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Natural radioactivity level in soils around Kolar Gold Fields, Kolar district, Karnataka, India

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Abstract The study on natural radioactivity level in the soil plays a significant role in health physics. The present study has been carried out with the aim of estimating activity concentration of radionuclides in soil samples collected at 30 places around Kolar Gold Fields, Kolar district using gamma ray spectrometry. Average values of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples of the present study are 27.3 ± 1.8, 63.1 ± 2.5 and 818 ± 6 Bq kg^{-1}, respectively. The average radium equivalent activity (Ra_{eq}), absorbed dose rate and annual effective dose have been calculated and compared with the referred safe values.

Keywords Primordial radionuclides · Soil · Dose · Hazard indices

Introduction

Soil is one of the essential natural resources available in upper layer of the earth crust. It consists of organic matter, mineral particles, air, organisms and water [1, 2]. Soil is derived from the parent rocks. The activity of radionuclides in soil mainly depends on activity of radionuclides present in the parent rock, types of rock, interaction of rock with water and meteorological parameters and chemical changes. Physiochemical properties of soil play a vital role in the distribution, concentration and behavior of radionuclides in soil [3–5]. People living in granite or mineralized sand areas receive more terrestrial radiation compared to other areas. The public living or working at high altitude receive more cosmic radiation [6–8]. Whether it is natural or artificial radionuclides, they are accessible for uptake by animals and plants and enter the human food chain [9]. When radionuclides enter the atmosphere, they undergo decay and get deposited on the surface of the earth by dry or wet deposition within relatively short periods. They initially get deposited on the top surface of the soil, but rapidly diffuse into the first few centimeters of the soil [10]. The activity of radionuclides in food grains also depends on the activity of radionuclides present on the top surface of the soil. Hence, assessment of radiological risk due to the radionuclides present in soil is very important.

The area of present study is around Kolar Gold Fields (KGF), Kolar located at latitude 13°07′48″N and longitude 78°13′48″E. The second deepest underground mines Bharath Gold Mine Limited (BGML) is located in the area of study. Geologically, the study area belongs to hornblende gneiss, closepet granite, quartzite, champion gneiss, metabasalt, dolerite dyke and grey granite. The metabasalt overlying the champion gneiss is composed of massive schistose and granular varieties of amphibolite showing primary volcanic structure such as pillows, variolites and amygdales. Post Dharwar intrusive present in the study area are granite, dolerite and quartz veins. Granite occurs as plutons, tongues and apophyses within the peninsular gneiss.

The key economic mineral deposit in the study area is gold. KGF is known to contain 26 numbers of gold bearing quartz lodes and the bulk of the metal has come from the

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main Champion quartz lode system having a strike length of 8 km and worked to a maximum vertical depth of about 3209 m. More than 800 tonne of gold has been produced from the mining. Major portion of the study area consists of granite and hornblende gneiss. The types of soil in study area are red sandy/loamy and lateritic. Geological map of the study area with selected places is as shown in Fig. 1. Kolar district is called the land of silk, milk, and gold.This study is important to provide baseline datafor the general public of the study area from the health point view. Furthermore, no research work on measurement of radionuclides concentration in the soil has been carried out in Kolar district till day.

Materials and methods

Collection and preparation of soil sample

The soil samples were collected at 30 different places of the study area. The places, which were free from surface runoff during heavy rain, were carefully selected. An area of $\sim$ 0.5 m^2 was cleared of vegetation and roots. The marked spot was dug up to a depth of 15 cm and $\sim$ 2 kg soil was collected at each place. Finally, the samples were mixed thoroughly and extraneous materials like plants, debris, big pieces of stones and pebbles were removed and the samples were transferred to a porcelain dish [11]. These samples were kept in an oven for overnight at 110 °C to remove water content in the samples. Then the samples were sieved through 200 μm mesh. About 300 g of each sample was taken and packed in a 300 ml plastic container and left for at least 40 days before taking readings to attain radioactive equilibrium between ^{226}Ra, ^{222}Rn and their progeny.

