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ORIGINAL PAPER

Annual committed effective dosage from natural radionuclides by ingestion of local food growing in mineral mining area, Sri Lanka

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Abstract Sri Lanka's largest mineral sand deposit occurs in Pulmoddai, and the surrounding area of the mineral sand deposit has been identified as a high natural background radiation area. The food crops grown in the area are used for human consumption. However, the long-term consumption of high radioactive foodstuff may cause health defects. The objective of the present study was to assess the radiological impact on individuals due to ingestion of foodstuffs grown in Pulmoddai area. Seasonal food crops growing in the area, including cereals, vegetables, nuts, fruits and yams were collected and used to prepare common meal plans consumed by the residents. Samples were analyzed with high-purity germanium gamma spectrometer for activity concentrations. Activity concentration of ^{40}K was observed in higher amounts in every food sample. Trace amounts of ^{137}Cs ^{232}Th and ^{7}Be were also identified. The total committed effective dosage to an adult from gamma-emitting radionuclides from cooked meals was 0.1482 mSv year^{-1}, and raw foodstuff was 0.0667 mSv year^{-1}, which are far below than the harmful levels declared by International Atomic Energy Agency. Results concluded that foodstuff and cooked meals consumed by the people who live in Pulmoddai, Sri Lanka, are radiologically safe.

Keywords Effective dosage · Foodstuff · Mineral sand deposit · Radioactivity concentration · Radionuclides

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Introduction

Earthlings are continuously exposed to natural and artificial radiation; therein, the natural radiation dose is much higher (El Samad et al. 2013). Natural, human-made, medical radiation and occupation radiation are the main four types of radiation exposures that can cause adverse health effects to humans (UNSCEAR 2000). Plant growth factors, including soil composition, air, fertilizers, pesticides, and irrigation water, are some factors that are influencing the radioactivity of fruits and vegetables (UNSCEAR 2000). The soil is the leading medium for supplying nutrients for plant growth. Different structural components in the soil will promote the gathering of radionuclides in the soil and keep in those for the long-time period (Jibiri et al. 2007a, b). During the nutrient uptake processes in soils, radionuclides can be absorbed via roots into plants. They are transferring to fruits and vegetables and then through plant materials to animals (Khan et al. 2011).

All foods consist of naturally occurring radionuclides such as ^{40}K, ^{232}Th, ^{238}U, and their associated progeny (UNSCEAR 2000). The concentration of natural radionuclides in foods varies with agricultural practices, geographical region, and type of food (WHO 2011). Green leafy vegetables and root vegetables are mainly contaminated during the rainy season with the fallouts (Tchokossa et al. 2013). Root vegetables like carrot, radish, and beet and yams like potato and cassava can be directly contaminated with soil radionuclides as their edible parts are inside the soil (Wickramasinghe et al. 2009). Storage and fallout during the growing season are the leading causes of grain contamination. Grazing and consumption of contaminated water by animals increase the accumulation of radionuclides in milk and meat (Tchokossa et al. 2013). Micro-fungi in mushroom increase the accumulation of radionuclides, and ^{137}Cs is the most significant contributor to the artificial radioactivity in mushrooms (Falandysz and Borovi 2013).

Population growth and industrialization are threatening factors to food security, and thus people are using lands which have high radioactivity for agricultural purposes (Jibiri et al. 2007a, b). The soil is the main media for supplying nutrients for plant growth. Accordingly, the final radioactivity of foodstuffs depends on the radionuclides accumulation level in the plants and uptake of radionuclides in soil via plant roots (Samavat et al. 2006). Radionuclides should have enough time to migrate into the root zone. ^{40}K and ^{232}Th, ^{238}U and daughter products of decay series of ^{232}Th, ^{238}U are responsible for natural radiation which is mainly responsible for radioactivity in the human diet (Ramachandran and Mishra 1989). Natural radionuclides are emitting gamma radiation (Bolca et al. 2007). Highly penetrable gamma radiation reaches all the body cells in the human body and can cause potential genetic hazards (Mlwilo et al. 2007). As there is a high level of radionuclides in soil, the foodstuff grown in high background radiation area can be contaminated with ^{226}Ra and ^{232}Th (Jibiri et al. 2007a, b).

Southwest of Tamil Nadu in India, Ramsar in Iran and Jos-Plateau in Nigeria are identified as high natural background radiation areas in the world. Radiological food safety of the above-mentioned areas had been evaluated by estimating radiological impact due to ingestion of foodstuffs to humans (Shanthi et al. 2010; Samavat et al. 2006; Jibiri et al. 2007a, b). It was found that annual effective dosage due to ingestion of foodstuff growing in high natural background area in South West India was 1.798 mSv year^{-1} (Shanthi et al. 2010). While annual effective dosage due to radionuclides intake in Jos-Plateau in Nigeria varied between 0.2 μSv year^{-1} (local beans) to 2164.1 μSv year^{-1} (yam), furthermore 1.73 μSv year^{-1} was the reported annual effective dosage in high natural background radiation area in Ramsar in Iran (Samavat et al. 2006; Jibiri et al. 2007a, b). Studies done on effective dosages due to ingestion of foodstuff in Iran and Nigeria are below the annual dose limit of 1 mSv for the general public, while South Indian foods have higher dosage than the global averages (Shanthi et al. 2010).

