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Radiation Dose to the Populace in Southern Peninsular India Through Foodstuff

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ABSTRACT

In an environment with the presence of elevated levels of primordial radionuclides, food is an important route by which radionuclides enter the body. The primary aim of the study was to estimate the dose characteristics received by typical members of the society with average food habits and living in the high background radiation area. The concentrations of ^{226}Ra, ^{238}U, ^{228}Ra, ^{232}Th and ^{40}K were determined in food crops, fish, drinking water and soil. Analyses of food samples were done using gamma ray spectrometry. The estimated total annual average effective dose due to the ingestion of ^{238}U, ^{232}Th and ^{40}K in fruits, vegetables, cereals, pulses and fish was 0.57 ± 0.1 mSv/y based on the dietary habits of the population in the area.

INTRODUCTION

Internal radiation exposure originates from ingestion, injection and inhalation, of which inhalation exposure is most important and widely studied. Exposure due to injection is quite rare. Radiation exposure through ingestion is almost consistent and regular, mainly through food and drink. Civilized communities do not obtain all their food from immediate locality. Rather, they consume food produced throughout the country, in general. In the present study, ingestion dose rates were evaluated in the southern peninsular region of India having a 57 km long high background radiation area. The inhabitants of this coastal region are exposed to external radiation levels much higher than the global average background levels, due to the presence of uranium, thorium and its decay products in the monazite sands bearing placer deposits. Earth borne radionuclides are ultimately transferred to man by eating animal meat or milk or directly from plants by using them as food. Radionuclides ingested in food and to a lesser extent, water, account for a substantial part of the average radiation dose received by various organs of the human body. The major occupation in the area is fishing, fish being the most common item in their food.

The approach of the present study was to estimate average doses from ingestion taking their food habits into consideration. In addition, an estimate was made of the possible distribution in doses from ingestion resulting from the activity concentrations in food and the extent to which people eat locally produced food. Since the food being consumed in the region is originated mostly from outside, a collective intake assessment will not be meaningful. Therefore, as far as possible an individualistic approach is adopted in the present investigation. Though there have been numerous studies on inhalation dose and external dose levels with a suitable accuracy for an individual, measurement of ingestion dose for the same is quite difficult on an individual basis. It is possible that the data on ingestion dose to Indian population can be different due to different radioactive contents, climatic condition, food habits and other conditions.

MATERIALS AND METHODS

The peninsular region selected for the study was the coastal strip extending into two districts in Kerala namely Kollam and Thiruvananthapuram and Kanyakumari district in Tamilnadu. The sampling locations were selected within one kilometre strip along the coastal line including the high background radiation area. For the present study, 100 locations, including those in the normal background area were selected. The study area is bound by latitude 8°00'N to 9°20'N and longitude 76°20'E to 76°80'E approximately. Samples were also collected from normal background region. The regions of sample collection are shown in the Fig. 1. A wide category of regularly used food items including vegetables, fruits, cereals, marine foodstuff and the whole meal was chosen for the investigations. All the vegetables and fruits were collected directly from the agricultural and domestic farms. Depending on the samples, 4 to 10 kilograms of samples were collected for the analysis. While collecting these samples, 2 to 3 kilograms of soil samples were also collected from the sites where the vegetables/fruits were grown. Other food items like cereals, pulses and marine food were collected from the local markets. The details of the samples and locations were recorded in a comprehensive data sheet along with the questionnaire regarding the dietary habits of the inhabitants. During the collection of vegetable samples directly from farmers we have made measurements of the ambient gamma activity also with a GM Tube based survey dosimeter.

Water samples were collected only from the natural water bodies, namely well, bore well and ponds which were used for drinking. The water samples were collected in clean plastic bottles (50 mL capacity). Bottles were pre-rinsed with distilled water and then with the experimental water and added with a drop of concentrated HNO_3 to reduce uranium absorption. Altogether 100 water samples were collected from various sources for analysis.

