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ORIGINAL ARTICLE

Assessment of radiological hazards and effective dose from natural radioactivity in rock samples of Hassan district, Karnataka, India

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Abstract

The natural primordial radionuclide activity concentrations in different types of rock samples in and around Hassan district were measured using gamma spectrometry-based high-purity Germanium detector. The average activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in rock samples varies from 29.4 ± 1.2 to 83.7 ± 1.7, 37.9 ± 1.2 to 198.4 ± 2.2, and 346.1 ± 9.0 to 1024.4 ± 19.4 Bq kg^{-1} with an average value of 50.9 ± 1.4, 79.6 ± 1.5, and 609.2 ± 12.8 Bq kg^{-1}, respectively. The radiological hazard indices such as radium equivalent activity, gamma index, alpha index, external and internal health hazard indices, absorbed dose rate and annual effective doses were estimated. The average value of radium equivalent activity is less than the criterion limit of 370 Bq kg^{-1}. The average indoor and outdoor annual effective dose values for rock samples are lower than the world average recommended value of 1 mSv y^{-1}. The study concludes that except granite rocks, all the rock samples analyzed are safe when used as construction materials and do not pose any significant radiation hazards.

Keywords Radionuclides · Health hazard indices · HPGe · Equivalent effective dose · Radium equivalent activity · Rocks

Introduction

The study of distribution of radionuclides in soil, rock and building materials is most important to know the health risk due to radiations coming from these materials (Damla et al. 2011). Major portion of the background radiation is coming from the primordial radionuclides such as ^{226}Ra, ^{232}Th, and ^{40}K which are present in the earth's crust (soil, rocks) and building materials. These radionuclides are not uniformly distributed; hence, the knowledge of their distribution in soil, rock, and building materials plays an important role in radiation protection and measurement (International Commission on Radiological Protection 1999). The radionuclides present in rocks are the sources of external and the internal radiation exposures in dwellings. The external exposure is due to gamma radiations originated from terrestrial and extra-terrestrial sources. Internal exposure is due to the ingestion of ^{226}Ra, ^{232}Th, and the radionuclides produced by the decay of these as well as ^{40}K through dietary intake and inhalation of radioactive inert gases, radon (^{222}Rn, a daughter product of ^{226}Ra) and thoron (^{220}Rn, a daughter product of ^{224}Ra), and their short-lived products. The specific activities of ^{226}Ra, ^{232}Th, and ^{40}K in rocks and the building raw materials mainly depend on geological and geographical conditions as well as geochemical characteristics of those materials (UNSCEAR 1993). Weathering of the earth's crust is the ultimate mechanism for the release of primordial radionuclides into the soil, which constitutes the principal sources of natural background radiation (Rangaswamy et al. 2016). The activity concentrations of primordial radionuclides such as ^{226}Ra, ^{232}Th, and ^{40}K in the soil samples largely depend on the mineral compositions of rock from which the soil is originating as well as the type of formation and transfer processes that are involved (International Commission on Radiological Protection 1984; Ningappa et al. 2008). The radiological impact from the natural radioactivity is due to radiation exposure of the body by gamma rays and irradiation of lung tissues from inhalation of radon and its progeny. From the health risk point of view, it is necessary to know the dose limits of public exposure and to measure

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the natural environmental radiation level due to the distribution of radionuclides in ground, air, water, foods, building interiors, etc. (El-Taher 2010). Therefore, it is important to measure the activity concentration of radionuclides in rock samples used as building materials for assessing the radiological risks to human health and for the use and management of these rocks.

It is very important to estimate the radionuclide activity concentration in rock samples because the local rocks are raw materials used for construction purposes. The indoor radon, thoron, and their progeny concentrations depend on the existence of natural radioactivity in the underlying soil and rock, and building materials. People spend about 80% of their time in indoor environment; therefore, it is important to assess the radiation hazards arising due to the use of rocks in construction of dwellings. Many researchers are being carried out to map radionuclides in rocks, natural radioactivity levels, and gamma dose rate all over the world. However, currently there were no available data from this study area on the natural radioactivity levels in rocks and radiological hazards assessment. This study has been conducted and reported for the first time on natural radioactivity measurements in rocks of Hassan district. The objective of the present study was to measure the activity concentrations of primordial radionuclides in different types of rocks in and around Hassan district to estimate the radiological risk, and secondly to generate baseline data of natural radioactivity in rock samples of the study area. Hence, this study will serve as baseline data for future natural radioactivity monitoring in rocks from Hassan district.

Geology of the study area

Hassan district is located on the border of the Western Ghats, in the southern part of Karnataka state. Figure 1 shows the study area of the Hassan district, Karnataka state, India. It lies between 12° 13′ and 13° 33′ north latitudes and 75° 33′ and 76° 38′ east longitudes. Hassan district is considered as Field Museum of Geology, since it consists of varieties of rocks as well as minerals. Geologically, Hassan district forms a part of Precambrian terrain. The major litho units are granitic gneiss, dunite, pyroxenite, peridotite, amphibolite, serpentinite, gabbroic rocks, granulites and horn-blende dykes with titaniferous magnetite, associated pegmatite

