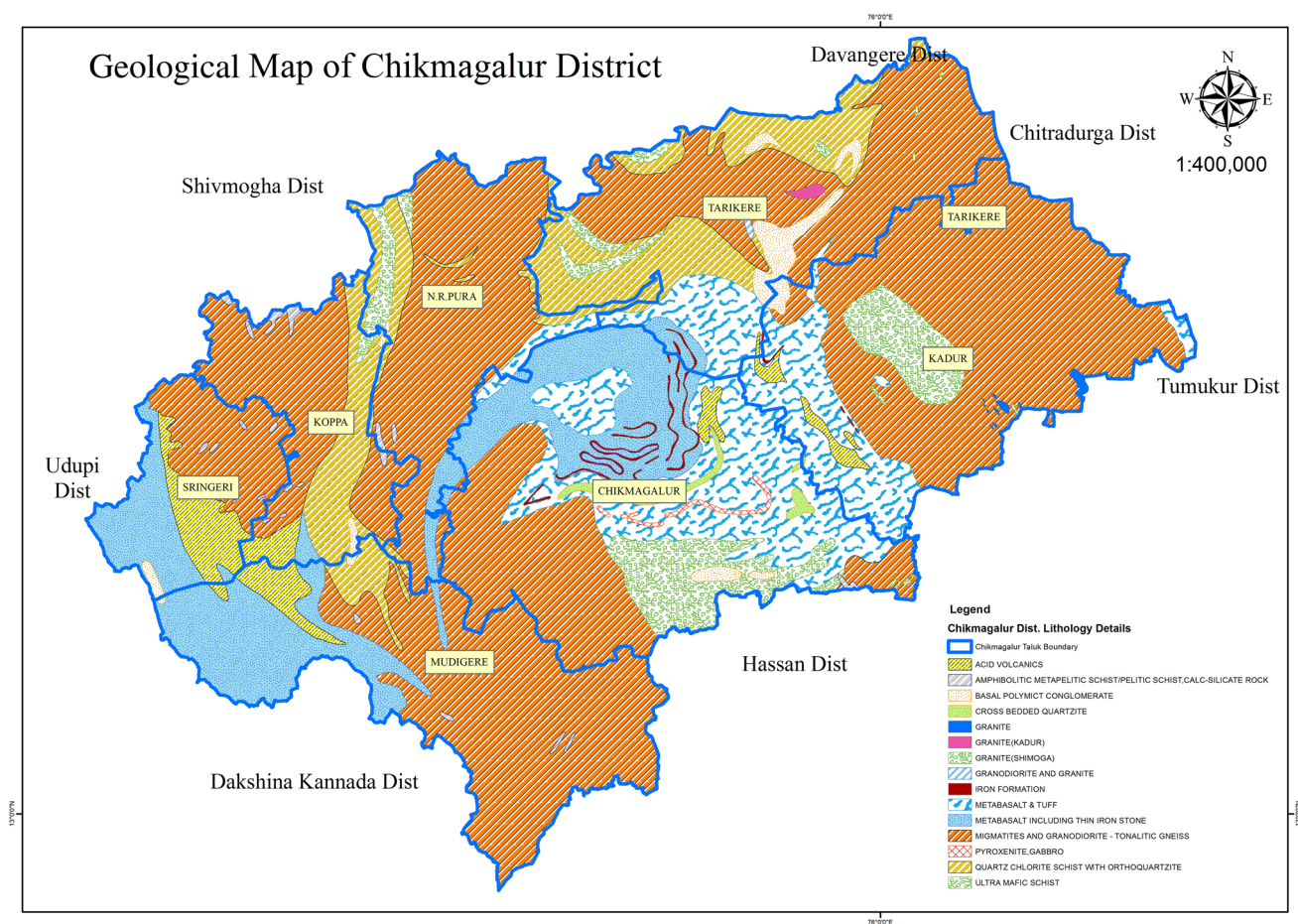


Fig. 1 Geological map of Chikkamagaluru district

where σ is the standard deviation of S , ε is the counting efficiency, S is the net counts/s under photo peak of intensity, A is the γ -abundance (%) of the radionuclides, w is the mass of the sample (g).

