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Correlation and statistical analysis between natural radioactivity and hazards in rocks from Kolar taluk, Karnataka

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Abstract
Naturally occurring radionuclides rocks are one of the possible sources of indoor and outdoor radiation. Samples were taken from Kolar taluk in Karnataka in order to evaluate the radioactive hazards and natural radioactivity levels in those samples. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in these samples were determined using NaI(Tl) gamma ray spectroscopy. The measured ranged from 5.05 to 171.43 (Bq kg^{-1}); 5.04 to 274.64 (Bq kg^{-1}); 287.23 to 2603.45 (Bq kg^{-1}) for ^{226}Ra, ^{232}Th, and ^{40}K. In this study, the yearly effective radiation dosage, air absorbed gamma radiation dose rate, and hazard index (H_{in}, H_{ex}), gamma index, activity utilization index, annual gonald dose equivalent were estimated. The study's demonstrate that potassium (^{40}K), a naturally occurring radionuclide, is higher than radium and thorium. The levels of the computed radionuclides were compared to other places in Karnataka and world average value. The relationship between radionuclides was examined using correlation and statistical methods, radiation parameters were also computed. Information on background radioactivity levels and the impacts of radiation on locals in the research area under inquiry is what this study aims to deliver.

Keywords Natural radioactivity · Statistical analysis · Correlation · Activity concentration

Introduction

Assessing the natural radioactivity levels in the environment is crucial for determining the radiation exposure levels of individuals. One reason for radioactivity in rocks, water, and air is naturally occurring radioactive materials found in the Earth's crust [1]. More than 60 naturally occurring radioactive elements may be found in rock, soil, water, and the air, among other sources of natural radiation. These radiations are mostly contributed by the decay series of ^{226}Ra, ^{232}Th, and singly occurring isotopes such as ^{40}K [2]. Since the earth's origin, radiation has come from a variety of natural sources. The fact that ^{226}Ra, ^{232}Th, and ^{40}K naturally occurring sources expose an average individual to around four to five times as much as man-made sources is not unexpected [3]. Exposure to radionuclides can occur by direct contact, inhalation of contaminated dust particles, or consumption of contaminated food and drink [4]. There are varying degrees of radioactivity in all rocks and soils. The ^{226}Ra, ^{232}Th, and ^{40}K naturally occurring radioisotopes are the most prevalent on Earth's surface observing several research on radioisotope amounts in different kinds of rocks [5–8]. The distribution of naturally occurring radionuclides, such as ^{226}Ra, ^{232}Th, and ^{40}K, as well as other radioactive elements, is contingent upon the origin of the rocks and the processes that lead to their concentration [9]. Any location's radioactivity level is determined by the kind of soil and the intake of minerals [10]. Natural environmental radioactivity is influenced by the local geology [11, 12]. Building materials include rocks like limestone, gneisses, tuffs, and granite [13]. In order to determine the current amounts of radioactive pollutants released into the environment or in living things, studies of radionuclide distribution and naturally occurring radioactivity levels are typically conducted. These studies are crucial for determining the effects of radiation exposure on humans [14]. In the study, natural radioactivity and radiation were assessed using rock samples from the Kolar area in Karnataka. Using a multivariate statistical method, this evaluation was carried out to provide comprehensive findings on the

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natural radioactivity and associated radiation hazards in the rock samples. This presumably involved the examination of several factors and data sets. This approach provides significant insights into the study's objectives and results by enabling a more complete and comprehensive understanding of the radioactivity data and its implications.

Methodology

Study area

The Kolar district's ten sites provided the rock samples. The easternmost district of the state is Kolar, which is situated in southern Karnataka. The sampling sites were selected at random. Sites were chosen without taking radioactivity into account. The latitude and longitude of the sampling site are mentioned in the fig. 1 and Table 1 below. The locations of the gathered rock samples begin in Kolar and conclude close to Kondarajanahalli.