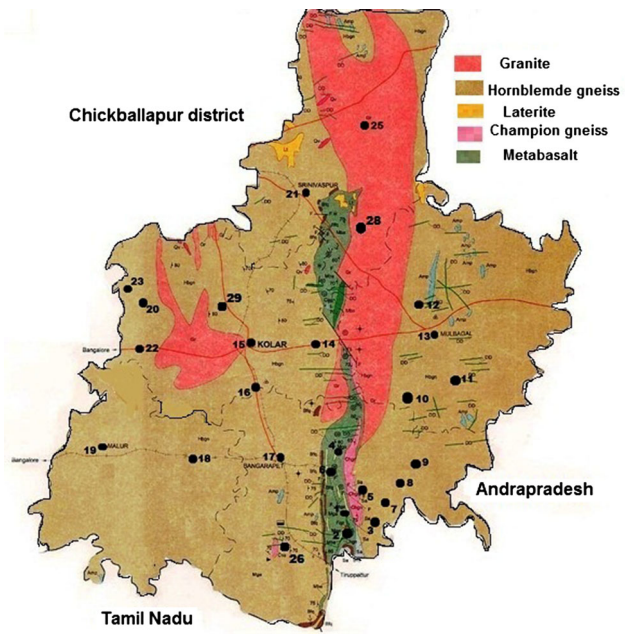

Fig. 1 Geological map of Kolar District with location numbers

Activity concentration of radionuclide

The gamma ray spectrometric procedure is used to determine the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the collected soil samples at different places of the study area [12]. The detector used is Hyper Pure Germanium (HPGe) detector (41% efficiency n-type detector, Canberra Industries, Inc., Meriden, CT, USA) coupled to a DSA-1000 with 16 K Multi Channel Analyzer. The detector was enclosed in a 0.1-m thick graded lead shield (Model 747, Canberra, USA). The detector has an in-built 2002 CSL FET cooled charge sensitive pre-amplifier. As discussed above, the output pulses from the detector are amplified using this pre-amplifier. The signal from the pre-amplifier is then fed to a computer controlled Digital spectrum analyser (DSA −1000) unit which is plugged to a PC. This DSA-1000 unit consists of linear amplifier, high voltage supply (0–5000 V), Analogue to Digital convertor (ADC), and a 16 K Multi Channel Analyser (MCA). This MCA is one of the most advanced systems with the option to analyse both the background and sample spectra, simultaneously. The MCA has built in Analogue to digital converter capable of producing highly accurate data transformation and categorisation. Each channel in the MCA is defined as an arbitrary interval of time, ranging from 10 ms to 1 s per channel.

Activity of ^{226}Ra, ^{232}Th and ^{40}K was determined from photo peaks of ^{214}Bi (609.3, 1129.3 and 1764.5 keV), ^{228}Ac (911.2 keV) and 1460.8 keV, respectively, after subtracting the background counts and applying Compton corrections. The detector efficiency calibration was performed using the IAEA quality assurance reference materials: RG U-238, RG Th-232 and RG K-1. The minimum detection levels (MDL) for the detecting system used in this study were 0.9, 1.2, and 4.0 Bq kg^{-1}, respectively, for ^{226}Ra, ^{232}Th, and ^{40}K, for a counting time of 60,000 s. The activity of radionuclides (in Bq kg^{-1}) is calculated by using the relation [13]

$$A\left(\text{Bq kg}^{-1}\right) = \frac{(s \pm \sigma) \times 100 \times 1000 \times 100}{EWa} \quad (1)$$

where A is the activity of radionuclide (Bq kg^{-1}), s is the net counts per second under the photo peak of intensity, σ is the standard deviation of s, E is the counting (%) efficiency, a is the gamma abundance (%) of the radionuclide's and W is the mass of the sample (kg).

Ambient gamma radiation level

Ambient gamma radiation levels in the outdoor atmosphere at all the places of soil samples have been collected and measured using scintillometer [Type SM 141D, ECIL]. The detector is a thallium activated sodium iodide crystal optically coupled to a photomultiplier. All the readings have been taken at 1 m above the ground level. At each place 5–6 readings have been taken, and then the average of all these readings has been taken. By using the conversion factor, exposure rate ($\mu R\ h^{-1}$) is converted into absorbed dose rate (nGy h^{-1}) 1 $\mu R\ h^{-1} = 8.7$ nGy h^{-1} [14].

