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Gamma Radiation Profile of the High Background Radiation Area along Southwest Coastal India and its Neighbourhood

Soniya Sukumaran Chettiar Rajamma[1] | Sunila Abraham[2] | Jojo Panakal John[1,3]✉

1. Centre for Advanced Research in Physical Science, Department of Physics, Fatima Mata National College (Autonomous), Kollam, 691001, India.
2. Postgraduate and Research Department of Physics, Christian College, Chengannur-689122, India.
3. Department of Applied Physics, The Papua New Guinea University of Technology, Lae, Papua New Guinea.

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ABSTRACT

Radioactive contamination of the earth's biosphere has always been a source of concern. From the health point of view, radiation exposure and dose delivered to human beings are of prime importance. Certain parts of coastal southwest districts of the state of Kerala in India namely Thiruvananthapuram (Trivandrum), Kollam (Quilon) and Alappuzha (Alleppey) are known high background radiation areas (HBRA) owing to the presence of rich quantities of thorium and uranium. Surface soil samples from these districts' HBRAs and adjoining regions were studied for their primordial radionuclide levels using NaI(Tl) based gamma-ray spectrometry. Specific activities of ^{226}Ra, ^{232}Th and ^{40}K nuclides in soil samples from the whole study area were between 4.7 Bq/kg to 130 Bq/kg, 6.5 Bq/kg to 611 Bq/kg and 101 Bq/kg to 1852 Bq/kg, respectively. Important dosimetric parameters namely radium equivalent activity (Ra_{eq}), absorbed gamma dose (D), Indoor and outdoor Annual Effective Dose equivalents (AED_{in} & AED_{out}), internal and external hazard indices (H_{in} & H_{ex}) for gamma exposure, and Excess Lifetime Cancer Risk (ELCR) were also determined to assess probable health effects on human beings residing in these regions. A comparison of average specific radioactivities and average indoor annual effective doses between the HBRA and Normal background Radiation Area (NBRA) is presented. Results show that the neighbouring regions have considerably lower radiation dosimetric parameters.

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INTRODUCTION

Radiation exposure

Radioactivity is ubiquitous and is present in living and nonliving things naturally. Radiation exposures to the environment arise from the presence of earthly radionuclides found in the surface soil, even though at trace levels. Natural environmental radiation varies depending on the amount of naturally occurring radionuclides in soil, water and air. Geophysical, geochemical and technological activities are also factors causing its variation from place to place and time to time. Extraterrestrial radiations constantly irradiate the biosphere contributing to the natural background radiation. Human beings receive exposure to radioactivity from the food, water and air we inhale. Several factors determine the annual dose we receive from background radiation (EPA, 2022).

*Corresponding Author Email: *jojo@fatimacollege.net*
panakal.jojo@pnguot.ac.pg

Major sources of radiation exposure

The natural radioactivity in soil samples mainly originates from ^{234}U, ^{235}U, ^{238}U, ^{226}Ra, ^{232}Th, ^{222}Rn and ^{40}K isotopes (Wang et al., 2017). The precise concentrations are related to the type of rocks from which the soil originated. The dispersal of natural radionuclides is not uniform in the earth's crust. Therefore, external radiation exposure generally varies by a factor of three or more around the world. The levels of naturally occurring radionuclides in surface soil are measured primarily to understand the spatial distribution of the radionuclides in the area. The results of investigations to assess the background levels of radionuclides in soils, can in turn be related to the absorbed dose rates in air (UNSCEAR, 2000). The effects of the radiation emitted by different radionuclides depend on the over-lining soil material (thickness and type), its chelating agents and physio-chemical properties (Belivermis et al., 2010).

Probable impacts on health

Long-term exposure to radionuclides like radium and thorium through inhalation of their progeny has severe health effects such as chronic lung diseases, acute leucopenia, anemia and necrosis of the mouth (FEPA, 1991). The levels of natural background radiation dose rates are reported to vary from 1.4 to 2.4 mSv per annum depending on the concentration of primordial radionuclides in the soil, and the latitude and longitude of the place (UNSCEAR, 1993). Above a specific threshold, ionizing radiations can impair the tissues and organs producing acute health effects (WHO, 2016; Ghiassi et al, 2004; Lubin, 2002).

High Background Radiation Areas

There are certain regions on earth with remarkably higher radiation levels as compared with the other regions. High background natural radiation areas on the earth include Ramsar (Iran), Guarapari (Brazil), Orissa and Kerala (India) and Yangjiang (China). Generations are being exposed to these extraordinary radiation fields (Vasconcelos, et al., 2013; Santos et al., 2008; Sohrabi and Esmaeli, 2002; Aliyu and Ramli, 2015; Shetty et al., 2011). HBRA has the natural radioactivity leading to chronic exposure that results in an annual effective dose to the public above a defined level (BEIR, 2006).