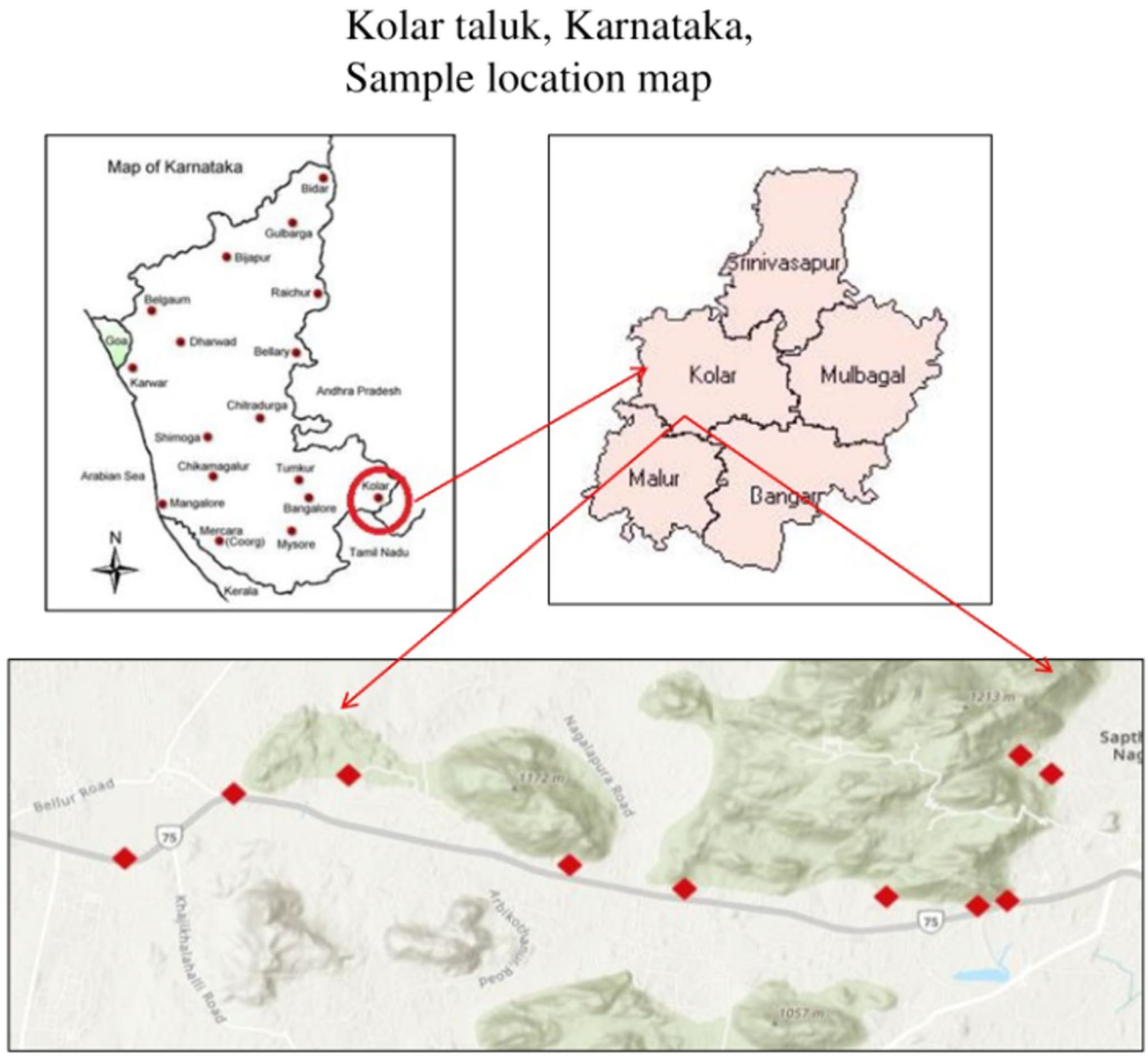

Fig. 1 Sampling Location Map

Table 1 Geographical information of sampling points

Sample Code	Sample location	Latitude	Longitude
KR1	Kolar	13.128187	77.998245
KR2	Kendatti Gollahali	13.13626	78.011066
KR3	Madivala	13.1386317	78.024438
KR4	Arabikothanur	13.127326	78.050108
KR5	Kaparasiddanahalli	13.124207	78.063519
KR6	Bettani	13.1232623	78.0870743
KR7	Kondarajanahalli	13.122115	78.097632
KR8	Vibhuthipura	13.141166	78.102709
KR9	Kandripura	13.138784	78.106248
KR10	Near Kondarajanahalli	13.1228479	78.1011921

Sample collection

A hammer was used to break the rocks and the pieces were collected from a particular spot. A master sample register contained comprehensive records that included the location date and sample description. Fragments were mixed separately and composited into a representative sample that weighed roughly two kilograms. Following preparation 200-milliliter plastic containers were used to store the samples for a predetermined 30 day period. Throughout this waiting period the progenitor radionuclides (^{226}Ra) to decompose into their offspring substances (^{222}Rn) until the point of equilibrium was reached. The samples were put through gamma ray spectroscopy following the storage time. Different radionuclides including ^{226}Ra, ^{232}Th and ^{40}K were measured for their activity concentrations using gamma ray spectroscopy. The natural radioactivity levels were evaluated and related radiation parameters were computed using the gamma ray spectroscopy results.

Gamma-ray spectroscopy

The TMCA32 programme is used to analyse the spectrum. The measurement was based on the natural radioactivity amounts of three naturally occurring long-live elements: ^{226}Ra, ^{232}Th, and ^{40}K. These elements are thought to be the photopeaks in the natural γ-ray spectra at 1764, 2614, and 1460 keV, respectively [15]. It was determined how well the detection system's calibration worked and this effort has made use of the outcomes. The following relation was used to compute the activity for the naturally occurring ^{226}Ra, ^{232}Th, and ^{40}K radionuclides [16, 17].

$$A = \frac{N}{\varepsilon \cdot \gamma \cdot t \cdot m} \quad (1)$$

where A (Bq kg^{-1}) is the activity concentration of radionuclides, N is the net peak area under the most prominent photo peaks determined by subtracting the corresponding count rate from the background spectrum acquired for the same counting time and Bq kg^{-1} is the radionuclide activity. The background-subtracted area of the most prominent gamma-ray peaks is used to calculate the measurements net count rate. ε is the detector efficiency of the gamma-ray, γ the absolute transition probability of gamma decay, *t* the counting time (s) and *m* the mass of the sample (kg).

