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Measurement of activity concentration of primordial radionuclides in soil samples from Thirthahalli taluk and the assessment of resulting radiation dose

G. M. Shilpa[1] · B. N. Anandaram[2] · T. L. Mohankumari[3]

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Abstract
The activity concentration of primordial radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in soil samples of Thirthahalli taluk were measured systematically by using a low background HPGe detector coupled to 16 K MCA. The measured activity concentration of ^{226}Ra lies between 5.1 ± 0.2 and 79.5 ± 1.7 Bq kg^{-1}with an average activity of 25.99 Bq kg^{-1}, ^{232}Th ranges from 5.1 ± 0.3 to 95.3 ± 2.2 Bq kg^{-1}with an average activity of 33.60 Bq kg^{-1}and that of ^{40}K varies from 18.3 ± 1.5 to 833.4 ± 17.5 Bq kg^{-1}with an average activity of 175.52 Bq kg^{-1}. Higher concentration of these radionuclides were found in the soil samples where the regional geology is granites. The consequential gamma dose and the corresponding radiation hazard was also estimated and is found to be within the permissible limits. The possible radiological impact on the public was also determined and these results are presented in this paper.

Keywords Gamma spectrometry · Gamma absorbed dose · Radiation hazard index · Excess life time cancer risk

Introduction

Man is continuously exposed to ionizing radiations arising from the primordial radionuclides such as ^{238}U, ^{232}Th and their decay products and ^{40}K. Long term exposures to radioactivity and inhalation of radionuclides have serious health effects such as chronic lung cancer and leukemia [1]. These radionuclides are present in environmental matrices such as rock, soil, water, building materials etc., to various levels. Soil is formed by weathering of rocks in the earth's crust, which makes the presence of radionuclides in the soil. Hence soil can be considered as the major component of radiation to the mankind. The radionuclide uptake by the plants from the soil leads to the radionuclides in the human food chain. Thus soil serves as a mediator for transfer of radionuclides to biological system. Further, it is used for many purposes such as construction of dwellings, building materials, land filling in playground, for streets, garden etc., contributing to the indoor and outdoor radiation exposure [2, 3]. Owing to this fact, the soil analysis for the presence of radionuclides is much significant for the radiological assessment and to provide reference data in observing possible future anthropomorphic impact and associated radiological risk to human health [4]. Research studies have revealed that natural environmental radioactivity and the associated external exposure due to gamma radiation depends mainly on the geological and geographical conditions of the study area [5–8]. Although the present study area is away from the high background areas, the preliminary study on gamma radiation survey has shown slightly higher radiation dose to the local population residing in this area [9] compare to all India average and world average values [8, 10]. Similar type of study was carried out in the surrounding taluk Shimoga [11] and the

✉ G. M. Shilpa
gmshilpa.82@gmail.com

B. N. Anandaram
bnaram@jnnce.ac.in

T. L. Mohankumari
mohankumari.tl@gmail.com

[1] Research and Development Center, Bharathiar University, Coimbatore, Tamilnadu, India

[2] Department of Physics, J.N.N. College of Engineering, Shivamogga, Karnataka, India

[3] Department of Physics, Sir M.V. Science College, Bhadravathi, Karnataka, India

results reported are of significant in the granatic region. Hence to obtain the radiation map for the entire Shimoga district, and also to provide the base line data for further radiological assessments. A systematic study has been carried out in 25 locations in and around Thirthahalli taluk which is first of its kind in this part of the world.

Study area

Thirthahalli is the taluk headquarters of Shimoga district, Karnataka state, located in the southern part of India. It lies between 13°14′N latitude and 75°14′E longitude with an average elevation of 602 m above mean sea level. It is characterized by the Malnad region having thick forest and rich vegetation and has an average rain fall of about 3397 mm [12]. The geological features indicate Migmatites and gneisses as the major deposition in this study area, where Quartz and chlorite schist forms the second major deposit found in east and north eastern part of this area. Few patches of acid volcanic and granites are noticed in eastern part, and Metabasalt formation in south western part of this area (Fig. 1).

Experimental

Materials and methods

Soil samples were collected from 25 various undisturbed locations situated in and around Thirthahalli taluk. Sampling locations are marked as shown in geological map. At each location, about 5–7 spots were chosen for grab sampling by marking a square of 15 cm × 15 cm × 30 cm, and from all these spots, the soil was collected. The soil was thoroughly mixed, stones and gravels are removed. About 3 kg of the resulting composite soil sample was stored in a polyethylene bag and brought to laboratory. The samples were allowed to dry overnight in an oven at a temperature of 90 °C, and then cooled. The dried sample was then sieved through 100 μm sieve. [13, 14]. About 250 g of sieved sample was filled in an air tight plastic container, sealed and then stored for a minimum period of 1 month to attain the secular equilibrium between ^{226}Ra and its daughters and then subjected to gamma spectrometry.

The activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples were determined by using gamma spectrometry employing 41% relative efficiency n-type, low-background HPGe detector (CANBERRA Industries, Inc., Meriden USA). The spectrum was acquired and analyzed by using a PC-based 16 K analyzer (DSA-1000, CANBERRA) and the GENIE-2000 software (CANBERRA Industries, Inc., Meriden USA). The detector efficiency calibration was performed using IAEA quality assurance reference materials RGU-238, RGTh-232, and RGK-1 and SOIL-6 procured from IAEA (efficiency calibration curve Fig. 2). The geometry of the analyzed material and the standard was taken uniform. The samples were counted long enough to reduce the counting error. The minimum detection levels (MDL) for gamma spectrometer system used in the present study were 0.9, 1.2 and 4.0 Bq kg^{-1} for ^{226}Ra, ^{232}Th, and ^{40}K respectively with a counting time of 60000 s. The activity concentration of ^{226}Ra was evaluated from the weighted mean of the activities of three photo peaks of ^{214}Bi (609.3, 1129.3 and 1764.5 keV) after applying the Compton corrections. In the case of ^{232}Th, one photo peak of ^{228}Ac (911.2 keV) and two photo peaks of ^{208}Tl (583.1 and 2614.5 keV) were used in the same way. The gamma line 1460.8 keV is used as a surrogate for the measurement of ^{40}K activity (Fig. 3).

Theory and calculations

The activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples was estimated using the relation [15]

$$A = (S \pm SD) \times \frac{100}{\varepsilon} \times \frac{100}{a} \times \frac{1000}{W}, \quad (1)$$

where A is Activity concentration of the radionuclide in Bq kg^{-1}, S is the Compton corrected and background subtracted net counts under the photo peaks, SD is the standard deviation = $\left(C_s/T_s^2 + C_b/T_b^2\right)^{1/2}$. C_s and C_b are the sample counts and background counts respectively, T_s and T_b are the counting time for sample and background respectively, ε is the photo peak efficiency (%) of the detector for corresponding energy determined through the ^{232}Th, ^{238}U and ^{40}K standard of similar geometry with respect to soil. a is the abundance of the characteristic gamma ray, and W is the weight of the sample in grams.

Radium equivalent Activity

The distribution of ^{226}Ra, ^{232}Th, and ^{40}K in soil is not uniform. Uniformity with respect to exposure to radiation has been in terms of radium equivalent activity (Ra_{eq}) in Bq kg^{-1} to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th, and ^{40}K. Radium equivalent activity is calculated using the following relation [8, 16, 17].

$$Ra_{eq} = A_{Ra} + (1.43 \times A_{Th}) + (0.077 \times A_K), \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil respectively.