HBRA in southwest coastal India

HBRA along the southwest coast of the Indian subcontinent is situated in the small state of Kerala spreading over mainly four coastal panchayaths (hamlets) namely Chavara, Neendakara, Panmana and Alappad. Kerala is a densely populated state in the southern peninsular region with the highest literacy rate (>95%) among the other states in India. It is flanked by the Arabian Sea on the west and Tamil Nadu on the east. The monazite-bearing sand along the southern coastal Kerala has a very high abundance of thorium and traces of uranium along with their decay products (Anitha et al., 2020). A large population in the region receives external whole-body doses of about 4.5 mGy annually on average from gamma rays along with 2.4 mSv inhalation dose from the radon exposure. High-end dose of the order of 10 mGy from gamma rays and a considerable inhalation dose of about 45 mSv/y has also been reported for the region [Eisenbud and Gessell, 1997; Sunta, 1993; Thampi, 2002]. Decades-long investigations have been held in the region to examine the possible correlation between natural radiation exposure and malignant health effects including cancer (Amma et al., 2021). The present study was carried out to analyse the surface soil samples and the results have been used to compare the specific activities of radionuclides in the HBRA with the neighbouring NBRAs and the extent of annual radiation dose received by the inhabitants in the two regions

MATERIALS AND METHODS

Soil sampling

Sampling locations were selected along the coastal region to cover the HBRA. The coastal belt in the three districts has an extent of more than 50 km length. Locations for soil sample collection along the coast were selected with a maximum separation of 5km between the sites. Interior areas adjoining the coast were selected randomly where the population is higher. The number of samples collected was more in Kollam district where the background radiation is relatively higher (Thomas et al., 2022).

Soil samples were collected from 81 different locations in the region of study. The locations of sample collection sites are shown in Figure1. Classification of locations (HBRA / NBRA) was done based on the reading of a personal radiation detector (RadEye-Thermoscientific, Germany). Locations having ambient gamma dose above 6 μR/h (» 0.6 mSv/y) were considered as HBRA. Soil samples were collected with a coring metal tool of two-inch diameter that can be forced into the ground so that undisturbed surface soil can be collected. This was done after removing the grass, gravel and other materials. The tubular tool was pushed in about 15 to 20 centimeters down to the surface soil so that the desired amount of soil can be collected. The soil remaining in the tube was pushed into a sample container with a unique sample identification number. For loose or sandy soil areas, scooping technique was used

Sample preparation

Collected samples were air dried at about 110°C in a hot air oven, homogenized and sifted using a 300 mesh sieve. The samples were transferred to the containers and were then sealed around the edges of the lids with plastic electrical tape to prevent the loss of radon and thoron isotopes. Hermetically sealed samples were shelved for about 28 days for the short-lived members of the uranium and thorium series to reach secular equilibrium (Jibiri et al., 2007).