Results and discussion

Distribution of radionuclides in soil samples

The average activity concentration of naturally occurring radionuclides such as ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected at places around KGF are measured using HPGe detector. The obtained values are summarized in the Table 1. From the Table 1, the average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are varied from 15.7 ± 2.5 to 41.9 ± 1.8, 37.0 ± 1.5 to 92.8 ± 3.6, and 481 ± 4 to 1125 ± 11 Bq kg^{-1} with an average value of 27.3 ± 1.8, 63.1 ± 2.5 and 818 ± 6 Bq kg^{-1}, respectively. The study shows that activity of ^{226}Ra and ^{232}Th is relatively lower than that of ^{40}K. Activity concentration of thorium is higher than that of radium at all locations [15]. The ratio of ^{232}Th and ^{226}Ra varies between 1.6 and 3.2 with an average value of 2.4. This ratio gives the sign of relative presence of uranium and thorium. The activity concentration of radium is lower than thorium at all places. This is due to pegmatite introduced in rocks and mineral composition [15].

From the Table 2, max concentration of radionuclides in soil samples have been observed at places such as Kolar, Nelawanki, Yalduru and Srinivaspur. This is due to types of rock from which the soil has been originated. The rocks in these locations are granite. Activity of radionuclides is more in granite rocks when compared to other types of rocks [16] Slightly lesser concentration of ^{226}Ra and ^{232}Th in soil samples have been observed at the locations of Narasapura, Masthi, Sugaturu when compared to Nelawanki, Yalduru, Srinivaspur and Kolar. This is due to geology of these locations that consists of hornblende gneiss and amphibolites. These consist of less activity of radionuclides compared to granitic rocks. The minimum concentration of ^{226}Ra and ^{232}Th in soil samples has been observed at the locations of Andersonpet, BEML Nagar, Marikuppam. This is because of local geology. These locations consist of metabasalt, metagabbro, quartzite and Schist, and these have less activity concentration of radionuclides compared to granitic rocks [17].

The present study reveals that the average activity concentration of ^{226}Ra is found less, and activity concentration of ^{232}Th and ^{40}K are found higher than the world average values of 32, 45 and 420 Bq kg^{-1} and Indian average values of 29, 64 and 400 Bq kg^{-1}, respectively [10]. The activity concentration of primordial radionuclides such as ^{226}Ra, ^{232}Th and ^{40}K in soil samples of different environment are compared with the values obtained in the study area and has been summarized in the Table 2.

The correlation between the activity concentrations of ^{226}Ra and ^{232}Th are shown in Fig. 2. This shows that there is a positive correlation between activity concentrations of ^{226}Ra and ^{232}Th with correlation coefficient 0.65. The correlation between ^{40}K and ^{226}Ra and ^{40}K and ^{232}Th are shown in Figs. 3 and 4. These correlations show positive values with the coefficient values of 0.49 and 0.45, respectively. The correlation shows the property of the soil in retaining these radionuclides under changing weather conditions. It indicates that the individual result for any one of the radionuclide concentration in every pair is a good interpreter of other concentration.

Radium equivalent activity (Ra_{eq})

In India, local soil is used as building material directly or indirectly. Ra_{eq} is calculated due to the presence of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in collected samples using their activity concentration using the relation [18, 19]

$$Ra_{eq}\left(Bq\ kg^{-1}\right) = A_{Ra} + 1.43A_{Th} + 0.07A_{K} \quad (2)$$

where A_{Ra}, A_{Th}, and A_K, are the measured activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively and the values are summarized in Table 3. The values vary between 102.3 and 242.7 Bq kg^{-1} with an average value of 174.8 Bq kg^{-1}, less than the criterion limit of 370 Bq kg^{-1} [18]. This shows that the collected soil samples of study area does not create any radiological hazard when it is used as building material for construction. Correlation between activity concentration of ^{232}Th and Ra_{eq} with the coefficient value 0.918 has been observed (Fig. 5). This shows that radium equivalent activity is mainly due to concentration of ^{232}Th in soil samples.