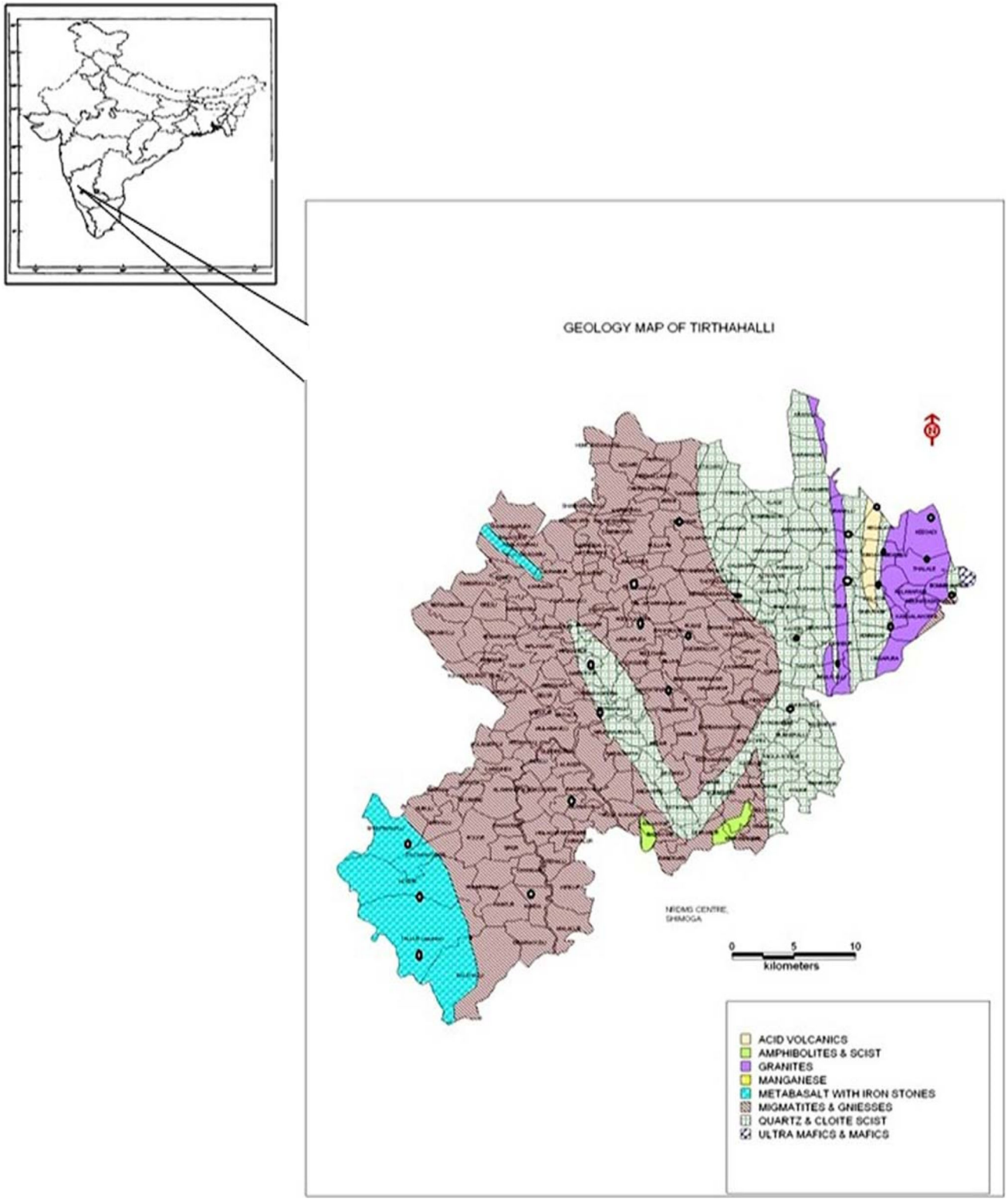

Fig. 1 Geological map of Thirthahalli taluk showing the soil sampling location

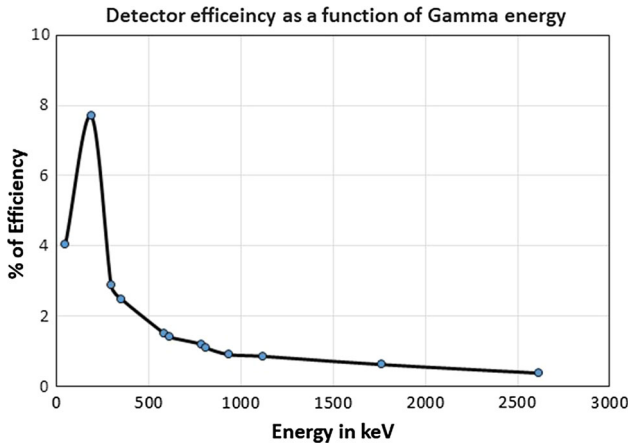

Fig. 2 Efficiency calibration curve

Estimation of absorbed dose rate and annual effective dose rate from soil radioactivity measurements

Outdoor external dose rate

The radiation dose in air at a height of 1 m above ground was estimated through the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil using the equation [18].

$$D_{\text{out}}\left(\text{nGy h}^{-1}\right) = (0.461 \times A_{\text{Ra}}) + (0.623 \times A_{\text{Th}}) + (0.0414 \times A_{\text{K}}), \quad (3)$$

where the coefficients 0.461, 0.623 and 0.0414 are the activity concentration to dose rate conversion factors of A_{Ra}, A_{Th} and A_{K} respectively in nGy h^{-1} per Bq kg^{-1}.

The outdoor annual effective dose rate (E_{out}) was calculated from the outdoor external radiation dose rate (D_{out}) using the relation [8]

$$E_{\text{out}}\left(\text{mSv year}^{-1}\right) = D_{\text{Out}}\left(\text{nGy h}^{-1}\right) \times 8760(\text{h}) \times 0.7 \times 10^{-6}\left(\text{Sv Gy}^{-1}\right) \times 0.2, \quad (4)$$

where 0.7×10^{-6} Sv Gy^{-1} is the dose conversion factor. 0.2 is outdoor occupancy factor. 8760 is the total number of hours in a year.

Indoor external dose rate

It is important to see that soil is used for preparation of building material for construction of dwellings in different forms. Based on the assumption that the primordial radionuclides have uniform distribution in clay bricks and building materials, the indoor external dose rate (nGy h^{-1}) were calculated for a standard room having a dimension of

