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Baseline assessment of doses and risk due to natural radionuclides in edible biota of Domiasiat, Meghalaya, India

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Abstract Radiation dose-risk assessment was carried out for cereal species *Brassica compestris var. dichotoma*, *Oryza sativa var. Shalum1*, *Zea mays*, *Lactuca indica*, *Cumunis sativum*, and *Clocasia esculanta* due to naturally available radionuclides ^{40}K, ^{238}U and ^{232}Th in Domiasiat area. The activity in biota and corresponding soil was measured by precipitation method using NaI(TI) detector. Transfer factor (TF) was for *Oryza* spp. (1.00E−01-^{40}K, 8.76E−05-^{232}Th, and 9.11E−05-^{238}U), for *Brassica* spp. (5.39E−01-^{40}K, 8.17E−04-^{232}Th and 2.96E−04-^{238}U) and for *Zea* spp. (3.41E−01-^{40}K, 5.84E−05-^{232}Th, 8.87E−05-^{238}U) etc., respectively. A detailed physio-morphological study of the biota and extensive investigation of ecosystem was carried out for assessment. The data was modeled using FASSET for dose estimation and obtained total dose was 1.58E−04 μGy h^{-1} in *Oryza* spp., 2.87E−04 μGy h^{-1} *Brassica* spp. and 6.90E−03 μGy h^{-1} in *Zea* spp. etc. The dose was compared with the UNSCEAR dataset for screening level dose for biota. *Zea* spp. was more susceptible for the chronic radiation exposure.

Keywords Domiasiat · Dose · Cereal species · *Zea* spp.

Introduction

Radiation study in the biota including human beings is crucial to the understanding of adverse effects of radiation. Incorporation of radiation into the biota in the natural ecosystem could be due to natural or anthropogenic factors. Harvesting of nuclear power is increasing noticeably at the global level and the associated activities may affect biota adversely. Developing nations like India need nuclear power generation for the growing energy requirement and so the radiation dose assessment to the biota as well as human one is a matter of concern from the environmental health safety point of view. This article examines incorporation of radiation dose to the native cereal species in the proposed uranium mining area and heavily consumable by the local people. The data being generated during the pre-mining condition would form a baseline data for comparison with the post-mining scenario.

The Atomic Minerals Directorate for Exploration and Research (AMDER) Government of India has reported the Uranium oxide ore (U_3O_8) with an average of 0.104% in (lower proterozoic) Shillong, group of rocks in Domiasiat, India (Fig. 1) and is amenable for open cast mining [1]. So it is of utmost importance to assess the radiation level to the different non-human biota in the area due to naturally occurring radionuclides. For health safety and environment point of view from the background radiation level; the estimation and assessment of doses to the non human biota is now widely in concern for the radioprotection and for the radiologist.

Naturally occurring radionuclide ^{40}K, ^{238}U and ^{232}Th are predominant in the study area [2]. They can subsequently accumulate in biota and be transferred through the food chain. Contamination of the environment by radionuclides inevitably results in an increase in the radiation

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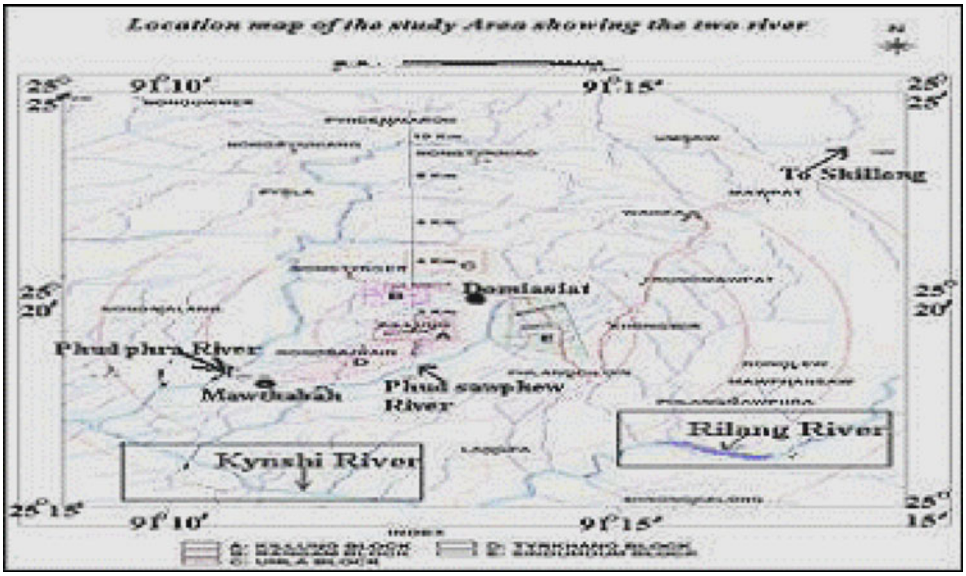

