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Assessment of natural radiation levels in the forest ecosystem of Shankaraghatta-Shivamogga District, India

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Abstract

The estimated mean value of activity of radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in the forest environment of Shankaraghatta are 11.52 ± 1.6, 19.94 ± 2.08 and 164.67 ± 3.2 Bq kg^{-1} for soil, and for building materials 48.53 ± 1.99, 63.20 ± 2.48 and 470.47 ± 6.59 Bq kg^{-1} respectively. The average indoor and outdoor Gamma Absorbed Dose rate and total Annual Effective Dose rate are less than the global average values. The forest ecosystem influenced in reducing the natural ambient gamma radiation levels. The constructions materials used for roads enhanced it. The entire measured hazard indices are far below the criterion limit of unity except pink granite and ceramic tiles contains higher activity of radionuclides.

Keywords Activity of ^{226}Ra ^{232}Th and ^{40}K · Gamma-radiation level · Forest ecosystem · Gamma-ray spectrometry · Hazard indices

Introduction

Natural gamma (γ)-radiation originated from the radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) of uranium (^{238}U, ^{235}U), thorium (^{232}Th) series and singly radionuclide potassium (^{40}K), which are occur at the trace level in the environment matrices such as surface soil, rock, water and building materials. Where ^{40}K radioisotope is a single natural radionuclide that makes up 0.0118% of total potassium in the earth crust [1]. About 80% of radiation coming from radionuclides present in soil [2].The concentrations of these radionuclides present in the soil of the earth differ from place to place since their levels rely on the origins of the soil and the type of rocks in the earth crust [1, 3, 4]. Soil is one of the most prominent natural resource available on the earth surface, which consists of minerals, organic components and radionuclides in varying quantities known as NORM's (Naturally Occurring Radioactive Materials) which in turn depend on nature of the parent rock and soil [5]. The total radiation emitted by the NORM's is known as terrestrial background radiations [5]. Soil is one of the important natural resource and is the main source of natural radionuclides formed by the weathering of rocks in the environment. That is used for various purposes, including building materials. In order to assess the activity concentration of soil and building materials significantly, it is important to measure the background radiation levels. The cause of indoor and outdoor human exposure is mainly due to natural radiation levels in the soil and its derivatives, which inturn is the source of γ-exposure and radon gases [1, 3, 6, 7]. Exposure to such radionuclides will damage tissue or organ, and causes various health effects. The long term exposure to ionizing radiation has produced hereditary, leukemia; cancer of different organs such as kidney, lungs, stomach, bones, and the structure of DNA may be change and causes some biological effects [4, 8–10]. Measurement of natural radioactivity in soil and building material is important to understand the behavior of natural ecosystem, which also produces the information needed for assessment of probable health risk [2, 3, 6, 11], and epidemiological studies. This type of measurement increases the demands for policy making to radiation protections. The radionuclides such as ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K present in soil are

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distributed non uniformly, hence the understanding of their distribution in soil is very important for radiation safety [5].

In view of this importance, the measurement of radionuclides in the Shankaraghatta forest–ecosystem plays an important role because of different geophysical and geographical conditions, and also the soil is covered by rich vegetation and thick forest. Therefore the behavior of radionuclides in this region plays a major role in plant uptakes. The forest plays an important role in the epidural and temporal distribution of radionuclides in this environment. The radionuclides are absorbed into soil corresponds to organic matter, clay carbonate Fe/Mn oxides and take part in biogeochemical process, therefore this distribution of radionuclides in soil is essential for many environmental studies [12]. Due to this we are selected Shankaraghatta, which is located on the bank of river Bhadra. The study area is surrounded by both dense and partial forest ecosystem along with agricultural lands. As per the existing literature survey, there have been many radiological surveys to determine the background radionuclides levels in soil samples and their radiological hazards [13, 14]. However there are few data are available for this type of study area. The aims and objectives of the present study consists of measurement of distribution of radionuclides in soil and building materials by using gamma ray spectrometry, measurement of ambient gamma dose rate, annual effective dose, hazard indices and dose to the public of this study area by using environmental radiation survey meter. The data obtained by the experiment are analyzed and explained in detail.

About the study area

The study area Shankaraghatta including Kuvempu University lies in between 75°39′30″ East longitude and 13°45′30″ North latitude is a hilly and a natural heritage site as shown in Fig. 1a–c. The grassy hillocks and great altitude truly make it the crowning jewel of the Western Ghats. Rich in biodiversity, this region is home to many endemic species of fauna. The jurisdiction of the Kuvempu University spreads over the districts of Shivamogga and Chikkamagaluru. The dense forest high hilly Malnad in the west and sparely forested tablelands, semi-Malnad in the east. To understand the distribution of radionuclides and external gamma radiation level, the study area is divided into three zones depending on the local geology and forest area covered. The first zone is partially covered by thin forest area consists of 15 different locations (Fig. 1a) and is comprises of Migmatite and Granodiorite. The second is covered by thick forest area and hillocks, it consists of 18 different locations and is attributed by Ultramafic Schist. The third zone is also covered by hills and thick forest it consists of only one location and is attributed by quartz, dolerite, schist and ortho quartzite. The major soil forms found in the study area are Clay; brown clay loamy, Red Sandy clay loam Habitation Mask [15] as shown in Fig. 1b. The study area comprises of rock formations belongs Migmatite, Granodorites–Tonalitic gnesis and Ultramafic Schist as shown in Fig. 1c.The University offers under-graduate, post- graduate and Ph.D. programmes in a wide range of disciplines. It has 35 Post-graduate Departments around 3500 students, 600 teaching and non teaching workers. The University has its headquarters at Jnana Sahyadri campus. It sprawls over an area of 230 acres of a lush green, picturesque locale providing the right ambience for higher education and research programs. The main buildings of the university have been constructed on small hillocks, thus blending naturally with the landscape.

Materials and methods

The sample locations are chosen based on the preliminary survey of background gamma radiation. Soil samples are collected at random from various locations around the study area. At one location 6–8 points each of area 0.5 m^2 are identified. Upper layer of the soil containing vegetative materials and organic materials were removed. After the collection, all samples were thoroughly mixed, with all noxious substances like plants, detritus, hunks of stone, and pebbles eliminated [16].

Sample preparation

To begin, initially about 2 kg soil collected from each location, soil samples are collected over a 0.5 m^2 surface area, and once plants and roots have been removed, a location is marked. The marked spot was dug up to a depth of 15 c, which was crushed into the finest powdered form possible before being sieved through 500 μm (0.5 mm) to remove the undesired particles. About 300 g of samples are subjected to air dry for several days in order to remove the moisture content in it. The cleansed and sieved samples then dried in an electric oven at temperature of 110 °C for 12 h make sure it has became moisture free and to achieve constant weight, thus formed powdered samples transferred to plastic containers and are stored in it, meanwhile care has taken that it is air tightened and are sealed externally using adhesive tapes. These homogenized samples were kept identical to that of reference materials as to their geometrical shapes, size and weight. Then kept aside for about a month (more than 7 times the half-lives of ^{222}Rn, and ^{224}Ra) at room temperature for to ensure that secular equilibrium has been established between radium and its daughter products further more; before being taken it to analysis using gamma ray spectrometry [17–20]. Similarly about 2 kg of each building materials samples such as cement, granite rocks, vitrified tiles, marbles, bricks collected locally and are powdered by

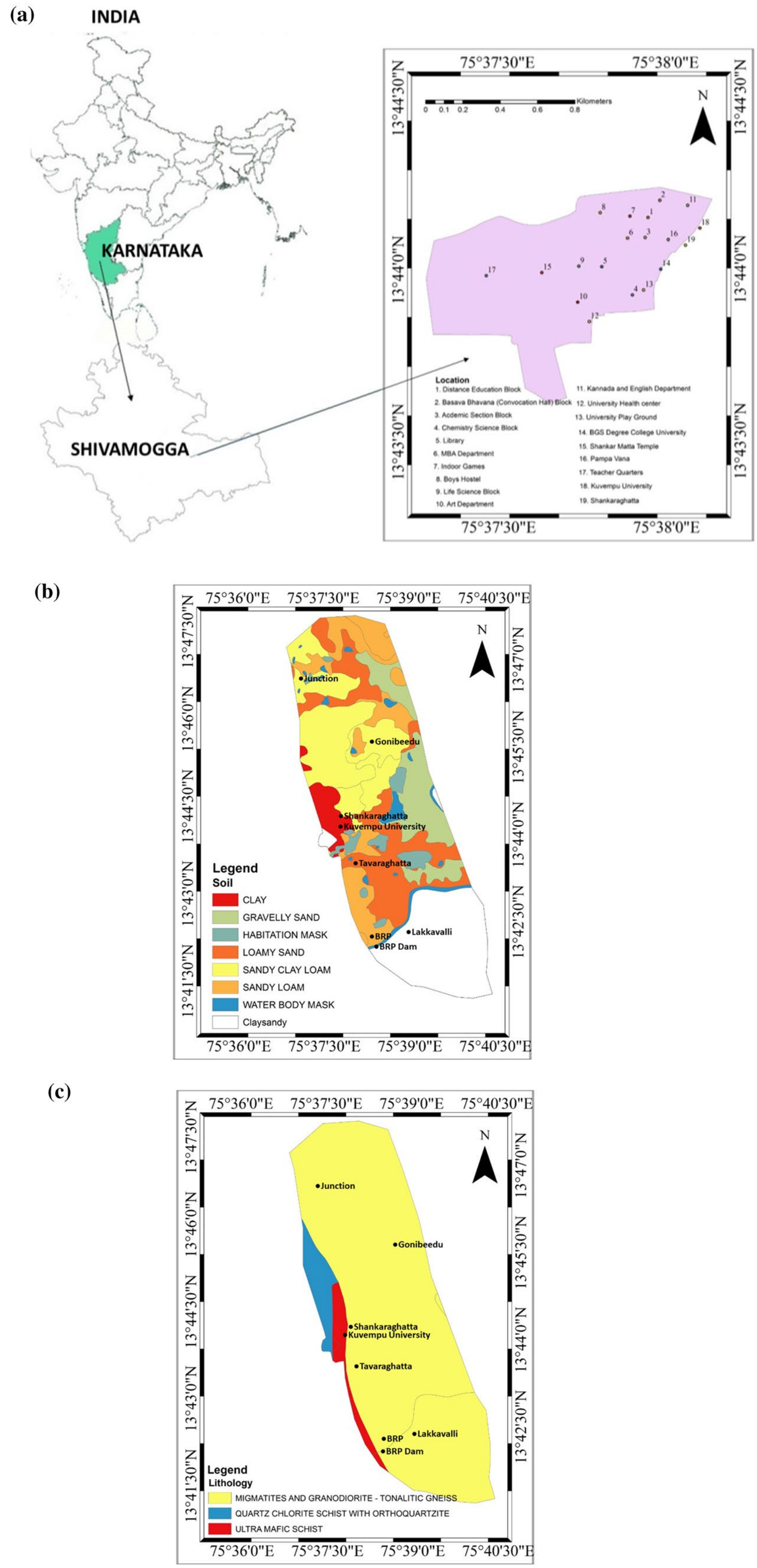

Fig. 1 **a** Natural ambient gamma radiation levels, distribution of radionuclides in soil and building materials in environment of Shankaraghatta (Zone-I). **b** Natural ambient gamma radiation levels, distribution of radionuclides in soil and building materials in environment of Shankaraghatta (Zone-II&III). **c** Natural ambient gamma radiation levels, distribution of radionuclides in soil and building materials in environment of Shankaraghatta (Zone-II&III)

using hammer and crushers. About 300 g of samples collected in polythene cover after that the same procedure is used for the preparation of building material samples as for soil.

Gamma-ray spectrometry

Gamma-ray Spectrometry provides a convenient, direct and non-destructive analytical method utilizing for the estimation of various gamma emitting radionuclides present in the environmental samples. It provides two types of detectors namely high efficiency scintillation detectors [NaI (Tl)] and high-resolution semiconductor detectors (HPGe detectors). There are numerous methods used for the detection of gamma emitting radionuclides in the environmental samples. However, the qualitative and quantitative gamma ray spectroscopy is one of the powerful techniques available for the non destructive estimation of samples in the environment matrix [21]. This techniques enables the use of large quantities of sample to be counted and this method reduces the extraneous background to very low values using suitable shielding arrangements and moreover due to its excellent separation capabilities it gives us much of information regarding all the radionuclides. Along with these features appropriate software codes that have now become available has made gamma spectroscopic technique one of the accurate method for estimating the activity concentration in the environmental samples and is cheaper when compared to other new methods; mass spectroscopy. In the present study 3′×3 NaI (Tl) detector based gamma spectrometer was used for the estimation of gamma emitting radionuclides in soil, and building materials.

Calibration of gamma ray spectrometer system

In order to get an accurate measurement, it is must to calibrate the counting system with standard sources of the same geometry and composition as the sample under test measurement.

Basic requirements needed for calibration is as follows;

- The distance between detector and sample should be constant for particular given calibration
- In order to avoid frequency of changing the standards, the selected sources must be of longer half life

Energy calibration

To determine the energy of each channel and to ensure the linearity exists between the energy and number of channel corresponding to that energy calibration should be carried out. The gamma spectrometry has been calibrated for a wide range of energy up to 3 MeV in order to accommodate all the natural radionuclides. The gamma energy emitter for ^{137}Cs has 661.65 keV, for ^{60}Co is 1173.24 and 1332.46 keV and 2614.5 keV gamma energy emitter of RG-Th(IAEA thorium standard) has been for the energy calibration purposes. The sources are kept at a distance of 5 cm and the spectrum was acquired for reasonable time so that photo peaks have sufficient counts for analysis, the region of interest (ROI) and centroid peak with channel number is identified. The spectrum analyzer has got provision to fit the peak in order to obtain the peak position in the channels. Energy of any channel is determined by using relation

$$E = (m \times \text{Channel number}) + b \tag{1}$$

where m—is the slope, b—is the intercept.