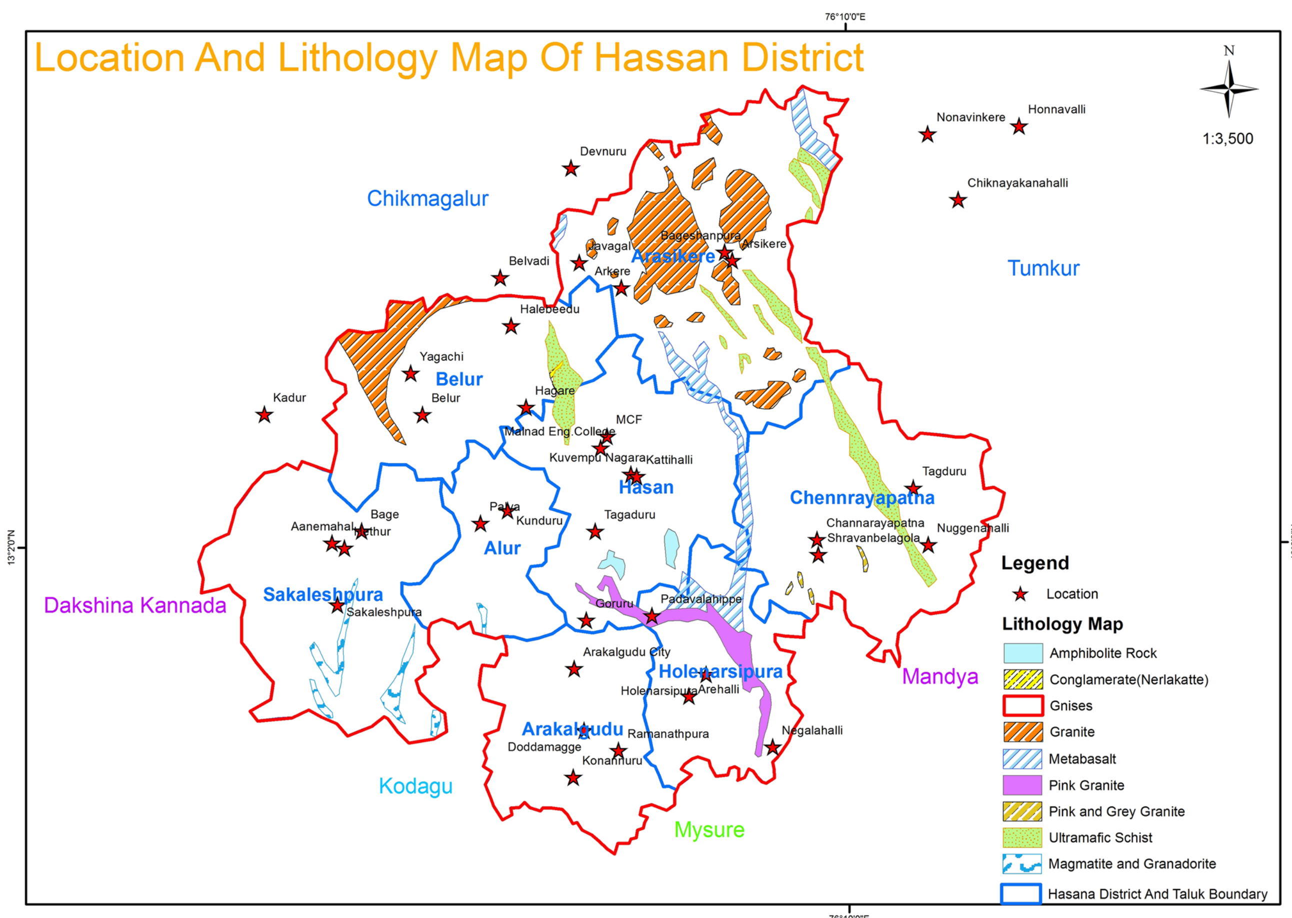

Fig. 1 The geological map of the study area

rocks and metamorphic rocks, steatite, Dharwarian schists and dyke rocks. The most important rock formations of the district are Nuggehalli and Holenarasipura schist belts. These two schist belts are the hosts of number of mineral deposits such as chromite, titaniferous magnetite, chalcopyrite, kaolin, asbestos, quartz, granites, gabbroid, ultramafic igneous rocks, dolerites, diorites, bauxite, magnesite, green granites (dykes), garnets, micas, kyanite, columbite, and tantalite.

Materials and methods

Collection and preparation of rock samples

Samples of rocks, such as granites, gneiss, greenstone, pegmatite, dolerites, dykes, pyrites, and schist, quartzite, were collected in the exposed study area. The surface rock was broken with a hammer. The broken rock pieces (gravel size) were collected. Finally, each individual sample was thoroughly mixed separately and composited from which a final sample of about 2 kg was taken and sealed in a polyethylene bag; date of sampling, sample description and location were noted on the sample container and also in a master sample register. The rock samples were powdered and sieved through 150 µm sieves and these samples were transferred to a porcelain dish and oven dried overnight at 110 °C (Rangaswamy et al. 2016). Finally, the prepared samples were weighted and sealed in a 250-ml plastic container and kept for a month before counting by gamma spectrometry to ensure that the radioactive equilibrium was reached between ^{226}Ra, ^{222}Rn, and its progeny.