Radiological parameters

Radium equivalent (Ra_{-eq})

The amount that corresponds to the sand's external γ radiation dosage is known as the radium equivalent concentration. To evaluate the distinct activity of sand with varying concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, the radium equivalent activity Ra_{-eq} is employed, as denoted by the subsequent expression UNSCEAR [14].

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

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K are represented by the letters $A_{Ra,}$ A_{Th} and A_K respectively. The basis for this is that the same gamma-ray dose equivalent is produced by 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K.

Absorbed dose rate (D_R)

One of the key factors influencing the natural background radiation is the concentration of radionuclide activity in rock sediments. According to UNSCEAR guidelines, all exposure rates are derived from radioactive sources in the rock sediment, and the activity concentration matches the total absorbed dose rate in the air at one metre above ground. This type of equation is typically used to estimate the gamma dose rate in indoor environments due to the presence of naturally occurring radioactive materials in building materials. D_R (nGy h^{-1}) [14, 18, 19].

$$D_{in} = 0.92\ C_{Ra} + 1.1\ C_{Th} + 0.08\ C_K \quad (3)$$

$$D_{out} = 0.462\ C_{Ra} + 0.621\ C_{Th} + 0.0417\ C_K \quad (4)$$

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

Annual effective dose (mSv y^{-1})

The annual effective dose (AED) is estimated by multiplying the dose rate received in the air by an adult by the indoor occupancy factor of 80 % and the conversion factor of 0.7 Sv Gy^{-1} [20]. The annual effective dose, expressed in mSv y^{-1}, was calculated considering the dose rate in air due to gamma radiation from naturally occurring radionuclides ^{226}Ra, ^{232}Th, and ^{40}K measured at one meter above the ground. The calculation follows the guidelines set forth in RP 112, with the annual effective dose limit set at 1 mSv y^{-1} [18].

$$AED_{in} = D_{in} \times 8760h \times 0.8 \times 0.7 \times 10^{-6} mSv\ y^{-1} \quad (5)$$

The (AED_{out}) is estimated from the outdoor external dose rate (D_{out}), time of stay in the outdoor or occupancy factor (20%) of 8760 h in a year and the conversion factor (0.7 Sv Gy^{-1}) to convert the absorbed dose in air to effective dose. During the present study, the (AED_{out}) was calculated using the following equations as per [21].

$$AED_{out} = D_{out} \times 8760h \times 0.2 \times 0.7 \times 10^{-6} mSv\ y^{-1} \quad (6)$$

Hazard index

The index of external hazards an indicator that is frequently used to assess the radioactive danger of construction materials is called H_{ex}. This is how it is computed.

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (7)$$

where A_{Ra}, A_{Th} and A_K stand for the same activities in the building material or surroundings as before representing ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}). A material that has an external gamma dose of 1.5 mSv y^{-1} is associated with a H_{ex} index of unity. Radium equivalent activity (Ra_{eq}) principles are applied by the H_{ex}. According to the estimate 370 Bq kg^{-1} for ^{226}Ra, 259 Bq kg^{-1} for ^{232}Th and 4810 Bq kg^{-1} for ^{40}K produce an equivalent gamma-ray dose rate [22, 23]. The index of internal danger (H_{in}) The internal hazard index factor should be determined in order to evaluate the radiation hazard risk posed by radon and its short-lived daughter products, which are dangerous to respiratory organs [24]. The internal hazard index (H_{in}), which is determined by the following equation, measures the internal exposure to radon and its daughter products.

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (8)$$

Gamma index

The gamma index (I_γ) is a useful tool for assessing the potential health risks associated with naturally occurring radioactivity in materials such as rocks, soil and building materials. The formula for the gamma index is. It is computed using the activity concentrations of three radionuclides that are frequently found in natural materials: potassium-40, radium-226 and thorium-232. [25].

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \leq 1 \quad (9)$$

where A_{Ra}, A_{Th}, and A_K are the activity concentrations (Bq kg^{-1}) of radium (^{226}Ra), thorium (^{232}Th), and potassium (^{40}K), respectively.

Activity utilization index (AUI)

AUI is a metric that is used to evaluate the radioactivity of radioactive materials in rocks or building materials in order to determine whether or not they can be used. In order to do this the external gamma dose rate must be calculated at a reference distance (like one meter) from the material and compared to any applicable regulatory or guideline limits. AUI determines whether a material satisfies safety standards for radiation exposure by integrating the activity concentration of radionuclides and the corresponding dose rates.

$$I = \frac{A_{Ra}}{50} f_{Ra} + \frac{A_{Th}}{50} f_{Th} + \frac{A_K}{500} f_K \leq 2 \quad (10)$$

The fractional contributions of gamma radiation from the actual concentrations of these radionuclides f_{Th} (0. 604), f_{Ra} (0. 462) and f_K (0. 041) to the total dose rate in air are taken into consideration [26, 27].

Excess lifetime cancer risk (ELCR)

The excess lifetime cancer risk (ELCR) was calculated using the equation:

$$ELCR_{Out} = AEDE_{out} * DL * RF \quad (11)$$

$$ELCR_{In} = AEDE_{in} * DL * RF \quad (12)$$

In this case RF represents the risk factor (Sv^{-1}) or the fatal cancer risk per sievert and DL stands for average lifespan (70 years). ICRP 103 recommended a public exposure level of 0. 05 to account for stochastic effects from low dose background radiation [28].

