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Evaluation of Natural Radioactivity Levels and Exhalation rate of ^{222}Rn and ^{220}Rn in the soil samples from the Kuthiran Hills, Kerala, India

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ABSTRACT

Background: Exposure to radon and its decay products is one of the important contributors of radiation doses to human population. Radon exhalation study is important for understanding the contribution of the soil towards the total radioactivity concentration found inside the dwellings.

Purpose: The aim of the present study is to investigate the radioactivity levels and radium and radon exhalation rates in soil samples collected from Kuthiran hills and nearby places in Thrissur district, Kerala state, India. On the basis of this data, radiological health hazard parameters are also evaluated.

Methods: About 18 soil samples were collected from the study location. The radium, thorium and potassium activity concentrations were analyzed by HPGe gamma ray spectrometer. The "can technique" using LR-115 type II plastic track detectors have been used for the measurement of radon exhalation rate in soil samples.

Results: The mean values of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were 64.60 Bqkg^{-1}, 109.03 Bqkg^{-1} and 972.67 Bqkg^{-1} respectively. The mean value of radon mass exhalation rate is 9.19 mBqkg^{-1}h^{-1} and thoron surface exhalation rate is and 237.9 mBqm^{-2}s^{-1}. The radium equivalent activity concentration of all the soil samples was below the level of 370 Bqkg^{-1}, recommended for building materials, by OECD 1979 (Organization for Economic Cooperation and Development).

Conclusions: The results show that the study area is safe, as far as the health hazard effects of radium and radon exhalation rate are concerned. This data will be helpful in establishing new regulations and safety limits, related to the radiation dose and radon activity in Kuthiran hills.

1. Introduction

Radon is an odourless, colorless, inert gas with isotopes having a half-life f 3.82 days and clearly taking place in gasoline produced through the decay of radium that is found in all rocks, constructing substances, and soils. Exhalation of ^{222}Rn, a radioactive inert gasoline, is associated with the presence of ^{226}Ra and its last precursor uranium inside the earth's crust. Although these elements occur virtually in all types of rocks and soils, their concentration varies with specific sites and the geological formation of materials [1]. The presence of radon gas is usually determined using techniques that depend on the identification of radon itself or its decay products. The radon gas is created because the first disintegration is made of ^{226}Ra. This gas can spread and escape through small openings and cracks because it is about seven times heavier than air and therefore tends to stay close to the ground. Radon reaches the atmosphere through soil. The exhalation rate is dependent on weather conditions (air pressure, humidity, and temperature) and the soil permeability [2]. The exhalation of radon atoms leads to the transport of them to the ground surface and, subsequently, to the atmosphere. Radon exhalation depends mainly on ^{226}Ra content, the mineral grain size, and other hydro-metrological conditions prevailing. Its transport on the earth is governed by geophysical and geochemical parameters. Grain size is one of the important factors that controls radon concentration and exhalation rate in soil. The effect of the grain size factor has been studied [3]. They determine how much radium is near the grain surface to allow radon to escape into pore spaces. LR-115 Solid state nuclear track detector (SSNTD) is widely used for the estimation ^{222}Rn and ^{220}Rn concentration in indoor air [4, 5]. Solid State Nuclear Track Detectors in track etch technique have been used in this study due to their simplicity, low cost, non-destructive, small size, and having integrating capability for large scale studies for the measurement of radon activity, and radon exhalation rates in various samples. The aim of this work

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is to investigate the radon exhalation concentration of soils found in Kuthiran hills and Kuthiran dual tunnel, situated in Thrissur district, Kerala, which belongs to one of the populated regions in India. We had earlier carried out another study, the activity concentration of naturally occurring radionuclides in the soils in this study area to see if they constituted any human health risks [6]. ^{222}Rn, ^{220}Rn exhalation rates were determined from the soil and rock samples for the estimation of source term. Standard measurement techniques and protocols were used for the measurement of exhalation rates, and a correlation study was performed as a follow-up.