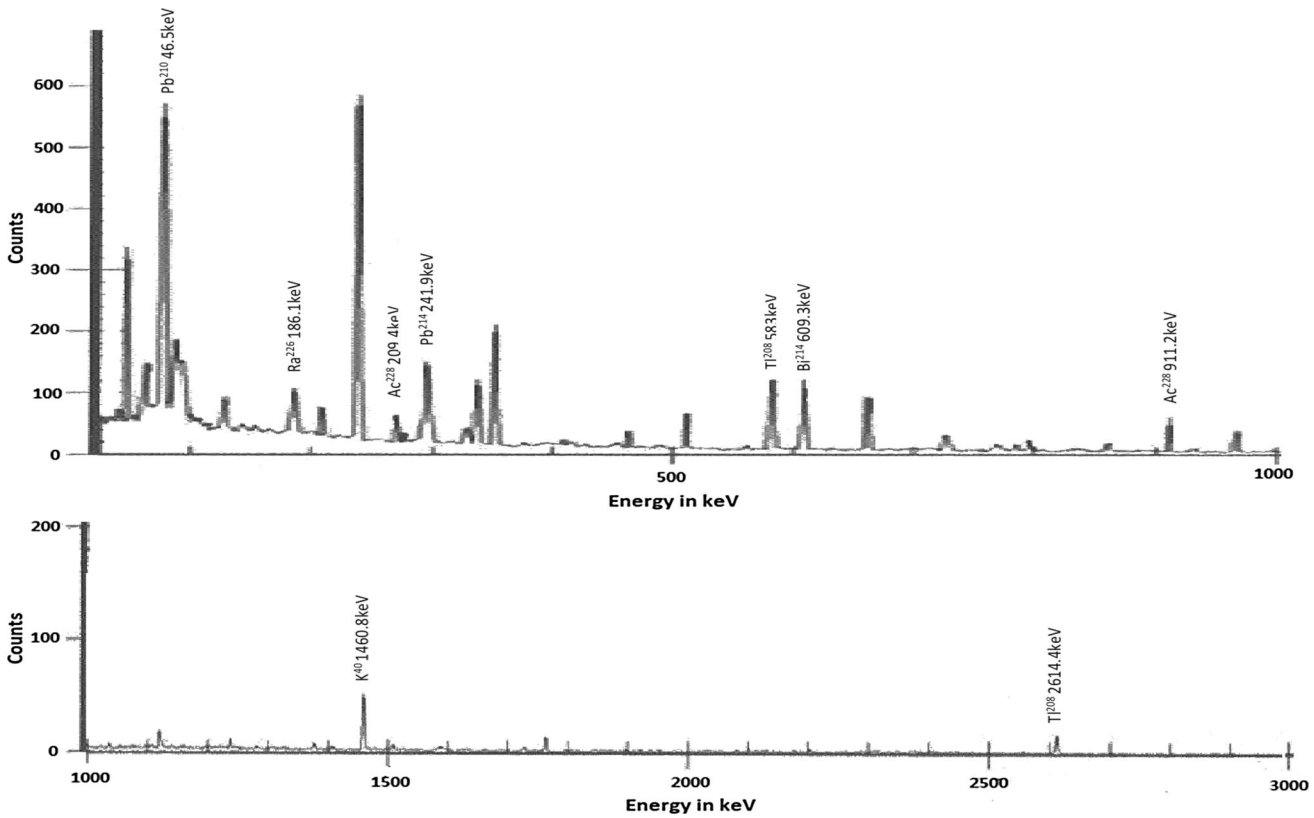

Fig. 3 Gamma spectrum showing gamma peaks of energy 0–1000 and 1000–3000 keV for soil sample from Kesthur location

Table 1 Activity concentration of primordial radionuclides in the soil samples

Regional geology	Locations	Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples in Bq kg^{-1}		
		^{226}Ra	^{232}Th	^{40}K
Granite	Keegadi	37.8 ± 0.9	60.8 ± 1.5	371.8 ± 9.9
	Thirthahalli hill	79.5 ± 1.7	95.3 ± 2.2	306.2 ± 10.7
	Kuruvalli	54.1 ± 1.2	57 ± 1.6	833.4 ± 17.5
	Kangalkoppa	35.1 ± 1.0	62.7 ± 1.8	154.3 ± 6.8
	Kelanarasi	44.1 ± 1.2	54.8 ± 1.4	186.1 ± 7.3
	Kikkeri	52.6 ± 1.3	69.7 ± 1.9	441.1 ± 11.8
	Siddeshwara hill	54.1 ± 1.3	50.7 ± 1.5	149.2 ± 7.3
Acid Volcanics	Hegalathi	29.6 ± 1.2	36.3 ± 1.5	129.3 ± 6.9
	Halaga	29.9 ± 1.1	32.1 ± 1.2	154.3 ± 6.9
Quartz and chlorite schist	Yadavalli	9.1 ± 0.5	14.1 ± 0.8	21.9 ± 3.9
	Thudur	5.9 ± 0.2	6.1 ± 0.3	39.6 ± 1.2
	Alase	5.3 ± 0.2	7.7 ± 0.3	37.5 ± 1.9
	Attigudde	21.2 ± 0.7	15.3 ± 0.9	63.9 ± 6.6
	Kannagi	9.3 ± 0.9	11.1 ± 1.3	102.2 ± 6.1
	Kalkurchi	6.8 ± 0.2	9.9 ± 0.4	18.3 ± 1.5
Metabasalt	Agumbe	5.1 ± 0.2	5.1 ± 0.3	51.1 ± 2.2
	Bellihalli	18.1 ± 1.1	23.2 ± 1.1	109.8 ± 5.9
	Hosur	8.7 ± 0.7	15.1 ± 0.9	146.1 ± 6.6
Migmatites	Malalur	15.1 ± 0.9	20.6 ± 1.5	116.1 ± 6.4
	Kesthur	27.2 ± 0.9	50.8 ± 1.5	180.3 ± 6.7
	Bobli	23.3 ± 0.9	36.8 ± 1.4	148.1 ± 6.8
	Kimmane	17.1 ± 0.8	20.5 ± 1.3	101.5 ± 5.6
	Nonbur	25.6 ± 0.9	40.2 ± 1.4	146.1 ± 6.6
	Thyrandur	5.2 ± 0.2	7.3 ± 0.3	28.6 ± 1.8
	Kavaledurga	25.2 ± 0.9	35.53 ± 1.3	349.2 ± 10.4

Parameters	Activity of ^{226}Ra in soil samples (Bq kg^{-1})	Activity of ^{232}Th in soil samples (Bq kg^{-1})	Activity of ^{40}K in soil samples (Bq kg^{-1})
Range	5.1–79.5	5.1–95.3	18.3–833.4
GM	19.3	25	117.2
GSD	2.3	2.3	2.5

4 m × 5 m × 2.8 m with wall thickness of 20 cm in nGy h^{-1} [19].

$$D_{\text{in}}\left(\text{nGy h}^{-1}\right) = 0.92A_{\text{Ra}} + 1.1A_{\text{Th}} + 0.084A_{\text{K}}, \quad (5)$$

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.

Similarly, indoor annual effective external dose rate (E_{in}) in air was calculated from the indoor external radiation dose rate (D_{in}) [8]

$$E_{\text{in}}\left(\text{mSv year}^{-1}\right) = D_{\text{in}}\left(\text{nGy h}^{-1}\right) \times 8760\ (\text{h}) \times 0.7 \times 10^{-6}\left(\text{Sv Gy}^{-1}\right) \times 0.8, \quad (6)$$

where 0.8 is indoor occupancy factor.