Estimation of ^{226}Ra, ^{232}Th, and ^{40}K in rock samples

The activities of ^{226}Ra, ^{232}Th, and ^{40}K in the rock samples were determined by gamma-ray spectrometry employing a 41% relative efficiency n-type low-background HPGe detector having a composite carbon window (Canberra, USA). This detector can be used for the measurement of gamma energies from 5 to 10 MeV. The composite carbon window allows about 90% gamma energies to pass through. The detector was enclosed in a 10-cm thick-graded lead shield (Model 747, Canberra, USA) to reduce the background. The Canberra, DSA-1000 (which consists of HV bias supply, ADC and 16K MCA) and GENIE-2000 softwares were used for data acquisition and analyses. The detector efficiency calibration was performed using the IAEA quality assurance reference materials: RG U-238, RG Th-232, RG K-1, and SOIL-6. The standard material and samples were taken in containers of same size and type so that detection geometry remained the same. Samples were counted long enough to reduce the counting error. The ^{226}Ra activity was evaluated from the weighed mean of the activities of three photopeaks of ^{214}Bi (609.3 keV, 1129.3 keV and 1764.5 keV) after applying Compton corrections. In the case of ^{232}Th, one photopeak of ^{228}Ac (911.2 keV) and two photopeaks of ^{208}Tl (583.1 keV and 2614.5 keV) were used in the same way. The activity of ^{40}K was derived from its 1460.8 keV gamma line. The activity of radionuclides (in Bqkg^{-1}) was calculated using the following relation (IAEA/RCA 1989):

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

where s is the net count per second under the photopeak of intensity, σ is the standard deviation of s, E is the photo-peak efficiency of the detector (%), A is the gamma abundance (%) of the radionuclides, and W is the mass of the sample (g).

Results and discussion

The average activity concentrations of the primordial radionuclides, such as ^{226}Ra, ^{232}Th, and ^{40}K, in the rock samples collected from different regions in and around Hassan district were summarized in Table 1. The mean value of ^{226}Ra, ^{232}Th, and ^{40}K radionuclide activity concentration in rock samples varies from 29.4 ± 1.2 to 83.7 ± 1.7, 37.9 ± 1.2 to 198.4 ± 2.2, and 346.1 ± 9.0 to 1024.4 ± 19.4 Bq kg^{-1} with an average value of 50.9 ± 1.4, 79.6 ± 1.5, and 609.2 ± 12.8 Bq kg^{-1}, respectively.

The natural radioactivity levels in rock samples vary from different sampling sites due to the variation of concentrations of ^{238}U, ^{232}Th, and ^{40}K in the geological formation. The lower activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in rock samples was observed at Kunduru, Palya, Doddamagge, Belur, and Hagare. This is due to the fact that the type of rocks in these locations are mainly schist, dolerite (green color), and diorites which contain lower activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K (Rafique et al. 2014). Slightly higher activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in rocks was observed in Ramanathapura, Byrapura, Halebeedu, Hethur, Neggalahally, Honnavally, Belavadi, and Chiknayakanahally. This is because these regions were attributed by gneiss, green granites, and altered gray granites, which contain slightly higher activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K. The highest average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in rock samples were found at Arehally, Arsikere, Javgal, Channaraypatna, Shravanabelagola, and Nuggehally. The types of rocks in these locations are granites, pegmatite-intruded pink granites and metamorphic rocks, and the regional rocks of chromite mineralization are pegmatite veins housed in granite rocks, both facies enriched in uranium-bearing minerals (Srinivasa et al. 2015). These rocks contain higher radioactivity concentrations as compared to other rock types (United Nations

Table 1 The average activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in different types of rock samples collected from in and around Hassan district