2. Materials and Methods

2.1. Location and Geology of Study Area

Kuthiran is a mountainous terrain in the Thrissur and Palakkad districts of Kerala state, south India. It is located (10.575°N, 76.375°E) on the banks of the Manali river, a major tributary of the Karuvannur river in the Thrissur district in Kerala, India, which has its source in the nearby mountains. It is a mountainous rocky terrain on the Thrissur-Palakkad highway (NH-544), which rewrote its history with the construction of the "largest" twin tube road tunnel in the country. The Kuthiran twin tube tunnels may have a length of almost 1 kilometer, while the width and peak would be 14 and 10 meters, respectively. Figure 1 shows the map of the sampling location. The area is hilly and mountainous with steep slopes, escarpments, elongated rocky summits, and slim 'V'-shaped valleys. The depth of the soil varies appreciably depending on erosion and vegetative cover. The soils are commonly immature due to slow weathering. Rocky outcrops and stones are observed at the surface. Gneissic boulders below, special degrees of weathering are noticed within the subsoil. The feel of the soil changes from sandy clay loam to clay with a reddish brown to very dark brown colour.

2.2 Radioactivity Analysis

Soil samples (2–3 kg) were collected and sealed in a polyethylene bag from 18 sites in the Kuthiran hills. Samples were collected from pits at a depth of around 15–20 cm by the random sampling method, in accordance with the standard IAEA (International Atomic Energy Agency) protocol. The samples were powdered and sieved through 125 m sieves and transferred to porcelain dishes, which were oven dried at 110 °C for 24 hours. Finally, the prepared samples were weighted and sealed in a 250 ml plastic container and kept for a month before being subjected to gamma spectrometry to ensure that the radioactive equilibrium was reached between ^{226}Ra, ^{222}Rn, and their progeny. The samples were then subjected to gamma ray spectrometry by using an ultra-low background p-type high purity germanium detector, having a 42% relative efficiency with an energy resolution of 2.1 keV at 1.33 MeV. Energy calibration was done using sealed standard sources. The international atomic energy agency (IAEA) provided standard reference sources RGU-I, RGTh-I, and RGK-I for efficiency calibration. The counts were recorded for 36,000 seconds. The ^{226}Ra activity was evaluated from the weighed mean of the activities of three photo peaks 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 concentration (Specific activity) in the sample was calculated by using the following equation[6]:

$$A = \frac{C}{\gamma \varepsilon t M}\left(Bqkg^{-1}\right) \tag{1}$$

where C is the counts above background, γ is the absolute gamma ray transition probability, $\in$ is the photo peak efficiency (%) of the detector, t is the exposure time in seconds and m is the mass in kg.

The hazard indices and dose parameters associated with the radioactivity in the soil were calculated using the following equations [7-9].

For radium equivalent activity Ra_{eq}:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \tag{2}$$

For External hazard index, H_{ext}:

$$H_{ext} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \tag{3}$$

For internal hazard index, H_{int}

$$H_{\text{int}} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \tag{4}$$

For absorbed dose rate D:

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.042A_K \tag{5}$$

For annual effective dose,

$$AEDE\left(mSvy^{-1}\right) = D \times \left(24 \times 365\right) \times 0.7 \times 0.2 \times 10^{-6} \tag{6}$$