The indoor and outdoor gamma absorbed dose rates (GADR) were calculated using the following equations by UNSCEAR [2].

$$D_{\text{in}} \text{ (nGy h}^{-1}\text{)} = 0.92C_{\text{Ra}} + 1.1C_{\text{Th}} + 0.08C_{\text{K}} \quad (2)$$

$$D_{\text{out}} \text{ (nGy h}^{-1}\text{)} = 0.462C_{\text{Ra}} + 0.604C_{\text{Th}} + 0.0417C_{\text{K}} \quad (3)$$

where C_{Ra} , C_{Th} and C_{K} are activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K in Bq kg^{-1} respectively.

The terrestrial GADR was determined using a portable GM tube-based environmental radiation dosimeter (ER709 manufactured by NUCLEONIX SYSTEMS, PVT LTD) in Hyderabad, India. The ER709 is specifically designed to function as a low-level survey meter in both indoor and

outdoor environments. The equivalent annual effective dose (AED) was calculated as described elsewhere [19, 20] using the formula as given below.

$$E_{\text{In}} \text{ (mSv y}^{-1}\text{)} = D \times 8760 \times 0.8 \times 0.7 \times 10^{-6} \quad (4)$$

$$E_{\text{Out}} \text{ (mSv y}^{-1}\text{)} = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (5)$$

The radium equivalent activity (Ra_{eq}) was calculated in this study to determine the risk of gamma radiation dose to humans. The following equation is used to calculate the radium equivalent activity [11, 20].

$$\text{Ra}_{\text{eq}} = C_{\text{Ra}} + 1.43C_{\text{Th}} + 0.07C_{\text{K}} \quad (6)$$

The concept of the hazard indices were used to evaluate the possible radiological risk posed to human by radionuclides and radon (^{222}Rn) present in the soil. The external and internal health hazard indices were estimated using the relations given below [20].

$$H_{\text{ex}} = \frac{C_{\text{Ra}}}{370} + \frac{C_{\text{Th}}}{259} + \frac{C_{\text{K}}}{4810} \quad (7)$$

$$H_{\text{in}} = \frac{C_{\text{Ra}}}{185} + \frac{C_{\text{Th}}}{259} + \frac{C_{\text{K}}}{4810} \quad (8)$$

Results and discussion

Distribution of natural radioactivity in soil samples

The average activity concentrations of primordial radionuclides present in soil samples collected from 25 different locations throughout the study area were calculated, and the results are shown in Table 1. In this study, the activity of ^{226}Ra , ^{232}Th and ^{40}K in the soil samples vary from 15.2 ± 0.6 to 58 ± 1.2 , 14 ± 0.6 to 86.20 ± 1.7 , and 224.5 ± 5.5 to 1650 ± 20.3 Bq kg^{-1} with a geometric mean value of 36.93 ± 1.0 , 51.60 ± 1.3 and 567.0 ± 11.0 Bq kg^{-1} respectively. According to UNSCEAR 2008 report, the Indian geometric mean activity concentration of ^{226}Ra , ^{232}Th and ^{40}K , in the soil samples are 29, 64 and 400 Bq kg^{-1} respectively [2]. From this study it is evident that, except ^{232}Th , the mean activity concentration of ^{226}Ra and ^{40}K are higher than the Indian average. According to UNSCEAR 2008 report, the world geometric mean activity concentration values of ^{226}Ra , ^{232}Th and ^{40}K for soil are 32, 45 and 412 Bq kg^{-1} respectively [14]. The estimated average values are slightly higher than world average values. The natural radioactivity in the soil depends on the activity of parent rock as well as the type of formation and transfer processes that are involved. In cores of such rock weathering and soil formation, chemical and geological interactions influence the distribution of primordial radionuclides and their decay products. The variation in the radionuclide concentration in the present study area depends on the local geological formation of the rocks. Generally, the higher radioactivity concentration was observed in granitic bed rock region while lower activity concentration was observed in sedimentary bed rock region [10, 12, 13].