The locally grown food crops were collected from local farmers and household growers. Only the edible portions of the plants were collected for the analysis (IAEA 1989). Ninety eight samples of 17 kinds of locally grown food crops and the soil in which they were grown were collected for analysis. Each sample was collected in clean polythene cover bearing a label with the details of location, nature of sample, date, etc. The samples were washed under tap water to remove all the attached dust, sand particles and dirt. From the samples collected, the edible parts were taken separately and its net wet weight was noted. Then samples were chopped and spread on a clean table and allowed to dry at room temperature under an infrared lamp for about 24 hours. Then the samples were dried in a hot air oven at 110°C for 24 hours, cooled and dry weight was recorded. Samples were then stored in a dust and moisture free polythene envelops. These coarse samples were then ground and further fired at about 300-320°C to make pure ash of the sample. The ashes of the samples were then transferred to clean sample containers of specific size and hermetically sealed. The samples were shelved for at least one month, to ensure secular equilibrium between the isotopes, before gamma spectroscopy analyses.

One hundred soil samples were also collected from the same location of the food samples for analysis as per the Environmental Measurements Laboratory Procedure Manual (HASL-300 1997). Sampling locations were recorded using a Geographical Position System (GPS). The soil samples were taken after removing 10 cm surface soil and brought to the laboratory in clean polyethylene covers. The soil samples were then dried in an oven for 24 h at 110°C and crushed, sieved and hemetically sealed. The samples were then stored for a period of 40 days to attain a secular radioactive equilibrium with the progeny nuclides.

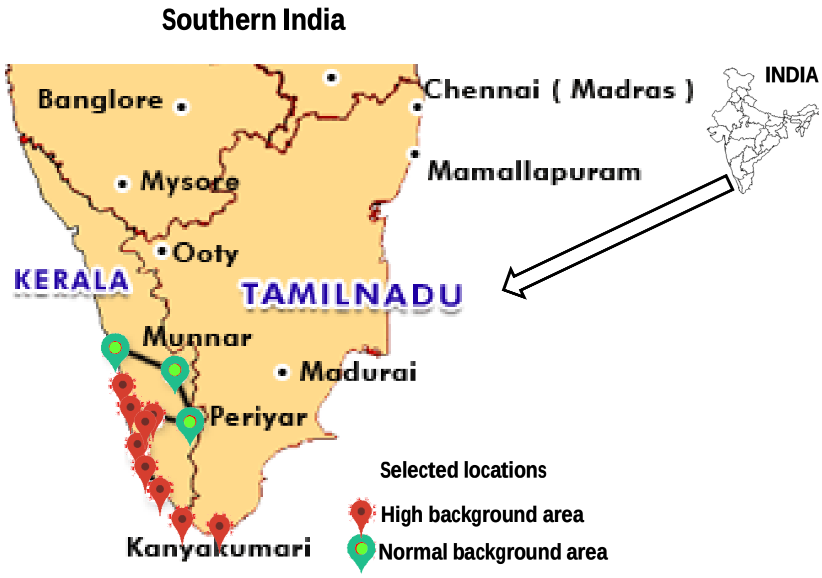

Fig. 1: Selected locations for sample collection in the study area.

Marine food is an inevitable part in the diet of the people living in the region. Twenty marine food samples which include fishes or prawns were collected for analysis. About 2 kg of each species was collected from the study area. The samples were cleaned and washed thoroughly with distilled water repeatedly for two or three times and dried in a hot air oven at 110°C for 24 hours, cooled and dry weight was recorded. These coarse samples were then ground and further fired at about 300-320°C to make pure ash of the samples. The samples were then cooled, powdered, sieved and stored in clean sample containers of specific size. The samples were shelved for at least one month before gamma spectrometric analyses. Grains and pulses collected for the analysis were washed, dried in an oven, powdered, fired into ash and sieved before sealing the samples hermetically in clean containers. The samples were analysed after a month.