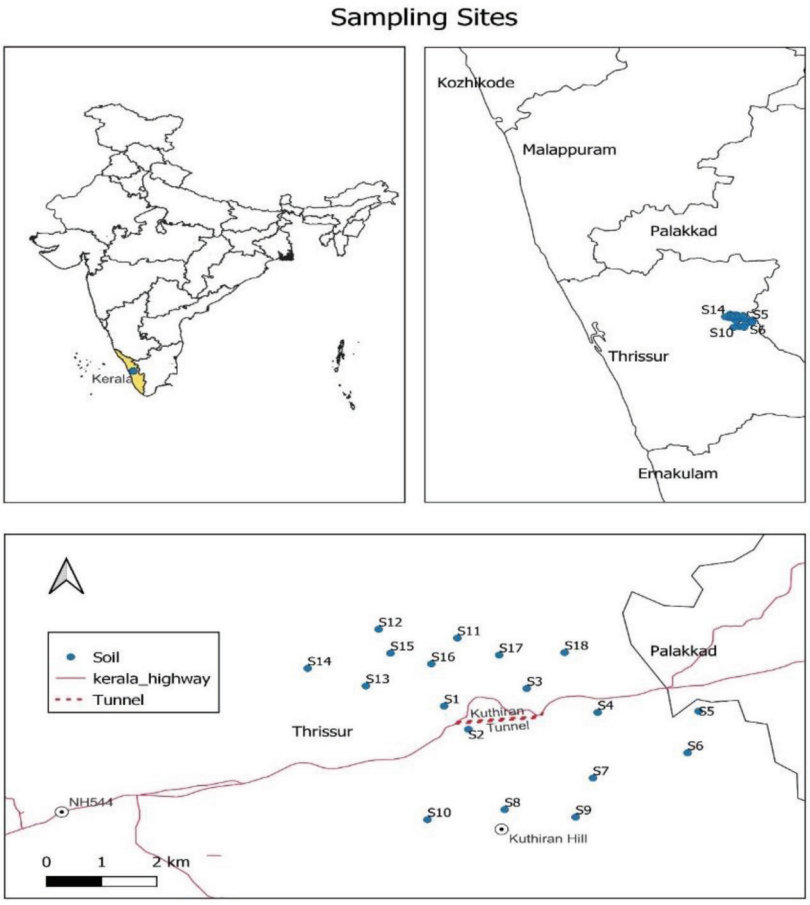

Figure 1: Map of the study area with soil samples collection points.

2.3. Closed Can Technique for Exhalation Rate

The closed-can technique is considered the most efficient method for the estimation of time-integrated radon exhalation rate. The accuracy of such measurements is determined by the material used and the amount used, as well as the geometry and dimensions of the can [10-12]. About 18 samples of soil were collected from the dual tunnels, Kuthiran hills and nearby places. The samples were crushed and dried for 24 hours at 110 °C. The dried samples were sieved using British standard mesh, fractionated into the size of 125 m from each sample. A 100-150 g sample was placed in a cylindrical can of 10 cm in height and 8 cm in diameter. A schematic diagram of the closed can technique is shown in Figure 2. In each can, the -sensitive LR-115 type-II solid state nuclear track detector of size 3 3 cm was fixed on the inner upper surface of the can. The sensitive face of the detector is freely exposed to the sample material in the can so that it can record the tracks due to alpha particles resulting from the decay of radon following the decay of radium [10, 11]. The LR-115 films were kept at approximately 7 cm from the sample to avoid the track contribution due to thoron as per the protocol [13]. The chambers were sealed with adhesive tape to minimize the leakage and left as such for 3 months (June-August, in the year 2021) so that the detectors could record alpha particles resulting from the decay of radon [10, 11], and [13].

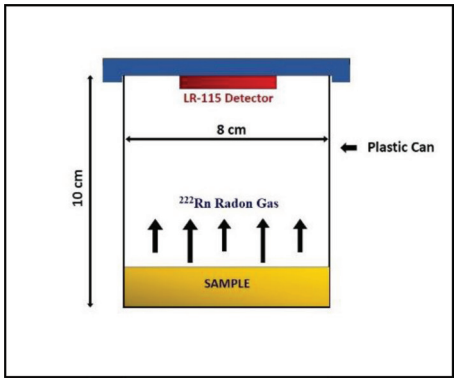

Figure 2: Experimental set up of closed can technique.

After the exposure, the detectors were removed and subjected to a chemical etching process in a 2.5 N NaOH

solution at 60 °C for 90 min in a constant temperature water bath for the revelation of tracks. The etched detectors were thoroughly washed and the red-sensitive layer was stripped for spark counting. The dried detectors were then used for alpha counting using the spark counter (PSI-SC1) procured from Polltech instruments. The detectors were first pre-sparked at 900 V and then tracks were counted at an operating voltage of 500 V, two or three times.

2.4. Effective Radium Content, Surface and Mass Exhalation Rate

The accumulated radon concentration was obtained from the track density (track cm^{-2}), using the calibration factor of 0.056 $tr.cm^{-2}d^{-1}Bq^{-1}m^3$ obtained from an earlier calibration experiment [11, 12, 14]. Once the radioactive equilibrium is established in a sealed can, the alpha particles released from the radon can be used to determine the ^{226}Ra radium content ($Bqkg^{-1}$) of soil samples. The radium concentration (C_{Ra}) in soil samples was calculated using the equations [11], [15-16].

$$C_{Ra} = \frac{\rho h A}{T_e K M} \tag{7}$$

Here, ρ is the track density, h (m) is the distance between the sample and the detector, K is the calibration factor, A (m^2) is the area of the cross section of the can, M (kg) refers to the mass of soil sample, and Te (days) denotes the effective exposure time. The detectors in cans record the ^{222}Rn concentration starting from zero activity to equilibrium activity [16]. The effective exposure time (T_e), which is related to the actual exposure time T and decay constant for ^{222}Rn, was calculated as follows:

$$T_e = T - \left(1 - e^{\lambda T}\right)\lambda^{-1} \tag{8}$$

The rate at which radon escapes or emanates from a solid into the surrounding air is known as the radon exhalation rate of the solid. This can be measured either per unit mass or per unit surface area of the solid. Measurement of the radon exhalation rate of soils and rocks is helpful to assess radon health hazards. The radon exhalation rate in terms of area and mass is calculated [11, 17] from the following relations (9) and (10)