Hazard indices

The ultimate use of the measured activity concentrations was to assess the radiological hazards. Radiological hazard indices such as alpha index, gamma index, internal hazard

Table 1 The average activity of ^{226}Ra, ^{232}Th and ^{40}K in soil samples with ^{232}Th/^{226}Ra ratio at different places of the study area

S. no	Place	Activity of radionuclides in Bq kg^{-1}			^{232}Th/^{226}Ra
		^{226}Ra	^{232}Th	^{40}K	
1	Robertson Pet	20.3 ± 1.2	63.3 ± 1.7	825 ± 16	3.1
2	Anderson Pet	19.8 ± 1.3	52.3 ± 2.9	608 ± 5	2.6
3	Marikuppam	16.0 ± 0.8	43.9 ± 3.3	748 ± 5	2.7
4	Sambhram hospital	17.2 ± 2.1	48.4 ± 1.2	626 ± 2	2.8
5	Krishnapuram	18.5 ± 1.9	38.7 ± 0.9	574 ± 4	2.1
6	BEML nagar	15.7 ± 2.5	37.0 ± 1.5	481 ± 4	2.3
7	Nachandlahalli	19.2 ± 1.5	54.7 ± 1.1	787 ± 2	2.8
8	Kyasamballi	23.4 ± 1.3	49.6 ± 1.5	891 ± 4	2.1
9	Bethamangala	24.4 ± 1.8	66.5 ± 2.7	768 ± 13	2.7
10	Bangaruthirupathi	25.8 ± 2.5	61.4 ± 3.6	859 ± 4	2.4
11	Tayalur	27.4 ± 1.6	44.3 ± 2.4	844 ± 4	1.6
12	Cheluvanayakanahalli	28.3 ± 1.9	68.3 ± 4.7	756 ± 6	2.4
13	Mulbagal	31.8 ± 2.3	68.1 ± 3.3	1071 ± 5	2.1
14	Thambihalli	29.6 ± 1.5	72.4 ± 3.5	881 ± 5	2.4
15	Kolar	41.9 ± 1.8	82.8 ± 4.3	1125 ± 11	2.0
16	Hudukula	25.6 ± 1.5	61.4 ± 3.4	884 ± 4	2.4
17	Bangarpet	21.1 ± 1.4	67.6 ± 2.5	764 ± 11	3.2
18	Tyakal	32.2 ± 2.4	65.9 ± 1.8	620 ± 7	2.0
19	Malur	35.6 ± 3.1	74.5 ± 3.1	1006 ± 6	2.1
20	Vemgal	27.6 ± 2.2	73.7 ± 2.2	870 ± 4	2.7
21	Srinivaspur	38.4 ± 1.3	84.2 ± 2.7	970 ± 5	2.2
22	Narasapura	33.1 ± 1.9	59.5 ± 1.7	731 ± 5	1.8
23	Kyalnur cross	29.6 ± 0.9	73.3 ± 2.1	823 ± 3	2.5
24	Narsapura industrial area	34.2 ± 1.8	76.3 ± 1.9	918 ± 6	2.2
25	Nelawaki	40.3 ± 2.3	92.8 ± 3.6	995 ± 8	2.3
26	Kamasandra	21.4 ± 1.3	47.6 ± 1.9	752 ± 7	2.2
27	Masthi	26.4 ± 0.8	56.5 ± 2.3	944 ± 3	2.1
28	Yalduru	29.4 ± 2.2	86.7 ± 2.4	878 ± 5	2.9
29	Sugaturu	35.6 ± 1.5	68.4 ± 3.1	768 ± 7	1.9
30	Vokkateri	29.3 ± 1.8	53.0 ± 1.6	775 ± 4	1.8
Minimum		15.7 ± 2.5	37.0 ± 1.5	481 ± 4	1.6
Maximum		41.9 ± 1.8	92.8 ± 3.6	1125 ± 12	3.2
Average		27.3 ± 1.8	63.1 ± 2.5	818 ± 6	2.4

index and external hazard index values have also been calculated for the soil samples from the study area.