Analyses of the samples were done using gamma ray spectrometry using 5" × 4" NaI (Tl) detector coupled with a 1K multichannel analyser. Detector was mounted in 3" thick lead well with a movable lid having the same thickness and the system was connected with a dedicated PC for data storage and analysis. The counting period for samples and background was set for 60000 s. The activity of ^{40}K was evaluated from the 1460 KeV photo peak of its own gamma, the activity of ^{226}Ra from 1764 KeV gamma of ^{214}Bi and that of ^{232}Th from 2614 KeV gamma of ^{208}Tl in its series. The minimum detectable levels (MDL) of the isotopes were determined as 4.7 Bq/kg for uranium, 14.3 Bq/kg for thorium and 27.18 Bq/kg for potassium. The shielding for the detector housed in the first floor of the lab with 3" lead well reduced the background radiation. The gamma spectra of the samples were recorded using a PC based multichannel analyser and processed using the software WinTMCA32 ScintiSPEC.

For the precise evaluation of ingestion dose, we studied the dietary habits of the population in the region. A data sheet comprising of the questions relating to the nature and amount of food intake of the inhabitants of the experimental region was used for this purpose. From a large number of responses of the people, we could determine the most commonly and widely used food materials and their approximate quantities.

RESULTS AND DISCUSSION

Dietary habits in the region: As a part of the study, we surveyed 96 families in the study area and took dietary habit data. From the analysis of these data, it has been found that most of the population takes breakfast prepared from rice flour (like appam, dosai, puttu, idlie, idiyappam, etc.) and meals for their lunch again with good amount of rice. For supper, majority take meals and a very few like (roti) chapattis made of wheat. Generally, they prefer white rice (free from husk) for their meals. Table 1 shows per capita average annual intake of diet by adults in the region. Results indicate the following facts about the food habits in general:

Table 1: Per capita average annual intake of diet by adults in the region.

Type of food	Range (kg)	Mean±SD(kg)
Rice	62-204	98±26
Grains	14-64	28±18
Leafy vegetables	06-17	12±6
Non-leafy vegetables	14-58	48±28
Tubers	24-37	34±14
Fruits	12-28	19±09
Fish	44-102	68±26
*Meals	376-530	447±74

*Wet weight

- 75% of the inhabitants consume 1-2 kg of fish, whereas 25% use 0-1 kg per week.
- 18% of the people use 1.4 - 2.8 kg of vegetables, whereas 82% use 0-1.4 kg week.
- 63% of the people use 0.2 kg of meat and the remaining consume less than 0.2 kg week.
- Rice and rice products are the major food item with an average of 98 kg per annum.

Radioactivity in food samples: Gamma-ray spectrometry was used to determine elemental concentrations of the radioactive isotopes of thorium, uranium and potassium in 98 food samples collected from the southern peninsular region. Average levels of radionuclides in locally grown food item are presented in Table 2. In almost all samples, uranium level was found to be below detectable level (BDL). Radium was detected only in yam (tuber) samples and the average concentration was 10 ± 1 Bq/kg. Thorium was found to be present in the range of 15-34 Bq/kg in food samples. Concentration of potassium was found to vary from 54-360 Bq/kg. The radioactivity concentration of ^{228}Th and ^{40}K in cowpea grown in the region was higher as compared with the other food stuffs. Tubers were found to contain about 20% higher radionuclides than non-leafy vegetables. Leafy vegetables accumulate about 2.5 times more radionuclides than non-leafy vegetables and tubers. The result shows that all vegetables predominantly absorb ^{40}K more than radium and thorium radionuclides (Table 3). The significant contributor to the effective dose in vegetables was found to be thorium. Spinach samples were found to have the highest potassium concentration (360 Bq/kg) among all vegetable samples. Potassium is a micronutrient and it may be ex-

Table 2: Average levels of radionuclides in locally grown food stuffs.

No	Sample	Number of samples analysed	Radium(^{226}Ra) (Bq/kg)	Thorium(^{228}Th) (Bq/kg)	Potassium (^{40}K) (Bq/kg)
1	Rice	5	BDL	17± 4	64 ± 14
2	Cow pea	4	BDL	34±6	315 ± 16
3	Plantain	7	BDL	18± 3	142 ± 12
4	Banana	6	BDL	18 ± 4	111 ± 10
5	Papaya	6	BDL	15± 3	54 ± 14
6	Cabbage	4	BDL	19± 4	158 ± 16
7	Spinach	10	BDL	21± 3	360 ± 21
8	Cauli flower	3	BDL	15± 4	112 ± 17
9	Ash Gourd	4	BDL	19± 4	105 ± 14
10	Ivy gourd	5	BDL	15± 3	99 ± 12
11	Stem of colacasia	3	BDL	17± 4	107 ± 16
12	Brinjal	3	BDL	17± 4	65 ± 18
13	Tapioca	8	BDL	19± 3	120 ± 21
14	Yam	8	10 ± 1	28± 3	101 ± 18
15	Colocasia	8	BDL	19± 4	121 ± 22
16	Elephant Foot	8	BDL	23± 3	133 ± 10
17	Nanakizhangu	6	BDL	27± 4	127 ± 20