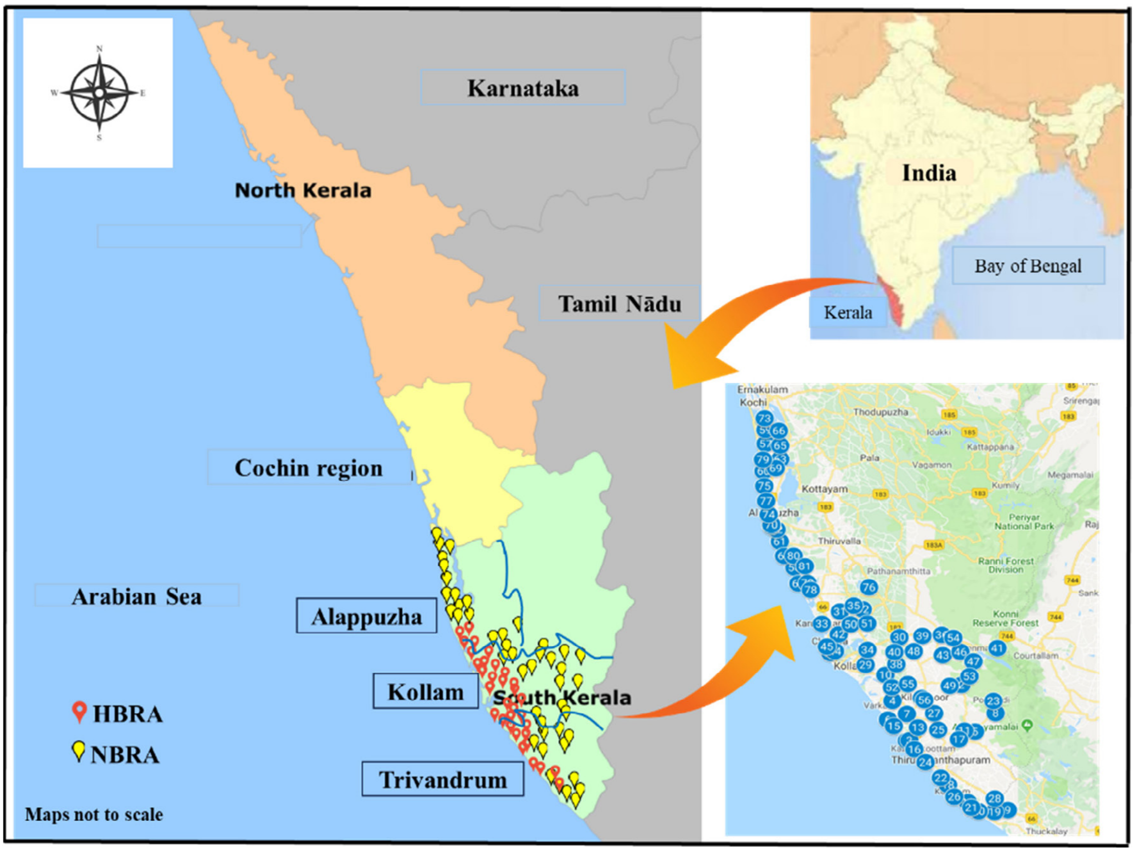

Fig. 1. Sampling locations in three different districts of southern Kerala

Gamma ray spectrometry

Specific activities of ^{226}Ra, ^{232}Th and ^{40}K were determined using a Gamma-ray spectrometer having a 3" × 3" NaI(Tl) well-type detector, housed in a cylindrical lead shield of 3" thickness. The output of the photodiode attached to the detector was coupled to a multichannel analyzer (MCA) through a preamplifier and associated electronics. The energy calibration of the detector was done using ^{137}Cs peak at 662 keV and two peaks of ^{60}Co with energy of 1172.6 keV and 1332.8 keV respectively. The activity of ^{40}K was evaluated from the 1460 keV photo peak and the activity of ^{226}Ra from the 1764 keV gamma line of ^{214}Bi; and that of ^{232}Th from the 2610 keV gamma line of ^{208}Tl. The specific activities of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in the soil samples were calculated using the equation (Khandaker et al., 2012):

$$\text{Specific Activity} = \frac{\text{cps} \times 1000}{\text{BI} \times E_{ff} \times W} \quad (1)$$

where cps is the net count per second, BI is the branching intensity and E_{ff} is the efficiency of the detector. W is the weight of the sample in grams. The uncertainties of the measured data were estimated by using quadratic sum of the following sources: statistical uncertainty, sample weight, detector efficiency and gamma-ray intensity (Asaduzzaman et al., 2016). The minimum detectable activity (MDA) of the spectrometer for ^{226}Ra, ^{232}Th and ^{40}K, were 4.7 Bq/kg, 6.5 Bq/kg and 28.2 Bq/kg respectively. MDAs for the spectrometer system were determined using the background count obtained for a sufficiently long counting time along with other parameters (Nurul et al., 2021; Done and Loan, 2016). Utmost care was taken during each stage namely sample preparation, calibration of the detector and counting. Uncertainties from counting statistics in the net count rate and that arising from determining the energy-dependent detection efficiency might cause a maximum of 10% error.

Radium equivalent activity (Ra_{eq})

The primordial radionuclides are not distributed homogeneously in the soil samples. The inhomogeneous sharing of these naturally occurring radionuclides is due to disequilibrium between parent nuclides and their decay products. The exposure of radionuclide concentrations was made uniform by presenting the term, radium equivalent activity (Ra_{eq}) in Bq/kg. (Beretka and Mathew, 1985).

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

where A_{Ra}, A_{Th} and A_K denote the specific activities of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. The rationality of evaluating Ra_{eq}, was that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th, or 4810 Bq/kg of ^{40}K produce the same gamma dose rate. Moreover, the level of radioactivity of the sample can be represented with a single value.

Absorbed dose rate (D)

The absorbed dose rate (D) due to the gamma radiation exposure in air at 1 m above the ground surface was estimated. Absorbed dose due to mean specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K was estimated using the formula (UNSCEAR, 2000; Aközcan, 2014).

$$D\ (nGyh^{-1}) = (0.462\ C_{Ra} + 0.604\ C_{Th} + 0.0471\ C_K) \quad (3)$$

Where C_{Ra}, C_{Th} and C_K are the specific activities (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K respectively. The constants in Equation 3 are the factors for the conversion of activity to dose.