Sl No.	Locations	Rock type	Activity of radionuclides in Bq kg^{-1}			
			^{226}Ra	^{232}Th	^{40}K	$^{232}Th/^{226}Ra$
1	Palya	Schist	30.7 ± 1.2	42.8 ± 1.3	421.6 ± 9.5	1.39
2	Kunduru	Schist	29.4 ± 1.2	37.9 ± 1.2	391.1 ± 9.1	1.29
3	Doddamagge	Gray granite	36.5 ± 1.3	54.8 ± 1.4	346.1 ± 9.0	1.5
4	Ramanathpura	Gray granite	42.9 ± 1.3	42.1 ± 1.2	564.5 ± 8.6	0.98
5	Arsikere	Pink granite	83.7 ± 1.7	198.4 ± 2.2	785.7 ± 17.1	2.37
6	Javgal	Metamorphic	69.6 ± 1.5	96.9 ± 1.7	698.8 ± 13.9	1.39
7	Byrapura	Quartzite	46.4 ± 1.3	65.3 ± 1.5	612.5 ± 13.4	1.41
8	Belur	Green granite	36.9 ± 1.2	78.9 ± 1.6	486.2 ± 11.6	2.14
9	Halebeedu	Green granite	43.7 ± 1.3	41.4 ± 1.3	516.5 ± 12.2	0.95
10	Hagare	Black granite	32.9 ± 1.2	54.1 ± 1.4	589.7 ± 8.0	1.65
11	Channarayapatna	Pink granite	63.3 ± 1.6	139.4 ± 1.9	615.8 ± 17.3	2.27
12	Thagaduru	Chromite	51.9 ± 1.3	79.4 ± 1.6	423.9 ± 9.6	1.53
13	Nuggehally	Titaniferous magnetite	61.3 ± 1.5	132.8 ± 1.9	536.7 ± 9.2	2.1
14	Shravanabelagola	Gray granite	74.7 ± 1.6	124.7 ± 1.8	641.2 ± 13.2	1.67
15	Malnad Eng college	Pegmatite	66.9 ± 1.4	98.7 ± 1.7	982.3 ± 17.8	1.72
16	MCF	Gray granite	57.0 ± 1.4	87.2 ± 1.6	956.1 ± 18.5	1.3
17	Gorur	Gray granite	53.8 ± 1.4	72.7 ± 1.4	604.5 ± 12.4	1.35
18	Holenarasipura	Ultra basic igneous	61.6 ± 1.5	78.6 ± 1.5	786.2 ± 17.0	1.46
19	Arehally	Pegmatite	78.7 ± 1.7	131.6 ± 1.6	1024.1 ± 19.4	1.67
20	Neggalahally	Gneiss	40.7 ± 1.3	44.4 ± 1.3	546.8 ± 12.9	1.09
21	Hethur	Gneiss	39.1 ± 1.2	48.9 ± 1.3	513.8 ± 12.2	1.25
22	Honnavalli	Gray granite	43.8 ± 1.3	58.4 ± 1.4	490.6 ± 12.7	1.33
23	Nonavinakere	Gray granite	55.7 ± 1.4	83.7 ± 1.6	589.7 ± 13.3	1.5
24	Chikkanayakanahally	Gray granite	45.7 ± 1.3	62.9 ± 1.5	347.9 ± 9.2	1.38
25	Belavadi	Quartzite	38.1 ± 1.2	49.6 ± 1.4	783.3 ± 17.0	1.3
26	Kadur	Gray granite	46.1 ± 1.3	58.2 ± 1.4	642.3 ± 13.5	1.27
27	Devanur	Gray granite	52.5 ± 1.4	72.3 ± 1.5	348.2 ± 9.1	1.38
	Minimum		29.4 ± 1.2	37.9 ± 1.3	346.1 ± 9.0	0.95
	Maximum		83.7 ± 1.7	198.4 ± 2.2	1024.4 ± 19.4	2.37
	Average		50.9 ± 1.4	79.6 ± 1.5	609.2 ± 12.8	1.5
	Median		46.2 ± 1.3	64.1 ± 1.4	520.5 ± 12.6	1.39

Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000; Rangaswamy et al. 2016; Ningappa et al. 2008). The higher ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations in the granite rocks may be due to their natural mineralogical compositions (El-Arabi 2007). Mineralogically, the granite gneisses are formed mainly through the intergrowth of quartz, k-feldspar, biotite, muscovite, silicate, and chlorite (Rangaswamy et al. 2016; Rafique et al. 2014). The radionuclides in the rock samples are directly linked with the minerals such as zircon, monazite, thorite, uranothorite, iron oxides, and fluorite. Zircon usually contains uranium and thorium concentrations which ranged from 0.01 to 0.19 and 1 to 2%, respectively (Cuney et al. 1987). Uranium in iron oxides is first trapped by adsorption (Speer et al. 1981). The high uranium content in the mineralized granite and pegmatite is attributed to the ability of iron oxide in them on adsorbing uranium (Shahul et al. 2014). The studied locations consist of variety of rock systems and these rocks consist of varying amount of primordial radionuclide activity concentrations. Among the studied rock samples, granites and pegmatite-intruded pink granites contain higher activity concentration of primordial radionuclides because of their mineral compositions.

The activity concentration of the radionuclides in samples follows the trend, $^{40}K > ^{232}Th > ^{226}Ra$. The higher activity concentrations of ^{40}K in the rock samples are possibly because principal potassium-bearing minerals in granites are feldspar, orthoclase, muscovite, biotite and mica. The abundance of potassium to some extent is proportional to silica content of the rocks. Since silica content of granite is high, consequently the associated radioactivity due to ^{40}K is also high (Ningappa et al. 2008). The ratio of ^{232}Th and ^{226}Ra was in the range of 0.80–1.96 with a median of 1.37. The median value can be used as an indicator of the relative occurrence of uranium and thorium. Activity concentration of thorium is higher than that of radium at all locations because this area is surrounded by pegmatite rocks intruded in granitic rocks (Ningappa et al. 2008). The average ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations of rock samples obtained from this study are found to be higher than the worldwide average activity concentration value of 50 Bq kg^{-1} for ^{226}Ra and ^{232}Th, and 500 Bq kg^{-1} for ^{40}K, respectively (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000). The results of the present investigation were compared with the average radioactivity concentration in the rocks of other regions of the world (Table 2).

Correlation between the combinations of radionuclides was carried out to understand the existence of these radionuclides together at a particular location. The correlation between the activity concentrations of ^{226}Ra and ^{232}Th in the rock sample is shown Fig. 2. In this case, the regression was found to be linear and positive. A good positive correlation coefficient (R^2) of 0.76 between ^{226}Ra and ^{232}Th was observed. It is as expected, since ^{226}Ra and ^{232}Th come from natural decay series of ^{238}U and ^{232}Th. A good positve correlation between ^{226}Ra and ^{232}Th may also due to the fact that these isotopes formed at the formation of the earth in equal concentrations.