Table 3: Average levels of radionuclides in each class of food.

No	Sample	Radium (^{226}Ra)(Bq/kg)	Thorium (^{228}Th)(Bq/kg)	Potassium (^{40}K)(Bq/kg)
1	Rice	BDL	16.7±4	63.9 ± 14
2	Cow pea	BDL	34±6	315±15
3	Leafy vegetables	BDL	19.65± 4	259.2±14
4	Non-leafy vegetables	BDL	16.66± 4	76.32±13
5	Fruits	BDL	16.8± 3	102.5± 10
6	Tubers	BDL	23.18± 4	120.2±15

Table 4: Radionuclides in marine food items.

No	Name of fish (Scientific name)	Uranium (U-238) (Bq/kg)	Thorium (Th-232) (Bq/kg)	Potassium (K-40) (Bq/kg)
1	Sardine (*Sardina pilchardus*)	BDL	BDL	78±24
2	Lizard fish (*Synodus indicus*)	BDL	16±4	50±14
3	Pony fish (Leiognathidae)	BDL	BDL	110±34
4	Croaker (*Micropogonias undulates*)	BDL	16±4	63±20
5	Pink perch (*Perca fluviatilis)*	BDL	BDL	79±26
6	Tada (*Cynoscion nobilis*)	BDL	BDL	42±12
7	Prawn (*Fenneropenaeus indicus*)	BDL	18±6	90±28
8	Jew fish (*Argyrosomus hololepidotus*)	BDL	BDL	34±14
9	Mackerel (*Scomber japonicas*)	BDL	BDL	65±18
10	False trivelli (*Lactarius lactarius*)	BDL	16±4	40±14
11	Ribbon fish (Trachipteridae)	BDL	BDL	70±24
12	Knife Fish (*Apteronotus albifrons*)	BDL	16±4	68±14
13	Eel (*Anguilliformes*)	BDL	BDL	93±13

pected that the soil characteristics favour the mobilization of potassium and its subsequent migration into the plant (Pietrzak et al. 2001).

Marine food: Being a coastal region and the majority of the population is involved in marine food production and processing fish and other marine food is an inevitable part of their daily diet. This fact is clear from our dietary habit study too (Table 4).

No sample among the marine food samples was found to have uranium in the detectable amount. Thorium was found to be present at a low level. Among all, thorium level was between MDL and 18 Bq/kg. Levels of potassium were found

Table 5: Distribution of natural radionuclides (Bq/kg) in soil samples from the study area (geometric mean values).

Location	No of samples collected	^{238}U(Bq/kg)	^{232}Th(Bq/kg)	^{40}K(Bq/kg)
Kollam (HBRA)	50	210 (0.7)	416 (0.6)	290 (0.7)
Manavalakurichi (HBRA)	40	118 (0.8)	99 (0.8)	185 (0.8)
Trivandrum (NBRA)	10	27 (0.8)	17 (0.6)	120 (0.4)
World average		25	25	370

Table 6: Average levels of absorbed dose and annual effective dose.

Location	Absorbed gamma effective dose rate nGy/h	Outdoor annual effective dose rate mSv/y
Kollam	368	0.45
Manavalakurichi	124	0.15
NBRA	28	0.34
World wide	42	0.52

to vary from 34 to 110 Bq/kg in the fish samples.

Soil radioactivity and external dose: The levels of radionuclides in the soil samples from the experimental area were highly heterogeneous and therefore, the geometric mean is presented in Table 5 with the geometric standard deviation in parentheses.