Fig. 1 Study area

exposure of natural populations of organisms that inhibit the area. Key questions that have been growing throughout the international arena and now in India as well include why should we protect the environment, what should we protect and how can we demonstrate protection of species other than humans from the radiation? It is the last which FASSET seeks to address, through consideration of sources, exposure, dosimetry and effects on target organisms and ecosystems [3]. FASSET thus supports decision-making mechanisms for regulating approaches to protecting the environment from the effects of ionizing radiation [4]. "Over the last decade a number of models, almost 15 and approaches have been developed for the estimation of the exposure of non-human biota to ionizing radiations. In some countries these are now being used in regulatory assessments" [5].

Experimental

Selected edible biota for radiation assessment

Maize

Maize (*Zea mays* also known in most English-speaking countries as corn), is a grass domesticated by indigenous peoples in Mesoamerica in prehistoric times. The kernel of maize has a pericarp of the fruit fused with the seed coat, typical of the grasses, and the entire kernel is often referred to as the seed. Maize meal is also used as a replacement for wheat flour, to make corn bread and other baked products. It is widely used as a cattle fodder as it makes a greater quantity of epigeous mass than other cereal plants. Digestibility and palatability are higher when ensiled and fermented, rather than dried. The local people consumed it as a boiled or the roasted corn. The dried and grind corn seed are used as a feed for the pigs in this area [6].

Oryza sativa var. shalum1

Oryza sativa var. shalum1 (common names include Asian rice) is the plant species known in English as rice. The standing crop is known as paddy. It is a monocot. Wild *Oryza* rice variety appeared in Ganges valley regions of northern India as early as 4530 and 5440 BC, respectively; although many believe it may have appeared earlier [7]. It is widely used crop in India and worldwide from the ancient time as a major food supplement. Rice is the staple for all classes in contemporary South East Asia, from Myanmar to Indonesia [8]. This is commonly cultivable variety of *Oryza* in low land of west Khasi Hills (the study area) and in the Cachaar area. It is heavily consumable crop species by the local tribal people.

Brassica compestris var. dichotoma

Brassica compestris var. dichotoma also known as sarson, Indian mustard and leaf mustard is a species of mustard plant. The leaves, the seeds, and the stem of this mustard variety are edible. The plant appears in some form in African, Indian, Chinese, Japanese, and Soul food cuisine. Cultivars of *Brassica compestris* var. dichotoma are grown as greens, and for the production of oilseed [9].

Cumunis sativam

It is a creeping vine mostly grown in the area at domestic level and commercial level both in summer season and eaten as salad. Some time it is also preserved or pickled for prolonged use in the local Khasi tradition. It is roughly cylindrical and elongated pepo (entire fruits) is edible [10].

Lactuca indica

It is a succulent herbaceous plant branching is sessile and grown in the area with long sessile green leaves. The plant leaves is harvested and used as a salad for roughage or cooked as supplementary vegetable with other main dishes. Leaves are also used in making burger as a roughage provider. The leaves have medicinal properties as well. In eastern region of India (Bihar, Bhagalpur) this is used as a prominent feed to the silkworm in sericulture industry [10].

Clocasia esculanta

It's a common underground stem mostly cultivated in the backyard farm or in the abandoned moist place in small scale in study area. It doesn't have much commercial importance as per. It is eaten as vegetable in the normal diet. It is of average size herb having a large oval size leaves with smooth surface due wax coating. Rhizome is of different shape (elongated to oval) and size having dark color Table 1.