The consequential mineral sand deposit occurs at Pulmoddai, Trincomalee district, the Northeast coast of Sri Lanka (Fig. 1); however, such an ensuring study has not been conducted yet. Pulmoddai is situated in Kuchchaveli divisional sector and 54.7 km away from Trincomalee town in Eastern province. The length of the deposit is around 6.4 km, with an average width of about 70 m (Amarasekera et al. 1983). The recent research study has investigated that the average gamma-ray absorbed dose rate of Pulmoddai soil was 195.70 nGy h^{-1}, and it is higher than the global average of 57 nGy h^{-1} (Warnakulasuriya et al. 2016). The median radioactivity concentration of ^{232}Th, ^{40}K and ^{226}Ra in Pulmoddai soil was 68.5 Bq kg^{-1}, 181.00 Bq kg^{-1} and 29 Bq kg^{-1}, respectively. Mean background radiation level of the study area was 0.77 μSv h^{-1} (6.65 mSv year^{-1}), and mean effective dose was 240.1 μSv year^{-1} (Warnakulasuriya et al. 2016). Annual effective gamma dose rates from Beruwala to Dondra in the South Western coastal strip of Sri Lanka were ranged from 0.01 to 75.38 mSv year^{-1} (Bandara and Mahawatte 2013), while the same from Crow Island to Beruwala in the Western coast of Sri Lanka ranged from 0.004 to 16.8 mSv year^{-1} (Withanage and Mahawatte 2013). Annual effective gamma dose rates from Beruwala to Dondra and Crow Island to Beruwala are higher than the Pulmoddai. However, the main focal point of the present study was Pulmoddai, as agricultural farms are in the vicinity of mineral sand deposit.

Weathering and erosion are the primary natural processes involved to produce beach sand deposits

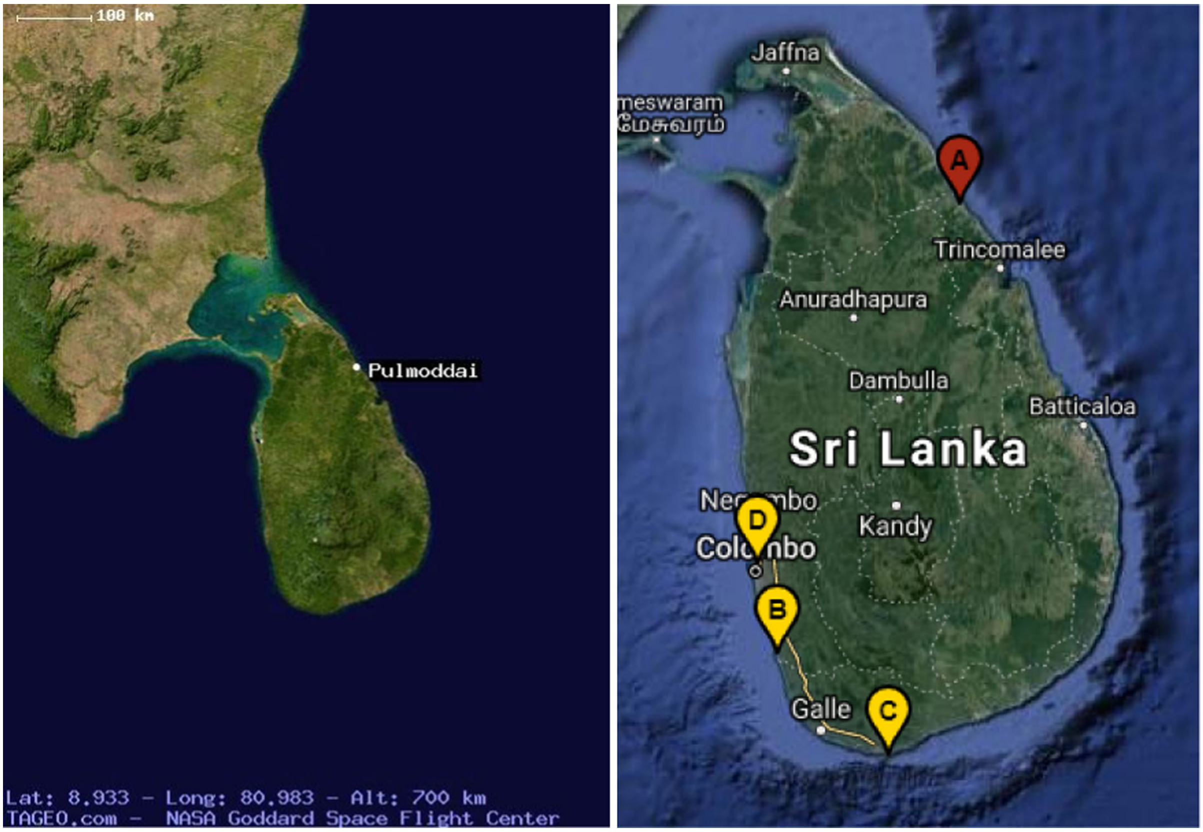

Fig. 1 Satellite view of Sri Lanka and location of Pulmoddai (A), Beruwala (B), Dondra (C) and Crow island (D)

from igneous or metamorphic rocks (Veiga et al. 2006). Black sand deposit of Pulmoddai consists of ilmenite associated with rutile, zircon, and monazite (Fernando 1986). The wealthiest part of the deposit contains about 95% of heavy mineral content. Ilmenite 70–80% (w/w), rutile 8–12% (w/w) and zircon 8–10% are the approximate composition of sand in the mineral processing plant (Amarasekera et al. 1983). The concentration of monazite present in the mineral sand deposit was 1.38% (Gamage et al. 2018). Mineral mining plant activities include mining, processing, and exporting heavy mineral beach sands. During the process of electromagnetic separation, the dust of mineral sand is released to the environment and highly radioactive waste like monazite is produced (Jibiri et al. 2007a, b).