The energy calibration of the graph is as shown in Fig. 2a

Efficiency calibration

It is calibrated with the use of standard sources such as RGU-I (Uranium), RGTh-I (Thorium) and RGK-I (Potassium) produced from IAEA, these standard samples are filled in container which is similar to that of sample's

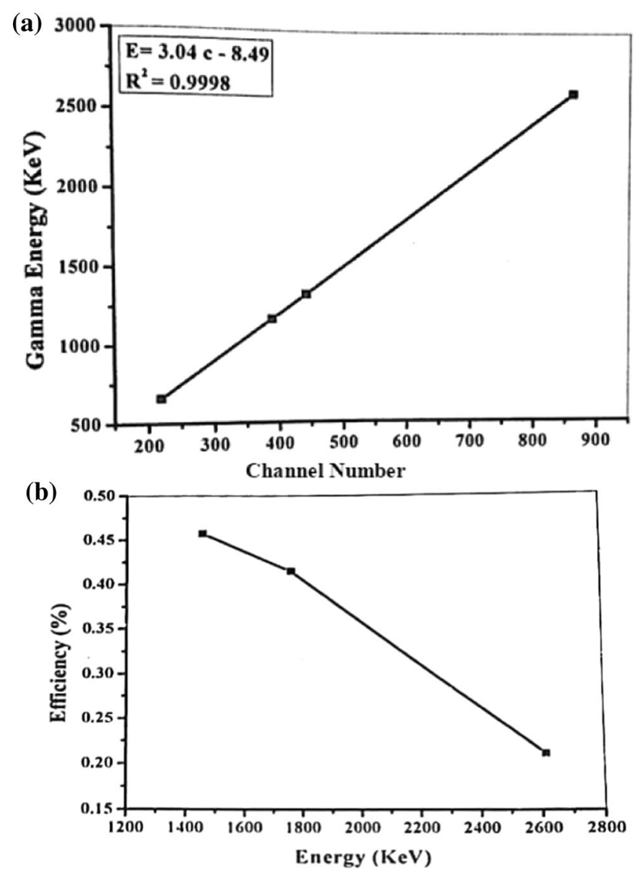

Fig. 2 **a** Energy Calibration graph of NaI(Tl) detector, **b** Efficiency calibration curve graphs

geometry. These samples were prepared as per the normal procedure and are kept for about month. The standard efficiency spectra were acquired for time period of 10,000 s, and the obtained spectrum is analysed for net counts under the photo peaks of gamma energies of interests using G-spec software.

The efficiency of gamma ray energies of various radionuclides can be determined with *g* use of following relation:

$$E(\%) = N \times \frac{100}{A_s} \times \frac{100}{G_a} \quad (2)$$

where *N*-represents background counts per second of the radionuclides, A_S-represents the activity of standard sources (Bq), G_a-represents the gamma abundance for particular energy.

The efficiency of calibration graph is as shown in Fig. 2b.

Estimation of activity of radionuclides present in soil and building materials

The activity of radionuclides of prepared samples was estimated by using Gamma ray spectrometry method. To obtain good statistics for activity of concentration of radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in soil and building materials GSPEC software is used. The Procedure is followed to estimate the activity.

To determine the activity of radionuclides, the formula has given by following equation [22]. (IAEA/RCA, 1989.)

$$A\left(\mathrm{Bq\,kg^{-1}}\right) = (\mathrm{C} \pm \mathrm{SD}) \times \frac{100}{P_E} \times \frac{100}{A_\gamma} \times \frac{1000}{W} \quad (3)$$

where the notations '*C*' is the Compton corrected background subtracted counts per second, SD-Standard deviation due to counting, P_E-The detector's photo peak efficiency (%), A_γ-The Gamma ray abundance (%), *W*-The sample's weight (in grams).

Scintillometer (type SM 141D, ECIL)

The ECIL, Scintillometer, model SM 141D is used to measure gamma radiation levels in the environment. It's a radiometric, geophysical, and environmental reconnaissance scintillometer that's tough, light, and portable. The radiation levels are displayed on the 216 LCD modules with antiglare and backlight facilities, which provide better visibility under direct sunlight and even in low light conditions, thanks to the microcontroller-based design and the large crystal volume. The scintillometer was calibrated at regular intervals using standard ^{137}Cs and ^{60}Co sources by ECIL (Electronics Corporation of India limited) standards.

Ambient gamma radiation level

An ambient gamma radiation levels in the outdoor and indoor atmosphere of the study area was measured with the use of Scintillometer (Type SM 141D, ECIL). A thallium-activated sodium iodide crystal is optically connected to a photomultiplier as the detector. Every reading was taken at a height of 1 m above the ground. At each place, 4–5 readings have been taken and with the use of factor of conversion (1 μR h^{-1} = 8.7 nGy h^{-1}), exposure rate (μR h^{-1}) is converted into an absorbed dose rate (nGy h^{-1}) [21, 23], and then it is converted into an equivalent effective dose rate using conversion factor 0.7 Sv y^{-1} [11].

Estimation of radiological hazard indices

Soil and building materials such as granite rocks, bricks, cement, sand, and tiles are utilised in the construction of the buildings. As a result, determining the radiation hazard level of these materials to mankind is essential. Radiation dangers arise from inhalation and ingestion of radioactive materials, which directly harm the living tissues and respiratory organs. Using the measured specific activity concentrations of radionuclides, the radiological hazard associated with soil and various construction materials were determined (^{226}Ra, ^{232}Th, and ^{40}K). Various forms of hazard indices have been defined previously [24–27].

The gamma index (I_γ)

The gamma index (I_γ) is radiation risk assessment parameter is used for identifying safe materials for construction purposes. I_γ has been introduced to account for the combined impact of ^{226}Ra, ^{232}Th, and ^{40}K as radiological hazard associated with soil and building material.

$$I_\gamma = \frac{S_{\mathrm{Ra}}}{300} + \frac{S_{\mathrm{Th}}}{200} + \frac{S_{\mathrm{K}}}{3000} \quad (4)$$

where the notations S_{Ra}, S_{Th}, and S_{K} are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively. Materials having $I_\gamma \leq \gamma \leq 2$ will make an increase of 0.3 mSv y^{-1} in the annual effective dose rate, whereas $2 \leq \leq I\gamma\gamma \leq \leq 6$ correspond to an increase of 1 mSv y^{-1} [27, 28].

The alpha index (I_α)

The radiation risk assessment parameter alpha index (I_α) is defined by Righi and Bruzzi [29]. This parameter (I_α)

gives us the excess of alpha radiation due to radon inhalation which originated from soil and dwellings.

$$I_{\alpha} = \frac{S_{Ra}}{200} \tag{5}$$

where S_{Ra} is the specific activities of ^{226}Ra in Bq kg^{-1}

Radium equivalent activity (Ra_{eq})

Primeval radionuclides plays prominent role in our environment and they are not uniformly distributed, in order to know the exposure rate; the total exposure rate is defined in terms of Radium equivalent activity (Ra_{eq}) in Bq kg^{-1}, which in turn used to compare the specific activity of materials containing variable amounts of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) [24, 26 and 28].

$$Ra_{eq}\left(Bq\,kg^{-1}\right) = S_{Ra} + 1.43 + S_{Th} + 0.077S_{K} \tag{6}$$

where the notations S_{Ra}, S_{Th} and S_{K} stand in for activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K in Bq kg^{-1}, respectively.

External hazard index (H_{ex})

The index parameter external hazard index (H_{ex}) has been used to assess the indoor radiation dose due to the external exposure of human beings to hazardous gamma radiation from natural radionuclides. H_{ex} is a radiation hazard index defined by Beretka and Mathew [26]. As per the UNSCEAR [24], the external hazard index (H_{ex}) is calculated by using the equation.

$$H_{ex} = \frac{S_{Ra}}{370} + \frac{S_{Th}}{259} + \frac{S_{K}}{4810} \le 1 \tag{7}$$

where the notations S_{Ra}, S_{Th} and S_{K} stand in for activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K in Bq kg^{-1} respectively. H_{ex} Value must be less than unity to keep the radiation hazard insignificant [30]. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370 Bq kg^{-1}).

Internal hazard index (H_{in})

Internal organs exposure to carcinogenic radon and its short-lived progenies are estimated by the use of internal hazard index (H_{in}) parameter. The internal hazard index is also hazardous to the respiratory organs, which is given by the equation [26].

$$H_{in} = \frac{S_{Ra}}{185} + \frac{S_{Th}}{259} + \frac{S_{K}}{4810} \le 1 \tag{8}$$

where the notations S_{Ra}, S_{Th}, and S_{K} stand in for the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. The safe use of a material in the construction of dwellings, H_{in} should be less than unity [31].

Indoor and outdoor gamma absorbed dose rate and annual effective dose rate

The absorbed dose rate (D) is measured using survey meter by holding it in the air at 1 m above the ground surface for the uniform distribution of the naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) and was calculated based on guidelines provided by [24, 32]. The absorbed dose rate (D_{out}) is calculated with the help of following formula:

$$D_{out}\left(nGy\,h^{-1}\right) = 0.462S_{Ra} + 0.604S_{Th} + 0.042S_{K} \tag{9}$$

And, the indoor absorbed dose rate (D_{in}) can be calculated by avail oneself of the following formula

$$D_{in}\left(nGy\,h^{-1}\right) = 0.92S_{Ra} + 1.1S_{Th} + 0.08S_{K} \tag{10}$$

where the notations S_{Ra}, S_{Th} and S_{K} stand in activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K in Bq kg^{-1}, respectively. Where, D_{out} and D_{in} indicates the outdoor and indoor absorbed dose rate in nGy h^{-1}. The coefficients of S_{Ra}, S_{Th} and S_{K} are the activity concentration to dose rate conversion factors in nGy·h^{-1} per Bq kg^{-1}. It is given that the global mean value of the ambient gamma radiation absorbed dose rate for an outdoor is 59 nGy h^{-1} and 84 nGy h^{-1} for indoor [24]. The annual equivalent effective dose rate for both indoor and outdoor was estimated from the out and out external gamma radiation dose rate (D) by taking into an account of 'occupancy factor' (OF) 0.2 for outdoor and 0.8 for indoor environment and the conversion factor (CF) from the absorbed dose rate in air to effective dose is 0.7 Sv y^{-1}for the adults. The E_{out} is calculated by avail oneself of the following equation proposed by UNSCEAR [24].

$$E_{Out} = \left(mSv\,y^{-1}\right) = D_{Out}\left(nGy\,h^{-1}\right) \times 8760 \times 0.2 \times 0.7 \times 10^{6} \tag{11}$$

where E_{out} is the outdoor annual effective dose rate expressed in mSv·year^{-1}.

Likewise, the indoor annual effective dose rate (E_{in}) is calculated by avail oneself of following equation proposed by UNSCEAR [24].

$$E_{In}\left(mSv\,y^{-1}\right) = D_{In}\left(nGy\,h^{-1}\right) \times 8760 \times 0.8 \times 0.7 \times 10^{6} \tag{12}$$

Annual gonadal dose equivalent (AGDE)

To estimate the dose received by different body organs and gonads UNSCEAR has formulated an equation and is given by;

$$\mathrm{AGDE} = 3.09 \times S_{\mathrm{Ra}} + 4.18 \times S_{\mathrm{Th}} + 0.314 \times S_{\mathrm{K}} \quad (13)$$

where the notations S_{Ra}, S_{Th}, and S_K stand in for the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively.

Excess lifetime cancer risk (ELCR)

The excess lifetime cancer risk is defined as the tendency that a person will develop cancer over his lifetime of radiation exposure. The cancer cell development due to exposure to ionizing radiation is not an immediate effect. It takes several years of time to develop. The cancer occurs only when an individual has reached an advanced age [33]. Therefore based on the estimation of AEDE values ELCR was estimated by the Eq. (11).

$$\mathrm{ELCER} = \mathrm{AEDE} \times \mathrm{MDL} \times \mathrm{RF} \quad (14)$$

where MDL represents the mean duration of life in years for Indian citizens equal to 70 and 0.057 is the risk factor to the public exposure [25, 34, 35].