Radiation indices measurements

Gamma index

The European commission has proposed an index called the gamma index (I_γ). It has been introduced to account for the combined impact of ^{226}Ra, ^{232}Th, and ^{40}K as radiological hazard associated with soil. Gamma index (I_γ) defined by the following relation [19].

$$I_\gamma = \frac{A_{\text{Ra}}}{300} + \frac{A_{\text{Th}}}{200} + \frac{A_{\text{K}}}{3000} \quad (7)$$

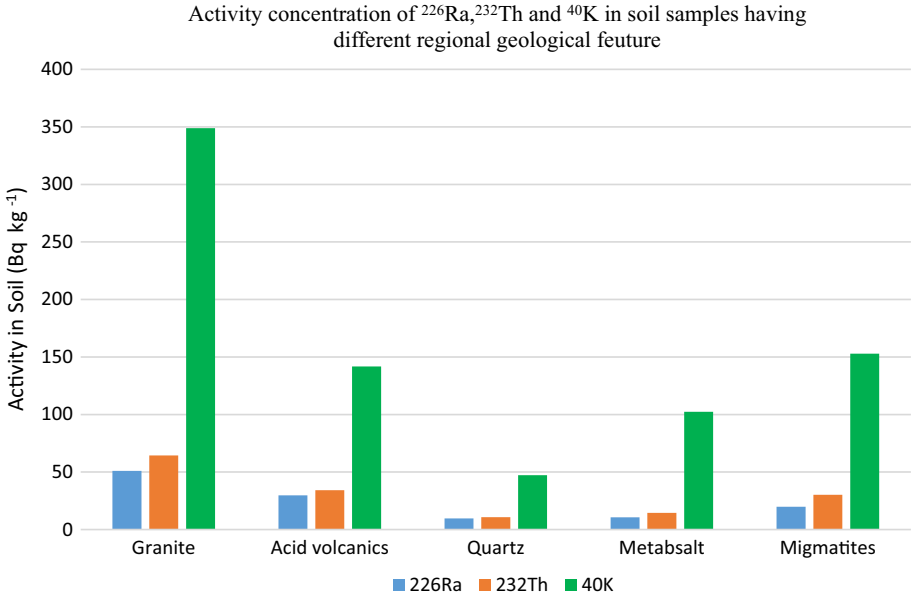

Fig. 4 concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples having different regional geological feature

Radiation hazard index

It provides the information about the radiation risk and possible damage due to radiation exposure. It is classified as

External hazard index (H_{ex}) The external exposure is due to direct gamma radiation from the soil, which imeasured by [20, 21].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}. \quad (8)$$

Internal hazard index (H_{in}) In addition to external radiation, radon and its short lived decay products are hazardous to the respiratory organs. The internal exposure due to radon and its daughter products has the largest contribution towards the average effective dose received by inhabitants. The combined internal exposure to gamma rays and radon is given by [20, 21].

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}. \quad (9)$$

Excess lifetime cancer risks (ELCR)

The probability of cancer risk to population from exposure to radiation in the study sample is a measure of ELCR. It was calculated based on the estimated values of annual effective dose, excess lifetime cancer risk (ELCR) was calculated using the following equation [1, 22]

$$\mathrm{ELCR(outdoor)} = E_{Out} \times LE \times RF, \quad (10)$$

$$\mathrm{ELCR(indoor)} = E_{in} \times \mathrm{LE} \times \mathrm{RF}, \quad (11)$$

where (E_{out}) and (E_{in}) are the outdoor and indoor annual effective doses respectively, LE is life expectancy (66) years and RF (Sv^{-1}) is fetal risk factor = 0.05.

Results and discussion

The specific activity of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples measured over 25 various locations in and around Thirthahalli taluk is presented in Table 1. It can be observed that activity concentration of ^{226}Ra lies between 5.1 ± 0.2 and 79.5 ± 1.7 Bq kg^{-1} with an average of 25.99 Bq kg^{-1}, ^{232}Th ranges from 5.1 ± 0.3 to 95.3 ± 2.2 Bq kg^{-1} with an average of 33.60 Bq kg^{-1} and that of ^{40}K varies from 18.3 ± 1.5 to 833.4 ± 17.5 Bq kg^{-1} with an average of 175.52 Bq kg^{-1}. The wide range of variation in the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K may be attributed to various factors like regional geology (Fig. 4), grain size distribution of the soil, clay and silt fraction in the soil, organic matter and mineral composition in the soil etc. which is not meassured in the present study. The average activity concentration of ^{226}Ra and ^{232}Th in soil samples in the study area was found to be higher than the Indian average value of 14.8 and 18.3 Bq kg^{-1} respectively, whereas that of ^{40}K is less than the Indian average value of 433.6 Bq kg^{-1} [23] Tables 2, 3, 4. Similar to the observations made elsewhere, in almost all soil samples, the ^{232}Th activity was found to be higher compared to that of ^{226}Ra. This is because, ^{226}Ra is more susceptible to solubility, whereas ^{232}Th is less soluble and hence adsorbed to soil [3, 24].

