Original Article

Study on natural radioactive elements in soil and rock samples around Mandya district, India

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Abstract

Context: The soil is a complex mixture of different compounds and rocks. In the natural environment, it is an important source of exposure to radiation due to naturally occurring, gamma emitting radionuclides which include ^{226}Ra, ^{232}Th and ^{40}K present in the soil. **Aims:** The study of distribution of these radionuclides in soil and rock is of great importance for radiation protection and measurements. **Materials and Methods:** The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil and rock samples collected in Mandya District, Karnataka state, India have been measured by gamma ray spectrometry. **Results:** The average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K (Bq/kg) are found to be 40.2, 62.3, and 317.5 Bq/kg, respectively, in soil samples and 30.5, 34.4, and 700.2 Bq/kg, respectively, in rock samples. **Conclusion:** The concentrations of radionuclides in soil samples are found to higher than in rock samples. The concentrations of radionuclides in soil and rock samples in the study area are slightly higher than Indian average and world average values

Keywords: Radiation dose, soil, HPGe detector

INTRODUCTION

Natural radionuclides in soil generate a significant component of the background radiation exposure of the population. The ^{226}Ra, ^{232}Th, and ^{40}K, which pose exposure risks externally due to their gamma ray emissions and internally due to radon and its progeny, are distributed everywhere in the earth's environment with different concentrations. The upper most layer of the earth is covered by soil. The soil is a complex mixture of different compounds and rocks in the natural environment. The natural radionuclides enter into the soil from the earth's crust where they have been present since its creation. The earth's crust is the principal source of natural radionuclides in soils and rocks.[1,2] The concentrations of natural radionuclides in rock have been found to depend on the local geological condition and as such they vary from one place to another. Higher concentrations and higher radiation levels are associated with igneous rocks, such as granite, and lower levels with sedimentary rocks. There are exceptions, however, as some shale and phosphate rocks have relatively high content of radionuclides.[2-4] Most of the granites contain radioactive elements such as ^{238}U, ^{232}Th, ^{40}K, and ^{226}Ra. In terms of natural radioactivity, granites exhibit an enhanced elemental concentration of U and Th compared with the very low abundance of these elements observed in the mantle and the crust of the Earth. Igneous rocks of granitic composition are strongly enriched in U and Th, compared with rocks of basaltic or ultramafic composition.[3,5]

Investigations and measurements of natural background radiation and radioactivity are of great importance in health physics, not only for many practical reasons but also for more fundamental scientific reasons. Since natural background radiation is the main source of human exposure, studies on the dose from this source and its effects on health can improve the understanding of radiation damage. Therefore, it is proposed to get the base line data about the distribution of ^{226}Ra, ^{232}Th, and ^{40}K at different places in Mandya district, Karnataka State, India. The study area is Mandya district, which is located in the southern maidan region of the Karnataka

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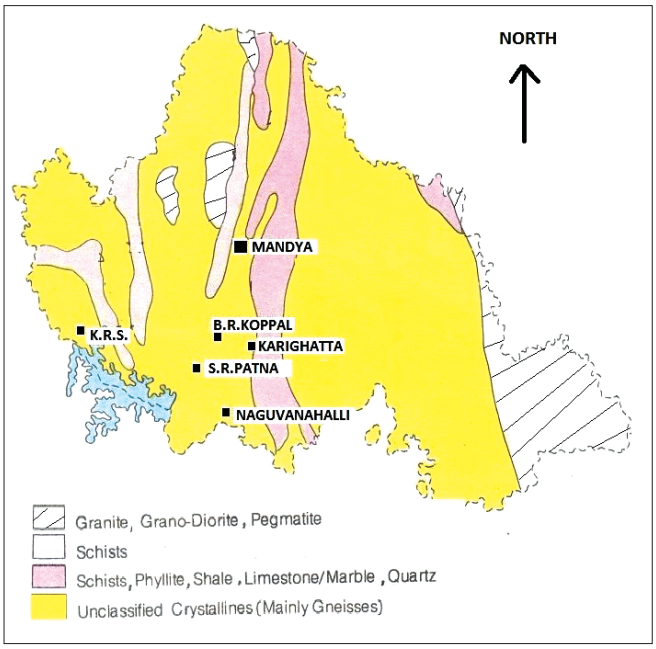