Annual gonad dose equivalent

According to UNSCEAR (1988) [29], the active bone marrow and the bone surface cells are the organs of interest. Since ^{226}Ra, ^{232}Th, and ^{40}K are particular activities found in building materials, the annual gonad dose equivalent (AGDE) (μSv y^{-1}) for individuals residing within a structure is determined using the formula below.

$$\mathrm{AGDE} = 3.09 \times A_{Ra} + 418 \times A_{Th} + 0.0317 \times A_K \quad (13)$$

Elemental concentration

Naturally ocuuring radioactivity levels are commonly expressed in one of two ways: parts per million (ppm) indicates the concentration of a specific radioisotope in the material while becquerels per kilogram (or gram) indicates the level of radioactivity generally or due to a particular isotope. C_{Th} (1 ppm) in rock is equivalent to 4.06 Bq kg^{-1}, C_{Ra} (1 ppm) in rock is equivalent to 12.35 Bq kg^{-1} and C_K 1(%) in rock is equivalent to 313 Bq kg^{-1} according to the IAEA [30, 31].

Radiogenic heat production

Rock heat may be calculated using estimates of ^{40}K, ^{226}Ra, and ^{232}Th concentrations from gamma ray spectroscopy. Thermal energy is released when naturally occurring radionuclides in the ground disintegrate; the majority of this energy is created by the decay of ^{40}K, ^{226}Ra, and ^{232}Th. The density of rock, ρ (kg/m^3), the concentration of radioelements C_K (%), C_{Ra} (ppm), and C_{Th} (ppm), and the heat production (HP) of rocks are connected by [29].

$$\mathrm{HP} = (3.48\ C_K + 9.52\ C_{Ra} + 2.56\ C_{Th})10^{-5}\ \left(\mu \mathrm{W\ m^{-3}}\right) \quad (14)$$

Result and discussion

The radionuclide (^{226}Ra, ^{232}Th and ^{40}K) activity concentration of rock samples were shown in table 2. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were found to be ranged from 5.05 to 171.43 Bq kg^{-1}, 5.04–274.64 Bq kg^{-1}, 287.23 to 2603.45 Bq kg^{-1} and the mean value of ^{226}Ra, ^{232}Th, ^{40}K is 21.40 Bq kg^{-1}, 141.03 Bq kg^{-1}, 1297.92 Bq kg^{-1}. For bellow detectable limit the value of 5.05 Bq kg^{-1} for ^{226}Ra and 5.04 Bq kg^{-1} for ^{232}Th limit of detector is used. So it gives uncertainty and bias into subsequent calculations of radiological parameters. The highest value radium found to be Kolar 171.43 Bq kg^{-1}, for thorium Bettani 274.64 Bq kg^{-1} and for potassium Kondarajanahalli 2603.45 Bq kg^{-1}. The lowest value for ^{226}Ra found to be Kendatti Gollahali, Madivala, Arabikothanur, Kaparasiddanahalli, Kondarajanahalli, Vibhuthipura, Kandripura, Near Kondarajanahalli (5.05); for ^{232}Th Kolar (5.04); and ^{40}K Kolar (287.23 Bq kg^{-1}). The ^{232}Th/^{226}Ra ratio shows how abundant ^{232}Th is in comparison to ^{226}Ra in the rock samples. 0.03 to 52.66 are the range of values and average value: 23.14; ^{40}K/^{226}Ra ratio shows how abundant ^{40}K is in the samples in comparison to ^{226}Ra. 1.68 to 515.53 are the range of values and average value 223.09; ^{40}K/^{232}Th ratio shows how abundant ^{40}K is in the samples in comparison to ^{232}Th, range from 3.01 to 101.00 and average value is 25.42. In particular the ^{40}K/^{226}Ra ratio exhibits a broad range ranging from very high values exceeding (KR7) to relatively low values around (KR1).

In Table 3 elemental concentration radium range is from 0.41 to 13.88 ppm, thorium range is from 1.24 to 67.65 ppm

Table 2 Activity Concentration (Bq kg^{-1}) and ratio of activities.

Sample Code	^{226}Ra (Bq kg^{-1})	^{232}Th	^{40}K	^{232}Th/^{226}Ra	^{40}K/^{226}Ra	^{40}K/^{232}Th
KR1	171.43±10.40	5.04	287.23±17.00	0.03	1.68	56.99
KR2	5.05	99.96±5.91	1271.14±75.21	19.79	251.71	12.72
KR3	5.05	168.92±9.99	1137.28±67.29	33.45	225.20	6.73
KR4	5.05	12.05±0.71	1217.01±72.01	2.39	240.99	101.00
KR5	5.05	217.16±12.85	654.08±38.70	43.00	129.52	3.01
KR6	42.53±2.52	274.64±16.25	1627.94±96.33	6.46	38.28	5.93
KR7	5.05	82.86±4.90	2603.45±154.05	16.41	515.53	31.42
KR8	5.05	52.13±3.08	1294.23±76.58	10.32	256.28	24.83
KR9	5.05	236.63±14.00	1656.01±97.99	46.86	327.92	7.00
KR10	5.05	265.92±15.73	1230.84±72.83	52.66	243.73	4.63
Minimum	5.05	5.04	287.23	0.03	1.68	3.01
Maximum	171.43	274.64	2603.45	52.66	515.53	101.00
Average	21.40	141.03	1297.92	23.14	223.09	25.42