Annual Effective Dose (AED)

The annual effective dose (AED) received by the members of the public due to the terrestrial gamma radiation in the outdoor environment from surface soil was calculated using the relation (Asaduzzaman et al., 2016; Ravisankar et al., 2015):

$$AED_{in}\ (mSv/y) = D\ (nGy/h) \times 8760\ hy^{-1} \times 0.8 \times 0.7\ (Sv/Gy) \times 10^{-6} \quad (4)$$

$$AED_{out}\ (mSv/y) = D\ (nGy/h) \times 8760\ hy^{-1} \times 0.2 \times 0.7\ (Sv/Gy) \times 10^{-6} \quad (5)$$

where 0.7 (Sv/Gy) is the effective absorbed dose conversion factor, 8760 is the number of hours per year, 0.8 and 0.2 are the indoor and outdoor occupancy factor (UNSCEAR, 2000).

Hazard indices (H)

The external hazard index (H_{ex}) is commonly employed to evaluate the radiation dose to individuals due to the external exposure to gamma radiation released from materials of interest. The external hazard index (H_{ex}) resulting from the exposure to primordial radionuclides in surface soil was calculated using the formula (Purnama and Damayanti, 2020):

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (6)$$

It is to evaluate the radiation hazards to respiratory organ due to the exposure of radioactive inert gas radon (^{222}Rn), thoron (^{220}Rn) and their short-lived decay products, internal hazard index is being used. It was calculated using the equation (Purnama and Damayanti, 2020; UNSCEAR, 1988]:

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (7)$$

It is suggested that for the safe use of the materials containing radionuclides, the value of H_{ex} and H_{in} should be less than unity (Khandaker et al., 2012; Kolo et al., 2015).

Excess Lifetime Cancer Risk (ELCR)

ELCR is an estimate of the additional risk that a person may develop cancer due to exposure to cancer-causing ionizing radiations above the normal risk without exposure to those radiations. It is the numerical difference between a cohort of people who develop or die from cancer in an exposed population and the corresponding proportion in a similar population without exposure (Mohammed and Ahmed, 2017). Potential excess cancer risk for the lifetime is a useful way to summarize risks from the exposure. In general, the quantity is estimated as the lifetime average daily intake for each exposure pathway and are then weighed by the amount of time spent. The excess lifetime cancer risk (ELCR) was calculated using the following formula (Thabayneh and Jazzar, 2013):

$$ELCR = AED_{total} \times DL \times RF \quad (8)$$

where AED_{total}, DL and RF are the total annual effective dose rate (mSv/y), the duration of life (70 years) and risk factor (per Sv) (fatal cancer risk per sievert) for stochastic effects. ICRP 60 uses values of 0.05 for the public (ICRP, 1991; Shoeib and Thabayneh, 2014). Global average for excess life time cancer risk from exposure to gamma is 0.29×10^{-3} (Taskin et al., 2009; Ezekiel, 2017).

RESULTS AND DISCUSSION

Specific radioactivities of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil samples were determined by the experimental procedure using the gamma ray spectrometer. Using the measured activities of radionuclides, gamma radiation dose and radiation dosimetric parameters namely radium equivalent activity, gamma radiation exposure in air at 1m from the surface, Indoor and outdoor annual effective doses to the human beings, radiation hazard indices and Excess Lifetime Cancer Risk were evaluated. Results obtained with descriptive statistics are summarized in Table 1. Because of large heterogeneity in the results of measurements of soil radioactivity, in addition to arithmetic mean (A.M.) and arithmetic standard deviation (ASD), geometric mean (G.M.), geometric standard deviation (GSD), skewness and kurtosis of the distributions are also presented. The results of the measurements show that there is very wide heterogeneity in the specific activities of radionuclides in the samples. The geometric mean is the most useful and acceptable representative value when the measures have large fluctuations and it is less affected by extreme values in a skewed distribution (Clark-Carter, 2010).

Specific activities of radionuclides

The specific activity of ^{226}Ra in the soil samples from Thiruvananthapuram district was found to vary from 4.7 Bq/kg to 130 Bq/kg. The specific activity of ^{232}Th varied from 6.5 Bq/kg to 372 Bq/kg and that for ^{40}K was found to vary from 103 Bq/kg to 1852 Bq/kg.

Table 1. Descriptive statistics of measured specific activities of radionuclides in soil and other parameters.