Figure 1: The study area

state. It lies between North latitudes 12˚13′ to 13˚04′ and East longitudes 76˚19′ to 77˚20′ [Figure 1]. The surface topography of the district is in the form of undulating plain positioned at an average elevation of 750-900 m amsl. The Melukote range of hills fallen a broken series of conspicuous peaks, which reach the highest altitude of 1159 m amsl. The Hulikere Kartigatta hill range near S.R. Patna and bold rugged low peaks near Sindhugatta are also noticeable. The soil of Mandya district is derived from granites and gneisses interpreted with occasional patches of schist in S.R. Patna, Mandya, and Pandavapura Taluks. The soils range from red sandy loams to red clay loam, very thin in ridges and higher elevations, and comparatively thick in valley portions. The soils in Mandya, Malavalli, Maddur, and Nagamangala taluks are thin gravelly and underlain with a murrum zone containing weathered rock. The soils are highly leached and poor in bases. The water holding capacity is low. On the other hand, the soil under the old channel areas of Malavalli, Pandavapura, and S.R. Patna are high in clay.

MATERIALS AND METHODS

Measurement of environmental radioactivity consists of the collection of soil and rock samples and estimation of their activity. Soil and rock samples were collected at different locations around Mandya district to determine the distribution of radionuclides in the soil and rock and correlate the same with radiation exposure level. Gamma spectrometry uses semiconductor detectors like Ge (Li) or Si (Li). In this investigation, a High Purity Germanium Detector (HPGe) spectrometer was used to measure the concentrations of gamma emitting radionuclides in soil and rock samples. The HPGe gamma ray spectrometer essentially consists of a detector element and cryostat–Dewar and electronic components of the analysis system.

The places, which were free from surface run-off during heavy rain, were carefully selected. An area of about 0.5 m^2 was marked and was cleared of vegetation and roots. The marked spot was dug up to a depth of 50 cm and about 2 kg of soil was collected at each spot. Finally, the samples were mixed thoroughly and extraneous materials such as plants, debris, big pieces of stones, and pebbles were removed.[6-8] Composite samples of about 2 kg were taken and sealed in a polythene bag. The samples were transferred to a porcelain dish and oven-dried overnight at 110°c. The samples were powdered and sieved through 150 mesh sieves, weighed, and sealed in a 500 ml plastic container, and kept for a month before counting by gamma spectrometry, in order to ensure that radioactive equilibrium was reached between ^{226}Ra, ^{222}Rn and its progeny. The activity of radionuclides was calculated using Eq. (1).[7]

$$\text{Activity (Bq/kg)} = \frac{(S \pm \sigma) \times 100 \times 1000 \times 100}{E \times W \times A}, \qquad (1)$$

where S = Net counts/s under the photopeak of interest, σ = Standard deviation of S, E = Counting efficiency (%), A = Gamma abundance of the radionuclides (%), and W = Mass of the sample (g).

In addition to the measurement of activity of radionuclides in soil and rock, we have also determined (i) radium equivalent activity (Ra_{eq}), (ii) representative level index ($I_{\gamma r}$), (iii) external hazard index (H_{ex}), (iv) internal hazard index (H_{in}), and (v) annual gonadal dose equivalent (AGDE).

i. Ra_{eq}: The radiation hazards associated with the radionuclides were estimated by calculating the Ra_{eq}. The Ra_{eq} is a weighted sum of activities of the above said three natural radionuclides and is based on the assumption that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th, and 4810 Bq/kg of ^{40}K produce the same gamma radiation dose rate. The use of materials whose Ra_{eq} exceeds 370 Bq/kg is discouraged in order to minimize radiation hazards.[1]

The Ra_{eq} was estimated by the relation,

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

where A_{Ra}, A_{Th}, and A_K are the activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg, respectively.

ii. $I_{\gamma r}$: A radiation hazard index used to estimate the level of γ-radiation hazard associated with the natural radionuclides in the material, $I_{\gamma r}$, is given as

$$I_{yr} = \left[\frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \right], \quad (3)$$

where A_{Ra}, A_{Th}, and A_K are the activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg, respectively and was calculated for the samples collected from different locations around Mandya district.[5,9,10]

iii. H_{ex}: The H_{ex} is defined as[5,9,10]

$$H_{ex} = \left[\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \right], \quad (4)$$

where A_{Ra}, A_{Th}, and A_K are the activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg, respectively.