Results and discussion

(a) Distribution of radionuclides in soil

The activity concentration of radionuclides (^{226}Ra ^{232}Th and ^{40}K), present in soil and building materials of the study area were determined by gamma ray spectrometry using NaI [Tl] detector. The average values of the activity concentrations of radionuclides, gamma absorbed dose (GAD) rate and equivalent effective dose rate are given in the Table 1. The recorded values of radionuclides (^{226}Ra ^{232}Th and^{40}K) in the soil samples of the entire study area varies from 6.5 ± 0.4 Bq kg^{-1} to 15.25 ± 2.6 Bq kg^{-1}, 10.49 ± 0.6 Bq kg^{-1} to 36.25 ± 3.5 Bq kg^{-1} and 50.16 ± 1.5 Bq kg^{-1} to 260.27 ± 4.6 Bq kg^{-1} with a median values of 11.52 ± 1.6, 19.94 ± 2.08 and 164.67 ± 3.2 Bq kg^{-1} respectively. The higher values of radionuclides (^{226}Ra ^{232}Th and ^{40}K) in soil was observed near the sports ground, chemical block, administrative office, nudi loka, social science block. These locations belong to second zone which consists mafic mineral schist, feldspar, kyanite, andalusite and staurolite and some garnet. These minerals contain higher activity of radionuclides [36, 37]. Slightly lesser activity concentration of radionuclides were observed at the prasanga, Biotech, Library science and computer Science block these locations are situated at the bottom of the hill towards the west. The rock system consists of ultramafic schist which is meta-igneous rocks with low silica content having lesser activity of radionuclides. Slightly lower activities of radionuclides were also observed in some locations of the first zone, which consists of some villages with thin forest. This zone is comprised by migmatite and granodiorite. The mineral compositions of these rocks are quartz, clays ortho clays, biotite, amphibol, hornblend and silicate [28]. The radionuclides are depends on the mineral composition of the feldspar and other mineral content [29]. Due to which lesser activity of radionuclides is observed in this zone. The lower activity of radionuclides is noticed at university quarters, BRP Quarters and Bhadra Dam. The university quarters are comprised by quartz, tolerite, schist, and orthoquartzite. Mineral composition of the rocks is tolerite minerals, quartz, and epizoite. These minerals may contain lower activity of radionuclides [38]. Hence lower activity is observed in these locations. The activity concentration of ^{40}K was found to be higher than that of ^{226}Ra and ^{232}Th in soil of all the locations of the study area. The abundance of ^{40}K is proportional to the silica content of the rock to some extent [39]. The activity concentration of thorium is higher than that of radium at all locations. The ratio of thorium (^{232}Th) and radium (^{226}Ra) was in the range of 1.61 to 2.90 the medium value can be used to determine the relative abundance of uranium and thorium in a given area. In the present study the estimated average activity concentration of ^{226}Ra, ^{232}Th, ^{40}K are 11.52 ± 1.60 Bq kg^{-1}, 19.94 ± 2.04 Bq kg^{-1} and 164.67 ± 3.28 Bq kg^{-1}respectively, these average values of radionuclides in the soil samples of the study area were found to be lower than the world average value 33, 45, 420 Bq $kg^{-1}$and Indian average value 29, 64, 400 Bq kg^{-1} [24]. The standard deviation, uncertainty and standard uncertainty in measurement of activity of radionuclides (^{226}Ra ^{232}Th and ^{40}K) using Bayesian statistics for soil is shown in Table 1. The estimated data shows confidence level of 95.45% (^{226}Ra = 3.66,^{232}Th = 2.59and ^{40}K = 25.50) and with the help of 'T' table we found the coverage factor $k = 2$.

Figure 3a–c Shows correlation between the absorbed dose rate and activity of radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) of soil. In comparison to ^{232}Th, the correlation between activity and total absorbed dose was determined to be ($R^2 = 0.90$), whereas the least relevant correlation was reported for ^{226}Ra ($R^2 = 0.70$) and ^{40}K ($R^2 = 0.78$). This is observed due to the fact that the major contribution is from Thorium content present in the soil [40]. Gamma absorbed dose is the energy imparted to a matter by ionizing radiation per unit mass of irradiated materials at the region of interest. The calculated activity concentration of radionuclides soil samples were used to estimate the GAD in air with the use of dose conversion coefficients of 0.46 nGy h^{-1}, 0.6 nGy $h^{-1}$and 0.042 nGy $h^{-1}$for ^{226}Ra, ^{232}Th, ^{40}K [24].

Table 1 Average activity of radionuclides and gamma absorbed dose rate of soil samples of the study area

S. no	Zones of location	Activity of Radionuclides (Bq kg^{-1})			^{232}Th/.^{226}Ra	AEDE (mSv y^{-1})			
		^{226}Ra Activity ± SD ± RUN	^{232}Th Activity ± SD ± RUN	^{40}K Activity ± SD ± RUN		GADR (nGy h^{-1})	E_{in}	E_{out}	E_{Total}
ZONE-I									
1	Shankaraghatta	9.53 ± 0.50 ± 0.25	15.26 ± 2.00 ± 1.00	70.15 ± 2.50 ± 1.25	1.60	16.57	0.08	0.02	0.10
2	Tipperudrappa Layout	10.51 ± 2.50 ± 1.25	17.21 ± 2.50 ± 1.25	80.37 ± 2.00 ± 1.00	1.64	18.63	0.09	0.02	0.11
3	Kudremukh Layout	11.24 ± 1.6 ± 0.80	16.33 ± 1.50 ± 0.75	100.27 ± 3.00 ± 1.50	1.45	19.27	0.09	0.02	0.12
4	Shanthi Nagara	10.10 ± 1.29 ± 0.60	14.27 ± 0.75 ± 0.35	90.42 ± 2.50 ± 1.25	1.41	17.08	0.08	0.02	0.10
5	BR Project	8.25 ± 0.50 ± 0.25	12.24 ± 0.57 ± 0.30	50.16 ± 1.50 ± 0.75	1.48	13.31	0.07	0.02	0.08
6	Near Bhadra Dam	7.54 ± 0.81 ± 0.40	10.49 ± 3.50 ± 1.75	65.21 ± 1.80 ± 0.90	1.39	12.56	0.06	0.02	0.08
7	Singanamane	12.50 ± 1.6 ± 0.80	13.46 ± 2.10 ± 1.05	110.37 ± 2 .60 ± 1.30	1.08	18.54	0.09	0.02	0.11
8	Fishery and Hand Post	11.52 ± 1.75 ± 0.85	15.52 ± 2.40 ± 1.20	95.79 ± 2 .00 ± 1.00	1.35	18.72	0.09	0.02	0.11
9	River turn Lodge	70.12 ± 0.57 ± 0.30	18.34 ± 2.40 ± 1.20	86.47 ± 1.50 ± 0.75	0.26	47.10	0.23	0.06	0.29
10	Lakkavalli	08.50 ± 0.81 ± 0.40	15.14 ± 1.40 ± 0.70	80.42 ± 1.70 ± 0.85	1.78	16.45	0.08	0.02	0.10
11	Kuvempu Nagara	10.34 ± 1.50 ± 0.75	14.25 ± 1.29 ± 0.65	130.25 ± 2.80 ± 1.40	1.38	18.85	0.09	0.02	0.12
12	Tavaraghatta	10.52 ± 1.50 ± 0.75	11.33 ± 1.00 ± 0.50	120.46 ± 2.50 ± 1.25	1.08	16.76	0.08	0.02	0.10
13	Malenahalli	09.15 ± 0.50 ± 0.25	13.32 ± 1.50 ± 0.75	98.45 ± 3.50 ± 1.75	1.46	16.41	0.08	0.02	0.10
14	Gonibeedu	11.47 ± 1.60 ± 0.80	14.27 ± 2.30 ± 1.15	110.26 ± 4.50 ± 2.25	1.24	18.55	0.09	0.02	0.11
15	Junction	12.5 ± 1.8 ± 0.90	19.34 ± 1.7 ± 0.85	125.09 ± 4.00 ± 2.00	1.55	22.71	0.11	0.03	0.14
ZONE-II									
1	Sports Ground	12.25 ± 2.10 ± 1.05	17.52 ± 3.00 ± 3.00	185.53 ± 3.60 ± 2.18	1.43	24.03	0.12	0.03	0.15
2	BGS College	11.52 ± 2.00 ± 1.00	16.54 ± 2.60 ± 2.60	189.25 ± 3.50 ± 1.75	1.44	23.26	0.11	0.03	0.14
3	Chemical Science Block	14.24 ± 2.50 ± 1.25	35.27 ± 2.10 ± 2.10	200.00 ± 4.50 ± 2.25	2.48	36.28	0.18	0.04	0.22
4	Ladies Hostel	12.5 ± 1.74 ± 0.87	36.25 ± 2.20 ± 2.20	260.27 ± 4.20 ± 2.10	2.90	38.60	0.19	0.05	0.24
5	Guest House	14.12 ± 2.50 ± 1.25	30.15 ± 2.40 ± 2.40	215.11 ± 4.60 ± 2.30	2.14	33.77	0.17	0.04	0.21
6	Shankara mata Temple	14.52 ± 2.60 ± 1.30	35.45 ± 2.50 ± 2.50	220.25 ± 4.50 ± 2.25	2.44	37.37	0.18	0.05	0.23
7	Social Science Block	13.33 ± 2.00 ± 1.00	20.22 ± 2.30 ± 2.30	210.30 ± 3.60 ± 1.80	1.52	27.20	0.13	0.03	0.17
8	Prasaranga	12.50 ± 1.80 ± 0.90	18.25 ± 2.00 ± 2.00	200.15 ± 3.50 ± 1.75	1.46	25.20	0.12	0.03	0.15
9	Bio Science Block	13.50 ± 2.50 ± 1.25	25.15 ± 3.20 ± 3.20	180.10 ± 3.00 ± 1.50	1.86	28.99	0.14	0.04	0.18
10	Library Science Block	12.45 ± 1.90 ± 0.95	22.24 ± 3.00 ± 3.00	225.20 ± 3.40 ± 1.70	1.79	28.64	0.14	0.04	0.18
11	Computer Science Block	11.48 ± 1.50 ± 0.75	18.32 ± 2.60 ± 2.6	235.50 ± 3.50 ± 1.75	1.60	26.26	0.13	0.03	0.16
12	Mlib	11.53 ± 1.60 ± 0.80	19.38 ± 2.50 ± 2.50	250.24 ± 3.00 ± 1.5	1.68	27.54	0.14	0.03	0.17
13	Boys Hostel	10.52 ± 0.80 ± 0.40	20.42 ± 2.00 ± 2.00	240.25 ± 3.50 ± 1.75	1.94	27.28	0.13	0.03	0.17
14	Commerce& MBA Block	9.54 ± 0.50 ± 0.25	18.17 ± 2.50 ± 2.50	230.15 ± 4.10 ± 2.05	1.90	25.05	0.12	0.03	0.15
15	Administrative Block	15.25 ± 2.40 ± 1.20	27.12 ± 1.60 ± 1.60	250.49 ± 4.50 ± 2.25	1.78	33.95	0.17	0.04	0.21

Table 1 (continued)

S. no	Zones of location	Activity of Radionuclides (Bq kg^{-1})			^{232}Th/^{226}Ra		AEDE (mSv y^{-1})		
		^{226}Ra Activity ± SD ± RUN	^{232}Th Activity ± SD ± RUN	^{40}K Activity ± SD ± RUN		GADR (nGy h^{-1})	E_{in}	E_{out}	E_{Total}
16	Distance Education	15.25 ± 2.40 ± 1.20	27.12 ± 1.60 ± 1.60	250.49 ± 4.50 ± 2.25	1.78	33.95	0.17	0.04	0.21
17	Basava Bhavana	15.25 ± 2.40 ± 1.20	27.12 ± 1.60 ± 1.60	250.49 ± 4.50 ± 2.25	1.78	33.95	0.17	0.04	0.21
18	Nudi Loka	14.54 ± 2.00 ± 1.00	30.15 ± 2.10 ± 2.10	240.30 ± 4.00 ± 2.00	2.07	35.02	0.17	0.04	0.21
ZONE-III									
1	Teachers quarters	06.52 ± 0.40 ± 0.20	10.49 ± 0.6 ± 0.60	50.16 ± 1.5 ± 0.75	1.61	15.65	0.08	0.02	0.10
	MAX	**15.25 ± 2.60 ± 1.30**	**36.25 ± 3.5 ± 1.75**	**260.27 ± 4.6 ± 2.30**	**2.90**	**38.60**	**0.19**	**0.05**	**0.24**
	MIN	**06.52 ± 0.40 ± 0.20**	**10.49 ± 0.6 ± 0.30**	**50.16 ± 1.50 ± 0.75**	**1.61**	**15.65**	**0.08**	**0.02**	**0.08**
	AV	**11.52 ± 1.60 ± 0.79**	**19.94 ± 2.04 ± 1.02**	**164.67 ± 3.28 ± 1.62**	**1.72**	**24.28**	**0.12**	**0.03**	**0.15**
	GM	**11.26 ± 1.40 ± 0.69**	**18.81 ± 1.90 ± 0.94**	**148.67 ± 3.12 ± 1.53**	**1.67**	**23.14**	**0.11**	**0.03**	**0.14**
	SD	**2.38 ± 0.71 ± 0.35**	**7.21 ± 0.70 ± 0.35**	**68.83 ± 0.97 ± 0.51**	**0.42**	**7.61**	**0.04**	**0.01**	**0.05**
	RUN	**0.41 ± 0.12 ± 0.06**	**1.24 ± 0.12 ± 0.06**	**11.80 ± 0.17 ± 0.09**	**0.07**	**1.31**	**0.01**	**0.00**	**0.01**
	SU	**4.36 ± 1.10 ± 0.55**	**12.88 ± 2.45 ± 0.72**	**105.05 ± 1.55 ± 0.77**	**0.64**	**11.47**	**0.05**	**0.01**	**0.08**

AV Average, *GM* Geometric mean, *SD* standard deviation, *RUN* random uncertainty, *SU* standard uncertainty

The bold representation in this tables are the minimum, maximum, average and uncertinity values that are given at the end of each table

The Fig. 4a–c shows correlation between ^{226}Ra and ^{232}Th ^{226}Ra and ^{40}K and ^{232}Th and ^{40}K present in soil samples. There exists is a strong and positive correlation between ^{226}Ra and ^{232}Th with correlation coefficient of $R^2 = 0.57$ and in between ^{226}Ra and ^{40}K the correlation coefficient of $R^2 = 0.46$ and similarly for ^{232}Th and ^{40}K it is observed $R^2 = 0.51$ respectively.