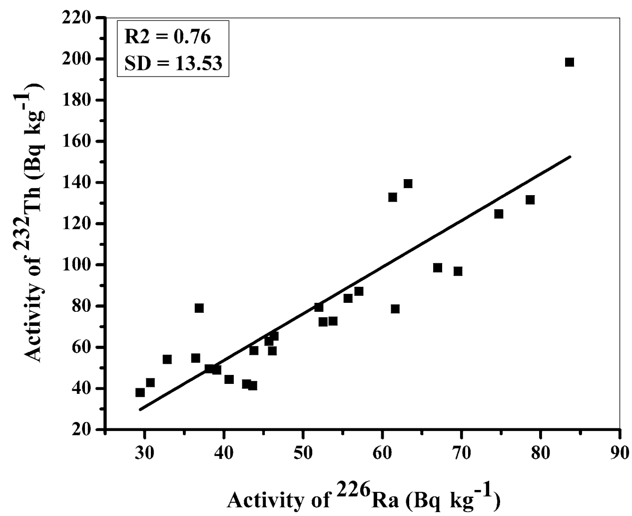

Fig. 2 Correlation between ^{226}Ra and ^{232}Th activity concentrations of rock samples

Table 2 Comparison of the average activity of ^{226}Ra, ^{232}Th, and ^{40}K in rock samples of Hassan district with different environs of the world

Country	Radioactivity concentrations (Bq kg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
World	50	50	500	(United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000)
Indian average	32	64	400	(United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000)
Indian	14.8	18.3	370	(Mishra and Sadasivan 1971)
Brazil	31	73	1648	(Anjos et al. 2005)
Egypt	15.64 ± 1.14	14.46 ± 1.08	405.7 ± 29.5	(Harb et al. 2008)
Nigeria	21.1–129	424–150	64.5–882	(Tufai et al. 1992)
Ghana	1.2–40	3.3–117.5	13.5–1510	(Ahmed et al. 2006)
Turkey	9.4–27.3	11.7–23.4	275.4–689.2	(Ahmed et al. 2006)
Nepal	17–100	24–260	32–541	(Wallova et al. 2010)
Cyprus	1–588	1–906	50–1606	(Tzortzis et al. 2003)
Azad Kashmir, Pakistan	28.46 ± 0.45	48.63 ± 1.12	666.7 ± 9.39	(Muhammad et al. 2013)
Bangalore rural district	93.2	306.2	1074.4	(Ningappa et al. 2008)
Granite region of Karnataka	32.4–165	32.4–530	400–1250	(Sannappa et al. 2010)
North Karnataka	52.76	71.51	1035	(Kerur et al. 2010)
Ramanagara and Tumkur districts	41.08 ± 2.12	86.26 ± 2.94	869.29 ± 3.78	(Rangaswamy et al. 2016)
Mysore city	52.9 ± 1.3	73.8 ± 1.8	750.1 ± 9.8	(Sannappa et al. 2003)
Hassan district	50.94 ± 1.4	79.55 ± 1.5	606.20 ± 12.8	Present study

Radiological characterization

To highlight the radiological risk related to the radionuclides present in the rocks, it is necessary to calculate and assess the radium equivalent activity, gamma index, alpha index, outdoor and indoor radiation hazard indices, air-absorbed dose rates and annual effective doses. Table 3 summarizes the calculated average values for the above parameters for rock samples.

Estimation of radium equivalent activity (Ra_{eq})

The radium equivalent activity (Ra_{eq}) was computed in this work to assess the gamma radiation risk to human beings. This compares the specific activity of the samples containing different amounts of ^{226}Ra, ^{232}Th, and ^{40}K (Amrani and Tahtat 2001). The radium equivalent concept allows a single index or number to describe the gamma output from different mixtures of ^{226}Ra, ^{232}Th, and ^{40}K in rock samples from different locations. It is accepted that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K produces the same gamma-ray dose rate. Since the distribution of radionuclides is not uniform, the exposure due to the radionuclides is estimated in terms of radium equivalent radioactivity. This index was calculated using the formula (Amrani and Tahtat 2001; Rangaswamy et al. 2016):

$$Ra_{eq} = C_{Ra}+1.43C_{Th}+0.07C_{K}, \quad (2)$$

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

The Ra_{eq} due to radionuclides in rock samples varied from 113.76 to 427.80 Bq kg^{-1} with an average value of

Table 3 Calculated radiation hazard indices such as absorbed dose, alpha index, gamma index, radium equivalent activity, external hazard index, and equivalent effective dose for rock samples