$$E_A = \frac{CV\lambda}{AT_e} \tag{9}$$

$$E_M = \frac{CV\lambda}{MT_e} \tag{10}$$

where E_A is the radon surface exhalation rate ($Bqm^{-2}h^{-1}$) and E_M is the radon mass exhalation rate (Bq $kg^{-1}h-1$), C is the integrated radon exposure ($Bqm^{-3}h$), V is the effective volume of can (m^3), λ is the decay constant for radon (h^{-1}), and A is the area covered by the can (m2) and M is the mass of the sample taken in the can (kg). The radon concentration in the samples contributing to indoor air due to surface exhalation can be calculated by the relation [18].

$$C_{Rn} = \frac{E_A S}{V\lambda_V} \tag{11}$$

where C_{Rn} is radon concentration (Bqm^{-3}), S is the internal surface area of the room (m^2), V is the room volume (m^3), and λ_v is the air exchange rate (h^{-1}). The maximum radon concentration from the building material was assessed by assuming the room as a cavity with S/V = 2.0 m^{-1} and air exchange rate of 0.5 h^{-1}

The annual exposure to potential alpha energy, E_p (WLM y^{-1}) is then related to the average radon concentration C_{Rn} following the expression[19],

$$E_p = \frac{C_{Rn} \times 8760 \times n \times F}{170 \times 3700} \tag{12}$$

where n is the fraction of time spent indoors taken as 0.8, 8760 is the number of hours per year, F is the equilibrium factor for radon, taken as 0.4, as recommended by the UNSCEAR [9], The radon progeny equilibrium is the most important factor while calculating the dose based on the measurement of radon concentration. From radon exposure, the effective dose equivalents (E_{Rn}) can be calculated using the dose conversion factor of 3.88 mSv $(WLM)^{-1}$[11, 20].

3. Results and Discussions

3.1. Activity Concentrations of ^{226}Ra, ^{232}Th and ^{40}K

In the present study, radionuclides (^{226}Ra, ^{232}Th and ^{40}K) activity concentrations (Bq/kg) in soil samples were determined using gamma spectrometry, and Raeq activity and absorbed dose rates were estimated and are presented in Table 1. The obtained activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K at this location are found to be relatively higher than the global average value (35, 30 and 400 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K, respectively). For soil samples, the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K varied from 31.28±0.68 $Bqkg^{-1}$ to 109.57±0.78 $Bqkg^{-1}$ with mean of 64.60±0.68 $Bqkg^{-1}$, 53.87±0.48 $Bqkg^{-1}$ to 160.51±1.84 $Bqkg^{-1}$ with mean of 109.39±0.83 $Bqkg^{-1}$ and 608±18 $Bqkg^{-1}$ to 1208±31 $Bqkg^{-1}$ with a mean of 961.71±24 $Bqkg^{-1}$, respectively. The mean activity concentrations obtained from the samples for ^{226}Ra, ^{232}Th and ^{40}K are higher than the global average values of 33, 45, and 412 $Bqkg^{-1}$, respectively, as recommended by the United Nations

Scientific Committee on Atomic Radiation Effects [9]. The average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the present study area is above the Indian average (28.60 Bqkg^{-1}, 30.96 Bqkg^{-1} and 432.7 Bqkg^{-1}) [22]. Figure 3(a) shows the activity concentration of soil samples in the present study region.

Table 1: Activity concentration and radiological of soil samples in the present study.