Dietary ingestion of radionuclides causes a radioactivity dosage in the human body. It can cause health hazards to people who consume contaminated foodstuff daily. ^{226}Ra is a daughter product of ^{238}U decay series and use to determine overall radioactivity risk (Bahari et al. 2007). Radiation associated health problems varies with radiation dosage received, duration of exposing (long term or short term), form of exposure (eating, drinking, and inhalation) and type of radionuclides (WHO 2017). Cancers are the primary health problems arising due to the long-term ingestion of the higher radionuclide concentration. Still, the type of cancer and target organs vary with the kind of radionuclide ingested (WHO 2011). Exposure to the ionizing radiation may damage human body cells. Damage cells are either die or undergo modifications. Cell modifications may develop certain types of cancers, including lung, breast, thyroid, and leukemia (UNSCEAR 2000).

The soil in an area is rich in natural radionuclides, and they may accumulate in food crops above desirable levels. After the end of civil war in the North-Eastern coast of Sri Lanka, population migration happened to Pulmoddai area and started the vegetable cultivation. Radiological impact due to ingestion of foodstuff to individuals should be estimated before reporting diseases in the late future. The study aims to determine activity concentrations of natural radionuclides in different crops grown in the area and to assess the committed effective dosage from gamma-emitting radionuclides to an adult who consumes locally grown food in the area.

Experimental methodology

Sample collection

This study focuses on the radiological impact on the general public by ingestion of foodstuff growing in the investigated high natural background radiation area in Pulmoddai, Sri Lanka (Fig. 1). Therefore, raw foodstuff and cooked meals were analyzed for radioactivity. An area with 5 km radius of center point Lanka Mineral Sand Ltd., Pulmoddai, Trincomalee District, Sri Lanka, was selected as the sampling location. Commonly grown crops in the sampling area and available food crops in the season (March and April 2017) were identified as the first step of sample collection. Then available foodstuffs were categorized into five categories as follows: cereals: rice (*Oryza sativa*) and maize (*Zea mays*); nuts: groundnut (*Arachis hypogaea*); vegetables: ladies fingers (*Abelmoschus esculentus*), long beans (*Vigna unguiculata*), drumsticks (*Moringa oleifera*), and coconut (*Cocos nucifera*); fruits: mango (*Mangifera indica* L.), lemon (*Citrus* L.); and Yams: cassava (*Manihot esculenta*). Each sample (1–2 kg) was collected from the farms and home gardens of villagers and ensured the coverage of the sampling area. The collected samples were directly transported to Gamma Laboratory at Atomic Energy Board in Colombo, Sri Lanka.

Sample preparation

The sample preparation and analysis were conducted in the International Atomic Energy Agency accredited Gamma Laboratory at Atomic Energy Board in Colombo, Sri Lanka. All the samples were prepared according to the guidelines, and recommendations are given by the International Atomic Energy Authority (IAEA 1989).

Pulmoddai is situated in the coastal area, and the people are not consuming well water due to the salinity. Yan Oya (> 50 km away) public water supply provides water to Pulmoddai area. Thus, sample preparation was done by using the surface water distributed by the municipal council. Vegetables and other foodstuffs were gently washed with municipal tap water in Colombo District and removed soil or debris in the outer surface. Afterward, samples were washed with distilled water. The peels of Cassava were removed, and non-edible parts of vegetables were cut off. The fresh weights of the foodstuffs were taken. Vegetables, fruits, and yams were cut into small pieces. Then the prepared samples were oven-dried at 105 ± 1 °C until the moisture got removed and constant weight achieved.

The identified standard meal plans in the sampling area were cooked, and portioning was done according to the recommendations of the Ministry of Health Sri Lanka. The weight of each meal plan was taken before freezing. The portioned meals were refrigerated at -20 ± 1 °C for 24 h and freeze-dried for 48 h in a tray freeze dryer (LABCONO Freeze zone 6).

Dried samples were ground with an agate mortar. Samples were sieved (2 mm mesh), filled into propylene cylindrical containers with Geometry 1, labeled with the respective code and sealed the containers with cellophane tape. Prepared samples were stored in dark place for 28 days to achieve the equilibrium of radionuclides such as thorium, radium and their short-lived progeny. After 28 days, samples were tested using Gamma Spectrometer (detector model—BE5030, cryostat model—7905-30U-ULB, preamplifier model—2002C) to analyze radionuclide levels.

Radionuclide analysis of raw and cooked foods

High-purity germanium detector (Canberra Inc.) with 81 mm diameter coupled to a Canberra Series 10 plus Multichannel Analyzer through a preamplifier base with a detector resolution of about 8% at 0.662 MeV was used to estimate activity concentrations of different radionuclides present in raw foodstuff samples and cooked meal plans. As the present study mainly focuses on gamma-ray-emitting radionuclides, photopeak at 1.46 MeV was used for measurement of ^{40}K while photopeak at 0.143 MeV was used for measurement of ^{235}U. The daughter radionuclide ^{212}Pb at 0.238 MeV was chosen as the indicator of ^{232}Th. Apart from those, photopeak at 0.477 MeV for ^{7}Be and that at 0.661 MeV for ^{137}Cs were selected.

Photopeak at 0.1760 MeV for ^{214}Bi was chosen to provide as an estimation of ^{226}Ra.