Sl No.	Locations	I_γ	I_α	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	D (nGy h^{-1})	E_{In} (mSv y^{-1})	E_{Out} (mSv y^{-1})	E_{Total} (mSv y^{-1})
1	Palya	0.46	0.15	124.39	0.34	0.42	57.63	0.28	0.07	0.35
2	Kunduru	0.42	0.14	113.76	0.31	0.39	52.8	0.26	0.06	0.32
3	Doddamagge	0.51	0.18	141.39	0.38	0.48	64.34	0.32	0.08	0.39
4	Ramanathpura	0.54	0.21	146.54	0.4	0.51	68.77	0.34	0.08	0.42
5	Arsikere	1.53	0.42	427.8	1.16	1.38	191.2	0.94	0.23	1.17
6	Javgal	1.02	0.34	277.28	0.75	0.94	128.1	0.63	0.16	0.79
7	Byrapura	0.69	0.23	186.94	0.5	0.63	86.42	0.42	0.11	0.53
8	Belur	0.68	0.18	187.21	0.51	0.61	85	0.42	0.1	0.52
9	Halebeedu	0.52	0.22	142.58	0.39	0.5	66.69	0.33	0.08	0.41
10	Hagare	0.48	0.16	132.56	0.36	0.45	59.95	0.29	0.07	0.37
11	Channarayapatna	1.11	0.3	308.07	0.83	1	138.2	0.68	0.17	0.85
12	Thagaduru	0.71	0.26	198.13	0.54	0.68	89.64	0.44	0.11	0.55
13	Nuggehally	1.15	0.31	317.56	0.86	1.03	144.3	0.71	0.18	0.88
14	Shravanabelagola	1.09	0.37	302.31	0.82	1.02	136.5	0.67	0.17	0.84
15	Malnad Eng college	1	0.28	271.1	0.73	0.89	125.5	0.62	0.15	0.77
16	MCF	0.99	0.33	267.33	0.72	0.9	124.6	0.61	0.15	0.76
17	Gorur	0.74	0.27	204.21	0.55	0.7	93.93	0.46	0.12	0.58
18	Holenarasipura	0.83	0.27	226.53	0.61	0.76	105	0.52	0.13	0.64
19	Arehally	1.26	0.39	345.75	0.93	1.15	158.6	0.78	0.19	0.97
20	Neggalahally	0.54	0.2	146.15	0.39	0.5	68.35	0.34	0.08	0.42
21	Hethur	0.55	0.19	148.61	0.4	0.51	69.03	0.34	0.08	0.42
22	Honnavalli	0.6	0.22	165.09	0.45	0.56	75.97	0.37	0.09	0.47
23	Nonavinakere	0.8	0.28	220.76	0.6	0.75	100.9	0.49	0.12	0.62
24	Chikkanayakanahally	0.58	0.23	162.38	0.44	0.56	73.59	0.36	0.09	0.45
25	Belavadi	0.64	0.19	169.59	0.46	0.56	80.36	0.39	0.1	0.49
26	Kadur	0.66	0.23	179.02	0.48	0.61	83.34	0.41	0.1	0.51
27	Devanur	0.65	0.26	182.7	0.49	0.64	82.45	0.4	0.1	0.51
	Minimum	0.42	0.14	113.76	0.31	0.39	52.8	0.26	0.06	0.32
	Maximum	1.53	0.42	427.8	1.16	1.38	191.2	0.94	0.23	1.17
	Average	0.78	0.25	210.1	0.57	0.72	96.29	0.47	0.12	0.59
	Median	0.68	0.23	186.94	0.5	0.63	85	0.42	0.1	0.52

210.10 Bq kg^{-1}. The average Ra_{eq} value of all the rock samples is less than the criterion limit of 370 Bq kg^{-1} (Amrani and Tahtat 2001) and as such these rocks do not pose any radiological hazard when used for the construction purpose.

External and internal health hazard indices (H_{ex} and H_{in})

The concept of the hazard indices was used to assess the potential radiological risk associated with human. Gamma radiation emitted by the radionuclides concern is an estimate of external hazard index that is determined using equation (Beretka and Mathew 1985; UNSCEAR 2008):

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{3}$$

^{222}Rn is a gaseous product of the decay of radium (^{226}Ra). It is short lived and constitutes a major source of internal radiation exposure (Farai and Vincent 2006). The internal exposure of living cells to radon and its daughter products is referred to as internal hazard index (H_{in}) and was estimated using equation (UNSCEAR 2008):

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810}, \tag{4}$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq kg^{-1}, respectively. The value of these indices must be less than 1 to keep the radiation hazards insignificant.

The calculated internal (H_{in}) and external (H_{ex}) radiation hazard indices of the rock samples are found to vary from 0.39 to 1.38 with an average value of 0.72 and 0.31 to 1.16 with an average value of 0.57, respectively. The average internal and external hazard indices values of the rock samples are less than unity and there is no potential radiation hazard due to the use of the studied materials for construction purposes.

Gamma index (I_γ)

The gamma index (I_γ), which is expressed as the sum of fractions of the measured activity concentrations in the sample, has been defined by the European Commission (European Commission (EC), Radiation Protection 112 1999) and it is given below

$$I_\gamma = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \tag{5}$$

The gamma index is correlated with the annual dose rates due to excess external gamma radiation caused by superficial material. The calculated gamma index (I_γ) values of all the studied rock samples varied in the range of 0.42–1.53 with an average value of 0.78. The value of I_γ must be less than 1 to keep the radiation hazard insignificant to the general population. The calculated average I_γ values of the rock samples are far below the criterion limit of unity as per European Commission of Radiation Protection reports (European Commission (EC), Radiation Protection 112 1999). Therefore, the rocks were found to be safe and did not pose any serious radiation hazard to the population living in this area.