The external gamma dose rates were determined from the activity of soil using the following equation using the dose conversion coefficients proposed by UNSCEAR (2000).

$$D\ (nGy/h) = 0.461\ C_{Ra} + 0.623\ C_{Th} + 0.0414\ C_K$$

Where, C_{Ra}, C_{Th} and C_K are the activity concentrations (Bq/kg) of radium, thorium and potassium in the samples. Annual estimated average effective dose equivalent received by a member has been calculated by using a conversion factor of 0.7 Sv/Gy, with an outdoor occupancy factor of 0.2 (UNSCEAR 2000).

Ingestion dose through food: The ingestion of radionuclide through food depends on the concentration of radionuclides in the food consumed. According to IAEA (IAEA 1989) it is recommended that food analysis for radionuclides to be based on the determination of radionuclides in individual food item rather than dealing with mixed diet sample. The average ingestion dose to the population has been calculated based on the average activity levels of the isotopes in dietary components using the following equation:

$$\text{Ingestion dose, } D\ (mSv/y) = (C_{Ra}DCF_{Ra} + C_{Th}DCF_{Th} + C_K\ DCF_K)\ I$$

Where, C_{Ra} - concentration of Ra(Bq/ kg), DCF_U - dose conversion factor for U (^{226}Ra) = 0.28 µSv/Bq, C_{Th} - concentration of Th (Bq/ kg), DCF_{Th} - dose conversion factor for Th (^{228}Th) = 0.072 µSv/ Bq, C_K - concentration of K (Bq/ k), DCF_K - dose conversion factor for ^{40}K = 0.0062 µSv/Bq and, I - is the annual intake of the food item.

Samples analysed were classified into six categories for estimating ingestion dose judiciously. We have evaluated the ingestion dose assuming the levels of uranium and thorium to be half of the MDL of the counting system, for the isotopes. The results are presented in the Table 7.

The total annual internal doses from ^{226}Ra, ^{228}Ra, ^{228}Th, ^{40}K in Korean foods were estimated to be 1.81, 6.79, 0.35 and 101 µSv/y (Choi et al. 2008) respectively. The result

Table 7: Estimated ingestion dose through food.

Sample	Average level (Bq/kg)			Annual intake rate I (kg)	Ingestion dose (mSv/y)			Ingestion dose (mSv/y)	Total ingestion dose (mSv/y)
	*C_{Ra}	*C_{Th}	C_K		D_{Ra}	D_{Th}	D_K		
Rice	2.35	7.15	64±2	98±26	0.064	0.050	0.039	0.15	0.57
Leafy vegetable	2.35	7.15	259±42	12±6	0.0079	0.0064	0.019	.033	± 0.1
Non leafy vegetables	2.35	7.15	76±23	48±28	0.032	0.024	0.023	0.08	
Fruits	2.35	7.15	102±32	19±09	0.012	0.0098	0.012	0.03	
Grains	2.35	7.15	315±46	36±18	0.0237	0.0187	0.0703	0.11	
Tuber	2.35	7.15	120±18	34±14	0.02238	0.0178	0.026	0.07	
Fish	2.35	7.15	32±18	68±26	0.045	0.035	0.014	0.09	

*Half of the MDL levels

obtained in a similar investigation held in Nigeria reported 2.38 µSv/y for the Jos plateau region (Jibiri et. al. 2007). According to UNSCEAR (UNSCER 2000) the total per capita exposure through ingestion of terrestrial radioisotopes should be 0.29 µSv, of which 0.17 µSv is from ^{40}K and 0.12 µSv is from thorium and uranium series. The result of the present study is almost double of the figure.

CONCLUSION

The inhabitants of the experimental area are exposed to external radiation higher than the global average due to the presence of uranium, thorium and its decay products in the monazite sands bearing placer deposits in this region. The activity concentrations of ^{40}K are much higher than those of uranium and thorium in plants. The ingestion dose from cereals (rice) was the highest due to the fact that the rate of consumption is maximum. The estimated average annual effective dose due to ingestion of radionuclides through food is 0.57 mSv/y based on the dietary habits of the population in the area. This figure is higher than annual average dose of 0.29 mSv reported by UNSCEAR (UNSCEAR 2008).

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