The calculated value of indoor and outdoor GADR were found to vary from 59.2 to 255.4 nGy h^{-1} and 31 to 135 nGy h^{-1} with a geometric mean value of 136.1 nGy h^{-1} and 71.8 nGy h^{-1} respectively. The mean value of both indoor and outdoor GADR are higher than the global average value of 84 nGy h^{-1} and 57 nGy h^{-1} respectively [2]. The indoor and outdoor AED rate in soil is found to vary from 0.29 to 1.23 mSv y^{-1} and 0.04 to 0.16 mSv y^{-1} with an average of 0.66 mSv y^{-1} and 0.08 mSv y^{-1} respectively. The total AED rate due to radionuclides in the soil samples is found to vary from 0.33 to 1.39 mSv y^{-1} with a geometric mean value of 0.75 mSv y^{-1} . The outdoor annual average effective

dose is lower than the average value for India 0.084 mSv y^{-1} [21], and slightly higher than the world average value of 0.073 mSv y^{-1} [2]. The total AED rate is less than the safety limit (1 mSv y^{-1}) as proposed by UNSCEAR [11, 14].

The values of indoor GADR measured with survey meter were found in the range of 79 to 297 nGy h^{-1} with a mean value of 170.36 nGy h^{-1} . This value is approximately two times more than the world average of 84 nGy h^{-1} [22]. Similarly, outdoor GADR were found in the range of 60 to 276 nGy h^{-1} with an average value of 148.16 nGy h^{-1} . This value is approximately three times higher than the global average of 59 nGy h^{-1} [2]. The heterogenous distribution of gamma absorbed dose rate in air is mainly because of the primordial radionuclides like ^{238}U , ^{232}Th and ^{40}K series elements and their decay products present in the earth's crust, in air, building materials, water, food and the human body. These radionuclides have contribution of 25% for ^{238}U , 40% for ^{232}Th and 35% for ^{40}K to total gamma absorbed dose rate in air. The gamma absorbed dose rate measured with survey meter are higher than the calculated gamma absorbed dose rate from the soil. This is mainly because of the sources of natural background radiation. During the measurement with survey meter radionuclides from the earth's crust, building materials, rocks, water, air, and surrounding environment contribute to the gamma absorbed dose rate but the calculated gamma absorbed dose rate is mainly from collected soil samples.

The values of AED measured with survey metre for indoor exposures vary from 0.39 to 1.46 mSv y^{-1} with a mean value of 0.84 mSv y^{-1} . For outdoor exposure, AED ranges from 0.07 to 0.34 mSv y^{-1} with an average value of 0.18 mSv y^{-1} . The total AED thus measured from the survey meter for adults living in study area varies from 0.47 to 1.79 mSv y^{-1} with an average of 1.03 mSv y^{-1} . Nambi et al., found the dose levels in India to be (0.44 mSv y^{-1}) [21], except for the HBRAs in the states of Kerala and Tamilnadu. Thus, the cumulative gamma ray dose in Chikkamagaluru district is ≈ 2.2 times more than the mean value for typical Indian background regions.

To explain the presence of these radionuclides together at specific locations, correlation studies were carried out between the combinations of radionuclides. Correlation studies give a statistic representation of how closely two variables co-vary; Fig. 2a–c represents correlations between the activity concentrations of ^{226}Ra and ^{232}Th , ^{226}Ra and ^{40}K , and ^{232}Th and ^{40}K in soil samples, respectively. In all cases, the regression was found linear and positive. The Pearson correlation coefficient (R) between ^{226}Ra and ^{232}Th is 0.85: this strong correlation is due to the radionuclides having some similarities in their environmental origin in the rocks from which soils were formed and their chemical behaviour. The high positive correlation also suggests that the samples obtained in this area are geochemically coherent.