iv. H_{in}: In addition to the H_{ex}, radon and its short-lived products are also hazardous to the respiratory organs. The H_{in} due to internal exposure to radon and its daughter products is quantified by the H_{in}, which is given by the equation as[5,9,10]

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

where A_{Ra}, A_{Th}, and A_K are the activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg, respectively.

v. AGDE: The gonadals, active bone marrow, and the bone surface cells are considered the organs of interest by UNSCEAR[2]. Therefore, the AGDE (μSvy^{-1}) owing to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K was calculated using the following formula[4,5,9,10]:

$$AGDE = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (6)$$

where A_{Ra}, A_{Th}, and A_K are the activities of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg, respectively.

Air-absorbed rates and annual effective dose. The total absorbed dose rate (nGy/h) in air due to the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K (Bq/kg) in air at 1 m above the ground surface was calculated using the following formula:

$$D(nGy/h) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K. \quad (7)$$

RESULTS AND DISCUSSION

The concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are measured in soil samples collected from Baburayana Koppal, Naguvana Halli, Karighatta, and Krishna Raja Sagar and in rock samples collected from Karighatta and Krishna Raja Sagar. The spectral data plot of soil and rock samples is shown in Figures 2-7. The photopeak of energy 609.31 keV (which is emitted by ^{214}Bi, a decay product of ^{226}Ra) with intensity of 43.30% was used for the quantitative determination of ^{226}Ra, the photopeaks of 583.19 keV with intensity 85.97% and 911.05 keV with intensity 27.7% were used for the quantitative determination of ^{232}Th, and the characteristic photopeak of ^{40}K is at 1460.8 keV with intensity 10.7%.[11] The