Table 2 Comparison of present ^{226}Ra activity measurements in soil with other environs

Activity of ^{226}Ra (Bq kg^{-1})		Region	References
Present study	Literature values		
5.1–79.5	8.3–46.3	Shimoga	Anandaram [11]
	2–12.9	Mysore	Nagaiah [26]
	14.38–50.49	Ramanagara and Tumkur	Shrilatha et al. [16]
	5.2–33.7	Bombay	Rao et al. [27]
	3.7–16.5	Kaiga	Karunakara et al. [28]
	37.04–63.3	Rajasthan	Saritha Mittal et al. [29]
	10.6–27.2	Egypt	Harb et al. [30]
	53.88–70.89	Iraq	Iman Tarik Al-Alawy [31]
	39.92–59.0	Soudi Arabia	Hammidalddin [32]
	14.8	All India average	Mishra and sadasivan [23]
	35	World average	UNSCEAR 2000 [8]

Table 3 Comparison of ^{232}Th activity measurements in soil with other environs

Activity of ^{232}Th (Bq kg^{-1})		Region	References
Present study	Literature values		
5.1–95.3	11.3–68.5	Shimoga	Anandaram [11]
	13.1–159.7	Mysore	Nagaiah [26]
	42.2–116.12	Ramanagara and Tumkur	Shrilatha et al. [16]
	7.4–21.5	Bombay	Rao et al. [27]
	18.8–272.1	Gudalor	Muguntha et al. [33]
	43.3–85.2	Rajasthan	Saritha Mittal et al. [29]
	46.93–68.31	Soudi Arabia	Hammidalddin [32]
	122.4–5834.4	Kerala	Ramachandran et al. [34]
	10.8–15.1	Egypt	Harb et al. [30]
	11.23–17.41	Iraq	Iman Tarik Al-Alawy [31]
	18.3	All India average	Mishra and sadasivan [23]
	30	World average	UNSCEAR 2000 [8]

Table 4 Comparison of ^{40}K activity measurements in soil with other environs

Activity of ^{40}K (Bq kg^{-1})		Region	References
Present study	Literature values		
18.3–833.4	119.7–1080.3	Shimoga	Anandaram [11]
	86.5–1216.6	Mysore	Nagaiah [26]
	388.98–1563.64	Ramanagara and Tumkur	Shrilatha et al. [16]
	324–368	Kalpakkam beach	Iyengar [35]
	76.5–425.2	Rajasthan	Saritha Mittal et al. [29]
	344.5–521	Egypt	Harb et al. [30]
	266.96–364.49	Iraq	Iman Tarik Al-Alawy et al. [31]
	433.6	All India average	Mishra and sadasivan [23]
	400	World average	UNSCEAR 2000 [8]