Table 1 Activity concentration of ^{226}Ra , ^{232}Th , ^{40}K , gamma absorbed dose, annual effective dose, and health hazard indices of soil samples

Sl no.	Locations	Activity of radionuclides (Bq kg^{-1})				Calculated				Measured				Hazard indices			
		^{226}Ra		^{232}Th	^{40}K	Absorbed dose (nGy h^{-1})		Annual effective dose (mSv y^{-1})		Absorbed dose (nGy h^{-1})		Annual effective dose (mSv y^{-1})		$R_{\text{a,eq}}$	H_{in}	H_{ex}	
		D_{in}	D_{out}	E_{in}	E_{out}	E_{total}	D_{in}	D_{out}	E_{in}	E_{out}	E_{total}	D_{in}	D_{out}	E_{in}	E_{out}	E_{total}	
1	Lakkavally	29.6±0.8	26.7±0.9	289.9±8.3	79.8	41.9	0.39	0.05	0.44	96	78	0.47	0.10	0.57	51.92	0.22	0.14
2	Rangenahally	44.2±1.1	52.8±1.3	424.5±11.4	132.7	70.1	0.65	0.08	0.73	174	138	0.85	0.17	1.02	76.89	0.33	0.21
3	Tarikere	33.5±1.0	42.4±1.2	394.8±6.5	109	57.5	0.53	0.07	0.6	162	135	0.79	0.17	0.96	63.9	0.26	0.17
4	Bukkambudi	21.8±0.9	34±1.1	371.1±6.4	87.1	46.1	0.43	0.06	0.49	79	65	0.39	0.08	0.47	50.37	0.19	0.14
5	Shivani	30.8±0.9	47.3±1.2	254.1±7.0	100.7	53.4	0.49	0.06	0.55	88	74	0.43	0.09	0.52	50.37	0.22	0.14
6	Bavikere	46.8±1.1	76.9±1.6	470.5±12.1	165.3	87.7	0.81	0.11	0.92	180	141	0.88	0.17	1.06	83.03	0.35	0.22
7	Malalichannahally	38.6±1.0	79.9±1.7	1650±20.3	255.4	134.9	1.23	0.16	1.39	297	269	1.46	0.33	1.79	165.7	0.55	0.45
8	Lingadahalli	41.1±1.0	66.4±1.6	584.3±12.7	157.6	83.4	0.77	0.11	0.88	184	169	0.90	0.21	1.11	86.09	0.34	0.23
9	Amruthapura	28.4±0.9	39.1±1.1	690.6±13.6	124.4	65.5	0.61	0.08	0.69	181	141	0.89	0.17	1.06	81.58	0.3	0.22
10	Ajjampura	28.9±0.9	49.3±1.3	1213.9±18.6	177.9	93.7	0.87	0.11	0.98	223	163	1.09	0.20	1.29	122.4	0.41	0.33
11	Kadur	33.7±1.0	41.3±1.2	299.5±7.2	100.4	53.1	0.49	0.06	0.55	94	88	0.46	0.11	0.57	56.76	0.24	0.15