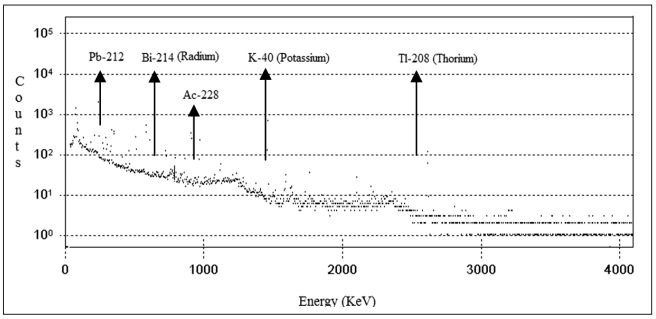

Figure 2: The spectral data plot of soil samples of B.R. Koppalu

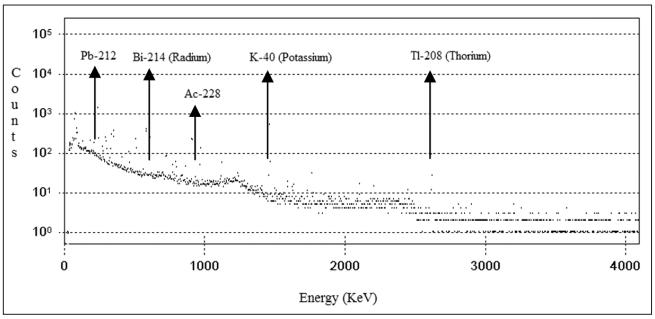

Figure 3: The spectral data plot of soil samples of Naguvana Halli

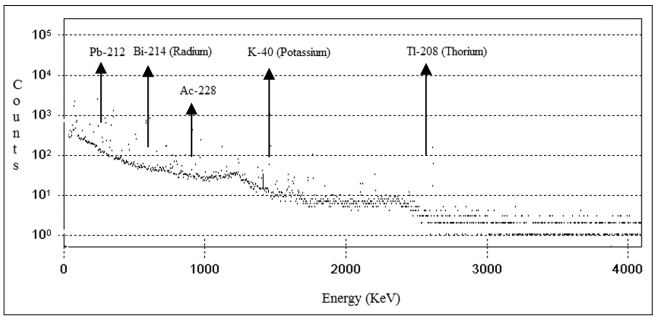

Figure 4: The spectral data plot of soil samples of Karigatta

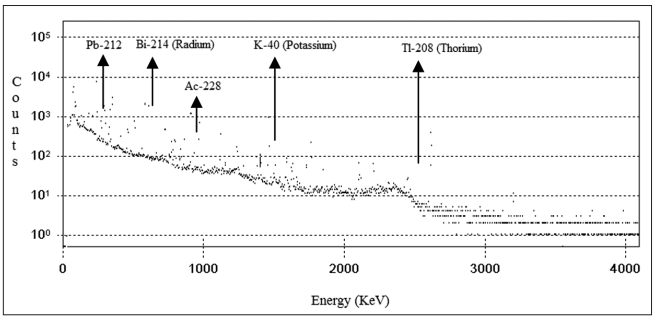

Figure 5: The spectral data plot of soil samples of K.R.S

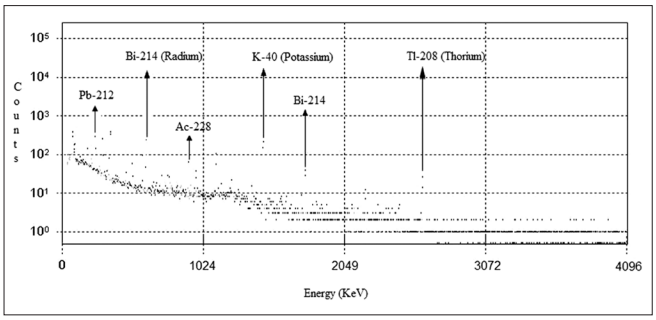

Figure 6: The spectral data plot of rock samples of Karigatta

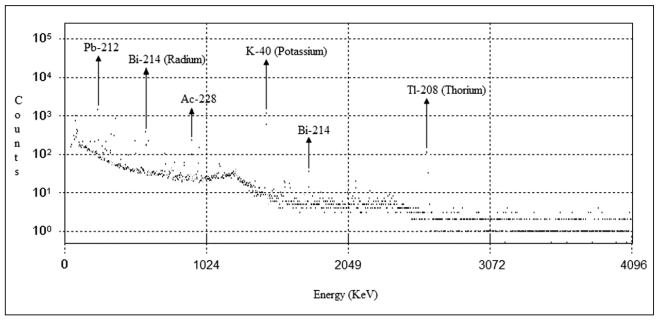

Figure 7: The spectral data plot of rock samples of K.R.S

Table 1: Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil samples and their hazard index

Locations	Activity (Bq/kg)				^{226}Ra/^{232}Th	$I_{\gamma r}$ (Bq/ kg)	H_{ex}	H_{in}	AG DE (μSvy^{-1})	Gamma absorbed dose (nGy/h)
	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}						
BRK	11.9±0.33	50.2±1.50	492.3±14.76	121.5	0.23	0.90	0.32	0.35	401.18	56.3
NH	13.0±0.41	36.3±1.08	359.8±10.79	92.6	0.35	0.68	0.24	0.28	304.87	42.9
KG	51.1±1.53	67.6±2.02	51.1±1.53	151.7	0.75	1.05	0.40	0.54	456.49	66.6
KRS	84.7±1.63	95.2±2.85	366.9±11.00	259.5	0.89	1.83	0.70	0.95	807.31	111.9
Average	40.2±1.28	62.3±1.86	317.5±9.52	156.3	0.75	1.11	0.41	0.53	492.46	69.4

BRK: Baburayana koppalu, NH: Naguvana halli, KG: Karigatta, KRS: Krishna Raja Sagar, R_{eq}: Radium equivalent activity, $I_{\gamma r}$: Respresentative level index, H_{in}: External hazard index, H_{in}: Internal hazard index, AGDE: Annual gonadal dose equivalent

Table 2: Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in rock samples and their hazard index

Locations	Activity (Bq/kg)				^{226}Ra/^{232}Th	$I_{\gamma r}$ (Bq/kg)	H_{ex}	H_{in}	AG DE (μSvy^{-1})	Gamma absorbed dose (nGy/h)
	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}						
KG	13.9±1.01	46.8±1.40	950.9±28.52	154.0	0.29	1.18	0.40	0.44	537.15	74.3
KRS	47.2±1.41	22.1±0.66	449.5±13.48	113.4	2.13	0.82	0.29	0.42	379.35	53.9
Average	30.5±1.21	34.4±1.03	700.2±20.9	133.7	1.21	1.00	0.34	0.43	458.25	64.1

BRK: Baburayana koppalu, NH: Naguvana halli, KG: Karigatta, KRS: Krishna raja sagar, R_{eq}: Radium equivalent activity, $I_{\gamma r}$: Respresentative level index, H_{ex}: External hazard index, H_{in}: Internal hazard index, AGDE: Annual gonadal dose equivalent

concentrations of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in soil samples and rock samples with their Ra_{eq}, $I_{\gamma r}$, H_{ex}, H_{in}, and AGDE were calculated and are shown in Table 1.