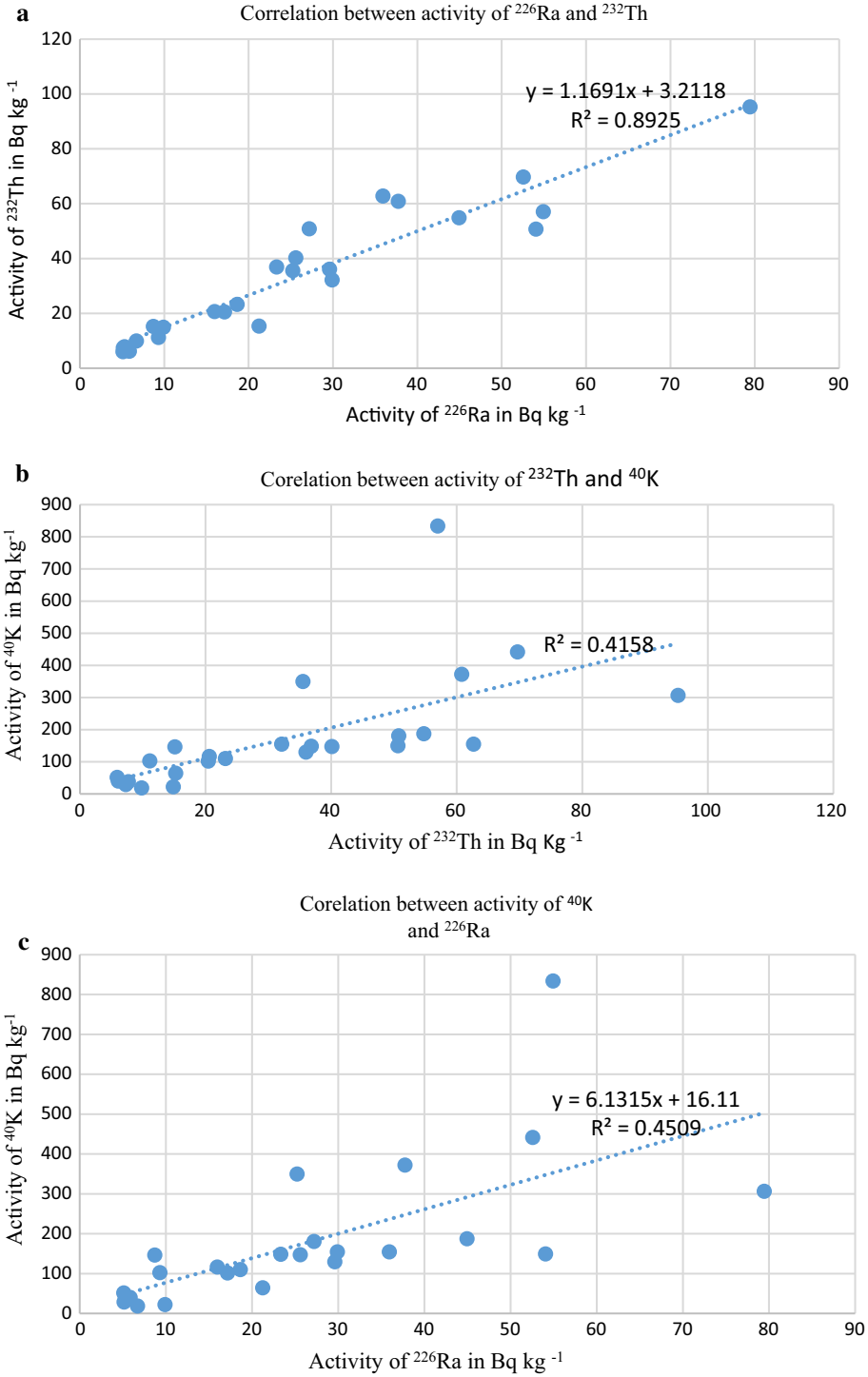

Fig. 5 **a** Correlation between activity concentration of ^{226}Ra and ^{232}Th in soil samples. **b** Correlation between activity concentration of ^{232}Th and ^{40}K in soil samples. **c** Correlation between activity concentration of ^{226}Ra and ^{40}K in soil samples

The correlation study with reference to the variation of ^{226}Ra, ^{232}Th and ^{40}K was done using the graphs shown in Fig. 5a, b and c. It can be observed that, all mutual comparison shows positive correlation, of which good correlation of 0.9 between ^{226}Ra and ^{232}Th, moderate correlation of the order of 0.4 with respect to ^{232}Th and ^{40}K and ^{226}R to ^{40}K was found. These variations may be due to change in the transport and adhering capacity of radionuclides with respect to the soil particles.

The absorbed gamma dose rate (D_{out}) in air at 1 m above the ground surface was estimated through the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil. The assessed outdoor absorbed dose rate ranges from 8.13 to 108.66 nGy h^{-1} with an average value of 40.18 nGy h^{-1},

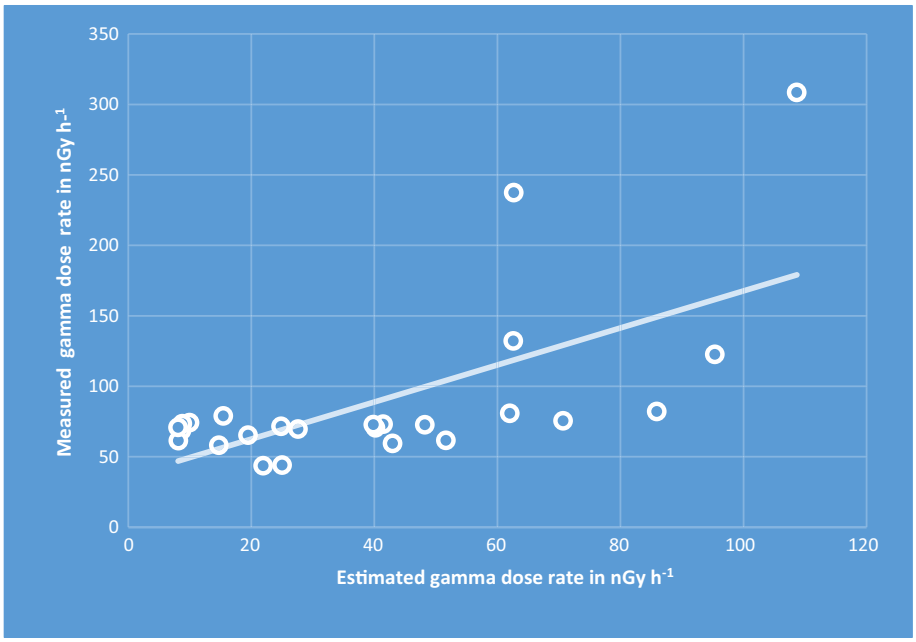

Fig. 6 Correlation between measured gamma dose rate and estimated gamma dose rate

which is below the world average value of 59 nGy h^{-1} [8]. The resulting outdoor annual effective dose rate (E_{out}) ranges from 0.009 to 0.13 mSv $year^{-1}$ with a mean value of 0.04 mSv $year^{-1}$ which is less than the worldwide average value of 0.07 mSv $year^{-1}$ [8]. It can be seen from Fig. 6 that, the measured gamma dose using radiation survey meter and estimated radiation dose through the above mentioned procedure agrees well with a positive correlation of 0.65.

Assuming that the same soil from the study area is used for the preparation of building materials, the indoor gamma radiation dose to the population was estimated and it lies between 15.22 and 203.62 nGy h^{-1} with an average value of 75.62 nGy h^{-1} which is comparable with the world average of 75 nGy h^{-1} [10]. Similarly, the corresponding annual effective dose rate (E_{in}) varies from 0.7 to 0.99 mSv $year^{-1}$ with a mean value of 0.36 mSv $year^{-1}$. The total annual effective dose from gamma exposure to the public residing in the study area is found to be 0.43 mSv $year^{-1}$.

The estimated radium equivalent activity from the knowledge of ^{226}Ra, ^{232}Th and ^{40}K in soil was found to be varied from 17.56 to 239.27 Bq kg^{-1} with an average of 87.57 Bq kg^{-1}. This indicates, the soil can be used for the construction purpose directly or indirectly, since the radiological hazard imposed is less significant. [2, 8, 25].

Outcome of the study

From the measured activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples, following factors are inferred

Radiation hazard index

(a) The estimated gamma index (I_γ) lies in the range of 0.063–0.84 with an average value of 0.30. These values are below the safe limit of 1, which proves that, the gamma radiation hazard from the soil in the present study is insignificant [19].