and potassium range is from 0.92 to 8.32% with the mean value of radium, thorium and potassium is 1.73 ppm, 34.74 ppm and 4.15%. Radiogenic Heat Production (RHP $\mu W/m^3$) range is from 0.6 to 6.39 $\mu W/m^3$ with mean value of 3.41 $\mu W/m^3$ (Fig. 2).

Radiological parameters

The radiological parameters assessed in the study show a range of values for different metrics. The Radium Equivalent Activity (Ra_{eq}) ranges from 107.47 to 549.22 Bq kg^{-1}, with a mean value of 318.68 Bq kg^{-1}, indicating moderate to high radioactivity in the samples. The indoor and outdoor dose rates range from 115.26 to 471.47 nGy h^{-1} and 60.57 to 258.09 nGy h^{-1}, respectively, averaging at 282.92 nGy h^{-1} (indoor) and 153.77 nGy h^{-1} (outdoor). Annual Effective Dose (AED) values are higher indoors 0.57 to 2.31 mSv y^{-1}, average 1.39 mSv y^{-1} compared to outdoors 0.07 to 0.32 mSv y^{-1}, average 0.19 mSv y^{-1}. Hazard indices (H_{ex} and H_{in}) vary from 0.31 to 1.51 and 0.33 to 1.63, respectively, with average values suggesting potential risks in some samples (Table 4). The Gamma Index (GI) ranges from 0.48 to 2.06, with an average of 1.23, indicating varying levels of gamma radiation hazard. The Excess Lifetime Cancer Risk (ELCR) is significantly higher indoors, ranging from 1.98 to 8.09, compared to 0.26 to 1.11 outdoors. The Activity Utilization Index (AUI) and Annual Gonad Dose Equivalent (AGEDE) also show some variation, with values suggesting moderate risk levels. When compared to the UNSCEAR 2000 guidelines, the results indicate that parameters like Ra_{eq}, indoor dose rate, indoor AED, and ELCR are slightly elevated, suggesting a higher potential health risk, while other parameters remain within normal limits.

Table 3 Elemental concentration ppm and Radiogenic heat production $\mu W/m^3$ in the rock samples from Karnataka

Sample Code	^{226}Ra ppm	^{232}Th	^{40}K %	RHP $\mu W/m^3$
KR1	13.88	1.24	0.92	3.86
KR2	0.41	24.62	4.06	2.2
KR3	0.41	41.61	3.63	3.4
KR4	0.41	2.97	3.89	0.6
KR5	0.41	53.49	2.09	4.11
KR6	3.44	67.65	5.20	6.39
KR7	0.41	20.41	8.32	2.31
KR8	0.41	12.84	4.13	1.35
KR9	0.41	58.28	5.29	4.78
KR10	0.41	65.50	3.93	5.17
Minimum	0.41	1.24	0.92	0.6
Maximum	13.88	67.65	8.32	6.39
Average	1.73	34.74	4.15	3.41

In Table 5 some significant differences and contributions can be seen when comparing the radionuclide activity concentrations from the present study in Kolar Taluk with those from earlier studies in Karnataka: the present study reports ^{226}Ra activity concentration of 25.44 Bq kg^{-1}, ^{232}Th of 141.53 Bq kg^{-1} and ^{40}K of 1297.92 Bq kg^{-1}. ^{238}U was recorded as 47.05 Bq kg^{-1} in the earlier studies conducted in Gadag which is substantially higher than in Kolar Taluk. This study contributes to the spatial diversity of data available for Karnataka by providing data specific to Kolar Taluk. A number of other districts including Ramanagara District, Tumkur District, Coorg District, Gadag, Gulbarga, Kottur and Kaiga environment have been the subject of earlier research all of which demonstrate variations in radionuclide levels based on geological and environmental factors. The current study in Kolar Taluk makes a contribution by completing geographical gaps in Karnataka radionuclide data. It offers current concentrations that are useful for risk assessment regulatory compliance and environmental monitoring. This study in Kolar Taluk adds to the body of knowledge about environmental radioactivity studies in Karnataka India by providing unique data on radionuclide activity concentrations and highlighting regional variability. The importance of localized studies in improving our comprehension of the distribution of natural radioactivity and its implications is highlighted by this comparative analysis.

Correlation analysis

Correlation coefficient R suggests that moderate level of connection between two variables. In correlation connection shows strength of the relation is weak or strong or fall somewhere in between. Positive correlation indicates that variable tends to move in same direction as one increases and other one also increases. Negative correlation indicates that variable tends to move in opposite direction as one increases other decreases.