(a) Activity Concentration of radionuclides in Building materials:

About 17 building materials were collected from the study area. The activity of radionuclides (^{226}Ra, ^{232}Th, and^{40}K) of the building material was estimated by gamma ray spectrometry. The activity concentration of radionuclides in building materials were summarized in Table 2. The activity concentration of ^{226}Ra, ^{232}Th, and^{40}K varies from 8.12 ± 0.30 Bq kg^{-1} to 150.27 ± 4.0 Bq kg^{-1}, 18.47 ± 0.2 Bq kg^{-1} to 200.17 ± 4.5 Bq kg^{-1} and 45.25 ± 2.0 Bq kg^{-1} to 1500.24 ± 14.5 Bq kg^{-1} with an average value of 48.53 ± 1.99 Bq kg^{-1}, 63.20 ± 2.48 Bq kg^{-1} and 470.47 ± 6.59 Bq kg^{-1}respectively. The higher values noticed in pink granite, slightly lower values in gray granite and lower values in the Black granite. This may be due to higher content of minerals compositions such as quartzite, silica, potassium feldspar is present in granite [34, 36].The different colours of the granite are due to variation in their chemical compositions [41]. The activity of marbles is same as local sand black granite. Marble is metamorphic rock consists of calcite and other minerals such as clay, silt, mica, quartzite, phirite iron oxide, graphite. The colour of the marble is due to the different mineral composition. This mineral composition may be very less radioactive nuclides; hence it is observed that the lower activity of radionuclides in marbles. The activity of radionuclides in ceramic is higher than that of vitrified tiles. Ceramic is admixture of illicit white clay kaolin white clay, calcite dolomite, sodium feldspar perilte, and talc, quartz and sand granule [42]. But vitrified tiles are a mixture of 60% clay 40% some mineral compositions. The ceramic contains more radionuclides than vitrified tiles; hence activity of radionuclides in ceramic is higher than that of vitrified tiles. The activity concentration in cement brick is higher compared to soil brick because the cement brick made-up of cement and granite rock jolly, these rocks contains higher activity of radionuclides [43].

The activity concentration in different types of cement is slightly higher than that of marble, black granite and sand because cement is made up of chemical combination of calcium, silicon, aluminium, iron and other ingredients. common materials is used to manufacture cement include limestone, chalk or marl combined with clay and, shells,

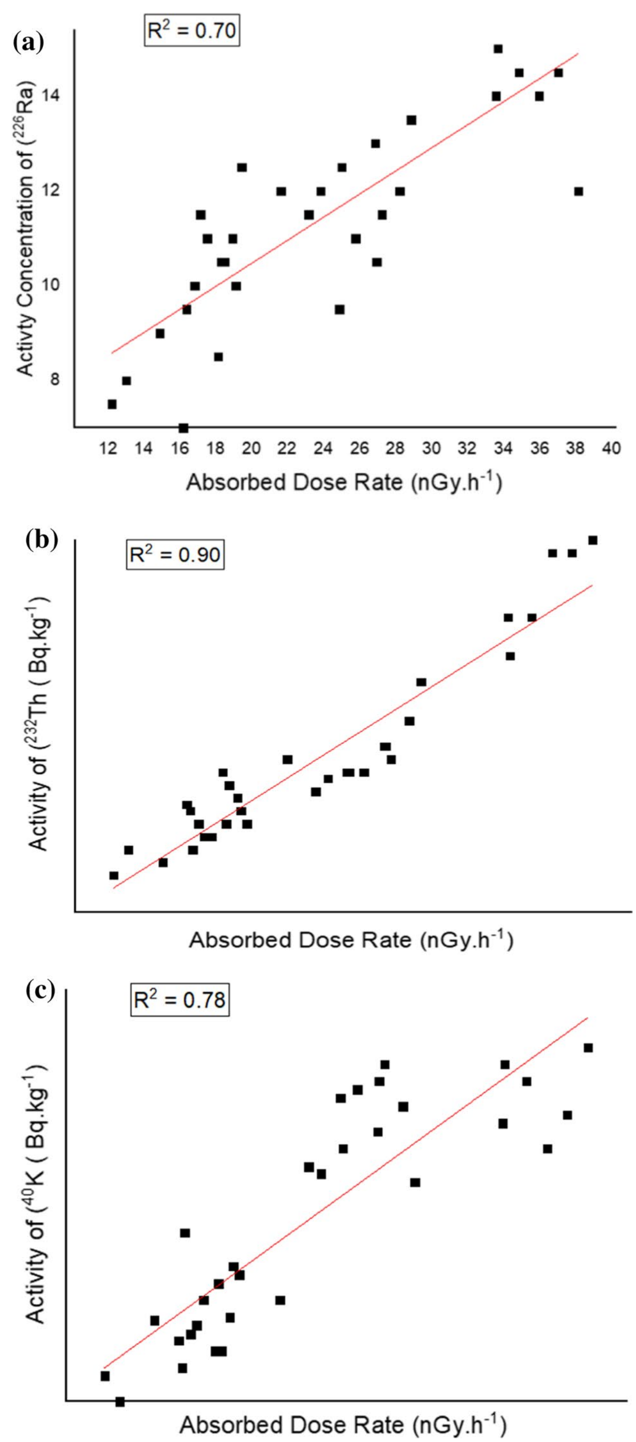

Fig. 3 **a** Correlation between calculatedabsorbed dose rate and ^{226}Ra concentration in soil samples of study area, **b** Correlation between calculatedabsorbed dose rate and ^{232}Th concentration in soil samples of study area, **c** Correlation between absorbed dose rate and ^{40}K concentration in soil samples of study area

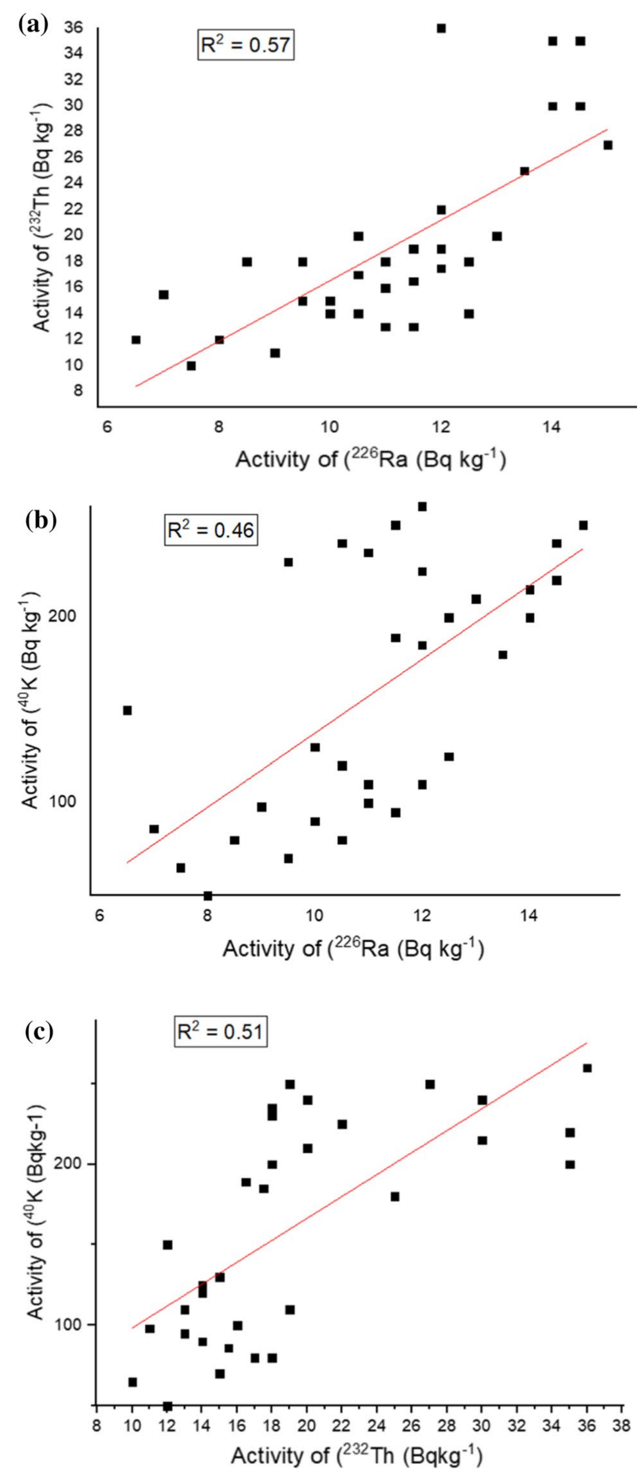

Fig. 4 **a** Correlation between the activity of ^{232}Th and ^{226}Rain soil samples, **b** Correlation between the activity of ^{226}Ra and ^{40}K in soil samples, **c** correlation between the activity of ^{232}Th and ^{40}K in soil samples

Table 2 Average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, gamma absorbed dose and annual effective dose in building materials samples of Shankaraghatta

S. no	Building materials	Activity of radionuclides(Bq kg^{-1})			^{232}Th/^{226}Ra	GADR (Din) nGy h^{-1}	AEDE (mSv y^{-1})		
		^{226}Ra Activity ± SD ± RUN	^{232}Th Activity ± SD ± RUN	^{40}K Activity ± SD ± RUN			E_{in}	E_{out}	E_{total}
Granites									
1	Pink granite	150.11 ± 4.10 ± 0.12	200.17 ± 4.20 ± 2.10	1500.24 ± 10.10 ± 5.05	1.33	478.30	2.34	0.60	2.93
2	Black granite	35.12 ± 2.20 ± 0.62	40.32 ± 3.50 ± 1.75	550.36 ± 8.00 ± 4. 00	1.14	120.69	0.58	0.10	0.70
3	Gray granite	95.34 ± 3.15 ± 0.40	90.05 ± 4.50 ± 2.25	1350.2 ± 12.10 ± 6.05	0.94	294.78	1.49	0.36	1.80
4	Black mix grey	65.24 ± 2.50 ± 030	105.32 ± 3.20 ± 1.60	1010.27 ± 6.2 ± 3.10	1.62	256.43	1.25	0.31	1.60
5	Maple red	53.30 ± 2.10 ± 0.12	79.94 ± 2.80 ± 1.40	1200.12 ± 14.5 ± 7.25	1.50	232.97	1.14	0.30	1.42
Marbles									
6	Rajasthan marble	14.19 ± 1.54 ± 0.20	25.26 ± 2.40 ± 1.20	60.22 ± 4.40 ± 2.20	1.78	45.65	0.22	0.05	0.27
7	Andra marble Kadapa	12.26 ± 1.62 ± 0.40	20.33 ± 1.80 ± 0.90	50.22 ± 3.20 ± 1.60	1.66	37.65	0.18	0.04	0.22
Tiles									
8	Ceramic tiles	150.27 ± 4.10 ± 0.42	175.49 ± 4.00 ± 2.00	390.46 ± 9.10 ± 4.55	1.16	362.52	1.77	0.44	2.21
9	Vitrified tiles	80.43 ± 3.50 ± 0.15	135.42 ± 3.20 ± 1.60	450.37 ± 13.00 ± 6.50	1.68	258.98	1.26	0.31	1.60
10	Mosaic tiles	38.41 ± 1.60 ± 0.20	42.61 ± 2.80 ± 1.40	355.15 ± 3.80 ± 1.90	1.11	110.62	0.54	0.13	0.67
Sand									
11	Sand-1	11.47 ± 1.45 ± 0.37	18.47 ± 1.60 ± 0.80	70.26 ± 5.00 ± 2.50	1.63	36.49	0.17	0.04	0.21
12	Sand-2	21.41 ± 1.20 ± 0.37	41.33 ± 1.80 ± 0.90	365.72 ± 3.20 ± 1.60	1.91	94.41	0.46	0.11	0.57
Cement									
13	Penna cement	15.53 ± 0.50 ± 0.12	19.51 ± 1.20 ± 0.60	45.25 ± 2.50 ± 1.25	1.25	39.36	0.19	0.05	0.24
14	Zuari cement	18.43 ± 0.30 ± 0.40	20.58 ± 0.20 ± 0.10	55.46 ± 2.80 ± 1.40	1.11	44.03	0.21	0.05	0.26
15	Ultratech cement	8.12 ± 0.40 ± 0.45	19.15 ± 0.90 ± 0.45	67.34 ± 5.50 ± 2.75	2.34	33.92	0.16	0.04	0.20
Bricks									
16	Soil brick	15.27 ± 1.80 ± 0.52	30.25 ± 2.50 ± 1.25	100.24 ± 4.10 ± 2.05	2.00	55.35	0.26	0.07	0.33
17	Cement bricks	40.15 ± 1.80 ± 0.50	52.26 ± 1.50 ± 0.75	376.10 ± 4.50 ± 2.25	1.30	124.51	0.60	0.15	0.76
	MAX	**150.27 ± 4.1 ± 0.62**	**200.17 ± 4.50 ± 2.25**	**1500.24 ± 14.50 ± 7.25**	**2.34**	**478.00**	**2.34**	**0.60**	**2.94**
	MIN	**8.12 ± 0.30 ± 0.12**	**18.47 ± 0.20 ± 0.10**	**45.25 ± 2.50 ± 1.25**	**0.95**	**33.70**	**0.17**	**0.04**	**0.21**
	AV	**48.53 ± 1.99 ± 0.33**	**63.20 ± 2.48 ± 1.23**	**470.47 ± 6.59 ± 3.29**	**1.50**	**154.00**	**0.76**	**0.19**	**0.94**
	GM	**32.46 ± 1.59 ± 0.29**	**44.98 ± 2.06 ± 1.03**	**245.17 ± 5.66 ± 2.83**	**1.46**	**104.90**	**0.51**	**0.13**	**0.64**
	SD	**46.01 ± 1.17 ± 0.15**	**58.40 ± 1.22 ± 0.60**	**491.31 ± 3.84 ± 1.91**	**0.40**	**109.80**	**0.54**	**0.13**	**0.67**
	RUN	**11.16 ± 0.28 ± 0.02**	**14.16 ± 0.29 ± 0.10**	**119.16 ± 0.93 ± 0.32**	**0.90**	**32.85**	**0.13**	**0.03**	**0.16**
	SU	**71.07 ± 1.90 ± 0.25**	**90.85 ± 2.15 ± 1.07**	**727.49 ± 6.00 ± 3.00**	**0.69**	**222.15**	**1.08**	**0.28**	**1.36**