Terrestrial environment and sampling

Domiasiat (Fig. 1) (N25016′30″ and E91°16′15″) is located in south western part of West Khasi Hills, District, Meghalaya, India. The general elevation of the area ranges between 500 and 1070 m above sea level. The area receives heavy rainfall, being about 1000 cm per annum and the temperature ranges 3–33 °C. The area has a thick forest cover and is major hot spot from the biodiversity point of view and it is in very pristine condition. Whakaji, Syngkai and Domiasiat sampling sites are scarcely populated rural area having disturbed agriculture ecosystem at the periphery of the forest ecosystem (Fig. 2). The soil is of lateritic type and in some area the soil formation layer is distinctively visible i.e. the stable organic layer of the soil for farming is still under formation and the rock type is of igneous and sedimentary both. The indigenous tribal people of this area are only involved in the shifting cultivation (Jhum) and causing environmental deterioration to the forest. The ecosystem is of semi natural disturbed agriculture type having the thick dense forest in surrounding. The farming practices is of traditional type without the much use of modern agriculture tools and only populated by the local tribal people of Meghalaya [11].

The native cereal species which are heavily consumed by different animal species including human beings are selected for the study. These species are the most common

Table 1 Selected edible biota from the Domiasiat

English name	Paddy	Maize	Mustard	Cucumber	Yam	Salad
Local Khasi Name	Khaw	Reiwhandem	Tyrso	Sokhya	Shriew	Salad
Kingdom	Plantae	Plantae	Plantae	Plantae	Plantae	Plantae
Order	Poales	Poales	Brassicales	Cucurbitales	Alismatales	Asteridae
Family	Poaceae	Poaceae	Brassicaceae	Cucurbitaceae	Araceae	Asterales
Genus	*Oryza*	*Zea*	*Brassica*	*Cumunis*	*Clocasia*	*Lactuca*
Species	*sativa*	*Z. Mays*	*compestris*	*sativam*	*esculanta*	*indica*

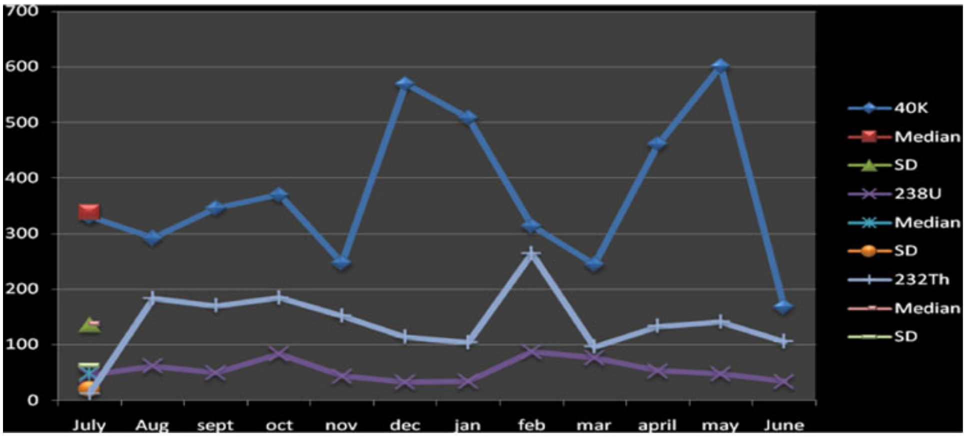

Fig. 2 Natural, Radionuclides Concentration in BqKg^{-1} in soil of Whakaji site

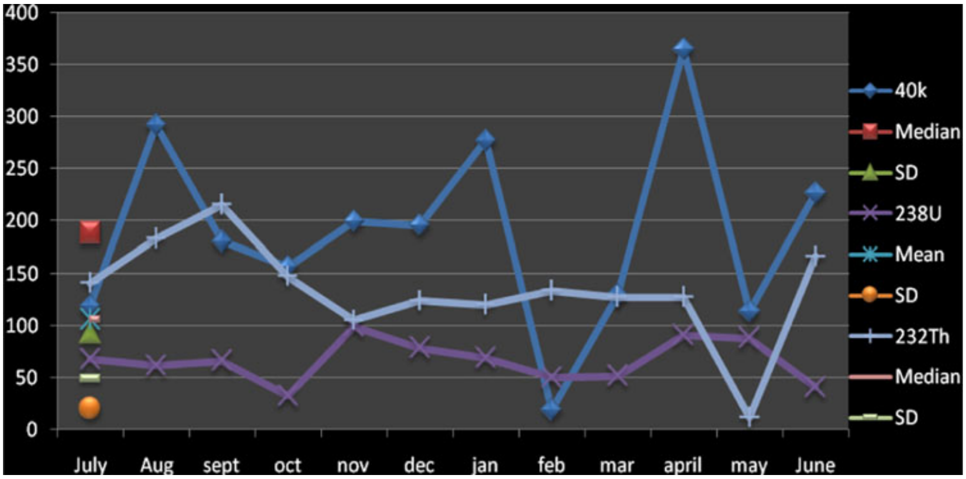

Fig. 3 Natural radionuclides concentration, median and SD Values in BqKg^{-1}in soil at the Domiasiat site