12	Antraghutte	40.2±1.0	36.2±1.1	224.5±5.5	94.8	49.7	0.46	0.07	0.53	134	127	0.66	0.16	0.81	57.49	0.26	0.16
13	Singtagere	32.8±1.0	45±1.2	477.1±10.3	117.8	62.2	0.57	0.08	0.65	178	166	0.87	0.20	1.08	69.54	0.28	0.19
14	Hirenalluru	43.5±1.1	52.6±1.3	494.8±10.4	137.5	72.5	0.67	0.08	0.75	179	140	0.88	0.17	1.05	81.6	0.34	0.22
15	Chowlahiriyur	36.9±1.0	48.4±1.2	513.9±12.4	128.3	67.7	0.63	0.08	0.71	175	167	0.86	0.2	1.06	76.47	0.31	0.21
16	Yagati	43.5±0.8	53.7±1.3	305.1±6.2	123.5	65.2	0.61	0.07	0.68	164	155	0.80	0.19	0.99	66.99	0.3	0.18
17	Lakshnipura	24.0±0.7	35.1±1.1	419.7±10.1	94.3	49.7	0.46	0.06	0.52	105	90	0.52	0.11	0.63	56.32	0.22	0.15
18	Chikkangala	41.1±1.1	68.8±1.5	484.3±10.4	152.2	80.7	0.74	0.09	0.83	176	152	0.86	0.19	1.05	78.39	0.32	0.21
19	Panchanahally	53.9±1.3	75.9±1.6	1230.6±18.7	231.5	122.1	1.13	0.14	1.27	268	276	1.31	0.34	1.65	148.7	0.55	0.4
20	Mathighatta	26.2±0.9	37±1.1	656.6±14.2	117.3	61.8	0.57	0.07	0.64	190	198	0.93	0.24	1.17	76.76	0.28	0.21
21	Birur	30.8±0.9	47.5±1.2	554.1±11.0	124.9	66.1	0.61	0.08	0.69	156	137	0.77	0.17	0.93	73.47	0.28	0.2
22	Yemmedoddi	15.2±0.6	14±0.7	372.9±6.5	59.2	31	0.29	0.04	0.33	83	60	0.41	0.07	0.48	43.91	0.16	0.12
23	Sakarayatpata	55.1±1.2	83.6±1.7	683.8±14.3	197.3	104.5	0.96	0.12	1.08	205	153	1.01	0.19	1.19	107.8	0.44	0.29
24	Nidaghatta	44.8±1.1	49.9±1.3	790.5±11.4	159.3	83.8	0.78	0.11	0.89	209	182	1.03	0.22	1.25	105.7	0.41	0.29
25	Devanur	58.0±1.2	86.2±1.7	323.1±6.6	174.1	92.3	0.85	0.12	0.97	279	240	1.37	0.29	1.66	82.88	0.38	0.22
	Min	15.2±0.6	14±0.7	224.5±5.5	59.2	31	0.29	0.04	0.33	79	60	0.39	0.07	0.47	43.91	0.16	0.12
	Max	58±1.2	86.2±1.7	1650±20.3	255.4	135	1.23	0.16	1.39	297	276	1.46	0.34	1.79	165.7	0.55	0.45
	Average	36.93±1.0	51.6±1.3	566.97±12.3	136.1	71.8	0.66	0.08	0.75	170.36	148.16	0.84	0.18	1.01	80.59	0.32	0.22