The table 6 presents the Pearson correlation coefficients and corresponding *p* values for the relationships between three features (^{40}K, ^{232}Th and ^{226}Ra). The correlation between ^{40}K and ^{226}Ra is −0.52 with a *p* value of 0.11, suggesting a moderate negative correlation that is not statistically significant at the 0.05 level. The correlation between ^{226}Ra and ^{232}Th is −0.34 with a *p* value of 0.32, indicating a weak negative correlation, which is also not statistically significant. The correlation between ^{40}K and ^{232}Th is 0.15 with a *p* value of 0.66, showing a very weak positive correlation that is not statistically significant. Overall, none of the correlations are statistically significant, indicating that there is no strong evidence of a meaningful linear relationship between these pairs of features. Correlations suggests that these radionuclides may not be directly related in this

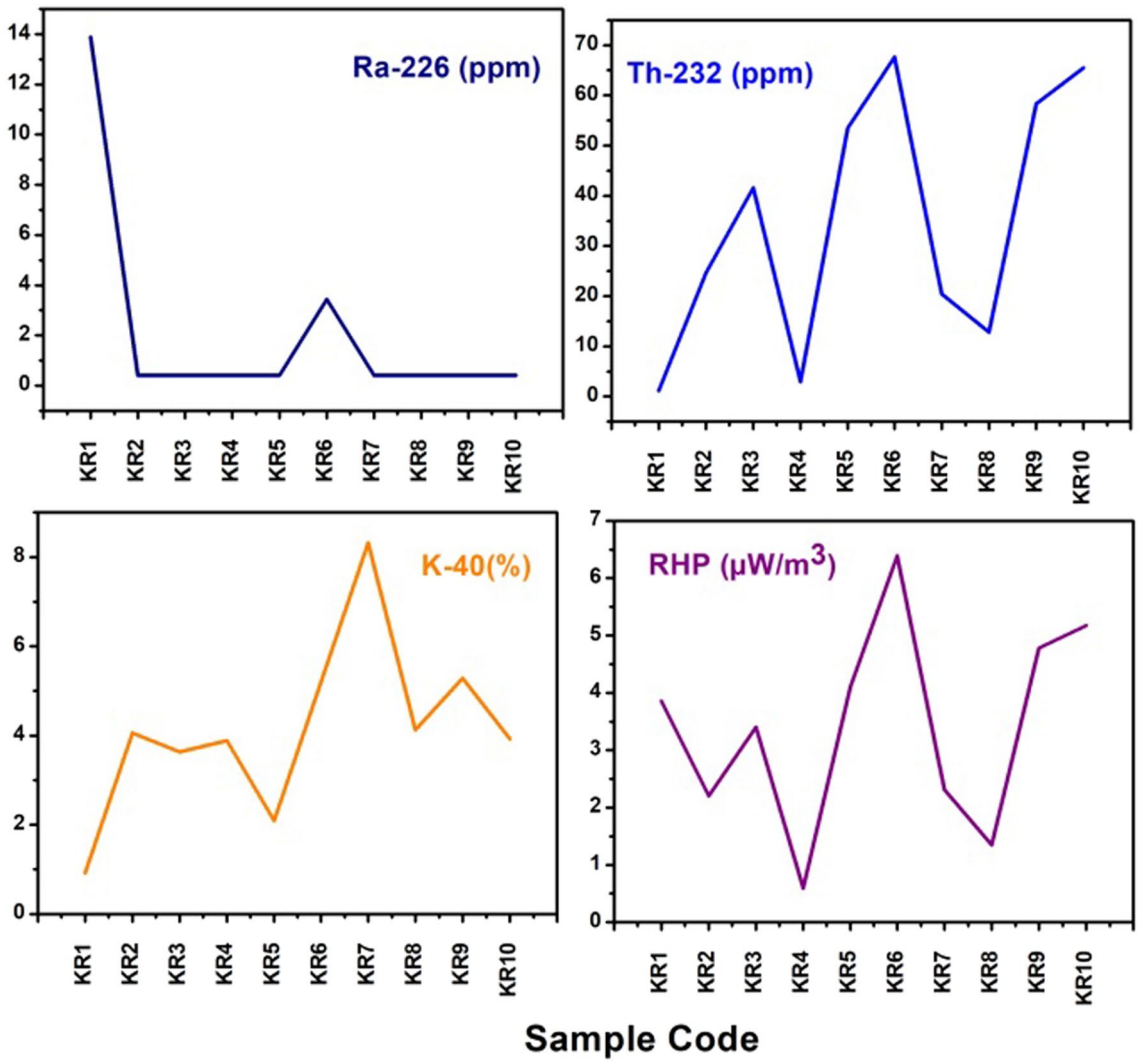

Fig. 2 Elemental concentration ppm and Radiogenic heat production μW/m^3

Table 4 Radiological Parameters for Karnataka rock samples

Sample Code	Ra_{eq}Bq kg^{-1}	D_R (nGy h^{-1})		AED (mSv y^{-1})		H_{ex}	H_{in}	GI	ELCR×10^{-3}		AUI	AGEDE mSv y^{-1}
		IN	OUT	IN	OUT			I_γ	OUT	IN	I	
KR1	198.74	186.24	94.31	0.91	0.12	0.54	1.01	0.69	0.40	3.20	0.44	0.64
KR2	236.97	216.29	117.41	1.06	0.14	0.66	0.68	0.94	0.50	3.71	0.23	0.83
KR3	326.22	281.44	154.66	1.38	0.19	0.90	0.92	1.24	0.66	4.83	0.37	1.08
KR4	107.47	115.26	60.57	0.57	0.07	0.31	0.33	0.48	0.26	1.98	0.05	0.45
KR5	361.37	295.85	164.46	1.45	0.20	0.99	1.00	1.32	0.71	5.08	0.46	1.13
KR6	549.22	471.47	258.09	2.31	0.32	1.51	1.63	2.06	1.11	8.09	0.68	1.79
KR7	305.78	304.07	162.35	1.49	0.20	0.87	0.89	1.30	0.70	5.22	0.20	1.18
KR8	170.19	165.53	88.68	0.81	0.11	0.48	0.50	0.71	0.38	2.84	0.13	0.64
KR9	459.35	397.42	218.34	1.95	0.27	1.27	1.29	1.75	0.94	6.82	0.51	1.52
KR10	471.47	395.63	218.80	1.94	0.27	1.30	1.31	1.76	0.94	6.79	0.57	1.51
Min	107.47	115.26	60.57	0.57	0.07	0.31	0.33	0.48	0.26	1.98	0.05	0.45
Max	549.22	471.47	258.09	2.31	0.32	1.51	1.63	2.06	1.11	8.09	0.68	1.79
Average	318.68	282.92	153.77	1.39	0.19	0.88	0.96	1.23	0.66	4.86	0.36	1.08

Table 5 Average value for activity concentration in other states of Karnataka