The counting time for measurement of activity concentration of the food sample was 72 ks. The net area under each corresponding photopeak in energy spectrum was computed by doing background corrections, such as subtracting Compton scattering and other background effects from the total area of the peak (Shanthi et al. 2010). The activity concentration of the sample was calculated by using formula 1.

$$C = \frac{\mathrm{Cn}}{\xi \mathrm{P}\gamma \mathrm{Ms}} \quad (1)$$

where C is the activity concentration of radionuclide (r) in the respective food samples (f) (Bq kg^{-1}). Cn is the counting rate under the corresponding photopeak, and ξ is detector efficiency at specific γ ray energy. Pγ is absolute transition probability of the specific γ ray activity. Ms is the mass of the food sample (kg) (Shanthi et al. 2010).

Committed effective dosage from raw materials and cooked foods

The potential for causing harm to humans by ionizing radiation is measured and expressed by committed effective dosage (WHO 2017). Committed effective dosage from the raw material and cooked foods would be increased with the age of the person. Therefore, it has been calculated for adults, children, and infants for further facile (UNSCEAR 1993).

$$D_{\mathrm{rf}} = \mathrm{Cr} A_{\mathrm{rf}} R_{\mathrm{f}} \quad (2)$$

Formula 2 is the metabolic model developed by the International Commission on Radiological Protection where D_{rf} is the effective dosage by ingestion of radionuclide (r) (Sv $year^{-1}$). Cr is the respective dose conservation factor for radionuclide (r). A_{rf} is the activity concentration of radionuclide (r) in the ingested food (f) in wet basis (Bq kg^{-1}), and R_{f} is the consumption rate of food item (f) (kg $year^{-1}$) (Nasreddine et al. 2008).

Results and discussion

Activity concentrations of radionuclides

The activity concentration of radionuclides present in current standard meal plans in Pulmoddai is summarized in Table 1. The activity concentrations are given in dry basis with the unit of Bq kg^{-1} and with activity uncertainty. A considerable amount of ^{40}K was present in all three meals plans. ^{7}Be was only detected in the meal plan of breakfast (MPB). Other radionuclides such as ^{137}Cs, ^{226}Ra, ^{232}Th, and ^{235}U were not detected in any meal plan at the respective minimal detectable activity (MDA). Those activities were below the minimum detection limit of the gamma spectrometer.

The activity concentrations of ^{40}K in meal plans were varied between 129.28 ± 19.92 Bq kg^{-1} and 163.24 ± 21.88 Bq kg^{-1}, according to Table 1. The maximum activity concentration level of ^{40}K was observed in meal plan lunch which contained rice, okra, eggplant, egg, and fried chicken. The lowest activity concentration level of ^{40}K was detected in meal plan dinner, which included naan roti, chicken kurma, and eggplant masala.

The activity concentrations of radionuclides in raw foodstuff are shown in Table 2. Large quantities of ^{40}K radionuclides were present in all foodstuffs, whereas a trace amount of ^{7}Be in long beans, ^{137}Cs in lemon, and ^{232}Th in ladies fingers was found. ^{235}U, ^{210}Pb, and ^{226}Ra radionuclides were not detected in any foodstuff at the respective minimal detectable activity (MDA). The activity of ^{40}K in raw foodstuffs ranged between 41.51 ± 5.48 Bq kg^{-1} (Rice) and 1183.72 ± 323.88 Bq kg^{-1} (Drumstick). Vegetables such as ladies fingers, drumstick, and long beans were identified with elevated levels of ^{40}K compared to other foodstuffs. Activity concentration of ^{40}K obtained for this study for ladies fingers (1059.46 ± 9.45 Bq kg^{-1}) was noticeably higher than the literature value of 213.0 ± 19.4 Bq kg^{-1} reported in Nigeria, while values of maize (160.83 ± 26.81 Bq kg^{-1}), cassava (158.32 ± 20.78 Bq kg^{-1}), and groundnut (192.59 ± 38.88 Bq kg^{-1}) were lower than Nigerian study values of 243.2 ± 21.2 Bq kg^{-1}, 539.6 ± 21.2 Bq kg^{-1}, and 398.6 ± 12.9 Bq kg^{-1}, respectively (Jibiri et al. 2007a, b).

Among all of the radionuclides, ^{40}K contributed noticeably for activity concentrations of cooked meal plans and raw foodstuffs. The following could be some of the reasons to have elevated ^{40}K activity concentration in prepared meal plans and fresh foodstuffs. ^{40}K level in the soil of Pulmoddai area is exceptionally high; therefore, soil-to-plant transfer factor will be elevated due to that. Besides that, Pulmoddai is

Table 1 Activity concentration of radionuclides present in identified common meal plans in Pulmoddai area

Meal plan code	Activity concentrations (Bq kg^{-1}—dried)						
	^{7}Be	^{40}K	^{137}Cs	^{210}Pb	^{226}Ra	^{232}Th	^{235}U
MPB	0.08 ± 0.75	143.77 ± 24.38	< 0.65	< 4.06	< 6.86	< 0.70	< 1.99
MPL	< 3.57	163.24 ± 21.88	< 0.51	< 3.56	< 5.62	< 0.59	< 1.55
MPD	< 4.04	129.28 ± 19.92	< 0.59	< 3.89	< 6.33	< 0.63	< 1.85

MPB meal plan breakfast, *MPL* meal plan lunch, *MPD* meal plan dinner

Table 2 Activity concentration of radionuclides in locally grown raw foodstuff in dry basis