Alpha index (I_α)

The alpha index ($I\alpha$) in Bq kg^{-1} gives the excess alpha radiation due to radon inhalation originating from building materials, such as soil, which is defined as [20]

$$I_\alpha = \frac{A_{\mathrm{Th}}}{200} \tag{3}$$

where A_{Ra} is the activity concentration of ^{226}Ra in Bq kg^{-1}. The recommended maximum concentration of ^{226}Ra is 200 Bq kg^{-1}, which gives I_α is equal to unity.

Alpha index (I_α) values of all the collected samples in the area of study vary from 0.08 to 0.21 with an average of 0.14 which is less than the recommended maximum value of 1. This shows that the radon exhalation from soil samples would cause indoor concentration less than 200 Bq m^{-3}.

Gamma index (I_γ)

As per the European Commission [21], gamma index ($I\gamma$) defined by the following relation [21]. It has been introduced to account for the combined impact of ^{226}Ra, ^{232}Th and ^{40}K as radiological hazard associated with material.

Table 2 Comparison of activity of radionuclides from soil samples collected from the study area with the values obtained at different regions of the world

Location	Activity of radionuclides (Bq kg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
Turkey	82.3–167	152–275	1015–1484	[24]
Spain	13–165	7–204	48–1586	[25]
Shabwah and Hadramout regions, Yemen	13.1–15.4	22.8–29.0	510.9–600.8	[26]
USA	8.0–160	4–130	100–700	[27]
Namibia	45–48	3–38	42–1100	[28]
Haryana (India)	13.3-21.4	34.6-54.4	298.8-398.8	[29]
Vishakapatnam (India)	19–66	61–366	99–1120	[30]
Ramanagar and Tumkur (India)	14.4–50.5	42.2–116.1	388.9–1563.6	[31]
Bangalore rural district (India)	32.4–55.2	39.9–214.3	485.4–1150.2	[16]
World average	32	45	420	[10]
Kolar (India)	15.7–41.9	37.0–92.8	481–1125	Present study

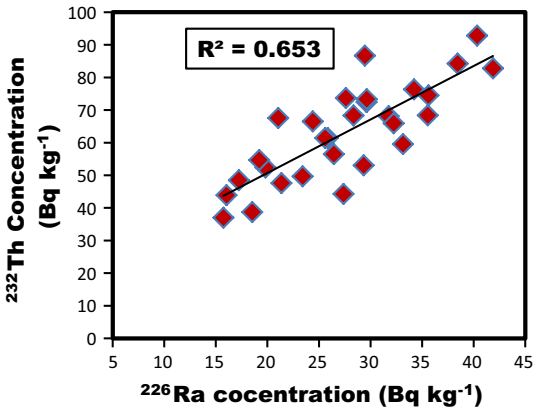

Fig. 2 Correlation between ^{226}Ra and ^{232}Th concentration of the soil samples

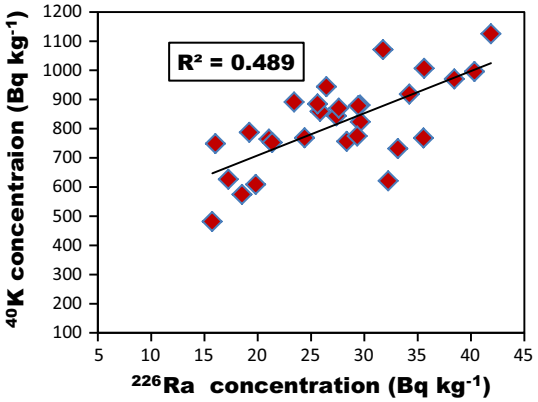

Fig. 3 Correlation between ^{226}Ra and ^{40}K concentration of the soil samples

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (4)$$

where A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K respectively in any material. Materials