Places (Karnataka)	^{226}Ra	^{238}U	^{232}Th	^{40}K	References
	Bq kg^{-1}				
Gadag	–	47.05	73.27	1061.99	[32]
Gulbarga	–	4.89	7.25	120.66	
Kottur	–	45.91	20.86	874.92	
Kaiga environment	–	4.3	8.1	349.6	[33]
Coorg district	8.89	–	70.87	512.45	[34]
Tumkur district	37.40	–	92.26	915.90	[35]
Ramanagara district	40.34	–	85.98	882.40	
Kolar taluk	21.40		141.03	1297.92	Present study
World wide		35	30	400	[14, 36]

Table 6 Correlation for activity concentration (Bq kg^{-1})

Var 1	var 2	Correlation	p
K-40	Ra-226	−0.52	0.11
Ra-226	Th-232	−0.34	0.32
K-40	Th-232	0.15	0.66

dataset, or that any relationship is too weak to be detected with the current sample size

Statistical analysis

Skewness and kurtosis

In probability skewness is a measure of the asymmetry of distribution. A distribution is asymmetry when its left and right side are not mirror images. A distribution can have left as negative, right as positive and zero as skewness. Kurtosis in statistics describes the distribution of the data set points of a particular differ from the data of a normal distribution. It may use to determine whether a distribution contain extreme values.

The table 7 includes data for three radioactive isotopes ^{226}Ra, ^{232}Th, and ^{40}K. The highest observed values for each isotope are 171.43 for ^{226}Ra, 274.64 for ^{232}Th, and 2603.45 for ^{40}K (Figs. 3, 4 and 5). This indicates the maximum concentration of these isotopes in the sample set. The lowest observed values for each isotope are zero for both ^{226}Ra and ^{232}Th, and 287.23 for ^{40}K. A minimum value of zero suggests that some samples had no detectable levels of ^{226}Ra and ^{232}Th. The average concentration of each isotope across all samples is 21.4 for ^{226}Ra, 141 for ^{232}Th, and 1298 for ^{40}K. These values give a central tendency of the isotope concentrations. The middle value when the data are ordered from least to greatest is zero for

Table 7 Activity Concentration (Bq kg^{-1}) Statistical Analysis

Variables	Ra-226	Th-232	K-40
Maximum	171.43	274.64	2603.45
Minimum	0	0	287.23
Mean	21.4	141.03	1297.92
Median	0	134.44	1250.99
Skewness	2.86	−0.01	0.60
Kurtosis	8.35	−1.74	1.95
SD	54.38	104.70	616
Mode	0	0	287.23
Sum	219.01	1415.31	12979.21