Food item	Activity concentrations (Bq kg^{-1})						
	^{7}Be	^{40}K	^{137}Cs	^{210}Pb	^{226}Ra	^{232}Th	^{235}U
Rice	< 3.27	41.51 ± 5.48	< 0.44	< 3.00	< 4.97	< 0.52	< 1.37
Maize	< 6.56	160.83 ± 26.81	< 0.62	< 3.75	< 7.00	< 0.75	< 1.94
Groundnut	< 4.20	192.59 ± 38.88	< 0.55	< 4.06	< 6.43	< 0.68	< 1.78
Ladies fingers	< 7.44	1059.46 ± 9.45	< 1.14	< 7.87	< 10.74	1.05 ± 1.16	< 3.11
Long beans	3.18 ± 1.58	734.89 ± 7.66	< 0.89	< 6.58	< 9.02	< 0.94	< 2.56
Drumsticks	< 8.48	1183.72 ± 323.88	< 1.21	< 9.48	< 13.28	< 1.38	< 3.69
Coconut	< 3.73	281.53 ± 36.98	< 0.59	< 3.85	< 5.79	< 0.60	< 1.59
Cassava	< 7.36	158.32 ± 20.78	< 0.52	< 3.67	< 5.53	< 0.55	< 1.52
Mango	< 5.79	470.79 ± 90.45	< 0.82	< 5.81	< 8.52	< 0.87	< 2.45
Lemon	< 3.40	445.22 ± 53.54	0.18 ± 0.3	< 4.38	< 5.83	< 0.59	< 1.65

situated in the coastline of Eastern province and beach sand contains high salt amount due to regression of seawater, which may cause elevated ^{40}K activity in foodstuff growing in the area. In the other hand, K is one of macronutrients present in the plant; automatically, ^{40}K level in plants may increase (Islam et al. 2014). Fertilizers are being used in high dosage to improve the harvest due to the lack of knowledge of farmers, and this may be another reason to have high ^{40}K activity concentration in foodstuff (Jibiri et al. 2007a, b). Sri Lankan soils are lacking phosphorus, and 41,000 tones of triplesuperphosphate (TSP) is imported into the country annually (FAO 2006). Sri Lanka is the leader in fertilizer usage in South Asia (Jayasumana et al. 2015). However, no specific data are available about fertilizer usage in Pulmoddai area. Potassium is more or less uniformly distributed in the body regardless of the amount of potassium consumed with diet. Therefore, the dose to an individual from potassium-40 will be relatively constant due to homeostatic control. For adults, the body content of potassium is about 0.18% and for children, about 0.2%. The annual equivalent doses in tissue from ^{40}K in the body are 165 and 185 μSv year^{-1} for adults and children, respectively (UNECEAR 2000).

Rice is the staple food in Sri Lanka. Thus, most of the meal plans considered in this study contained rice or rice flour. The rice used for this study had directly harvested from paddy fields of sampling location. Meal plan lunch, which includes the highest quantity of rice (2 cups), showed the maximum activity concentration of 163.24 ± 21.88 Bq kg^{-1} on a dry basis. Nevertheless, this value is higher than the standard meal plans of Sri Lanka (Jayasinghe et al. 2018). Activity concentration of rice (BG360 variety) was 41.51 ± 5.48 Bq kg^{-1} on a dry basis. However, the activity concentration of the present study is lower than the activity concentration of rice 120.27 ± 15.8 Bq kg^{-1} (wet basis) growing in high natural background area in South India (Shanthi et al. 2010). Storage and fallout during the growing season are the main courses for grain contamination with radionuclides (Tchokossa et al. 2013).

Among all food categories, vegetables showed the highest activity concentrations. Activity concentration of drumsticks was 1183.72 ± 323.88 Bq kg^{-1}, ladies fingers was 1059.46 ± 9.45 Bq kg^{-1}, and long beans was 734.89 ± 7.66 Bq kg^{-1}. Activity concentrations of vegetables in this study are higher than in the other research done in South India (Shanthi et al. 2010). Natural radionuclide ^{232}Th was present only in ladies fingers (1.05 ± 1.16 Bq kg^{-1}) which was lower than the reported values in other studies. There are two primary processes that can cause radionuclide contamination. The first one is plant uptake of soil radionuclides from the soil, and the second is the direct deposition of fallout radionuclides on the plant surface. Radionuclide accumulation in edible parts of the plant enhances the activity concentrations of those radionuclides (Asaduzzaman et al. 2015). Unlike root vegetables and grains, outer peel of vegetables like ladies fingers, drumsticks, and long beans is not removing during cooking. Therefore, stringy nature of outer peel of vegetables may promote fallout and effluent radionuclide deposition. Further confirmation of this phenomenon is needed to be carried out using separate sections (skin, flesh parts, etc.) of such vegetables which is not addressed in the present study.

Committed effective dosage due to ingestion

Only natural radionuclide present in all meal plans above minimum detectable activity was ^{40}K. Therefore, committed effective dosage was calculated considering activity concentrations of ^{40}K in meal plans. The radionuclides intake of individuals was calculated using consumption rates of different foods given in Table 3. The highest committed effective dosage 0.0707 mSv year^{-1} resulted from meal plan lunch followed by 0.0392 mSv year^{-1} from meal plan breakfast and 0.0383 mSv year^{-1} from meal plan dinner, which were similar to each other. The total committed effective dosage from ingestion of cooked meal plans in this study was 0.1482 mSv year^{-1} (Table 4).