(b) The calculated external hazard index (H_{ex}) for the soil samples of the study area is presented in Table 5. It lies between 0.04 and 0.64 with an average value of 0.18, which confirms that, the study area is in the zone of normal background radiation level and the population group in this area is receiving the radiation dose within the permissible limit.

(c) The estimated indoor radiation hazard index ranges from 0.06 to 0.86 with an average value of 0.23 signifying that soil from these regions is safe and can be used as a construction material without posing any significant radiological threat to population.

Cancer risk

The calculated average excess life time cancer risk (ELCR) to the public due to outdoor exposure ranges from 0.031×10^{-3} to 0.45×10^{-3} with an average value of 0.15×10^{-3}. Similarly, the calculated ELCR due to indoor exposure ranges from 0.23×10^{-3} to 3.26×10^{-3} with an average value of 1.21×10^{-3}. However, the total ELCR lies within the permissible limit of 1.45×10^{-3} [1] which

Table 5 Absorbed dose rate, annual effective dose, excess lifetime cancer risk, radium equivalent activity, gamma index, external and internal hazard indices from soil

Locations	Outdoor hazards indices						Indoor hazard indices			
	D_{out} (nGy h^{-1})	E_{out} (mSv $year^{-1}$)	H_{ex}	ELCR × 10^{-3} outdoor	Iγ	Ra_{eq} (Bq Kg^{-1})	D_{in} (nGy h^{-1})	E_{in} (mSv $year^{-1}$)	H_{in}	ELCR × 10^{-3} indoor
Keegadi	70.69	0.03	0.41	0.10	0.55	37.76	132.88	0.65	0.51	2.14
Thirthahalli hill	108.66	0.13	0.64	0.45	0.84	237.12	203.62	0.99	0.86	3.26
Kuruvalli	95.35	0.11	0.54	0.38	0.74	194.81	183.27	0.89	0.69	2.93
Kangalkoppa	62.03	0.03	0.37	0.10	0.48	136.43	115.02	0.56	0.46	1.84
Kelanarasi	62.611	0.07	0.37	0.24	0.48	136.42	117.35	0.57	0.49	1.88
Kikkeri	85.93	0.1	0.5	0.35	0.67	183.14	162.11	0.79	0.64	2.60
Siddeshwara hill	62.67	0.07	0.37	0.24	0.48	136.98	118.02	0.57	0.51	1.88
Hegalathi	41.45	0.07	0.24	0.24	0.32	90.19	77.74	0.38	0.32	1.25
Halaga	40.2	0.04	0.23	0.14	0.31	86.67	75.83	0.37	0.31	1.22
Yadavalli	14.74	0.01	0.08	0.03	0.11	32.71	27.31	0.13	0.11	0.42
Thudur	8.16	0.009	0.04	0.03	0.063	17.4	15.47	0.07	0.06	0.23
Alase	8.82	0.01	0.05	0.03	0.068	19	16.55	0.08	0.06	0.26
Attigudde	21.95	0.02	0.12	0.07	0.16	47.55	41.71	0.2	0.18	0.66
Kannagi	15.47	0.01	0.08	0.03	0.12	32.42	29.43	0.14	0.11	0.46
Kalkurchi	9.99	0.01	0.06	0.03	0.077	22.09	18.55	0.09	0.07	0.29
Agumbe	8.18	0.01	0.04	0.03	0.063	17.2	15.54	0.07	0.06	0.23
Bellihalli	27.6	0.04	0.16	0.14	0.21	59.52	51.91	0.25	0.21	0.82
Hosur	19.5	0.02	0.11	0.07	0.15	40.61	36.96	0.18	0.13	0.59
Malalur	25.02	0.03	0.14	0.10	0.19	53.59	47.14	0.23	0.19	0.75
Kesthur	51.64	0.06	0.3	0.21	0.4	112.45	96.04	0.47	0.38	1.55
Bobli	39.85	0.08	0.23	0.28	0.31	86.41	74.45	0.36	0.29	1.18
Kimmane	24.86	0.01	0.14	0.03	0.19	53.52	46.82	0.23	0.19	0.75
Nonbur	42.9	0.05	0.25	0.17	0.33	93.32	80.07	0.39	0.32	1.28
Thyrandur	8.13	0.04	0.04	0.14	0.063	17.65	15.22	0.07	0.06	0.23
Kavaledurga	48.23	0.05	0.27	0.17	0.37	100.5	91.64	0.45	0.34	1.48

designates the study area is a safer zone from the radiation point of view.

Conclusion

- Out of the 25 soil samples collected from various locations in and around Thirthahalli taluk, 28% of the samples have shown higher concentration of ^{226}Ra, 48% of the samples have shown higher concentration of ^{232}Th and 8% of the samples have shown higher concentration of ^{40}K compared to the world average. However, the measured average activity concentration of ^{226}Ra and ^{40}K concentration in soil samples are less than the world average values and that of ^{232}Th concentration is marginally higher than the world average value.
- The mean value of radium equivalent activity is well within the recommended safe limit value of 370 Bq kg^{-1}. The gamma index, external and internal hazard index in soil samples are less than unity, representing that the public residing in this region are in safer zone from the radiation.
- 44% of the measured samples have shown higher ELCR than the permissible limit of 1.45×10^{-3}. However, the average value of ELCR in the present study is well within the permissible limit.

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