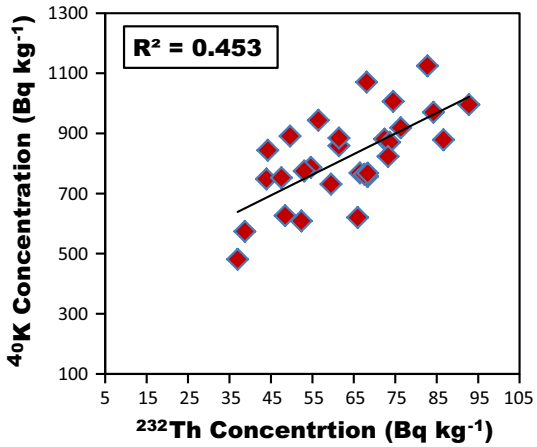

Fig. 4 Correlation between ^{232}Th and ^{40}K concentration of the soil samples

having $I_\gamma \leq 2$ will make an increase of 0.3 mSv in the annual effective dose. Whereas $2 < I_\gamma \leq 6$ correspond to an increase of 1 mSv year^{-1} [20, 21]. Gamma index (I_γ) values in soil samples of the area of study vary from 0.398 to 0.930 with an average value of 0.679, within the recommended safe limit of 1 as per European Commission [21].

Internal hazard index (H_{in})

The internal exposure to radon and its daughter products is controlled by the internal hazard index (H_{in}) and is given by the relation [21]

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

where A_{Ra}, A_{Th}, and A_K, represent the measured activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. For safe use of soil H_{in} should be < 1 [22]. Internal hazard index (H_{in}) values of all the collected

Table 3 Radium equivalent activity, absorbed dose (calculated and measured) and annual effective dose of soil samples at different places of the study area

S.no	Place	Ra_{eq} (Bq kg^{-1})	Absorbed dose (Calc.) (nGy h^{-1})		Absorbed dose (Meas.) nGy h^{-1})	Annual effective dose (μSv $year^{-1}$)		
			Indoor	Outdoor	Outdoor	E_{in}	E_{out}	Total dose = (E_{in} + E_{out})
1	Robertson pet	168.6	157.1	82.0	132.4	773.4	100.6	874
2	Anderson Pet	137.3	126.9	66.1	93.2	622.6	81.1	703.7
3	Marikuppam	131.2	125.9	65.1	96.3	617.6	79.9	697.5
4	Sambhram hospital	130.4	121.8	63.4	72.5	597.4	77.7	675.1
5	Krishnapuram	114.1	107.9	55.9	82.3	529.1	68.5	597.6
6	BEML nagar	102.3	95.6	49.7	89.8	468.8	60.9	529.7
7	Nachandlahalli	152.5	143.9	74.7	86.4	706.1	91.6	797.8
8	Kyasamballi	156.8	151	78.0	102.3	740.7	95.6	836.3
9	Bethamangala	173.3	160.2	83.5	108.2	785.7	102.4	888.1
10	Bangaruthirupathi	173.8	163.5	84.9	112.3	801.9	104.1	906
11	Tayalur	149.7	144.8	74.6	109.3	710.1	91.5	801.6
12	Cheluvanayakanahalli	179.0	164.8	85.9	103.5	808.3	105.4	913.7
13	Mulbagal	204.1	194.1	100.5	135.4	952.1	123.2	1075.4
14	Thambihalli	194.8	180.9	94.2	127.3	887.3	115.5	1002.8
15	Kolar	239.0	224.1	116.3	157.3	1099.2	142.6	1241.7
16	Hudukula	175.3	165.4	85.8	97.3	811.4	105.2	916.7
17	Bangarpet	171.2	157.9	82.4	103.7	774.4	101	875.4
18	Tyakal	170.0	154.3	80.6	92.4	757.1	98.9	855.9
19	Malur	212.6	199.3	103.4	148.8	977.6	126.9	1104.4
20	Vemgal	193.9	179.5	93.5	117.4	880.7	114.7	995.4
21	Srinivaspur	226.8	209.5	109.1	134.2	1027.8	133.8	1161.6
22	Narasapura	169.4	157.4	81.8	124.8	772.1	100.3	872.3
23	Kyalnur cross	192.1	177	92.3	136.8	868.4	113.2	981.6
24	Narsapura industrial area	207.7	192.6	100.2	142.7	944.8	122.9	1067.7
25	Nelawaki	242.7	222.8	116.2	158.2	1093	142.5	1235.5
26	Kamasandra	142.1	135.2	70.0	87.6	663.1	85.8	749
27	Masthi	173.2	165.7	85.7	98.4	812.9	105.1	917.9
28	Yalduru	214.9	196.2	102.6	166.7	962.5	125.8	1088.3
29	Sugaturu	187.1	172.4	89.8	145.3	845.9	110.1	955.9
30	Vokkateri	159.4	150.4	77.9	96.6	737.7	95.5	833.3
Minimum		102.3	95.6	49.7	72.5	468.8	60.9	529.7
Maximum		242.7	224.1	116.3	166.7	1099.2	142.6	1241.7
Average		174.8	163.3	84.9	115.3	801.0	104.1	905.1