Natural radionuclides present in raw foodstuffs above the minimum detectable activity were ^{40}K and ^{232}Th. ^{232}Th was present in an incredibly tiny amount which was not enough to calculate committed effective dosage. Therefore, committed effective dosage was calculated considering activity concentrations of ^{40}K. The highest committed effective dosage 0.0267 mSv year^{-1} was resulted from rice (BG360 variety), while the lowest committed effective dosage 0.00004 mSv year^{-1} was resulted from mango (Table 5). When considering food categories, 0.0312 mSv year^{-1} was the highest committed effective dosage resulted from cereals.

Conversely, fruits showed the lowest committed effective dosage, 0.0010 mSv year^{-1}, while the total committed effective dosage from ingestion of raw foodstuff was 0.0667 mSv year^{-1}. It was found that committed effective dosages from both cooked meal plans and fresh foodstuff in this study are noticeably higher than the annual effective dose. That may occur due to ingestion of radioactive elements in Sri Lankan common meal plans, which was ranged from 0.030 to 0.051 mSv year^{-1} (Jayasinghe et al. 2018), which indicates that there is an effect for the foodstuff grown in the area by mineral sand deposits.

The annual committed effective dosage resulting from dietary intake of ^{40}K was 0.1482 mSv year^{-1} in cooked meal plans and 0.0667 mSv year^{-1} in raw foodstuffs, respectively, for the adult consumer in this study. The total exposure per person from ingestion of natural radionuclides is 0.3 mSv year^{-1}, of which 0.17 mSv year^{-1} from ^{40}K and 0.12 mSv year^{-1} from uranium and thorium series (UNSCEAR 2000). Annual dose limit due to ingestion of foods to an adult is 1 mSv year^{-1} (IAEA 2011). The committed effective dosages obtained from this study lie well below than both natural dosage and dose limit. Outer parts of the fruits and vegetables grown in the area were contaminated with fine dust and sand. Therefore, removal of the skin of root vegetables, avoiding foodstuff growing in high radioactive soils and washing fruits and vegetables to remove soil particles are some preventive measures to avoid exposing to radioactivity due to ingestion of foods. However, washing will not reduce the radioactivity in foodstuff. It will only reduce the risk of contamination of radionuclides in the fine sand particles with fruits and vegetable.

Pulmoddai is a high natural background radiation area due to the presence of mineral sand deposit. The study done in high natural background radiation area in South India showed annual committed effective dosage of 1.795 mSv year^{-1} and out of that 0.460 mSv year^{-1} came from ^{40}K (Shanthi et al.

Table 3 Food items and respective annual consumption rates

Food item	Fresh wt. (kg)	Dry wt. (kg)	Dry wt./fresh wt.	Consumption rate[a] (kg $year^{-1}$) per person (DCS 2012:2013)
Rice (BG360)	0.037	0.032	0.8649	119.98
Maize	0.032	0.015	0.4687	9.64
Groundnut	0.051	0.047	0.9216	1.30
Ladies fingers	0.263	0.025	0.0950	1.41
Long beans	0.308	0.029	0.0941	2.02
Drumsticks	0.392	0.041	0.1046	0.67
Coconut	0.328	0.146	0.4451	36.33
Cassava	0.511	0.142	0.2779	10.19
Mango	0.518	0.054	0.1042	0.14
Lemon	0.834	0.164	0.1966	1.87

[a]Consumption rates are given on a wet basis

Table 4 Annual committed effective dosage from common meal plans

Meal plan code	Activity concentration[a] of ^{40}K (Bq kg^{-1})	Committed effective dosage (mSv $year^{-1}$)
MPB (breakfast)	143.77 ± 24.38	0.0392
MPL (lunch)	163.24 ± 21.88	0.0707
MPD (dinner)	129.28 ± 19.92	0.0383
Total		0.1482

MPB meal plan breakfast, *MPL* meal plan lunch, *MPD* meal plan dinner

[a]Activity concentration is given in dry basis

Table 5 Food categories and their respective annual committed effective dosages (CED)

Food category	Food item	Activity concentration[a] of ^{40}K	Dose coefficient ^{40}K (μSv Bq^{-1})	CED (mSv $year^{-1}$)	Category CED (mSv $year^{-1}$)
Cereals	Rice	41.51 ± 5.48	0.0062	0.0267	
	Maize	160.83 ± 26.81	0.0062	0.0045	0.0312
Nuts	Groundnut	192.59 ± 38.88	0.0062	0.0014	0.0014
Vegetables	Ladies fingers	1059.46 ± 9.45	0.0062	0.0009	
	Long beans	734.89 ± 7.66	0.0062	0.0009	
	Drumsticks	1183.72 ± 323.88	0.0062	0.0005	
	Coconut	281.53 ± 36.98	0.0062	0.028	0.0303
Yams	Cassava	158.32 ± 20.78	0.0062	0.0028	0.0028
Fruits	Mango	470.79 ± 90.45	0.0062	0.00004	
	Lemon	445.22 ± 53.54	0.0062	0.0010	0.0010
Total CED					0.0667

[a]Activity concentration is given in dry basis

2010). A study conducted in Jos-Plateau, Nigeria, showed 2.38 mSv $year^{-1}$ annual committed effective dosage (Jibiri et al. 2007a, b), and Pakistan showed 0.186 mSv $year^{-1}$ (Akhter et al. 2007). The present study committed effective dosages are below than the committed effective dosages reported thought out the world in high natural background radiation areas.