AV average, *GM* geometric mean, *SD* standard deviation, *RUN* random uncertainty, *SU* standard uncertainty

The bold representation in this tables are the minimum, maximum, average and uncertinity values that are given at the end of each table

blast furnace slag, silica sand and iron ore. These materials are contains most important naturally occurring radionuclides such as ^{226}Ra, ^{232}Th, ^{40}K and trace metals [43]. Hence, it is observed higher values of radionuclides compared to marbles and the activity concentration of radionuclides (^{226}Ra, ^{232}Th, ^{40}K) typically less than the world average value which is of 50, 50, 500 Bq kg^{-1}respectively as mentioned in UNSCEAR 1993 reports [42–44]. The average activity concentration of the building materials varies from 48.53 ± 1.99 Bq kg^{-1}, 63.20 ± 2.48 Bq kg^{-1}; thorium (^{232}Th) concentration found to be higher than the world average values because granitic rocks contains higher concentration of ^{238}U and ^{232}Th [16, 30, 45] and for potassium (^{40}K) 470.47 ± 6.59 Bq kg^{-1} which is slightly less when compared to typical world average values of 50, 50and 500 Bq kg^{-1}respectively [46]. The standard deviation, uncertainty and standard uncertainty in measurement of activity of radionuclides (^{226}Ra ^{232}Th and ^{40}K) using Bayesian statistics for building material sample is as shown in Table 2. The estimated data shows confidence level of 95.45% (^{226}Ra = 24.22,^{232}Th = 30.25and ^{40}K = 258.47) and with the of 'T' table we found the coverage factor $k = 2$.

The Fig. 5a–c shows correlation between ^{226}Ra and ^{232}Th ^{226}Ra and ^{40}K and ^{232}Th and ^{40}K present in the building materials. There is a strong and positive correlation exists between ^{226}Ra and ^{232}Th with a correlation coefficient of $R^2 = 0.93$ and in between ^{226}Ra and ^{40}K the correlation coefficient of $R^2 = 0.$ 51 and similarly for ^{232}Th and ^{40}K it is observed $R^2 = 0.51$ respectively.

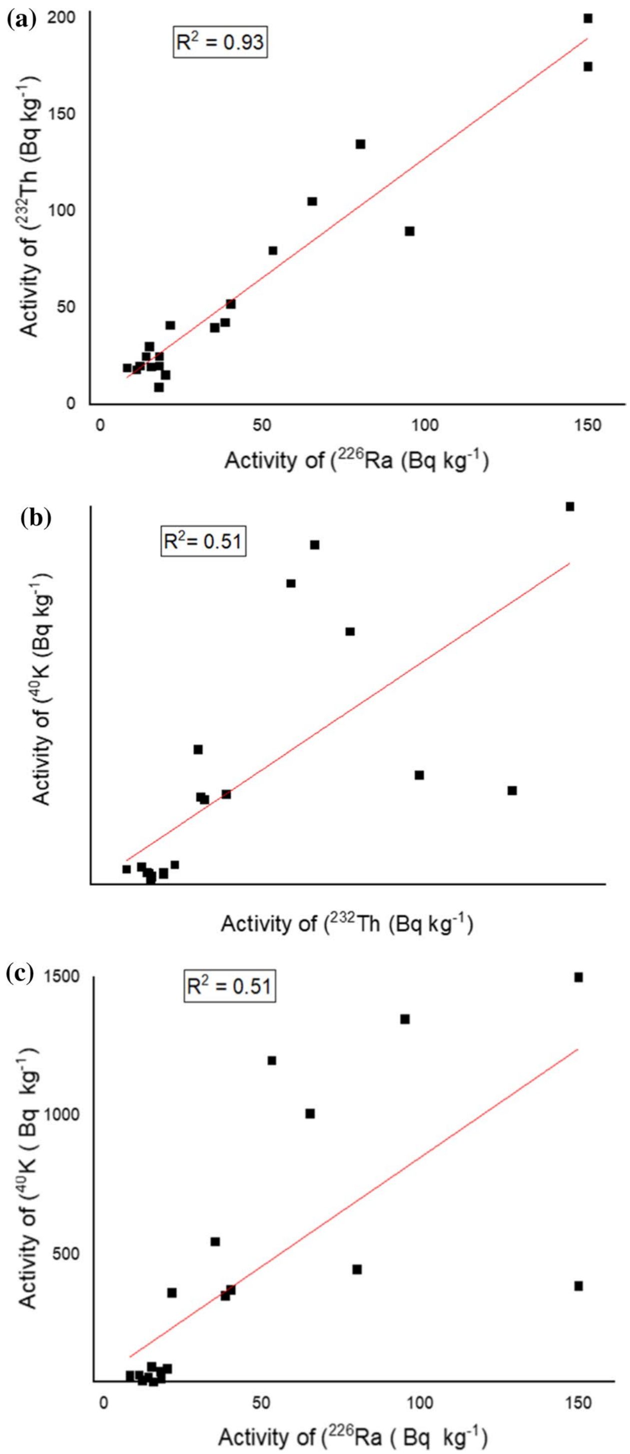

Fig. 5 **a** Correlation between the activity of ^{226}Ra and ^{40}K in Building material samples, **b** correlation between the activity of ^{232}Th and ^{40}K in Building material samples, **c** Correlation between the activity of ^{226}Ra and ^{40}K in Building material samples

(b) Distribution of gamma radiation levels in indoor and outdoor atmosphere:

The gamma absorbed dose rate for both in indoor and outdoor atmosphere have been calculated by estimating the activity of radionuclide in soil and building material and measured gamma exposure rate. The estimated absorbed dose rate can be converted into equivalent effective dose rate by using conversion factor 0.7 Sv $y^{-1}$and occupation factor i.e., the fraction of a time spent in indoor and outdoor atmosphere are 0.8 and 0.2 respectively. Were given in the Table 3 [24].The indoor measured ambient GAD rate of entire location varies from 3.8 ± 0.12 nGy h^{-1}, to 97.9 ± 1.3 nGy h^{-1}, with a mean value of 33.6 nGy h^{-1} and average value of 42.8 ± 0.6. The outdoor measured ambient GAD rate of the entire study area varies from 5.74 ± 0.4 nGy h^{-1} to 52.2 $\pm$ 1 nGy h^{-1} with a mean value of 17.3 and average value of 21.3 ± 0.8. The higher values outdoor gamma absorbed dose rate and annual effective dose rate are observed in the location such as sports ground near, boys, ladies hostel, and Guest House administrative block. The Gamma exposure rate depends on the local geology formation of rocks, mineral compositions and activity of radionuclides present in soil, parent rocks [17, 34, 36, 45, 47]. These locations are attributed by ultramafic rocks. The activity of radionuclides in soil shows higher when compared to the other locations (Table 1) except for the bioscience, library science building and Prasaranga. These locations shows slightly less gamma absorbed and equivalent effective dose rates, because these locations are surrounded by thick forest and upper layer of soil is highly humous and it contains more organic materials and this may be acts as shielding for gamma radiation. Hence notice slightly low activity. Higher depth of the soil may be contains higher activity of radionuclides present in soil. In the first zone slightly low GAD and AED was also noticed at the some of the locations and villages, in this zone GAD and AED rates don't vary significantly. This is because entire zone is comprised by migmatite and granodiorite. The activity of radionuclides present in the soil of these locations are also doesn't vary significantly as given in the Table 2. The locations such as University Quarters, BRP quarter and Bhadra Dam show lower value of GAD and AED. This may be due to the lower activity values of radionuclide present in the soil of these locations (Table 1).When comes to second zone which is the university campus; Shankaramata cave and Indoor Games building found that the outdoor GAD and AED is higher when compared to indoor. Because the cave formed from ultramafic rock consists of dunite which indeed has the lowest content of radioactive minerals [48]. And an Indoor game building's flooring is made up of wood; which in turn may acts as shielding for gamma. The University campus area is quite different when compared to the all the locations of zone-I. Because 20 to 30% of the campus

Table 3 Average measured ambient Gamma exposure rate, absorbed dose, and equivalent effective dose rate of the study area (Zone-I)

S. no	Zones of location	Absorbed dose D (nGy h^{-1})		Annual effective dose E (mSv y^{-1})		
		Indoor GAD ± SD ± RUN	Outdoor GAD ± SD ± RUN	Indoor	Outdoor	Total
ZONE-I						
1	*Shankaraghatta*					
a	Black granite	71.77 ± 0.95 ± 0.48	30.45 ± 0.50 ± 0.25	0.25	0.04	0.39
b	Vitrified	41.32 ± 0.50 ± 0.25	30.45 ± 0.50 ± 0.25	0.25	0.04	0.24
c	Andra marble	39.15 ± 0.57 ± 0.29	30.45 ± 0.50 ± 0.25	0.25	0.04	0.23
d	State highway	–	71.77 ± 1.29 ± 0.65	0.65	0.35	0.35
2	*Tipperudrappa layout*					
a	Pink granite introduced by gray	82.65 ± 0.50 ± 0.25	32.62 ± 1.29 ± 0.65	0.65	0.04	0.44
b	Black Mix pink	73.95 ± 0.57 ± 0.25	32.62 ± 1.29 ± 0.65	0.65	0.04	0.40
c	Red-oxide	47.85 ± 0.57 ± 0.28	32.62 ± 1.29 ± 0.65	0.65	0.04	0.27
3	*Kudremukh layout*					
a	Andra marble	36.97 ± 1.0 ± 0.50	28.71 ± 0.57 ± 0.29	0.29	0.04	0.22
b	Cement	47.85 ± 0.57 ± 0.29	28.71 ± 0.57 ± 0.29	0.29	0.04	0.27
c	Gray granite	65.25 ± 0.57 ± 0.29	28.71 ± 0.57 ± 0.29	0.29	0.04	0.36
4	*Shanthi nagara*					
a	Red-oxide	45.67 ± 1.0 ± 0.50	26.10 ± 1.50 ± 0.75	0.75	0.03	0.25
b	Cement	47.85 ± 0.6 ± 0.29	26.10 ± 1.50 ± 0.75	0.75	0.03	0.26
c	Mosaic tiles	50.03 ± 0.50 ± 0.25	26.10 ± 1.50 ± 0.75	0.75	0.03	0.28
d	Vitrified	43.50 ± 0.81 ± 0.41	26.10 ± 1.50 ± 0.75	0.75	0.03	0.24
5	*BRP quarters*					
a	Red oxide	45.67 ± 1.0 ± 0.50	17.40 ± 0.40 ± 0.20	0.20	0.02	0.24
b	Cement	43.50 ± 0.81 ± 0.41	17.40 ± 0.40 ± 0.20	0.20	0.02	0.23
c	Magna tiles	50.03 ± 0.50 ± 0.25	17.40 ± 0.40 ± 0.20	0.20	0.02	0.27
6	*Near Bhadra Dam*					
a	Cement	43.50 ± 0.81 ± 0.25	26.10 ± 0.50 ± 0.25	0.25	0.03	0.24
7	*Singana Mane*					
a	Black Granite	69.60 ± 0.81 ± 0.41	32.19 ± 0.81 ± 0.41	0.41	0.04	0.38
b	Pink Mix Gray	82.65 ± 0.57 ± 0.29	32.19 ± 0.81 ± 0.41	0.41	0.04	0.44
c	Cement	56.55 ± 0.81 ± 0.43	32.19 ± 0.81 ± 0.41	0.41	0.04	0.32
8	*Fishery office and hand post*					
a	Kadapa	41.32 ± 0.50 ± 0.25	34.80 ± 1.50 ± 0.75	0.75	0.04	0.24
b	Red-oxide	43.50 ± 0.81 ± 0.41	34.80 ± 1.50 ± 0.75	0.75	0.04	0.25
c	Vitrified tiles	45.67 ± 1.0 ± 0.50	34.80 ± 1.50 ± 0.75	0.75	0.04	0.26
9	*River turn lodge*					

Table 3 (continued)