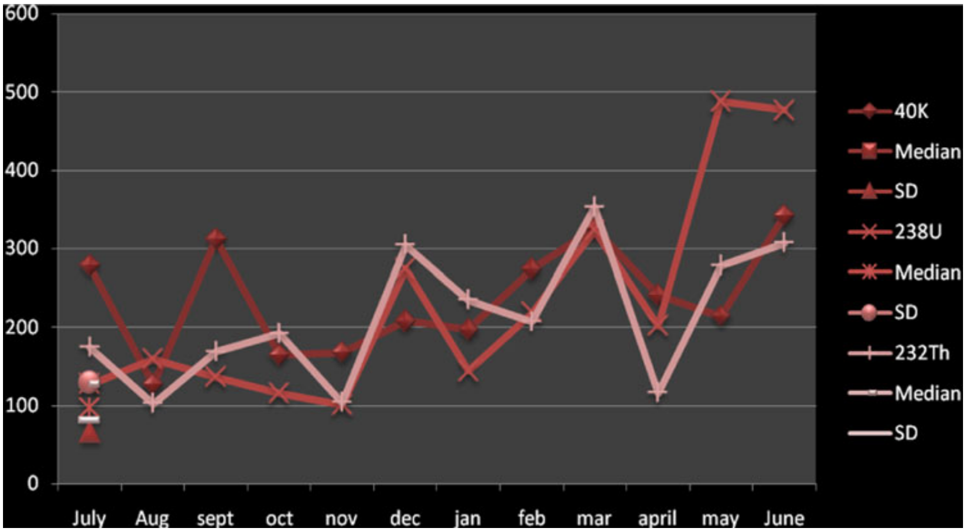

Fig. 4 Natural radionuclides concentration, median and SD Values in BqKg^{-1} in soil at the Syngkai site

dietary supplement to the local people and uses it in different ways in the preparation of their traditional dishes. All the biota is from the semi natural disturbed agriculture ecosystem of the study area (Fig. 1). The soil and biota sampling had been continuously done for 12 months for the activity measurement (Figs. 2, 3, 4, Appendix 1).

The entire study area was fragmented in three zones, as per [12] Indian protocol for baseline survey, core zone, buffer zone 1 and buffer zone 2 for this research. Three sampling sites were designated: two in core zone and one in buffer zone 1(Fig. 5) for soil and biota sampling [12].

The native edible biotas which were heavily consumed by different animal species including human beings were selected for the study. All biota were sampled randomly from the semi natural disturbed agriculture ecosystem of study area. The soil and biota sampling had been continuously done on monthly basis for 12 months for activity measurement (Fig. 5; Table 3). The biota sampling had been done in cultivable season of particular cereal species for measuring the radionuclide concentration directly from the agriculture land. All sampled plant species completed their entire life cycle (death and decay) within the ecosystem of the studied soil (Table 3). Sampling was done in triplicate from different sampling sites of the core zone and buffer zone 1 to keep the uniformity in results from the designated sites only (Red asterisk) Fig. 5.

Estimation of radionuclides

Sample preparation and analysis was done as per the USEPA protocol for the radionuclides measurement in

Fig. 5 Sampling location

flora, fauna and soil. Biota sample were cleaned dried ground and burnt at 450 °C in a muffle furnace to get the white ash for radionuclides measurement. Similarly soil samples were collected at the depth of 10 cm and 1 kg of soil sample carried in a zip-lock plastic bag to the lab. Radionuclides concentration of (^{40}K and ^{232}Th) in biota was measured using Gamma Spectrometer (Table 2). Activity concentrations in the corresponding soil samples are also measured (Appendix 1) using Gamma-ray Spectrometer consisting of NaI detector housed 10 per the USEPA protocol for the radionuclides measurement in flora, fauna and soil. Radionuclides concentration of ^{40}K, and ^{232}Th in biota was measured using Gamma Spectrometer (Table 2). Activity concentrations in the corresponding soil samples are also measured (Appendix) using Gamma-ray Spectrometer consisting of NaI(TI) detector and calibrated using High Purity Germanium detector(HpGe) housed 10 in 7.5 cm thick lead shielding, PC coupled 8 K MCA card and associated electronics. Minimum detection limit for 100 g plant sample for ^{40}K, ^{232}Th was 0.016 and 0.008 BqKg^{-1}, respectively. ^{238}U was determined by the average concentration of ^{210}Pb and ^{214}Bi [13, 14].