Conclusions

Main radionuclides identified in foodstuffs and meal plans from Pulmoddai were $^{40}K^{32}Th$, ^{7}Be and ^{137}Cs. The average annual effective dose from dietary intake of ^{40}K is estimated equal to 0.1482 mSv $year^{-1}$ in cooked meal plans and 0.0667 mSv $year^{-1}$ in raw foodstuffs for the adult consumer. Committed effective dosages gained from the study are lower than the 1 mSv $year^{-1}$ maximum committed effective dosage due to ingestion of foods (IAEA 2005). Therefore, consumption of foodstuffs growing in Pulmoddai area is radiologically safe.

References

Akhter, P., Khan, H. M., Ismail, M., & Khan, K. (2007). Radiological impact of dietary intakes of naturally occurring radionuclides on Pakistani adults. *Food and Chemical Toxicology, 45*(2), 272–277.

Amarasekera, J., Ismail, M. G. M. U., & Kumarasinghe, J. S. N. (1983). The upgrading of ilmenite from Sri Lanka by the oxidation–reduction–leach process. *International Journal of Mineral Processing, 10,* 161–164.

Asaduzzaman, K., Khandaker, M. U., Amin, Y. M., & Mahat, R. (2015). Uptake and distribution of natural radioactivity in rice from soil in North and West part of peninsular Malaysia for the estimation of ingestion dose to man. *Annals of Nuclear Energy, 76,* 85–93.

Bahari, I., Mohsen, N., & Abdullah, P. (2007). Radioactivity and radiological risk associated with effluent sediment containing technologically enhanced naturally occurring radioactive materials in among (tin tailings) processing industry. *Journal of Environmental Radioactivity, 95*(2–3), 161–170.

Bandara, M., & Mahawatte, P. (2013). Radioactivity of sand in the coastal strip from Beruwala to Dondra, Sri Lanka. In *69th annual sessions of Sri Lanka Association for the advancement of science, Sri Lanka at December 2013*. Retrieved May 24, 2019, from https://www.researchgate.net/publication/282942358_Radioactivity_of_sand_in_the_coastal_strip_from_Beruwala_to_Dondra_Sri_Lanka.

Bolca, M., Sac, M. M., Cokuysal, B., Karali, T., & Ekdal, E. (2007). Radioactivity in soils and various foodstuffs from the Gediz River Basin of Turkey. *Radiation Measurements, 42*(2), 263–270.

Chandrajith, R., Seneviratna, S., Wickramaarachchi, K., Attanayake, T., Aturaliya, T. N. C., & Dissanayake, C. B. (2010). Natural radionuclides and trace elements in rice field soils in relation to fertilizer application: Study of a chronic kidney disease area in Sri Lanka. *Environmental Earth Sciences, 60,* 193–201.

El Samad, O., Baydoun, R., Nsouli, B., & Darwish, T. (2013). Determination of natural and artificial radioactivity in soil at North Lebanon province. *Journal of Environmental Radioactivity, 125,* 36–39.

Falandysz, J., & Borovi, J. (2013). Macro and trace mineral constituents and radionuclides in mushrooms: Health benefits and risks. *Applied Microbiology Biotechnology, 97,* 477–501.

Fernando, L. J. D. (1986). *Mineral resourcers of Sri Lanka. Science education series no 17*. Retrieved August 8, 2017, from http://thakshana.nsf.ac.lk/slstic/NA-110/NA%20_110%20_%20i.pdf.

Food and Agriculture Organization of the United Nations. (2006). *Improving plant nutrient management for better farmer livelihoods, food security and environmental sustainability*. Retrieved May 25, 2019, from http://www.fao.org/3/ag120e/AG120E12.htm.

Gamage, S. S. N., Verunika, W. P. H., Waduge, V. A., & Siriwardana, C. H. E. R. (2018). Determination of rare earth element contents in the Pulmoddai-based monazite. *International Journal of Advance Research, 6*(7), 1229–1236. https://doi.org/10.21474/ijar01/7480.

Hussain, M. Y., & Rani, M. (2010). Quantitative measurement of natural radioactivity in vegetable and meat before and after cooking. *Pakistan Journal of Agriculture Science, 47*(2), 153–156.

International Atomic Energy Agency. (1989). *Measurement of radionuclides in food and the environment, a guide book*. Technical report series 295. Retrieved July 2, 2017, from http://www-pub.iaea.org/books/IAEABooks/1398/Measurement-of-Radionuclides-in-Food-and-the-Environment.

International Atomic Energy Agency. (2005). Derivation of activity concentration values exclusion, exemption and clearance. *Safety Report Series* (Vol. 44, pp. 1020–6450). Vienna: IAEA.

International Atomic Energy Agency. (2011). *Radiation protection and safety of radiation sources: International basic safety standards*. Retrieved July 5, 2017, from http://wwwpub.iaea.org/MTCD/publications/PDF/Pub1467_web.pdf.

Islam, A., Begum, A., Yeasmin, S., & Sultana, M. S. (2014). Assessment of dose due to natural radionuclides in vegetables of high background radiation area in the south-eastern part of Bangladesh. *International Journal of Radiation Research, 12*(3), 271–275.

Jayasinghe, C., Molligoda, V., Attanayaka, T., & Waduge, V. (2018). Estimation of annual effective dose due to ingestion of radioactive elements in Sri Lankan common meal plans. *Environmental Geochemistry and Health*. https://doi.org/10.1007/s10653-018-0200-2.