S. no	Zones of location	Absorbed dose D (nGy h^{-1})		Annual effective dose E (mSv y^{-1})		
		Indoor GAD ± SD ± RUN	Outdoor GAD ± SD ± RUN	Indoor	Outdoor	Total
a	Wood and cement	50.03 ± 0.50 ± 0.25	39.20 ± 1.29 ± 0.65	0.65	0.05	0.30
10	*Lakkavalli*					
a	Black mix pink granite	71.77 ± 0.81 ± 0.41	32.60 ± 0.57 ± 0.29	0.29	0.04	0.39
b	Andra marble	52.20 ± 0.50 ± 0.25	32.60 ± 0.57 ± 0.29	0.29	0.04	0.30
c	Rajasthan marble	41.32 ± 0.81 ± 0.41	32.60 ± 0.57 ± 0.29	0.29	0.04	0.24
d	Red-oxide	45.67 ± 0.51 ± 0.26	32.60 ± 0.57 ± 0.29	0.29	0.04	0.26
11	*Kuvempu nagara*					
a	KadapaTiles	43.50 ± 0.81 ± 0.41	33.93 ± 0.57 ± 0.29	0.29	0.04	0.25
b	Red-oxide	45.67 ± 0.9 ± 0.45	33.93 ± 0.57 ± 0.29	0.29	0.04	0.26
c	Cement	47.85 ± 1.29 ± 0.65	33.93 ± 0.57 ± 0.29	0.29	0.04	0.27
d	Gray granite	73.95 ± 0.57 ± 0.29	33.93 ± 0.57 ± 0.29	0.29	0.04	0.40
12	*Tavaraghatta*					
a	Cement	50.03 ± 0.57 ± 0.29	30.45 ± 0.57 ± 0.29	0.29	0.04	0.29
b	Red-oxide	47.85 ± 0.81 ± 0.41	30.45 ± 0.57 ± 0.29	0.29	0.04	0.27
c	Kadapa	43.50 ± 0.50 ± 0.25	30.45 ± 0.57 ± 0.29	0.29	0.04	0.25
13	*Malenahalli*					
a	Cement	50.02 ± 0.50 ± 0.25	33.06 ± 0.57 ± 0.29	0.29	0.04	0.29
b	Bare	34.80 ± 0.57 ± 0.29	33.06 ± 0.57 ± 0.29	0.29	0.04	0.21
14	*Gonibeedu*					
a	Cement	50.03 ± 0.50 ± 0.25	29.58 ± 0.4 ± 0.20	0.20	0.04	0.29
b	Bare	36.97 ± 1.00 ± 0.50	29.58 ± 0.4 ± 0.20	0.20	0.04	0.22
15	*Junction*					
a	Black granite	73.95 ± 1.29 ± 0.65	33.06 ± 0.75 ± 0.38	0.38	0.04	0.40
b	Red-oxide	47.85 ± 0.81 ± 0.41	33.06 ± 0.75 ± 0.38	0.38	0.04	0.27
c	Bare	34.80 ± 1.29 ± 0.65	33.06 ± 0.75 ± 0.38	0.38	0.04	0.21

Table 4 Average measured ambient Gamma exposure rate, absorbed dose, and equivalent effective dose rate of the study area (Zone-II)

S. no	Zones of locations	Absorbed dose D (nGy h^{-1})			Annual effective dose E (mSv y^{-1})					
		Indoor GAD ± SD ± RUN	Outdoor soil GAD ± SD ± RUN	Outdoor interlock GAD ± SD ± RUN	E_{in}	E_{out} soil	E_{out} Interlocks	E_{out} Tar Road	E_{total}	Total of all samples
1	Sports Ground Near Ceramic Tiles	43.50 ± 0.81 ± 0.41	41.32 ± 0.57 ± 0.29	50.02 ± 0.5 ± 0.25	0.21	0.05	0.24	0.08	0.26	0.59
2	BGS College Ceramic Tiles	47.85 ± 1.29 ± 0.65	30.45 ± 0.5 ± 0.25	60.90 ± 0.50 ± 0.25	0.23	0.07	0.29	0.08	0.27	0.65
3	Chemical Science Block Ceramic Tiles	52.20 ± 0.50 ± 0.25	39.15 ± 0.57 ± 0.29	56.55 ± 0.57 ± 0.29	0.25	0.04	0.27	0.08	0.30	0.66
4	Ladies Hostel Ceramic Tiles	58.72 ± 0.95 ± 0.48	41.76 ± 0.81 ± 0.41	58.72 ± 0.50 ± 0.25	0.28	0.05	0.28	0.08	0.34	0.71
5	Guest house Ceramic Tiles	50.02 ± 0.50 ± 0.25	40.02 ± 0.57 ± 0.29	63.07 ± 1.20 ± 0.65	0.24	0.05	0.30	0.08	0.29	0.68
6	Shankaramata Temple									
a	(a)Rock cave	8.70 ± 0.50 ± 0.25	26.10 ± 0.4 ± 0.20	58.72 ± 0.50 ± 0.25	0.04	0.03	0.29	0.08	0.07	0.44
b	(b)Ganesh Temple pink granite	78.30 ± 0.81 ± 0.41	52.20 ± 1.29 ± 0.65	58.72 ± 0.50 ± 0.25	0.38	0.06	0.28	0.08	0.45	0.82
7	Social-Science Block ceramic tiles	52.20 ± 0.50 ± 0.25	34.8 ± 1.29 ± 0.65	50.02 ± 0.89 ± 0.45	0.25	0.04	0.24	0.09	0.30	0.63
8	Prasaranga vitrified	45.67 ± 0.95 ± 0.48	30.45 ± 0.5 ± 0.25	50.02 ± 0.89 ± 0.45	0.22	0.03	0.24	0.08	0.26	0.59
9	Bio Science Block	56.55 ± 0.5 ± 0.25	32.19 ± 0.5 ± 0.25	50.02 ± 0.89 ± 0.45	0.27	0.03	0.24	0.09	0.31	0.65
10	MLIB Library Science Ceramic	52.2 ± 0.81 ± 0.41	26.10 ± 0.4 ± 0.20	65.25 ± 0.57 ± 0.29	0.25	0.03	0.32	0.09	0.29	0.69
11	Computer-Science Block	54.37 ± 0.95 ± 0.48	30.45 ± 1.29 ± 0.65	65.25 ± 0.57 ± 0.29	0.26	0.03	0.32	0.08	0.30	0.70
12	Library block white granite marble	56.55 ± 0.5 ± 0.25	28.27 ± 0.5 ± 0.25	65.25 ± 0.57 ± 0.29	0.27	0.03	0.32	0.08	0.31	0.71
13	Boys Hostel Ceramic Tiles	52.20 ± 0.5 ± 0.25	32.19 ± 0.57 ± 0.29	56.55 ± 0.57 ± 0.29	0.25	0.03	0.27	0.06	0.29	0.64
14	MBA Department Block Ceramic Tiles	47.85 ± 1.29 ± 0.65	31.32 ± 0.75 ± 0.38	54.37 ± 1.25 ± 0.63	0.23	0.03	0.26	0.08	0.27	0.62
15	Administrative Block									
a	(a) Pink Granite	97.87 ± 0.95 ± 0.48	40.45 ± 1.29 ± 0.65	63.07 ± 1.25 ± 0.63	0.48	0.05	0.30	0.09	0.53	0.93
b	(b) White Gray Granite	82.65 ± 0.50 ± 0.25	40.45 ± 1.29 ± 0.65	63.07 ± 1.25 ± 0.63	0.40	0.04	0.30	0.09	0.45	0.853
16	Distance Education Block Black mix Pink granite	67.42 ± 0.50 ± 0.25	40.45 ± 1.29 ± 0.65	52.20 ± 0.81 ± 0.41	0.33	0.04	0.30	0.08	0.38	0.77
17	Basava Bhavana Black & Graygranite	69.60 ± 0.57 ± 0.29	40.45 ± 1.29 ± 0.65	52.20 ± 0.81 ± 0.41	0.34	0.05	0.25	0.08	0.39	0.73
18	Nudi Loka Gray granite	67.4 ± 0.95 ± 0.48	28.27 ± 0.95 ± 0.48	65.25 ± 0.57 ± 0.29	0.33	0.03	0.32	0.10	0.36	0.78
19	Indoor Games Wooden base	30.45 ± 0.50 ± 0.25	39.15 ± 0.57 ± 0.29	65.25 ± 0.57 ± 0.29	0.15	0.04	0.32	0.08	0.19	0.60

Table 5 Average measured ambient Gamma exposure rate, absorbed dose, and equivalent effective dose rate of the study area (Zone-III)

S. nos	Zones of locations	Absorbed dose D(nGy h^{-1})		Annual effective dose E (mSv y^{-1})		
		Indoor GAD ± SD ± RUN	Outdoor GAD ± SD ± RUN	E_{in}	E_{out}	Total
ZONE-III						
	Teachers quarters					
1	(a) Vitrified	45.67 ± 0.95 ± 0.48	23.92 ± 0.50 ± 0.25	0.22	0.03	0.25
	(b) Ceramic	52.20 ± 0.81 ± 0.41	23.92 ± 0.50 ± 0.25	0.26	0.03	0.29
2	Teachers quarters sports ground near	52.20 ± 0.81 ± 0.41	8.70 ± 0.80 ± 0.41	0.26	0.01	0.27
Total average measured ambient Gamma exposure rate, absorbed dose, and equivalent effective dose rate of the study area(Zone-I, Zone-II and Zone-III)						
	MAX	**97.87 ± 1.29 ± 0.65**	**52.20 ± 1.50 ± 0.75**	**0.48**	**0.06**	**0.53**
	MIN	**8.70 ± 0.50 ± 0.25**	**8.70 ± 0.40 ± 0.20**	**0.05**	**0.01**	**0.08**
	AVERAGE	**42.80 ± 0.80 ± 0.37**	**21.34 ± 0.80 ± 0.40**	**0.22**	**0.03**	**0.25**
	GM	**33.70 ± 0.70 ± 0.35**	**17.3 ± 0.74 ± 0.36**	**0.17**	**0.02**	**0.19**
	SD	**23.50 ± 0.24 ± 0.12**	**13.5 ± 0.38 ± 0.20**	**0.12**	**0.02**	**0.14**
	RUN	**3.86 ± 0.03 ± 0.20**	**2.21 ± 0.05 ± 0.27**	**0.19**	**0.03**	**0.02**
	SU	**48.29 ± 0.39 ± 0.65**	**25.35 ± 0.55 ± 0.75**	**0.21**	**0.02**	**0.22**

AV average, *GM* geometric mean, *SD* standard deviation, *RUN* radom uncertainty, *SU* standard uncertainty, *GAD* gamma absorbed dose

The bold representation in this tables are the minimum, maximum, average and uncertinity values that are given at the end of each table

outdoor area is covered by interlocks and tar road**.** Here the average values of outdoor GAD and AED rates from the interlocks and tar road of the outside of all the buildings of the university campus compared to outdoor soil locations are given in the tabvle-3.0.The data shows the GAD rate and AED rate all the interlocks and tar road of the all locations is higher than the indoor GADR of locations such as Sports ground near, BGS College, Guest house, Prasaranga, MLIB, Computer science, Library block and MBA blocks. This shows that the man made materials i.e., interlocks and tar road material are responsible for enhanced outdoor gamma radiation levels.

The measured Outdoor GAD and AED rates are higher than the indoor GAD and AED for interlocks in the locations of zone-II (Tables 3, 4, 5) such as BGS College, Guest house, MLIB, Computer Science block and Library Science block. Because the interlocks of the buildings in those locations are made up of M-sand and since M-sand is produced by Gray granite rocks, these rocks contain higher activity of radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) [45]. Which enhance and in turn influence for the higher concentration of outdoor GAD. In the remaining locations of Zone II (Tables 3, 4, 5) interlocks are made up of local sand, which shows slightly lesser value compared to interlocks made-up of M-sand. The GAD and AED rates of single layer tar road are found to be highest and the Shankaraghatta state highway and Nudi Loka/Kannada department road is also shown highest gamma value for outdoor. This may be due to the less tar content present in it. In all other locations the tar road consists of double thick layer of tar, which serves as shielding may be due to this less GAD value is observed. The ambient GAD and AED for cement road is 52.2 ± 0.5 nGy $h^{-1}$and 0.3 ± 0.5 mSv y^{-1} when compared to tar road and is found to be 67.4 ± 0.5 nGy $h^{-1}$and 0.3mSvy^{-1} 5 mSv y^{-1}. Hence the material used for the tar road construction and the tar content in it will decide the GAD and AED rate. The average indoor measured GAD rate is as shown in Table 3. The indoor GAD and AED rate is mainly depends on the type of the building materials used for construction, local geology, types of buildings and ventilation conditions [49], the indoor GAD and AED rate are higher than the outdoor in all locations of these zones except indoor sports building, Shankaramata Cave and University Quarters. Because the entire university quarters building area is attributed by Quartz, chlorite schist and orthoquartzite. The flooring of the sports building is covered with the wooden materials, which containing lower activity of radionuclides and shielding the gamma radiations emitted from the ground. The higher values of GAD rate were observed in granites flooring at all locations of all this regions, the lower activity were observed in wooden and marble floorings of dwellings of the all the locations.