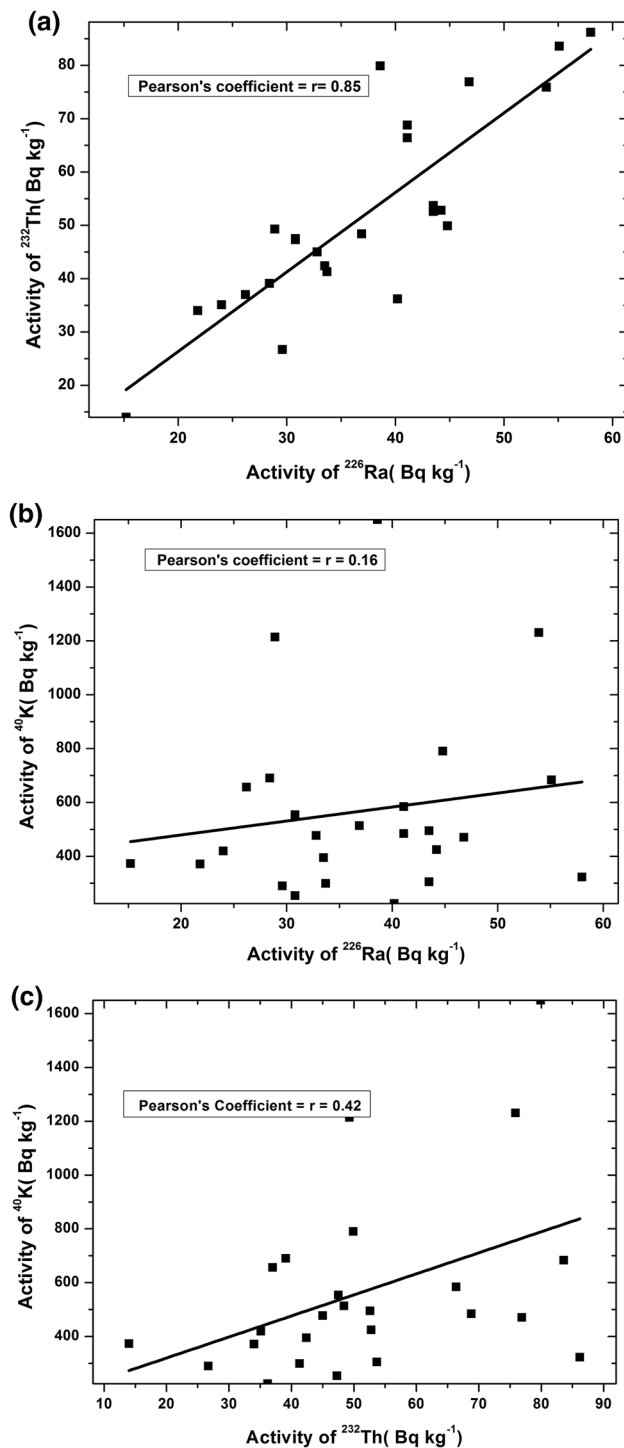


Fig. 2 **a** Correlation coefficient (R) between ^{226}Ra and ^{232}Th activity concentration in soil samples. **b** Correlation coefficient (R) between ^{226}Ra and ^{40}K activity concentration in soil samples. **c** Correlation coefficient (R) between ^{232}Th and ^{40}K activity concentration in soil samples

Comparatively a poor correlation coefficient between ^{226}Ra and ^{40}K ($R=0.16$) and between ^{232}Th and ^{40}K ($R=0.42$) was observed. This poor correlation predicts that a poor

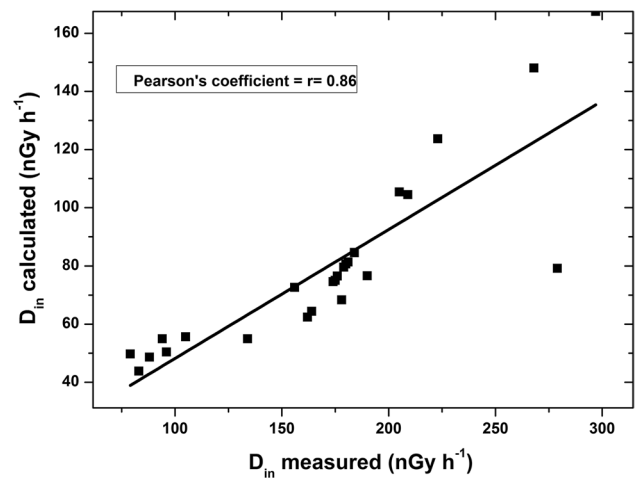


Fig. 3 Correlation coefficient between measured gamma absorbed dose rate and estimated gamma absorbed dose rate in soil

existence or a poor geochemical coherence between the radionuclides in the environs of the studied soil samples as compared to the ^{226}Ra and ^{232}Th . However, a positive correlation can also be due to the soil's ability to maintain these radionuclides under different environmental conditions.

The correlation study between estimated GADR rate in soil samples and measured GADR rate is also performed, and it is shown in the Fig. 3. From the Fig. 3, it is evident that there is a good positive correlation with a correlation coefficient of $R=0.86$ is observed. This indicates that the measured GADR and AED are mainly depending on activity concentration of the radionuclides in soil and depends on the various rock formations, forming the structure and geological process of the earth at the region [23]. Locations and lithological compositions of bedrock appear to be responsible for variations in radioactivity. The highest radionuclides activity concentration and higher AED was observed in some locations are mainly attributed by granite, which have more of primordial radionuclides (^{226}Ra , ^{232}Th and ^{40}K) than other rock types. The lowest activity was observed in some other locations are attributed by schiest and gneiss.