samples range from 0.328 to 0.783 with an average value of 0.561. All the values are found to be less than the maximum limit of 1 as per European Commission [21].

External hazard index (H_{ex})

The external hazard index (H_{ex}) evaluates the indoor radiation dose rate due to the external exposure to gamma radiation from the natural radionuclides, which is given by the relation [10]

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

where A_{Ra}, A_{Th}, and A_K, represent the measured activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The maximum value of H_{ex} is unity. External hazard index (H_{ex}) values of all samples vary from 0.285 to 0.674 with an average value of 0.488 less than the recommended value. This shows that, soil from these locations is safe and can be used a building material for construction without posing any considerable radiological threat to public.

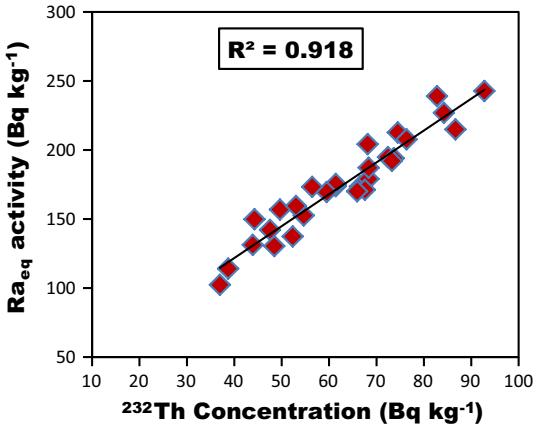

Fig. 5 Correlation between ^{232}Th and Ra_{eq} activity concentration of the soil samples

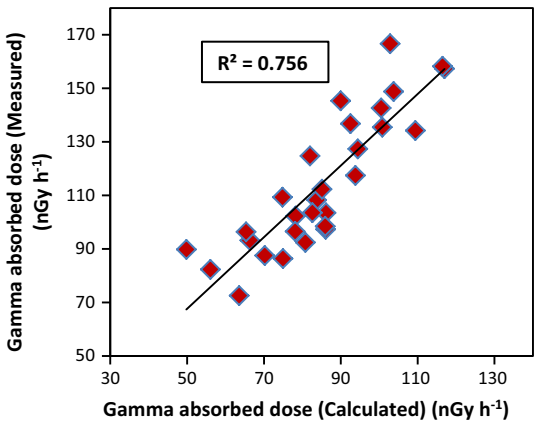

Fig. 6 Correlation between gamma absorbed dose measured values using scintillometer with calculated values using activity of radionuclides in soil

Absorbed dose rate (D)

The indoor absorbed gamma dose rate in air (D_{in} nGy h^{-1}) at a height of $\sim$ 1 m above ground level due to individual natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil samples has been calculated by using equation [21];

$$D_{in}\left(\text{nGy h}^{-1}\right) = 0.92A_{Ra} + 1.1A_{Th} + 0.084A_{K} \quad (7)$$

where 0.92, 1.1 and 0.084 are the activity to indoor dose rate conversion factors in nGy h^{-1} per Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The indoor absorbed dose lies between 95.6 and 224.1 nGy h^{-1} with an average value of 163.3 nGy h^{-1} (Table 3).