Statistical parameter	Specific activities and radium equivalent activity (Bq/kg)				Radiation dose			Radiation hazard indices		ELCR × 10^{-3}
	C_{Ra}	C_{Th}	C_K	R_{eq}	D (nGy/h)	AED_{in} (mSv/y)	AED_{out} (mSv/y)	H_{ex}	H_{in}	
THIRUVANANTHAPURAM										
Min	4.7	6.5	103	32	16.22	0.08	0.02	0.09	0.09	0.35
Max	130	372	1852	645	278.24	1.36	0.34	1.74	2.05	5.97
A.M.	**40**	**99**	**536**	**220**	**99.38**	**0.49**	**0.12**	**0.59**	**0.70**	**2.13**
ASD	34	82	310	128	54.75	0.27	0.07	0.35	0.40	1.17
G.M.	**23**	**61**	**465**	**181**	**83.54**	**0.41**	**0.10**	**0.49**	**0.58**	**1.79**
GSD	1.32	1.17	1.73	1.96	1.89	1.89	1.88	1.96	1.98	1.89
Skewness	0.59	1.11	2.35	0.94	0.94	0.84	1.04	4.48	0.86	0.85
Kurtosis	0.68	1.06	7.37	1.15	0.94	0.93	0.94	1.13	1.76	0.94
KOLLAM										
Min	4.7	6.5	101	27	13.90	0.07	0.02	0.07	0.07	0.3
Max	124	611	1330	1078	471.01	2.31	0.58	2.91	3.20	10.11
A.M.	**31**	**120**	**557**	**245**	**109.87**	**0.54**	**0.13**	**0.66**	**0.74**	**2.36**
ASD	33	139	279	220	94.47	0.46	0.09	0.60	0.65	2.02
G.M.	**16**	**62**	**484**	**179**	**82.9**	**0.41**	**0.1**	**0.5**	**0.5**	**1.78**
GSD	1.46	1.57	1.78	1.20	1.10	1.10	1.10	1.21	1.21	1.10
Skewness	0.93	1.95	0.91	2.08	2.11	2.11	2.11	2.08	2.05	2.11
Kurtosis	0.27	3.22	0.74	4.27	4.51	4.51	4.51	4.26	4.19	4.51
ALAPPUZHA										
Min	4.7	6.5	262	28	14.46	0.07	0.02	0.07	0.08	0.31
Max	95	226	656	447	196.51	0.96	0.24	1.21	1.44	4.22
A.M.	**24**	**70**	**403**	**154**	**69.78**	**0.34**	**0.09**	**0.42**	**0.48**	**1.5**
ASD	28	60	83	103	44.36	0.22	0.05	0.28	0.33	0.95
G.M.	**14**	**45**	**395**	**124**	**57.5**	**0.28**	**0.1**	**0.3**	**0.4**	**1.23**
GSD	1.03	1.89	1.22	1.96	1.88	1.88	1.87	1.96	1.00	1.88
Skewness	1.05	1.06	0.92	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Kurtosis	0.41	0.15	0.64	2.24	0.26	0.24	0.25	0.24	0.21	0.26

Specific activity of radionuclides in the soil samples from Kollam had ranged from 4.7 Bq/kg to 124 Bq/kg, 6.5 Bq/kg to 611 Bq/kg, 101 Bq/kg to 1330 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K respectively. Soil samples from the Alappuzha district had ^{226}Ra, ^{232}Th and ^{40}K specific activities from 4.7 Bq/kg to 95 Bq/kg, 6.5 Bq/kg to 226 Bq/kg, and 262 to 656 Bq/kg respectively. From the descriptive statistics of results presented in Table 1, it can be deciphered that the mean values given in the table cannot be considered representative values for the respective quantities. In these cases, the geometric mean would better represent the quantities. The obtained data are negatively skewed in all the cases. Kurtosis for the radium being small negative, the distribution is almost flat. At the same time, radium equivalent values have a peak for its distribution as indicated by its kurtosis.

In general, measured radioactivity in soil samples collected from the Kollam district show relatively higher mean activities compared to the other two districts. The mean values of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from the Kollam and Thiruvananthapuram districts show higher than their respective global average values of 35 Bq/kg, 30 Bq/kg and 400 Bq/kg (UNSCEAR, 2000).

Radium equivalent activity

The mean value of Ra_{eq} also shows variability similar to the activity concentration with decreasing order in soils samples from Kollam, Thiruvananthapuram and Alappuzha districts. The average Ra_{eq} values are less than the maximum admissible value of 370 Bq/kg for the three districts. Therefore, in general, the surface soil in the entire region of study may not pose any significant radiological hazard for the public. However, there are radioactive pockets in the high background radiation area of Kollam district (Neendakara and Chavara) and certain regions (Kayikara and Kadinamkulam) in Thiruvananthapuram district with significantly high radium equivalent activity.