Sample Code	Activity concentration (Bq.kg^{-1})			Raeq (Bq.kg^{-1})	Dose rate, D (nGyh^{-1})	Hazard Indices		AEDE (mSvy^{1})
	^{226}Ra	^{238}Th	^{40}K			H_{ext}	H_{Int}	
S1	31.28	138.26	1162	318.47	146.42	0.86	0.94	0.18
S2	74.45	118.31	608	290.45	131.21	0.78	0.99	0.16
S3	57.38	126.45	1042	328.44	146.34	0.86	1.02	0.18
S4	84.23	131.25	981	347.45	159.10	0.94	1.17	0.20
S5	67.36	147.25	732	334.29	150.58	0.90	1.08	0.18
S6	48.25	160.51	1208	370.80	169.61	1.00	1.13	0.21
S7	53.62	112.54	870	281.54	129.03	0.76	0.91	0.16
S8	60.18	124.32	912	308.18	140.92	0.83	0.99	0.17
S9	42.46	82.26	815	222.85	103.29	0.60	0.72	0.13
S10	109.57	102.35	940	328.31	151.64	0.89	1.18	0.19
S11	64.85	92.44	785	257.48	118.53	0.70	0.87	0.15
S12	98.28	78.38	669	261.88	120.64	0.71	0.97	0.15
S13	36.74	63.25	1011	205.03	97.34	0.55	0.65	0.12
S14	40.67	53.87	829	181.54	85.90	0.49	0.60	0.11
S15	71.36	102.65	1142	306.08	142.59	0.83	1.02	0.17
S16	78.48	98.84	1328	322.08	151.33	0.87	1.08	0.19
S17	68.21	109.38	1194	336.56	147.37	0.85	1.04	0.18
S18	75.34	120.15	1280	345.71	160.75	0.93	1.14	0.20
Average	64.60	109.03	972.67	297.04	136.25	0.79	0.97	0.17
World limit	30	35	400	370	59	1	1	0.7

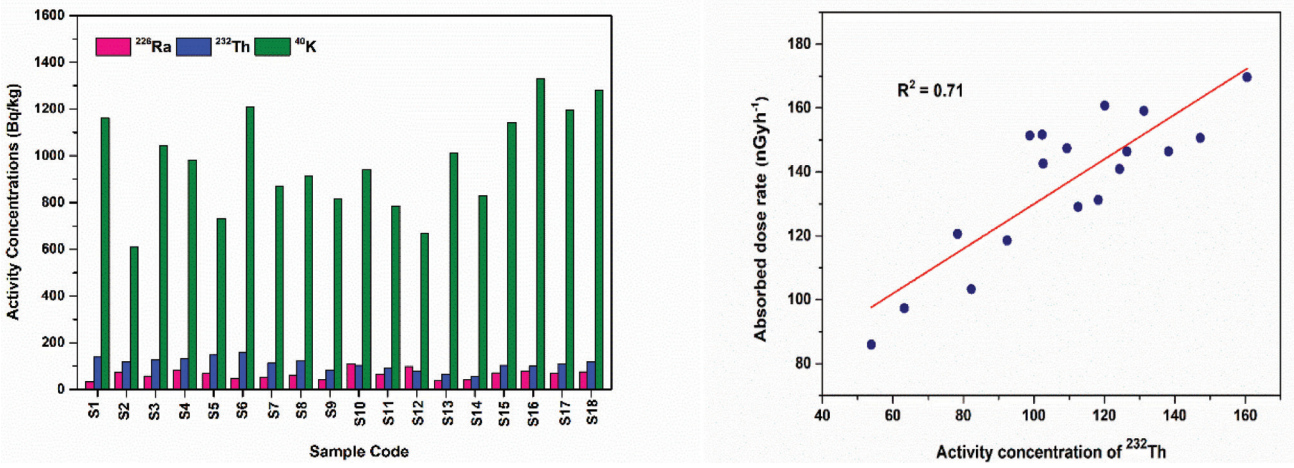

Figure 3(a): Activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K observed in present study (right). 3(b). correlation plot between D and ^{232}Th concentration (left).

The radium equivalent (Raeq) activity has been calculated to compare the natural activity concentration of soil samples containing different radionuclides and is found to be within the range of 181.54 to 370.80 Bqkg^{-1}, with an average value of 297.04 Bqkg^{-1}. The maximum permissible value of Raeq activity recommended for radiation exposure to mankind is 370 Bqkg^{-1}, which results in an effective dose of 1 mSv for the general human population. The observed absorbed dose rate (D) in soil samples from the present study ranged from 85.90 to 169.61 nGyh^{-1}, with an average value of 136.25 nGyh-1. Figure 3(b) depicts the relationship between 232Th activity concentration and absorbed dose rates D in soil samples. A positive correlation coefficient (R^2) of 0.71 between D and the ^{232}Th concentration was observed. It shows the dominance of ^{232}Th concentration in the present study. It is observed from Table 1, that all absorbed dose rate values in the present study are far beyond the worldwide range of 59 nGyh^{-1}. The radiological parameters such as hazard indices (H_{ex} and H_{in}), and annual effective dose equivalent (AEDE) values are also given in Table 1. The calculated H_{ex} value ranges from 0.71 to 1.01 with a mean value of 0.79, which is below the criterion value of 1 for soil samples, respectively. Most of the internal hazard due to analysed samples is just below the criterion value, i.e., < 1. Hint value ranges from 0.72 to 1.18 with a mean value of 0.97. The mean outdoor annual effective dose rate values for the studied soil samples were lower than the world average value of 0.70 mSvy–1 indicating that radionuclide concentration in the study area contributes only a low-level radiation hazard to the population [9]. The estimated outdoor AEDE values for soil samples vary from 0.12 to .20 mSvy^{-1}, with a mean value of 0.17 mSvy^{-1}.