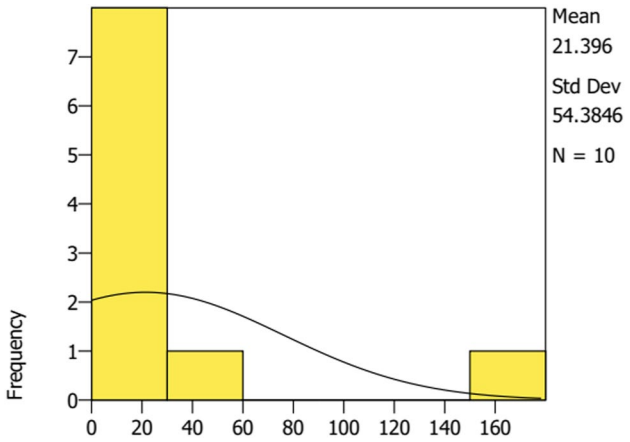

Fig. 3 Frequency distribution for ^{226}Ra

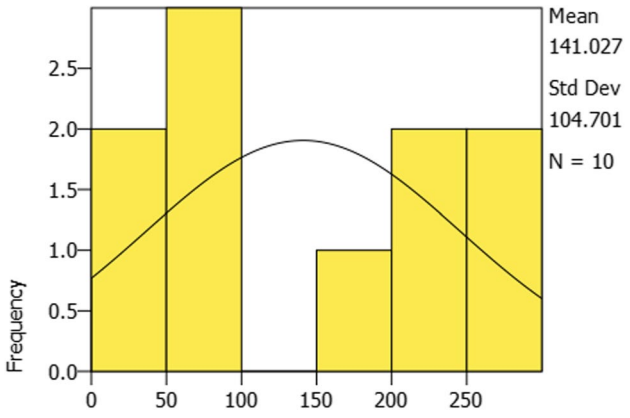

Fig. 4 Frequency distribution for ^{232}Th

^{226}Ra, 134.44 for ^{232}Th, and 1250.99 for ^{40}K. A median of 0 for ^{226}Ra suggests that more than half of the samples had no detectable ^{226}Ra. This measures the asymmetry of the data distribution. ^{226}Ra has a skewness of 2.86, indicating a highly positively skewed distribution. ^{232}Th

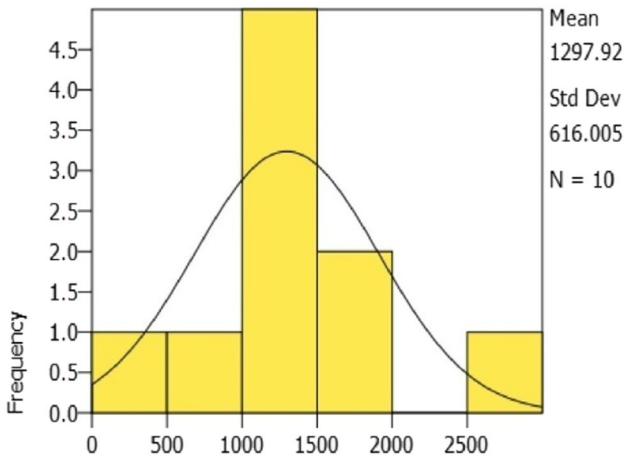

Fig. 5 Frequency distribution for ^{40}K

has a skewness of −0.01, indicating a slightly negatively skewed distribution. ^{40}K has a skewness of 0.60, indicating a moderately positively skewed distribution. This measures the tailedness of the data distribution. ^{226}Ra has a kurtosis of 8.35, indicating a highly peaked distribution with heavy tails. ^{232}Th has a kurtosis of −1.74, suggesting a flatter distribution than a normal distribution. ^{40}K has a kurtosis of 1.95, indicating a slightly peaked distribution. The standard deviation, which measures the dispersion or spread of the data, is 54.38 for ^{226}Ra, 104.70 for ^{232}Th, and 616 for ^{40}K. These values indicate the variability of each isotope's concentration. The number of samples analyzed for each isotope is 10, which means all statistical measures are based on 10 data points for each isotope. The frequency distribution is described as Normal for ^{226}Ra, meaning the data is approximately normally distributed. For ^{232}Th and ^{40}K, the distribution is described as Peaked, indicating that these data sets have a higher peak than a normal distribution. It provides an overall estimate of the total amount of these constituents that are present. Finally these statistics offer a thorough summary of the datasets ^{226}Ra, ^{232}Th, and ^{40}K distribution variability and central tendency. To comprehend their environmental or geological significance and possible impacts they draw attention to variations in their means spreads (standard deviations) shapes (kurtosis) and skewness. Both descriptive statistics and correlation analysis provides a comprehensive understanding of the data, indicating that while there are observed relationships, they are not statistically significant.

Conclusion

In summary important results are obtained from the analysis of radionuclide activity concentrations in rock samples from Kolar Taluk. Mean values of 21.40 Bq kg^{-1}, 141.03 Bq kg^{-1}, 1297.92 Bq kg^{-1} respectively, indicate the wide variation in ^{226}Ra, ^{232}Th and ^{40}K concentrations across the samples. These elements relative abundance in the samples can be understood by examining the ratios of $^{232}Th/^{226}Ra$, $^{40}K/^{226}Ra$ and $^{40}K/^{232}Th$ which show different relationships between them. The elemental composition of potassium, thorium and radium is further explained by their respective elemental concentrations which have mean values of 1.73 ppm, 34.74 ppm and 4.15%. With the exception of slightly higher levels of radiological parameters in comparison to UNESCAR 2000 standards, radiological parameters such as annual effective doses, activity utilization index and hazard indices show values within acceptable limits. The study fills in geographic data gaps and provides crucial information for risk assessment and environmental monitoring by highlighting the regional variability in natural radioactivity levels within Karnataka. Additionally the datasets statistical analysis highlights the distributional features of ^{226}Ra, ^{232}Th and ^{40}K emphasizing their asymmetries variability and central tendencies. These results highlight the value of localized studies in comprehending the consequences of natural radioactivity in the environment in addition to adding to the body of knowledge already available about environmental radioactivity in Karnataka.

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Declaration

Conflict of interest There are no conflicts of interest.

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