Absorbed dose

The mean values of absorbed dose rate in air due to the radionuclides in soil from Thiruvananthapuram, Kollam and Alappuzha districts were 99.38 ± 54.75 nGy/h, 109.87 ± 94.47 nGy/h and 69.78 ± 44.36 nGy/h respectively. The geometric mean values for the three districts were 83.54(1.89) nGy/h, 82.9(1.10) nGy/h and 57.5(1.88) nGy/h respectively. The estimates of absorbed dose rates for Thiruvananthapuram and Kollam are greater than the world average of 59 nGy/h (UNSCEAR, 2000). Variations of external gamma dose to the population from radionuclides in soil for all three districts are displayed against the Lat-long coordinates in Figure 2. The absorbed dose rates range from 13.9 to 471.01 nGy/h for the whole study area with both AM and GM exceeding the global average of 59 nGy/h. Except a few locations the absorbed dose rates are more than the global average.

Annual Effective Dose

The indoor annual effective dose (AED_{in}) ranged from 0.08 to 1.36 mSv/y (Mean = 0.49 ± 0.27 mSv/y) in Thiruvananthapuram, 0.07 to 2.31 mSv/y (Mean = 0.54 ± 0.46 mSv/y) in Kollam and 0.07 to 0.96 mSv/y (Mean = 0.34 ± 0.22 mSv/y) in Alappuzha. The outdoor annual effective dose rates (AED_{out}) varied from 0.02 to 0.34 mSv/y (Mean = 0.12 ± 0.07 mSv/y) in Thiruvananthapuram, 0.02 to 0.58 mSv/y (Mean = 0.13 ± 0.09 mSv/y) in Kollam and 0.02 to 0.24 mSv/y (Mean = 0.09 ± 0.05 mSv/y) Alappuzha. The outdoor annual effective dose resulting from the exposure to radionuclides in the soil in some places of the Kollam district show values exceeding the world average from terrestrial gamma rays (UNSCEAR, 2000). The profile of the indoor annual effective dose rate to the population from radionuclides in soil for all three districts is presented in Figure 3.

The indoor annual effective dose varies in the range of 0.07–2.31 mSv and the outdoor

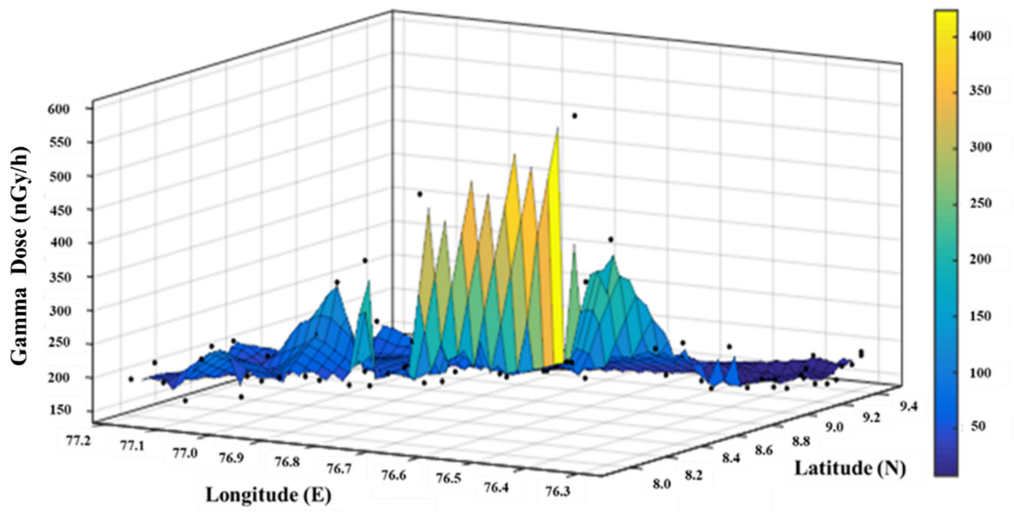

Fig. 2. Absorbed dose to the population from the radionuclides in soil for the whole area.