The values of indoor gamma dose rate of the entire study area varies from 3.8 ± 0.1 nGy h^{-1}, to 97.9 ± 1.3 nGy h^{-1}, with a mean value of 33.6 nGy $h^{-1}$and the average values of entire indoor GAD rate is found to be 42.8 ± 0.8, this is less than the world average of 84 nGy h^{-1}, and the outdoor

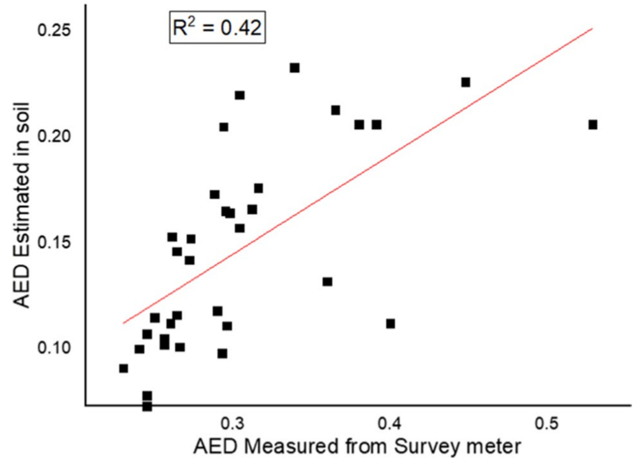

Fig. 6 **a** Correlation between measured AED and estimated AED from the soil

gamma dose rate values of the entire study area varies from 5.7 ± 0.4 nGy h^{-1}, to 52.2 ± 1.5 nGy h^{-1}, with the mean value of 17.3 nGy h^{-1}, and with an average value of 21.3 ± 0.8 which is less than the outdoor world average values outdoor gamma absorbed dose rates the world average value of 59 nGy h^{-1}, respectively [25]. The standard deviation, uncertainty and standard uncertainty in measurement of using Bayesian statistics for gamma radiation levels in indoor and outdoor atmosphere is as shown in Tables 3, 4, 5.The estimated data shows confidence level of 95.45% and with the help of '*T*' table we found the coverage factor $k=2$.

Malanca et al. [50] studied the correlation between measured and estimated GAD to observed significant positive correlation between the measured and estimated GAD is not observed in general. Alencar and Freitas they have given reason that; the non-existence of correlation is due to the treatment of the samples before gamma spectrometry-factors such as, humidity; compactness degree and density in situ are different for dried samples [51].On the flip side, they have also reported a significant positive correlation with the high correlation coefficient value between measured and estimated gamma dose rate. In order to know the correlation coefficient between measured and calculated annual effective dose due to radionuclides in the soil samples. We have performed the correlation studies and plotted a graph between AED as directly obtained from survey meter and the estimated AED from soils as shown in Fig. 6b.

Hazard indices

To compare the specific activity of radionuclides (^{226}Ra, ^{232}Th, ^{40}K) with the use of standard index parameter called Radium equivalent activity, which signifies radiation risk assessment associated with them. In the entire zones of soil's radium equivalent varies from 26.80 Bq kg^{-1} to 83.50 Bq $kg^{-1}$with a mean value of 49.70 Bq kg^{-1}. Similarly for building materials the values varies from 37.2 to 551.5 Bq $kg^{-1}$with a mean value of 106.22 Bq kg^{-1}. All the values are found to be fall within a safe limit of the world average permissible limit for radium equivalent activity is 370 Bq kg^{-1} [24].

The radiological hazard indices of the soil and building materials are given in Table 6. The calculated Gamma Index (I_γ) values for soil of the first zone ranged from 0.1to 0.17 with a mean value of 0.13 and 0.05 to 0.08 with a mean value 0.06 for second zone and for the third zone 0.040. The Gamma Index value for the entire study area of all zone varies from 0.04 to 0.17with a mean value of 0.09. Similarly, for building materials, the range is 0.13–2 with a mean of 0.38. According to the European Commission of Radiation Protection studies, the mean value of I_γ must be less than 1 to maintain the radiation risk assessment inconsequential to the general population. The mean I_γ values of the soil and building materials are much below the criteria limit of unity (1 mSv y^{-1}); the mean I_γ value of the area's building materials was found to be within the safe level, posing no substantial radiation hazard to the population living in and around the study area. The estimated average values of Internal and External hazard index (H_{in} and H_{ex}) in soil samples of the entire zone are 0.14, 0.17 respectively. For building material the average values of H_{in} and H_{ex} is 0.13, 0.10 respectively. Since these values found to be $< < 1$ (Table 7) and are in safe limit**,** hence in according to the report of Radiation Protection [25]. The health hazards due to these soil samples are insignificant (ECRP-1999) [27]. According to the UNSCEAR-2000 [24] report to estimate the dose received by the different body organs such as active bone marrow, Gonads and bone surface cells. The Annual Gonadal Dose Equivalent (AGDE) value of soil of entire study area found to vary from 0.09 to 0.27 $mSvy^{-1}$with a mean value of 0.160 mSv y^{-1}, which is less than the global average value of 0.30 $mSvy^{-1}$ and similarly for building materials AGDE values varies from0.12 to 1.8 mSv $y^{-1}$with a mean value of 0.33 mSv y^{-1} which is slightly higher than the global average value of 0.30 mSv y^{-1}.The calculated ELCR from annual effective dose equivalent varies from 0.3 to 0.9 with an average value of 0.6 these values higher than the global average value of 0.29×10^{-3} [47].

The standard deviation, uncertainty and standard uncertainty in measurement of hazard indices activity of radionuclides (^{226}Ra ^{232}Th and ^{40}K) using Bayesian statistics for gamma radiation levels in soil and building materials is as shown in Tables 6 and 7. The estimated data shows confidence level of 95.45% and with the help of '*T*' table we found the coverage factor $k=2$.

The correlation between the radionuclides of building material samples ^{226}Ra, ^{232}Th, ^{40}K with radium equivalent is

Table 6 Measured radiological hazard indices in soil sample of the Shankaraghatta environment

S. nos	Locations	Activity of radionuclides (Bq kg^{-1})			Ra_{eq} (Bq kg^{-1})	Hazard indices		Alpha index	Gamma index (Iγ)	AGDE (mSv y^{-1})	ELCR
		^{226}Ra Activity ± SD ± RUN	^{232}Th Activity ± SD ± RUN	^{40}K Activity ± SD ± RUN		Hex	Hin				
ZONE-I											
1	Shankaraghatta	9.53 ± 0.50 ± 0.25	15.26 ± 2.0 ± 1.00	70.15 ± 2.50 ± 1.25	36.34	0.10	0.12	0.05	0.13	0.11	0.40
2	Tipperudrappa Layout	10.51 ± 2.50 ± 1.25	17.21 ± 2.5 ± 1.25	80.37 ± 2.00 ± 1.00	40.97	0.10	0.14	0.05	0.15	0.13	0.45
3	Kudremukh Layout	11.24 ± 1.6 ± 0.80	16.33 ± 1. ± 0.85	100.27 ± 3.00 ± 1.50	41.58	0.10	0.14	0.06	0.15	0.13	0.46
4	Shanthi Nagara	10.1 ± 1.25 ± 0.64	14.27 ± 0.7 ± 0.75	90.42 ± 2.50 ± 1.25	36.95	0.10	0.13	0.05	0.13	0.12	0.41
5	BR Project	8.25 ± 0.50 ± 0.25	12.24 ± 0.6 ± 0.35	50.16 ± 1.50 ± 0.75	29.01	0.08	0.10	0.04	0.10	0.10	0.32
6	Near Bhadra Dam	7.54 ± 0.81 ± 0.40	10.49 ± 3.5 ± 0.3	65.21 ± 1.80 ± 0.90	26.80	0.07	0.09	0.04	0.10	0.09	0.30
7	Singanamane	12.5 ± 1.57 ± 0.80	13.46 ± 2.1 ± 1.75	110.37 ± 2.60 ± 1.30	47.64	0.13	0.16	0.06	0.17	0.15	0.53
8	Fishery and Hand Post	11.52 ± 1.75 ± 0.87	15.52 ± 2.4 ± 1.05	95.79 ± 2.00 ± 1.00	37.40	0.10	0.13	0.06	0.14	0.12	0.42
9	River turn Lodge	70.12 ± 0.57 ± 0.28	18.34 ± 2.4 ± 1.20	86.47 ± 1.50 ± 0.75	35.80	0.10	0.12	0.04	0.13	0.11	0.40
10	Lakkavalli	08.5 ± 0.57 ± 0.40	15.14 ± 1.4 ± 1.20	80.42 ± 1.70 ± 0.87	40.40	0.10	0.13	0.04	0.15	0.13	0.44
11	Kuvempu Nagara	10.34 ± 1.50 ± 0.75	14.25 ± 1.3 ± 0.70	130.25 ± 2.80 ± 1.4	41.50	0.10	0.14	0.05	0.15	0.13	0.47
12	Tavaraghatta	10.52 ± 1.5 ± 0.75	11.33 ± 1.0 ± 0.65	120.46 ± 2.50 ± 1.25	39.80	0.10	0.14	0.05	0.15	0.13	0.45
13	Malenahalli	09.15 ± 0.5 ± 0.25	13.32 ± 1.5 ± 0.50	98.45 ± 3.50 ± 1.75	32.30	0.09	0.11	0.05	0.12	0.10	0.36
14	Gonibeedu	11.47 ± 1.57 ± 0.80	14.27 ± 2.3 ± 0.75	110.26 ± 4.50 ± 2.25	38.06	0.10	0.13	0.05	0.14	0.12	0.43
15	Junction	12.5 ± 1.80 ± 0.90	19.34 ± 1.7 ± 1.15	125.09 ± 4.00 ± 2.00	42.15	0.11	0.15	0.06	0.15	0.14	0.48

S. nos	Locations	Activity of radionuclides (Bq kg^{-1})			Ra_{eq} (Bq kg^{-1})	Hazard indices		Alpha index	Gamma index (Iγ)	AGDE (mSv y^{-1})	ELCR
		^{226}Ra Activity ± SD ± RUN	^{232}Th Activity ± SD ± RUN	^{40}K Activity ± SD ± RUN		Hex	Hin				
ZONE-II											
1	Sports ground	12.25 ± 2.10 ± 1.05	17.52 ± 3.00 ± 1.50	185.53 ± 3.60 ± 1.8	51.30	0.14	0.17	0.19	0.06	0.17	0.58
2	BGS College	11.52 ± 2.00 ± 1.00	16.54 ± 2.60 ± 1.30	189.25 ± 3.50 ± 1.75	49.70	0.13	0.17	0.18	0.06	0.16	0.57
3	Chemical Science Block	14.24 ± 2.50 ± 1.25	35.27 ± 2.10 ± 1.05	200.00 ± 4.50 ± 2.25	79.50	0.21	0.25	0.29	0.07	0.25	0.88
4	Ladies Hostel	12.5 ± 1.74 ± 0.85	36.25 ± 2.20 ± 1.10	260.27 ± 4.20 ± 2.1	83.50	0.23	0.26	0.31	0.06	0.27	0.93
5	Guest House	14.12 ± 2.50 ± 1.25	30.15 ± 2.40 ± 1.20	215.11 ± 4.60 ± 2.3	73.50	0.20	0.24	0.27	0.07	0.24	0.82
6	Shankara mata Temple	14.52 ± 2.60 ± 1.30	35.45 ± 2.50 ± 1.25	220.25 ± 4.50 ± 2.25	81.50	0.22	0.26	0.30	0.07	0.26	0.90
7	Social Science Block	13.33 ± 2.00 ± 1.00	20.22 ± 2.30 ± 1.15	210.30 ± 3.60 ± 1.8	57.80	0.16	0.19	0.21	0.07	0.19	0.66
8	Prasaranga	12.50 ± 1.80 ± 0.90	18.25 ± 2.00 ± 1.00	200.15 ± 3.50 ± 1.75	53.60	0.14	0.18	0.20	0.06	0.18	0.61
9	Bio Science Block	13.50 ± 2.50 ± 1.25	25.15 ± 3.20 ± 1.60	180.10 ± 3.00 ± 1.50	63.10	0.17	0.21	0.23	0.07	0.20	0.70
10	Library Science Block	12.45 ± 1.90 ± 0.95	22.24 ± 3.00 ± 1.50	225.20 ± 3.40 ± 1.70	60.80	0.16	0.20	0.23	0.06	0.20	0.70
11	Computer Science Block	11.48 ± 1.50 ± 0.75	18.32 ± 2.60 ± 1.30	235.50 ± 3.50 ± 1.75	54.80	0.15	0.18	0.20	0.06	0.18	0.63
12	Mlib	11.53 ± 1.60 ± 0.80	19.38 ± 2.50 ± 1.25	250.24 ± 3.00 ± 1.50	57.90	0.16	0.19	0.22	0.06	0.19	0.67
13	Boys Hostel	10.52 ± 0.80 ± 0.40	20.42 ± 2.00 ± 1.00	240.25 ± 3.50 ± 1.75	57.60	0.16	0.18	0.22	0.05	0.19	0.66

Table 6 (continued)