Jayasumana, C., Fonseka, S., Fernando, A., Jayalath, K., Amarasinghe, M., Siribaddana, S., et al. (2015). Phosphate fertilizer is a main source of arsenic in areas affected with chronic kidney disease of unknown etiology in Sri Lanka. *SpringerPlus, 4,* 90. https://doi.org/10.1186/s40064-015-0868-z.

Jayawardena, R., Byrne, N. M., Soares, M. J., Katulanda, P., & Hills, A. P. (2012). Food consumption of Sri Lankan adults:

An appraisal of serving characteristics. *Public Health Nutrition, 16*(4), 653–658.

Jibiri, N. N., Farai, I. P., & Alausa, S. K. (2007a). Estimation of annual effective dose due to natural radioactive elements in ingestion of foodstuffs in tin mining area of Jos-Plateau, Nigeria. *Journal of Environmental Radioactivity, 94,* 31–40.

Jibiri, N. N., Farai, L. P., & Alausa, S. K. (2007b). Activity concentrations of ^{226}Ra, ^{228}Th, and ^{40} K in different food crops from a high background radiation area in Bitsichi, Jos Plateau, Nigeria. *Radiation and Environmental Biophysics, 46,* 53–59.

Khan, H. M., Ismail, M., Khan, K., & Akhter, P. (2011). Measurement of radionuclides and gamma-ray dose rate in soil and transfer of radionuclides from soil to vegetation, vegetable of some northern area of Pakistan using γ-ray spectrometry. *Water, Air, and Soil pollution, 219*(1–4), 129–142.

Mlwilo, N. A., Mohammed, N. K., & Spyrou, N. M. (2007). Radioactivity levels of staple foodstuffs and dose estimates for most of the Tanzanian population. *Journal of Radiological Protection*. https://doi.org/10.1088/0952-4746/27/4/008.

Nasreddine, L., Samad, O. E., Hwalla, N., Baydoun, R., Hamze, M., & Massin, D. P. (2008). Activity concentrations and mean annual effective dose from gamma-emitting radionuclides in the Lebanese diet. *Radiation Protection Dosimetry, 131*(4), 545–550.

Ramachandran, T. V., & Mishra, U. C. (1989). Measurement of natural radioactivity levels in Indian foodstuffs by gamma spectrometry. *International Journal of Radiation Applications and Instrumentation Part, 40*(8), 723–726.

Samavat, H., Seaward, M. R. D., Aghamiri, S. M. R., & Reza-Nejad, F. (2006). Radionuclide concentrations in the diet of residents in a high level natural radiation area in Iran. *Radiation and Environmental Biophysics, 45,* 301–306.

Shanthi, G., Kumaran, J. T. T., Raj, G. A. G., & Maniyan, C. G. (2010). Natural radionuclides in the South Indian foods and their annual dose. *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors, and Associated Equipment, 619*(1–3), 436–440.

Tchokossa, P., Olomo, J. B., Balogun, F. A., & Adesanmi, C. A. (2013). Assesment of radioactivity content of foods in oil and gas producing area in Delta State, Nigeria. *International journal of science and technology, 3*(4), 245–250.

United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR). (1993). *Sources and effects of ionizing radiation*. Retrieved July 6, 2017, from http://www.unscear.org/docs/publications/1993/UNSCEAR_1993_Report.pdf.

United Nations Scientific Committee on the effects of Atomic Radiation (UNSCEAR). (2000). *Sources and effects of ionizing radiation*. Retrieved July 6, 2017, from http://www.unscear.org/docs/publications/2000/UNSCEAR_2000_Report_Vol.I.pdf.

Veiga, R., Sanches, N., Anjos, R. M., Macario, K., Bastos, J., Iguatemy, M., et al. (2006). Measurement of natural radioactivity in Brazilian beach sands. *Radiation Measurements, 41,* 189–196.

Warnakulasuriya, T., Weerakkody, T., Williams, S., Wickremasinghe, R., Waduge, V., Ediriweera, D., et al. (2016). Gamma spectroscopy measurements of soil from the vicinity of a mineral sand processing plant in the Eastern Coast of Sri Lanka. In *61 annual meeting of the Health Physics Society, Washington, USA, July 2016*. Retrieved July 10, 2017, from https://www.researchgate.net/publication/305683638_Gamma_Spectroscopy_Measurements_of_Soil_From_The_Vicinity_of_a_Mineral_Sand_Processing_Plant_In_The_Eastern_Coast_of_Sri_Lanka.

Wickramasinghe, H. M., Takigawa, S., Matsuura-Endo, C., Yamauchi, H., & Noda, T. (2009). Comparative analysis of starch properties of different root and tuber crops of Sri Lanka. *Food Chemistry, 112*(1), 98–103.

Withanage, A. P., & Mahawatte, P. (2013). Radioactivity of beach sand in the south western coast of Sri Lanka. *Radiation Protection Dosimetry, 153*(3), 384–389. https://doi.org/10.1093/rpd/ncs107.

World Health Organization. (2006). *Guidelines for drinking water quality*. Retrieved September 2, 2017, from http://www.who.int/water_sanitation_health/dwq/fulltext.pdf.

World Health Organization. (2011). *Nuclear accidents and radioactive contamination of foods*. Retrieved July 8, 2017, from http://www.who.int/foodsafety/fs_management/radionuclides_and_food_300311.pdf?ua=1.

World Health Organization. (2017). *Ionizing radiation, health effects and protective measures*. Retrieved July 9, 2017, from http://www.who.int/mediacentre/factsheets/fs371/en/.