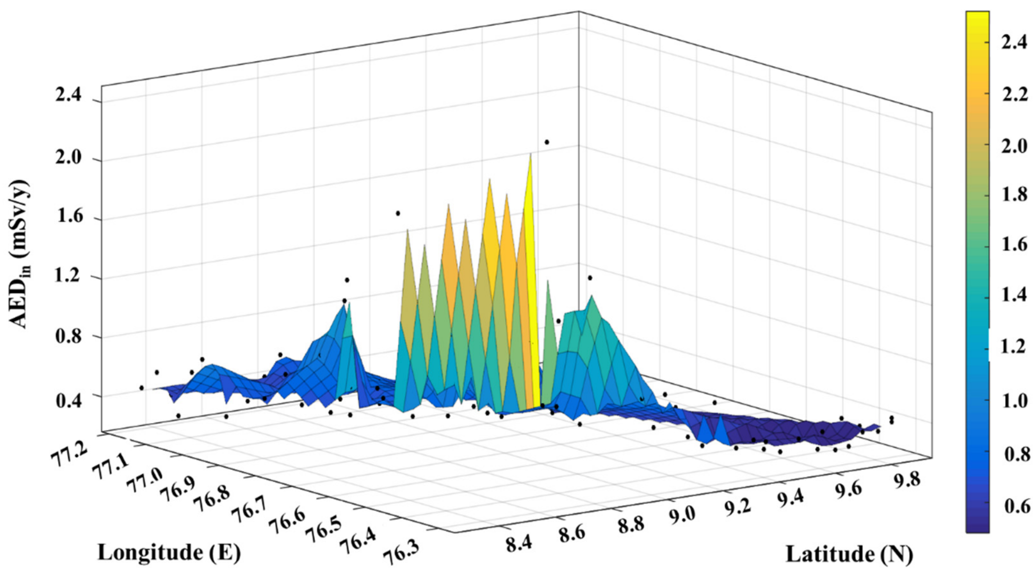

Fig. 3. Indoor annual effective dose rates to the population in the whole study area.

annual effective dose varies from 0.02–0.58 mSv for the three districts taken together. The average value of the indoor annual effective doses was of the same order as that of the world average value of 0.48 mSv for Thiruvananthapuram and was slightly above for Kollam district.

Hazard indices

The calculated value of the external hazard index (H_{ex}) was found to be in the range from 0.09 to 1.74 and the average was 0.59 with a standard deviation of 0.35 (GM = 0.49) for Thiruvananthapuram district. The values were found to exceed 1 for the samples from certain locations namely Kadinamkulam, Kayikara and Karamcode in the district. The mean H_{ex} for Kollam and Alappuzha districts were 0.66 ± 0.60 (GM= 0.5) and 0.42 ± 0.28 (GM=0.3) respectively. The H_{ex} values were found to exceed 1 for samples from the Alumkadavu region

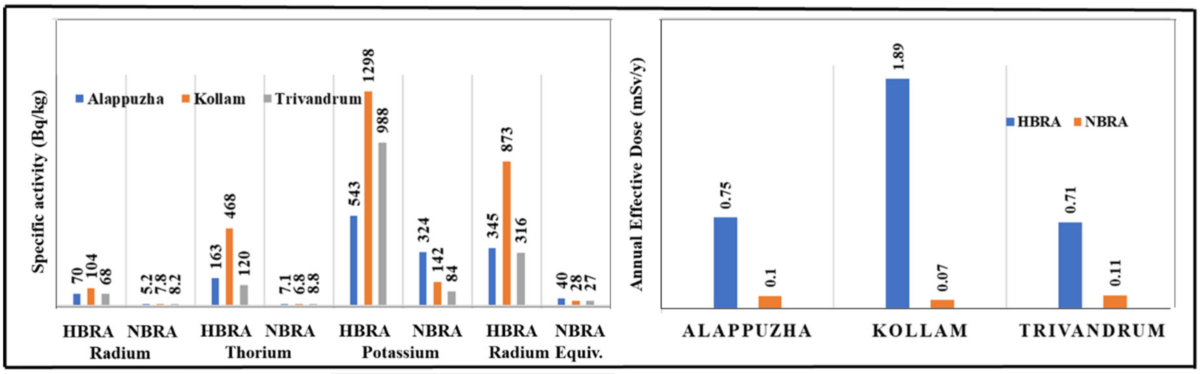

Fig. 4. A comparison of radioactivities and indoor doses between the HBRA and NBRA

Table 2. Comparison of average specific radioactivity in soil and indoor annual effective dose between HBRA and NBRA in coastal Kerala.

District	The ratio of average specific radioactivity (Bq/kg)				The ratio of AED_{in} (mSv/y)
	C_{Ra}	C_{Th}	C_K	R_{eq}	
Alappuzha	13.5	23.0	1.7	8.6	7.5
Kollam	13.3	68.8	9.1	31.2	27.0
Trivandrum	8.3	13.6	11.8	11.7	6.5

of Kollam and the Arattupuzha region of Alappuzha.