3.2. Radon and Radium Exhalation

The effective radium content (C_{Ra}), surface exhalation rate (E_A), mass exhalation rate (E_M), radon concentration contributing to indoor air (C_{Rn}), and the annual exposure to potential alpha energy, Ep (WLMy^{-1}) of the soil samples analysed by the can technique are shown in Table 2.

Table 2: Effective radium content (C_{Ra}), surface exhalation rate (E_A), mass exhalation rate (E_M), annual exposure to potential alpha energy (E_p) and the effective dose equivalents (E_{Rn}) of soil samples.

Sample Code	C_{Ra} (Bqkg^{-1})	E_A (mBqm^{-2}h^{-1})	E_M (mBqkg^{-1}h^{-1})	C_{Rn} (mBqm^{-3})	Ep (WLMy^{-1})	E_{Rn} (μSvy^{-1})
S1	9.36	149.25	6.25	597	2.66	10.32
S2	12.62	244.57	10.25	978.26	4.36	16.92
S3	14.37	268.97	11.27	1075.87	4.79	18.60
S4	20.46	263.04	11.02	1052.17	4.69	18.19
S5	15.11	228.21	9.56	912.85	4.07	15.78
S6	20.14	322.94	12.13	1246.75	5.76	22.34
S7	19.89	194.32	8.14	777.29	3.46	13.44
S8	12.35	210.29	8.81	871.17	3.75	14.55
S9	15.38	162.51	6.81	650.03	2.90	11.24
S10	17.3	275.00	11.52	1099.99	4.90	19.02
S11	13.5	211.25	8.85	844.99	3.77	14.61
S12	24.52	289.43	12.02	1157.73	5.16	20.02
S13	19.1	191.09	8.01	764.37	3.41	13.22
S14	22.79	174.18	7.30	696.73	3.11	12.05
S15	16.6	312.94	7.47	1212.77	5.58	21.65
S16	18.69	307.23	8.10	1166.9	5.48	21.25
S17	14.16	216.82	9.22	867.28	3.87	15.00
S18	18.6	260.10	8.72	990.41	4.64	17.99
Average	16.94	237.90	9.19	942.36	4.24	16.45

The effective radium content (Table 2) was found to vary from 9.36 to 24.52 Bqkg^{-1}, with a mean value of 16.94 ± 0.64 Bqkg^{-1}. The average value of effective radium content obtained from the present study is lower than the recommended value of 370 Bqkg^{-1}, as recommended by the organisation for economic cooperation and development. To find out the annual effective doses contributed by the exhaling radon in the indoor air, the contribution of radon from soil to indoor radon was determined using the estimated surface exhalation rates. The surface exhalation rate (Table 2) was found to vary from 149.25 to 322.94 mBqm^{-2}h^{-1}, with a mean value of 237.90 mBqm^{-2}h^{-1} for the grain size of 125 µm soil samples in the studied area. The average values of surface exhalation rates obtained in this study are lower than the world average value of 57.6 mBqm^{-2}h^{-1} [21]. In the case of mass exhalation rate, it was found to vary from 6.25 to 12.13 mBqm^{-2}h^{-1}, with a mean value of 9.19±0.32 mBqm^{-2}h^{-1}, for soil samples. Figures 4(a) and 4(b) show the Box-whisker plot for the exhalation parameters. The estimated annual exposure to potential alpha energy (Ep) of soil samples was found to vary from 2.66 to 5.76 WLMy^{-1}, with a mean value of 4.24 WLMy^{-1}. In Table 2, the calculated values of the annual effective dose equivalents obtained from radon concentrations contributing to indoor air were also given in Table 2. It was found to vary from 10.32 to 22.34 µSvy^{-1} with a mean value of 16.45 µSvy^{-1}. The estimated annual effective dose is less than the world acceptable limit of 0.3 mSvy^{-1}[11].