S. nos	Locations	Activity of radionuclides (Bq kg^{-1}) ^{226}Ra Activity ± SD ± RUN	^{232}Th Activity ± SD ± RUN	^{40}K Activity ± SD ± RUN	Ra_{eq} (Bq kg^{-1})	Hazard indices Hex	Hin	Alpha index	Gamma index (Iγ)	AGDE (mSv y^{-1})	ELCR
14	Commerce& MBA Block	9.54 ± 0.50 ± 0.25	18.17 ± 2.50 ± 1.25	230.15 ± 4.10 ± 2.05	53.00	0.14	0.17	0.12	0.05	0.18	0.61
15	Administrative Block	15.25 ± 2.40 ± 1.20	27.12 ± 1.60 ± 0.8	250.49 ± 4.50 ± 2.25	71.32	0.19	0.23	0.26	0.08	0.23	0.80
16	Distance Education	15.25 ± 2.40 ± 1.20	27.12 ± 1.60 ± 0.80	250.49 ± 4.50 ± 2.25	72.90	0.20	0.24	0.27	0.08	0.24	0.82
17	Basava Bhavana	15.25 ± 2.40 ± 1.20	27.12 ± 1.60 ± 0.80	250.49 ± 4.50 ± 2.25	72.90	0.20	0.24	0.27	0.08	0.24	0.82
18	Nudi Loka	14.54 ± 2.00 ± 1.00	30.15 ± 2.10 ± 1.05	240.30 ± 4.00 ± 2.00	75.90	0.20	0.24	0.28	0.07	0.25	0.85
	ZONE-III										
19	Teachers quarters	06.52 ± 0.40± 0.20	10.49 ± 0.60±0.40	50.16 ± 1.50 ± 0.75	35.21	0.10	0.10	0.01	0.04	0.12	0.40
	MAX	**15.25 ± 2.60 ± 1.30**	**36.25 ± 3.50 ± 1.60**	**260.27 ± 4.60± 2.30**	**83.50**	**0.23**	**0.30**	**0.31**	**0.17**	**0.27**	**0.93**
	MIN	**6.52 ± 0.40 ± 0.20**	**10.49 ± 0.60 ± 0.40**	**50.16 ± 1.50 ± 1.50**	**26.80**	**0.07**	**0.02**	**0.01**	**0.04**	**0.09**	**0.03**
	AVERAGE	**11.25 ± 1.59 ± 0.94**	**19.69 ± 2.04 ± 1.12**	**163.76 ± 3.27 ± 1.92**	**52.61**	**0.14**	**0.14**	**0.15**	**0.10**	**0.17**	**0.59**
	GM	**10.98 ± 1.39 ± 0.84**	**18.54 ±1.90 ± 1.08**	**147.95 ± 3.11 ± 1.90**	**50.14**	**0.13**	**0.11**	**0.11**	**0.09**	**0.16**	**0.56**
	SD	**2.39 ± 0.70 ± 0.34**	**7.23 ± 0.69 ± 0.29**	**68.17 ± 0.96 ± 0.29**	**16.46**	**0.05**	**0.07**	**0.10**	**0.04**	**0.05**	**0.18**
	RUN	**0.41 ± 0.12 ± 0.17**	**1.24 ± 0.12 ± 0.14**	**11.69 ± 0.16 ± 0.14**	**2.82**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**	**0.03**
	SU	**11.99 ± 1.1 ± 0.55**	**12.88 ± 1.45 ± 0.60**	**105.05 ± 1.55±0.40**	**28.35**	**0.08**	**0.14**	**0.15**	**0.06**	**0.09**	**0.45**

AV average, *GM* geometric mean, *SD* standard deviation, *RUN* random uncertainty, *SU* standard uncertainty

The bold representation in this tables are the minimum, maximum, average and uncertinity values that are given at the end of each table

Table 7 Radiological hazard indices in building material sample of the Shankaraghatta environment

S. nos	Locations	Activity of radionuclides (Bq kg^{-1})			Ra_{eq} (Bq kg^{-1})	Hazard indices		Alpha Index	Gamma Index (Iγ)	AGDE (mSv y^{-1})	ELCR
		^{226}Ra Activity ± SD ± RUN	^{232}Th Activity ± SD ± RUN	^{40}K Activity ± SD ± RUN		Hex	Hin				
1	Pink granite	150.42 ± 4.00 ± 2.00	200.25 ± 4.0 ± 2.00	1500.50 ± 10.00 ± 5.00	551.50	1.50	1.90	0.80	2.00	1.80	0.01
2	Black granite	35.50 ± 2.00 ± 1.00	40.15 ± 3.50 ± 1.75	550.45 ± 8.00 ± 4.00	134.60	0.40	0.50	0.18	0.5	0.50	0.003
3	Gray granite	95.12 ± 3.00 ± 1.5	90.35 ± 4.50 ± 2.25	1350.27 ± 12.00 ± 6.00	327.70	0.90	1.10	0.48	1.22	1.10	0.01
4	Black mix grey	65.25 ± 2.50 ± 1.25	105. 35 ± 3.0 ± 1.50	1010.25 ± 6.20 ± 3.12	293.40	0.80	1.00	0.33	1.08	1.00	0.01
5	Maple red	53.15 ± 2.00 ± 1.00	79.92 ± 2.80 ± 1.40	1200.24 ± 14.5 ± 7.25	259.70	0.70	0.80	0.27	0.98	0.90	0.01
6	Rajasthan marble	14.2 ± 1.50 ± 0.75	25.15 ± 2.00 ± 1.00	60.35 ± 4.00 ± 2.00	54.40	0.20	0.20	0.07	0.19	0.20	0.001
7	Andra marble kadapa	12.25 ± 1.60 ± 0.80	20.25 ± 1.80 ± 0.90	50.20 ± 3.00 ± 1.50	44.50	0.10	0.20	0.06	0.16	0.10	0.001
8	Ceramic tiles	150.30 ± 4.0 ± 2.00	175.17 ± 4.00 ± 2.00	390.08 ± 9.00 ± 4.50	430.30	1.20	1.60	0.8	1.50	1.30	0.01
9	Vitrified tiles	80.45 ± 3.50 ± 1.75	135.45 ± 3.00 ± 2.00	450.11 ± 13.00 ± 6.50	307.70	0.80	1.10	0.4	1.09	1.00	0.01
10	Mosaic TILES	38.45 ± 1.60 ± 0.80	42.26 ± 2.00 ± 1.50	355.12 ± 3.80 ± 1.90	126.60	0.30	0.40	0.20	0.46	0.40	0.003
11	Sand-1	11.38 ± 1.40 ± 0.70	18.15 ± 1.60 ± 1.00	70.5 ± 5.00 ± 2.50	42.10	0.10	0.10	0.06	0.15	0.10	0.001
12	Sand-2	21.42 ± 1.20 ± 0.64	41.25 ± 1.80 ± 0.8	365.74 ± 3.20 ± 1.60	46.90	0.30	0.40	0.10	0.40	0.40	0.002
13	Penna cement	15.52 ± 0.50 ± 0.25	19.52 ± 1.20 ± 0.87	45.12 ± 2.50 ± 1.25	50.80	0.10	0.20	0.08	0.16	0.10	0.001
14	Zuari cement	18.22 ± 0.30 ± 0.15	20.08 ± 0.20 ± 0.64	55.50 ± 2.00 ± 1.00	40.50	0.10	0.20	0.10	0.18	0.20	0.001
15	Ultratech cement	8.17 ± 0.40 ± 0.20	19.05 ± 0.90 ± 0.43	67.32 ± 5.50 ± 2.75	59.10	0.10	0.10	0.04	0.14	0.10	0.001
16	Brick	15.07 ± 1.80 ± 0.87	30.15 ± 2.50 ± 1.25	100.15 ± 4.00 ± 2.00	143.50	0.20	0.20	0.10	0.23	0.20	0.001
17	Cement bricks	40.15 ± 1.800.87	52.2 ± 1.50 ± 0.75	376.18 ± 4.50 ± 2.25	50.80	0.40	0.50	0.20	0.52	0.50	0.003
	MAX	**150.42 ± 4.00 ± 2.00**	**200.25 ± 4.50 ± 2.25**	**1500.50 ± 14.5 ± 7.25**	**551.50**	**1.50**	**1.90**	**0.80**	**2.00**	**1.80**	**0.01**
	MIN	**8.17 ± 0.30 ± 0.15**	**18.15 ± 0.20 ± 0.43**	**45.12 ± 2.00 ± 1.00**	**40.50**	**0.10**	**0.10**	**0.04**	**0.14**	**0.10**	**0.001**
	AV	**48.32 ± 1.90 ± 0.97**	**62.90 ± 2.40 ± 1.30**	**470.30 ± 6.50 ± 3.24**	**174.30**	**0.50**	**0.60**	**0.24**	**0.64**	**0.60**	**0.004**
	GM	**32.20 ± 1.6 ± 0.79**	**46.90 ± 2.00 ± 1.18**	**244.70 ± 5.50 ± 2.74**	**116.40**	**0.30**	**0.40**	**0.16**	**0.44**	**0.40**	**0.002**
	SD	**39.05 ± 1.0 ± 0.57**	**47.30 ± 1.00 ± 0.55**	**427.10 ± 4.00 ± 1.95**	**158.50**	**0.40**	**0.50**	**0.23**	**0.60**	**0.50**	**0.003**
	RUN	**6.69 ± 0.17 ± 0.10**	**8.11 ± 0.19 ± 0.10**	**73.25 ± 0.69 ± 0.33**	**27.18**	**0.07**	**0.09**	**0.04**	**0.10**	**0.09**	**0.00**
	SU	**71.12 ± 1.85 ± 2.00**	**91.05 ± 2.15 ± 2.00**	**727.69 ± 5.00 ± 3.12**	**255.50**	**0.07**	**0.90**	**0.38**	**0.93**	**0.85**	**0.05**

AV average, *GM* geometric mean, *SD* standard deviation, *RUN* random uncertainty, *SU* standard uncertainty

The bold representation in this tables are the minimum, maximum, average and uncertinity values thatare given at the end of each table

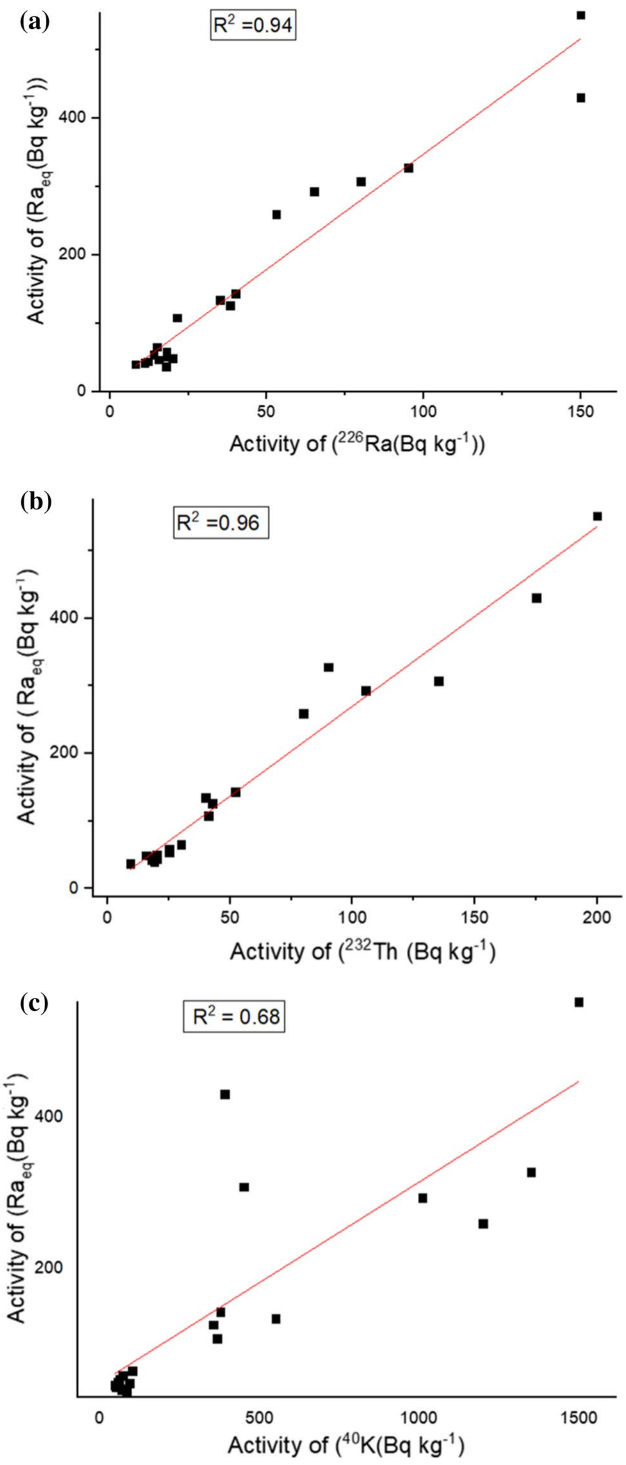

Fig. 7 **a** Correlation between ^{226}Ra and Ra_{eq} activity of building material sample, **b** Correlation between ^{232}Th and Ra_{eq} activity of building material sample, **c** correlation between ^{232}Th and Ra_{eq} activity of building material sample

shown in Fig. 7a–c. It shows a linear and strong correlation coefficient of $R^2 = 0.94.0.96$ and 068 respectively.

Conclusion

The activity concentration of radionuclides ^{226}Ra,^{232}Th, ^{40}K in the soils of the study area was inspected using NaI(Tl) Gamma Ray Spectrometry is found lower than the global average values [25]. The average values of activity concentration among the radionuclides in soil and building materials follows the trend $^{40}K > ^{232}Th > ^{226}Ra$. The permissible world average value for absorbed dose rate is 55 nGy h^{-1} [24], and the permissible world average value of annual effective dose is 1 mSv y^{-1} [24]. The total GAD and AED rates of the study area to the public are lower than the global average values as recommended by international Commission on Radiological Protection [47]. The values of radiation risk assessment parameters such as Alpha Index, Gamma Index External Hazard Index, and Internal Hazard Index, all these come within the safe limit. Calculated average values of all the hazard indices of soil and building material samples are in the safer limit and will not cause health risk to the public of the area. The man made materials i.e., interlocks materials used around the building for decorative purpose, it will enhance the gamma radiation levels. The overall estimated data shows confidence level of 95.45% with coverage factor $k = 2$ for soil and building material samples. The forest influences in reducing the gamma radiation levels as the maximum area is covered by humous over top of the soil which serves as natural shielding. The activity of radionuclides in indoor gamma radiation is mostly influenced by soil type and construction materials.

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