The activity of ^{226}Ra in soil samples varies from 11.9 Bq/kg to 84.7 Bq/kg with an average of 40.2 Bq/kg and activity of ^{232}Th varies from 36.3 Bq/kg to 95.2 Bq/kg with an average of 62.3 Bq/kg. The concentrations of ^{226}Ra and ^{232}Th are found to be highest at Krishna Raja Sagar. The highest amount of ^{226}Ra and ^{232}Th in soil depends to a large extent on the mineral composistion of the host rocks. The rocks in this region are granite, which have more of ^{226}Ra than other rock types. The activity of ^{40}K in soil samples varies from 51.1 Bq/kg to 492.3 Bq/kg with an average of 317.5 Bq/kg. Highest activity of ^{40}K is found in the soil sample of Baburayana Koppal. This may be due to excess use of chemical fertilizers in the agricultural lands in this region.

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in rock samples of Karighatta and Krishna Raja Sagar are shown in Table 2. The average values of ^{226}Ra, ^{232}Th, and ^{40}K are found to be 30.5, 34.4, and 700.2 Bq/kg, respectively. The concentrations of radionuclides in soil samples are found to higher than in rock samples. The process of soil formation can change the distribution of the radionuclides in the ^{238}U decay chain. Certain elements in soil are enriched compared to their content in the source rock. The extent a soil is affected by pedogenesis is different from soil to soil.[12,13] In soil developing from carbonate stone, U, Ra, and Th are enriched by a factor of about 10-20, whereas in soils developing from other parent materials like sandstone, the nuclides are generally concentrated by about 1.5-2 times.[12-14] The processes of soil formation will modify the weathered rock material and finally give the soil the properties that distinguish the soil from the source substance.[15,16] In the study area, unclassified crystalline rocks mainly carbonate and gneisses types of rocks and in some areas igneous rocks of granitic composition were found. Studies by several researchers also showed

that the concentration of radionuclide is enriched in soil than in the source material.[17-20] The average values of Ra_{eq}, $I_{γr}$, H_{ex}, H_{in}, and AGDE due to radionuclide in rock samples are found to be 133.7 Bq/kg, 1.00 Bq/kg, 0.34, 0.43, and 458.25 ($μSvy^{-1}$) and the ratio of $^{226}Ra/^{232}Th$ is found to be 1.21.

The average values of ^{226}Ra, ^{232}Th, and ^{40}K concentration reported for normal background areas of Indian soil are 15, 18.36, and 369.6 Bq/kg, respectively, and the corresponding world average values are 30, 45 and 420 Bq/kg, respectively.[2,21] The world average absorbed dose rate in outdoor air from terrestrial gamma rays in normal background ranges from 18 nGy/h to 93 nGy/h with an average of 57 nGy/h, whereas in this study area, the gamma absorbed dose rate estimated from radionuclide in soil varies from 42.9 nGy/h to 111.9 nGy/h with an average of 69.4 nGy/h. The concentrations of radionuclides in soil and rock samples in the study area are slightly higher than Indian average and world average values.

CONCLUSION

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, in soil and rock samples collected in Mandya district, have been measured by gamma ray spectrometry. The activity of ^{226}Ra in soil samples varies from 11.9 Bq/kg to 84.7 Bq/kg with an average of 40.2 Bq/kg and activity of ^{232}Th varies from 36.3 Bq/kg to 95.2 Bq/kg with an average of 62.3 Bq/kg. The activity of ^{40}K in soil samples varies from 51.1 Bq/kg to 492.3 Bq/kg with an average of 317.5 Bq/kg. Highest activity of ^{40}K is found in the soil sample of Baburayana Koppal. The concentrations of radionuclides in soil samples are found to higher than in rock samples. The concentrations of radionuclides in soil and rock samples in the study area are slightly higher than Indian average and world average values.

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