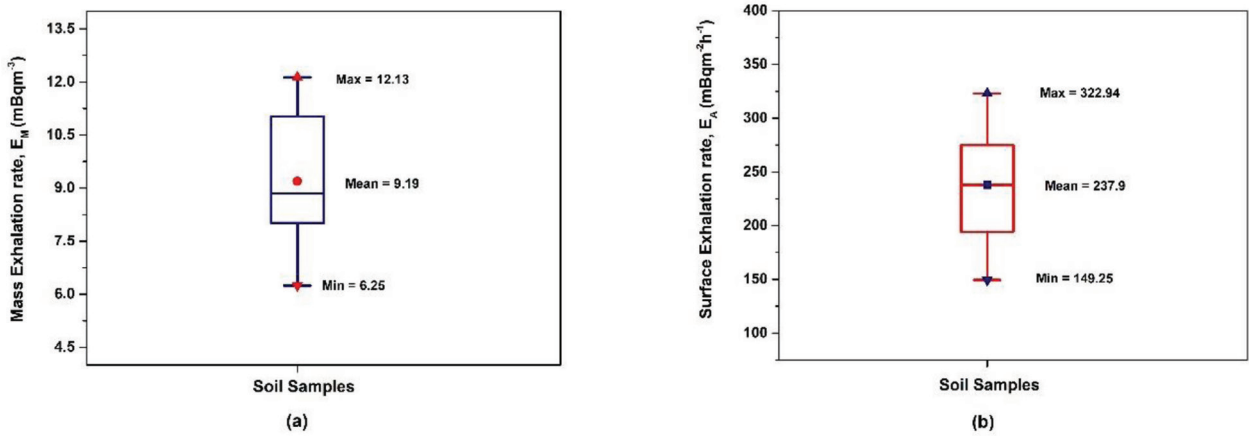

Figure 4: Box Whisker plot for (a) Mass Exhalation rate and (b) Surface Exhalation rate.

The radon concentration contributing to indoor air (Table 2) ranges from 597 to 1246.75 mBqm^3, with a mean value of 942.36 mBqm^3.high radium concentration in soil samples is found at Kuthiran Hill and Tunnels. The mass exhalation rate and surface exhalation rate in rock samples are found to be high in tunnels. Figure 5 (a) shows the relation between surface and mass radon exhalation rates.

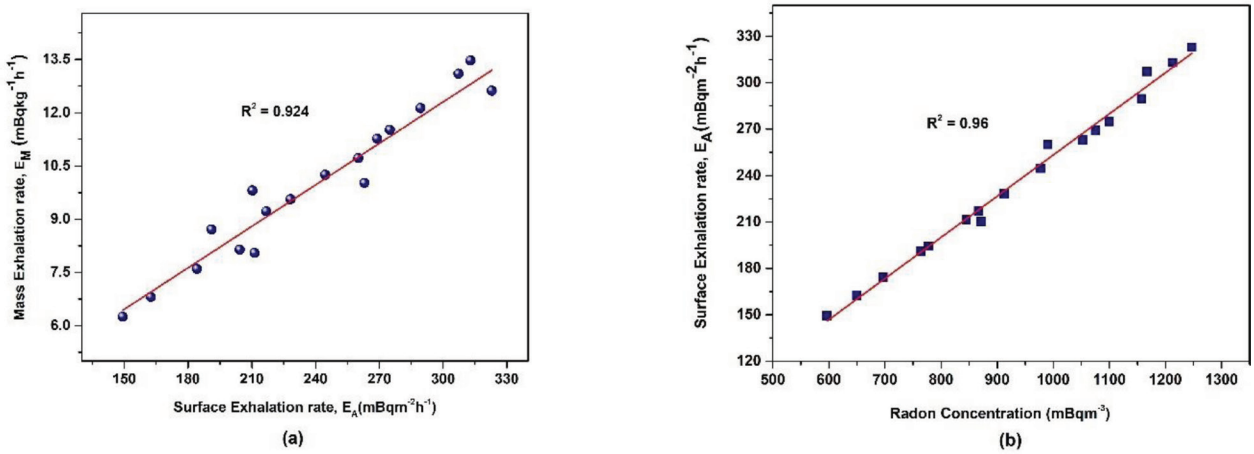

Figure 5: (a) Relationship between surface and mass radon exhalation rate and (b) relationship between surface exhalation rate and radon concentration.