Radium equivalent activity (Ra_{eq}) and health hazard indices

The estimated Ra_{eq} activity value due to radionuclides present in the soil samples varies from 43.90 to 165.7 Bq kg^{-1} with a geometric mean value of 80.59 Bq kg^{-1} . All the Ra_{eq} values of the present study are $< 370 \text{ Bq kg}^{-1}$, the criterion limit recommended by UNSCEAR 2000 [2]. The calculated internal (H_{in}) and external (H_{ex}) radiation hazard indices values of soil samples varies from 0.16 to 0.55 with an average value of 0.32 and 0.12 to 0.45 with a geometric mean value of 0.22 respectively. It is reported

Table 2 The average activity concentration of ^{226}Ra , ^{232}Th , and ^{40}K recorded in literature for different region soil samples

Country	Activity concentration (Bq kg ⁻¹)			References
	^{226}Ra	^{232}Th	^{40}K	
World average	33	45	420	[18]
Indian average	29	64	400	[18]
China	40	59.6	751.2	[24]
Italy	26.9	79	680	[25]
Greece	53	21	654	[26]
Coastal Karnataka	35.0	29.8	117.5	[27]
Mysore city	30.9	61.0	374	[28]
Bangalore	16.9	15.2	486.7	[29]
Bangalore rural	40.7	93.1	750.4	[30]
Bangalore	26.2	53.1	635.1	[31]
Mandya	40.57	72.76	639.92	[32]
Granite region of Karnataka	52.9	73.8	750.1	[33]
Mysore city	13.67	21.26	220	[34]
Kaiga	31.3	27.5	159.9	[35]
Gogi region	36	85	859	[36]
Udupi and Karkala taluks	34.4	45.3	198.6	[37]
North Karnataka	18.94	38.86	546.3	[38]
Tumkur district	36.59	80.37	844.65	[10]
Ramanagara district	33.14	80.01	791.24	[10]
Chikkamagaluru district	36.93	51.60	566.97	Present study

that generally the values of (H_{in}) and H_{ex} is less than 1 [23]. The geometric mean values for H_{ex} and H_{in} due to natural radionuclides present in soil are less than unity which is highly acceptable and within safe limit [11, 22]. The hazard indices H_{in} , H_{out} are much less than one, indicates that there is no significant health hazards due to soil samples taken from this study area. The soil is suitable for construction of buildings.

The average activity concentration of the three primordial radionuclides as obtained in the present investigated soil are compared with the values reported in other parts of India and world as shown in Table 2 [24–38]. The average ^{226}Ra , ^{232}Th and ^{40}K activity concentration of the present results slightly higher than the similar results reported from Mysore city, Bangalore, Coastal Karnataka, Udupi and Karkala taluks of Karnataka state [27–29, 37]. The obtained average activity concentrations are lower than the similar results report from granite regions of Karnataka state, Ramanagara district, Tumkur district, Bangalore rural district and Mandya district of Karnataka state [10, 30, 32, 33].

Conclusions

From the study it is observed that the average activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in soil of the study area was slightly higher than Indian and world average values. The estimated indoor and outdoor GADR was varying between 59.2 to 255.4 nGy h⁻¹ and 31 to 135 nGy h⁻¹ with an average value of 136.1 nGy h⁻¹ and 71.8 nGy h⁻¹ respectively. The calculated average indoor and outdoor gamma absorbed dose rate values are higher than the world average value of 84 nGy h⁻¹ and 57 nGy h⁻¹. The measured gamma absorbed dose rate values are higher than calculated gamma absorbed dose rate. The calculated total AED rate is less than the safety limit of 1 mSv y⁻¹ as proposed by UNSCEAR. The calculated average values of all the hazard indices were lower than the criterion limits. The soil samples could be used as building materials, indicating that soil samples were not significant sources of radiation health hazards. The soil is suitable for construction of buildings.

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