Alpha index (I_α)

Alpha index (I_α) is the assessment of the excess alpha radiation due to the radon inhalation originating from the building materials (Megumi et al. 1998; Stoulos et al. 2003). The alpha index was determined by the following formula:

$$I_\alpha = \frac{C_{Ra}}{200} \tag{6}$$

Alpha index (I_α) ≤ 1 corresponds to a ^{226}Ra activity concentration ≤ 200 Bq kg^{-1}. When the activity concentration of ^{226}Ra in a rock exceeds the value of 200 Bq kg^{-1} ($I_\alpha > 1$), it is possible that the radon exhalation from this material could cause indoor radon concentration exceeding 200 Bq m^{-3} (Righi and Bruzzi 2006). The calculated alpha index (I_α) values for rocks are found in the range of 0.14–0.42 with an average value of 0.25. From the result, it is concluded that the activity concentrations of ^{226}Ra in all the samples are less than the recommended upper limit of 200 Bq kg^{-1}. The alpha index values for all rock samples are less than unity. This reveals that the radon exhalation from the rocks would cause indoor concentration less than 200 Bq m^{-3}.

Gamma-absorbed dose rate in air

The absorbed dose rates (D) due to gamma radiation in air have been calculated based on the guidelines provided by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000). The UNSCEAR has given the dose conversion factors for converting the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K into doses (nGy h^{-1} per Bq kg^{-1}) as 0.462, 0.604, and 0.0417, respectively. Using these factors, the external gamma-absorbed dose rate (D) due to rocks is calculated using the formula (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000)

$$D(\text{nGy h}^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K. \tag{7}$$

For rock samples, the calculated results of absorbed dose rates range from 52.80 to 191.20 nGy h^{-1} with an average value of 96.29 nGy h^{-1} which is higher than the population-weighted average value of global primordial radiation of 55 nGy h^{-1}(United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000).

Annual effective dose (AED)

The indoor annual effective dose rates (E) are evaluated using the conversion coefficient from the absorbed dose in air to the effective dose (0.7 SvG y^{-1}) and the indoor occupancy factor (0.8) implied that 80% of time is spent indoors, as proposed in UNSCEAR (UNSCEAR 1993). Thus, the annual effective dose (mSv y^{-1}) received by a building occupant due to the activity in the rocks and building materials was estimated using the following equation:

$$E_{In} = D \times 8760 \times 0.8 \times 0.7 \times 10^{-6}. \tag{8}$$

Similarly, the outdoor annual effective dose in rock samples is estimated from the net absorbed gamma radiation dose rate (D) by taking into account the outdoor occupancy factor 0.2 and the conversion factor from absorbed dose rate in air to effective dose 0.7 SvG y^{-1} for the adults. The E_{Out} is calculated using the following equation proposed by UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000):

$$E_{Out} = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6}, \tag{9}$$

where E_{Out} is the outdoor annual effective dose in mSv y^{-1}.

The calculated indoor annual effective dose rates of the rocks samples are found to vary from 0.26 to 0.94 mSv $y^{-1}$with an average value of 0.47 mSv y^{-1}. Similarly, the calculated outdoor annual effective dose rate of rock samples varies from 0.06 to 0.23 mSv y^{-1} with an average value of 0.12 mSv y^{-1}. The total annual effective dose rates for rocks are found to vary from 0.32 to 1.17 mSv $y^{-1}$with an average value of 0.59 mSv y^{-1}. From the results, it is clear that the average annual equivalent effective dose rate for rock samples is within the safety limit (1 mSv y^{-1}) as proposed by UNSCEAR (UNSCEAR 2008) and as recommended by the International Commission on Radiological Protection for the individual members of the public (International Commission on Radiological Protection 1999).

Conclusion

The gamma-ray spectrometry technique has been used to determine the ^{226}Ra, ^{232}Th, and ^{40}K activity levels in rock samples. The results reveal that the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the rocks are slightly higher than the world average values. The highest average activity was observed in granite rocks. The estimated radiological hazard indices such as radium equivalent activity, gamma index, alpha index, external hazard index, internal hazard index, and annual effective dose rate are well within the world average values. The average outdoor gamma-absorbed dose rates are slightly higher than the population-weighted average value of global primordial radiation of 55 nGy h^{-1}. Except pink granites from Arsikere, the average indoor and outdoor annual effective dose values in rock samples were found to be lower than the safety limit (1 mSv y^{-1}) as proposed by UNSCEAR (UNSCEAR 2008). From the radiological point of view, all the rock samples (except granites, pegmatite-intruded pink granites) of the study area are safe for construction purposes. The data obtained in this study will serve as baseline data for assessing the radiation exposure of the residents.

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References

Ahmed NK, Abbady A, El-Arabi AM, Michel R, El-Kamel AH, Abbady AGE (2006) Comparative study of the natural radioactivity of some selected rocks from Egypt and Germany. Indian J Pure Appl Phys 44:209–215

Amrani D, Tahtat M (2001) Natural radioactivity in Algerian building materials. Appl Radiat Isot 54:687–689

Anjos RM, Veiga R, Soare T, Santos AM, Aguiar JG, Frasca MH (2005) Natural radionuclide distribution in Brazilian commercial granites. Radiat Meas 39:245–253

Beretka J, Mathew PJ (1985) Natural radioactivity of Australian building materials, industrial wastes and by products. Health Phys 48:87–95

Cuney M, LeFort P, Wangeg (1987) Geology of granites and their metallogenetic relations. Science Press, Moscow, pp 852–873

Damla N, Cevik U, Kobya AI, Celik A, ildirim (2011) Assessment of natural radioactivity and mass attenuation coefficients of brick and roofing tile used in Turkey. Radiat Meas 46:701–708