Figure 5 (a) shows that a strong positive correlation has been observed between radon mass and surface exhalation rate (R^2= 0.924). The highest values of E_A and E_M were measured in the samples S6 and S7, while the lowest values were measured in S1. This is because there is a direct relationship between the levels of radon and exhalation. ^{222}Rn exhalation rate depends on radioactive disintegration of ^{226}Ra to produce radon, the moisture condition of the soil in the vicinity of the escaped radon atom, the direction of recoil of radon gas in the grain and its diffusion in the pore space [23]. Similarly, Figure 5 (b) shows a strong positive correlation between surface exhalation rate and radon concentration (R^2= 0.96). Hence, there is a positive relationship between radon exhalation and the concentrations of both radon and radium in soil. The variation in the exhalation rate of radon is due to the nature of the samples, emanation factors of radon from them, a diffusion coefficient of radon in different samples and the radium content of the samples [24]. Furthermore, the concentration of radium and radon depends on the type of rocks, the geological formation of rocks in the study area, and stone cracks due to the breaking of bedrock. Radium is abundant in bedrocks, and when bedrocks are destroyed and fissured, radon gas can diffuse through the structure of the bedrock and increase the concentration of radium [25]. The concentration of radium determines the number of radon atoms formed and emanates from the mineral sources [24]. The higher values of radium in soil samples can cause a significant increase in environmental radon in these areas. Although, the presence of uranium and radium bearing minerals in host rocks and their interaction with soil is the main cause of the high radon exhalation rate in soil. The high level of radon exhalation rate in soil samples may be attributed to the geological structure of Kuthiran hills due to the influence of the Western ghats, which are mainly composed of monazites, limonite, quartz, marble, gneiss, copper ore, etc. The study has confirmed that soil gas radon and ^{226}Ra content in the study area and, consequently, the associated radon exhalation does not expose human health to the associated risk.

3.3. Comparison with the Previous Works in India

Table 3 represents the values of radon mass exhalation rates and thoron surface exhalation rates, previously reported in different parts of India. The average value of ^{222}Rn mass and surface exhalation rates estimated in the present investigated region is comparable with the recent studies.

Table 3: Comparison of radium content, area exhalation rate and mass exhalation rate of the soil sample in the present work, with that of other studies carried out in India.

Serial No.	Location	C_{Ra} (Bqkg^{-1})	E_A (mBqm^{-2}h^{-1})	E_M (mBqkg^{-1}h^{-1})	References
1	Dilli- Jeypore, Assam.	21.6	700	21	[25]
2	Nangal, Punjab.	-	27.1	1.2	[12]
3	Aravali hills, Haryana.	-	746	34.6	[26]
4	Bulandshahr, Uttar Pradesh.	14.1	600.74	23.1	[27]
5	Northern Rajasthan.	12.45	495.32	14.96	[28]
6	Godda, Jharkhand.	14.52	590.69	17.36	[27]
7	Hamirpur district, HP.	-	35.11	22.51	[29]
8	Hassan, Karnataka.	-	140	28.2	[10]
9	Cauvery river, Karnataka.	118.95	293.6	108.53	[30]
10	Chamaraja, Karnataka.	14.7	391.5	18.6	[24]
11	Coastal Regions, Kerala.	2.25	338	17.0	[11]
12	Tirur, Kerala.	104.37	0.62	0.024	[27]
13	Kuthiran hills, Kerala.	16.94	237.9	9.19	Present Study

The ^{220}Rn surface exhalation rate is found to be significantly lower than the values reported in other states. The inconsistency may be due to variation in the radium content of the soil samples, lithology of the selected sampling sites and measurement from the track's contribution due to thoron.

Conclusion

Systematic investigations of radionuclides activity concentration have been undertaken using gamma ray spectrometric analysis and the exhalation rates have been estimated using closed can technique for the soil samples

of Kuthiran hills and Tunnel, Thrissur district, Kerala. The mean activity concentration values of the radionuclides were found to be greater than the world average limit. From the estimated radiological hazard parameters, some values go beyond the recommended limit of UNSCEAR, especially from samples near Kuthiran tunnel, the place coming under the western ghats of south India. However, the exhalation rates and related parameters were found to be below the recommended level by the UNSCEAR 2000. A strong correlation was observed between radon gas in soil and radon surface and mass exhalation rate. From this study there is a positive correlation between radon exhalation and the concentrations of radon and radium in soil. Based on the results of this study, the authors conclude that the soil of the study area does not pose any radiological health hazard to the public residing or working in this area.

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Authorship Contribution

Vishnu C V conducted the investigation, developed the suitable methodology, and was involved with the writing (original draft) of the manuscript. Antony Joseph guided with the conceptualization of the work and provided supreme supervision in the submitted work.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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