The average internal hazard indexes H_{in} for the three districts were estimated as 0.70 ± 0.40 (GM = 0.58), 0.74 ± 0.65 (GM = 0.5), 0.48 ± 0.33 (GM = 0.4) for Thiruvananthapuram, Kollam and Alappuzha respectively, which are lower than unity. However, certain locations namely Kadinamkulam, Kayikara, Koppam in Thiruvananthapuram district, Alumkadavu, Elampalloor, Neendakara and Chavara in Kollam district and Arattupuzha and Harippad in Alappuzha district were found to have values exceeding the permissible value of unity.

Excess Life Time Cancer Risk

The range of ELCR was 0.35 x 10^{-3} to 5.97 x 10^{-3} with an average of (2.13 ± 1.17) x 10^{-3} for the whole experimental region. The estimated ELCR values for most of the locations are higher than the world average of 0.29 x 10^{-3} (Taskin, 2009).

Comparison of HBRA with NBRA

Figures 2 and 3 very clearly indicate that the rates of absorbed dose and annual effective dose are highly localized and the regions flanked by it are relatively much lower dose rates. Figure 4 demonstrates the heterogeneity of specific activities of radionuclides between high and normal background radiation areas and the difference in annual effective dose delivered by these nuclides.

The extent of variation of radionuclide activity in the surface soil samples from the high background and normal background regions are numerically compared and presented in the Table 2. The activity of thorium is two order higher in Kollam district. In all other cases, the ratio of specific activities of radionuclides and annual effective dose rates for HBRA to NBRA are manyfold.

Table 3 depicts the comparison of current results for specific activities of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil samples with similar studies held in Asia. Results of our research have shown that specific activities of natural radionuclides in the soil samples of the area under study do not differ considerably from the reported results.

Table 3. Comparison of present results with those available in the literature

	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Reference
Laos	32.57	41.10	295.07	Leuangtakoun et al., 2019
Philippines	14	16	212	Moriones et al., 1989
Malaysia	21±4	21±3	290±20	Khandakher et al., 2012
Bangladesh	86.0	43.4	448	Abedin et al., 2022
Mizoram	33.47	67.00	942.25	Chhangte et al., 2018
Rajasthan	50.28	34.16	587.45	Mehra, et al., 2021
Coastal Kerala	7.0	101.3	53.2	Vineethkumar et al., 2018
Trivandrum	23	61	465	
Kollam	16	62	484	Present study
Alappuzha	14	45	395	

CONCLUSIONS

A detailed and systematic analysis of the soil samples collected from the southwest coastal districts of Kerala reveals the heterogeneity of radionuclide distribution in the region. Experimentally obtained results of radiometric analyses of soil samples collected from the Kollam district show relatively higher mean activities compared to the other two districts with considerable presence of thorium. The samples from Kayikara and Kadinamkulam regions of Thiruvananthapuram district and from the Arattupuzha region of the Alappuzha district also show specific activity levels higher than the permissible level. The mean values of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from Kollam and Thiruvananthapuram districts have higher than their respective global averages. However, the average value of radium equivalent activity of the soil samples is less than the recommended limit of 370 Bq/kg (OECD, 1979). The results of estimation of external gamma absorbed dose rates for Thiruvananthapuram and Kollam are greater than the world average. The average value of the indoor annual effective doses was of the same order as that of world average value of 0.48 mSv for Thiruvananthapuram and was slightly above for Kollam district. The average internal hazard indexes H_{in} and external hazard index H_{ex} for the three districts were found less than the limit of unity. Nevertheless, there are localized pockets where these indices were found greater than unity. The ELCR values for most of the samples are higher than the world average and the total average is also higher than the world average (2.9 x 10^{-3}).

Thorium present in the soil has higher specific activities and the isotope contributes more to the external gamma absorbed dose (D) as compared with thorium and potassium. For equal specific radioactivities of the three radionuclides, thorium would impart 30% more dose as compared with radium and about 12 times the dose with respect to potassium. At the same time, radium contributes more to the internal hazard index as compared with thorium and potassium. A comparison of average specific radioactivity and indoor annual effective dose between HBRA and NBRA shows Kollam is a region with potential radiation exposure. Measured specific activities of radionuclides in soil samples with similar studies held in Asia are in good agreement with the present results.

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The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

LIFE SCIENCE REPORTING

Background Radiation and Cancer Excluding Leukemia in Kerala, India –Karunagappally Cohort Study.

No life science threat was practiced in this research.

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