El-Arabi AM (2007) ^{226}Ra, ^{232}Th and ^{40}K concentrations in igneous rocks from eastern desert, Egypt and its radiological implications. Radiat Meas 42:94–100

El-Taher A (2010) Gamma spectroscopic analysis and associated radiation hazards of building materials used in Egypt. Radiat Prot Dosim 138:158–165

European Commission (EC), Radiation Protection 112 (1999) Radiological protection principles concerning the natural radioactivity of building materials, directorate-general environment, nuclear safety

Farai IP, Vincent UE (2006) Outdoor radiation level measurement in Abeokuta, Nigeria with thermo luminescent dosimetry. Niger J Phys 18:121–126

Harb S, El-Kamel AH, Abd El-Mageed AI, Abbady A, Wafaa Rashed (2008) Concentration of U-238, U-235, Th-226, Th-232 and K-40 for some granite samples in Eastern Desert of Egypt. In: Proceeding of the 3rd environmental physics conference, Aswan, Egypt, pp 109–117

IAEA/RCA (1989) Health physics division, regional work on environmental sampling and measurement of radioactivity for monitoring purposes (BARC, Kalpakkam, India), p 85

International Commission on Radiological Protection (1984) Principles for limiting exposure of the public to natural sources of radiation. Perganon, Oxford
International Commission on Radiological Protection (1999) Protection of the public in situations of prolonged radiation exposure. Publication 82, Elsevier Science B.V, Amsterdam
Kerur BR, Rajeshwari T, Anil Kumar S, Narayanhi K, Rekha AK, Hanumaiah B (2010) Radioactivity levels in rocks of North Karnataka, India. Indian J Pure Appl Phys 48:809–812
Megumi K, Oka T, Doi M, Tsujimoto T, Ishiyama T, Katsurayama K (1998) Relationship between the concentrations of natural radionuclides and mineral composition of the surface soil. Radiat Prot Dosim 24:69–72
Mishra UC, Sadasivan S (1971) Natural radioactivity levels in Indian Soils. J Sci Ind Res 30:59–62
Muhammad R, Abdul J, Abdul RK, Saeed UR, Muhammad B, Azhar M, Matiullah (2013) Radiometric analysis of rock and soil samples of Leepa valley; Azad Kashmir, Pakistan. J Radioanal Nucl Chem 298:2049–2056
Ningappa C, Sannappa J, Karunakara N (2008) Study on radionuclides in granite quarries of Bangalore rural district, Karnataka, India. Radiat Prot Dosim 131:495–502
Rafique M, Khan AR, Jabbar A, Rahman SU, Kazmi SJA, Nasir T, Arshed W, Matiullah (2014) Evaluation of radiation dose due to naturally occurring radionuclides in rock samples of different origins collected from Azad Kashmir. Russ Geol Geophys 55:1073–1082
Rangaswamy DR, Srilatha MC, Ningappa C, Srinivasa E, Sannappa J (2016) Measurement of natural radioactivity and radiation hazards assessment in rock samples of Ramanagara and Tumkur districts, Karnataka, India. Environ Earth Sci 75:373–383
Righi S, Bruzzi L (2006) Natural radioactivity and radon exhalation in building materials used in Italian dwellings. J Environ Radioact 88:158–170
Sannappa J, Chandrashekara MS, Sathish LA, Paramesh L, Venkataramaiah P (2003) Study of background radiation dose in Mysore city, Karnataka State, India. Radiat Meas 37:55–65
Sannappa J, Ningappa C, Prakash Narasimha KN (2010) Natural radioactivity levels in granite regions of Karnataka state. Indian J Pure Appl Phys 48:817–819
Shahul HP, Sankaran PG, Satheesh KG, Mathiyarasu R (2014) Measurement of gamma radiation from rocks used as building material in Tiruchirappalli district, Tamil Nadu, India. J Radioanal Nucl Chem 300:1081–1088
Speer J, Solberg T, Becker S (1981) Petrography of the uranium bearing minerals of the Liberty Hill pluton. South Carolina: phase assemblages and migration of uranium in granitoid rocks. Econ Geol 76:162–175
Srinivasa E, Rangaswamy DR, Sannappa J (2015) Determination of radon activity concentration in drinking water and evaluation of the annual effective dose in Hassan district, Karnataka state, India. J Radioanal Nucl Chem 305:665–673
Stoulos S, Manolopoulou M, Papastefanou C (2003) Assessment of natural radiation exposure and radon exhalation from Building materials in Greece. J Environ Radioact 69:225–240
Tufai MN, Ahmed SM, Mirza NM, Khan HA (1992) Natural radioactivity from the building materials used in Islamabad and Rawalpindi, Pakistan. Sci Total Environ 121:283–291
Tzortzis M, Tsertos H, Christofides S, Christodoulides G (2003) Gamma measurements and dose rates in commercially used tiling rocks (granites). J Environ Radioact 70:223–235
United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000) Sources and effects of ionizing radiation. New York
UNSCEAR (1993) Sources and effects of ionizing radiation. Report to general assembly, with scientific annexes, United Nations, New York
UNSCEAR (2008) Report to the general assembly. Annex B exposures of the public and workers from various sources of radiation. New York
Wallova G, Kamala KA, Wallner G (2010) Determination of naturally occurring radionuclides in selected rocks from Hetaunda area, Central Nepal. J Radioanal Nucl Chem 203:713–718

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