The outdoor absorbed gamma dose rate (D_{out} nGy h^{-1}) in air has been calculated using the equation;

$$D_{out}\left(\text{nGy h}^{-1}\right) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_{K} \quad (8)$$

where A_{Ra}, A_{Th}, and A_{K}, are the measured activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. 0.462, 0.604 and 0.0417 are corresponding dose coefficients. The outdoor absorbed dose lies between 49.7 and 116.6 nGy h^{-1} with an average value of 84.9 nGy h^{-1} (Table 3), which is higher than the population weighted average value for outdoor 59 nGy h^{-1} [10]. Outdoor absorbed gamma dose with ^{226}Ra, ^{232}Th and ^{40}K concentration of the soil samples shows good correlation coefficients of 0.789, 0.886 and 0.755, respectively. The measured value of absorbed gamma dose from scintillometer varies from 72.5 to 166.7 nGy h^{-1} with an average value of 115.3 nGy h^{-1} (Table 3). Figure 6 shows positive correlation between radiation dose measured from scintillometer and the calculated dose from activity concentration of radionuclides in the soil samples with correlation coefficient of 0.756.

Table 4 Comparison of average outdoor annual effective dose rate from present study with the values obtained at other parts of the world

Region	Average annual eff. dose (μSv year^{-1})	References
China	76.0	[31]
Egypt	39.2	[32]
Switzerland	55.2	[10]
Thailand	94.4	[10]
Serbia and Montenegro	81.9	[33]
Cyprus	10.7	[34]
Iran	87.1	[10]
Kirklareli, Turkey	144.0	[35]
Brazil	552.0	[36]
Vishakhapatnam (India)	130.0	[37]
Gogi region (India)	110.0	[38]
Ramanagara and Tumkur(India)	116.0	[29]
World average	70	[10]
Kolar (India)	104.1	Present study

Annual effective dose

Indoor and outdoor annual effective dose rate (E_{in} and E_{out} in μSv year^{-1}) are estimated from calculated indoor and outdoor absorbed gamma dose (D_{in} and D_{out} in nGy h^{-1}) by using the equations;

$$E_{in}\left(\text{mSv year}^{-1}\right) = D_{in} \times 8760 \times \text{OF} \times \text{CF} \quad (9)$$

$$E_{out}\left(\text{mSv year}^{-1}\right) = D_{out} \times 8760 \times \text{OF} \times \text{CF} \quad (10)$$

where D_{in} and D_{out} are the indoor and outdoor absorbed dose respectively in nGy h^{-1}, OF is the Occupancy Factor and it is 0.2 for outdoor and 0.8 for indoor. CF is the Conversion Factor from absorbed dose rate in air to effective dose received by the person (0.7×10^{-6} Sv year^{-1}). The time spent in the indoor and outdoor is 8760×0.8 and 8760×0.2 hy^{-1}, respectively. The values are presented in Table 3. The indoor annual effective dose value varies between 468.8 and 1099.2 μSv year^{-1} with an average value of 801.0 μSv year^{-1} and the outdoor values lie between 60.9 and 142.6 μSv year^{-1} with an average value of 104.1 μSv year^{-1} which is higher than the world average value of 70.0 μSv year^{-1} [10]. Total dose values vary between 529.7 and 1241.7 μSv year^{-1} with an average value of 905.1 μSv year^{-1}. This average value is less than the recommended safe limit of 1000 μSv year^{-1} by ICRP for the individual members of the public [23]. A comparative study of average outdoor annual effective dose rate obtained from the present work has been made with the different areas of the world, and is mentioned in Table 4.

Conclusion

The present study reveals that activity of thorium is more than that of radium in soil samples in and around of Kolar Gold Field, Kolar District. It has been observed that soil originated from granitic region has higher activity of radionuclides than the soil originated from gneiss, metabasalt, metagabbro, amphibolites. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples were 27.3, 63.1 and 818 Bq kg^{-1}, respectively. The values of activity concentration of ^{232}Th and ^{40}K in soil samples of the study area are higher than Indian and Global average values. The radium equivalent activity (174 Bq kg^{-1}) is found less than the recommended safe value (370 Bq kg^{-1}). The absorbed dose rate is calculated from activity of radionuclides and found greater than the world average value. The measured dose rate (84.9 nGy h^{-1}) and calculated absorbed dose rate (115.3 nGy h^{-1}) are exceeding the world average (59 nGy h^{-1}). The calculated values of hazard indices were less than unity.

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