Energy calibration and efficiency evaluation of the Gamma-Spectrometer was done by using standards obtained from IAEA in the appropriate matrix. The standard were packed in similar plastic containers which were used for soil and plant samples storage and counted after allowing time for attaining secular equilibrium. Soil samples were counted for 80,000 s and plants samples were counted for 1,50,000 s. ^{40}K in the sample was evaluated from 1460.8 keV peak, from a calibrated KCl standard solution and compared. ^{232}Th was estimated from 2614.53 keV. The details of measured average activity due to ^{40}K, ^{238}U and ^{232}Th are in (Appendix 1).

Result and discussion

Calculation of transfer factor and doses [15]

The site specific TF and Dose was obtained for all these three radionuclide separately in all the by the use of formula.

TF = Biota activity/Soil activity
External dose
Dose = Σ Soil activity × DPUCext
Internal dose, Dose = Σ TF × DPUC$_{int}$
Total Dose = External + Internal

Table 2 Measured concentration, calculated activity, obtained transfer factor, DPUC, pH

Edible-Biota	Measured concentration[a]			Activity calculated BqKg^{-1b}			Transfer factor (TF) obtained BqKg^{-1} per Bqm^{-2}y^{-1}			DPUC$_{ext}$ (µGy h^{-1} per Bqkg^{-1})^{c}			DPUC$_{int}$(µGy h^{-1} per Bqkg^{-1})			p^{H} of Soil(average core zone)
	^{40}K (ppm)	^{232}Th (ppm)	^{238}U (ppb)	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U	
Oryza sativa var.shalum1	887.5	3.7	0.9	28.59	0.015	0.011	1.00E−01	9.11E−05	8.76E−05	4.50E−07	2.80E−09	2.90E−04	2.90E04	2.40E−03	2.30E−03	4.0–6.3
Brassica compesteries var.dichotoma	4743	12	8.4	152.80	0.488	0.102	5.39E−01	2.96E−04	8.17E−04	4.50E−07	1.50E−09	2.90E−04	2.90E04	2.40E−03	2.40E−03	
Zea mays	3003	3.6	0.6	96.76	0.014	0.007	3.41E−01	8.87E−05	5.84E−05	2.40E−05	1.90E−08	2.90E−04	2.90E04	2.40E−03	2.40E−03	
Cumnis sativum	1012	0.4	9	32.61	0.00163	0.11	1.15E−01	9.85E−06	8.70E−05	4.50E−07	2.90E−09	2.80E−09	2.90E−04	2.40E−03	2.30E−03	
Latuca indica	1843	6.5	3.7	59.39	0.026	0.045	2.09E−01	1.60E−05	3.60E−05	2.9E−05	9.6E−08	8.9E−08	2.90E−04	2.40E−03	2.30E−03	
Clocasia esculanta	3726	20	4	120.06	0.081	0.0489	4.2E−01	4.90E−05	3.80E−05	2.70E−05	3.50E−08	4.50E−08	2.90E−04	2.40E−03	2.30E−03	

[a] Kharbuli et al. 2007

[b] Calculated

[c] FASSET

Discussion

The average overall soil activity was the lowest in Domiasiat, 130.0 BqKg^{-1} and the highest were in Syngkai area, 226.6 BqKg^{-1} due to all these three radionuclides (Figs. 2, 4). ^{238}U concentration was found highest in Syngkai area, 230.4 (Median, 96.6; SD, ±129.0) BqKg^{-1} (Fig. 5; Table 3). The transfer factor values in all the biota were in the range of 1.01E−05–5.7E−01 for all the radionuclides in the area. (Table 2). The obtained result has shown that transfer factor (TF) in *Oryza sativa* due to all these three radionuclide was in range of (1.07E−01–8.76E−05) on dry weight basis (Table 2).^{40}K alone has the TF values ranges 1.00E−01–5.39E−01 in all the biota and maximum.

It may be because of the abundance of potassium in soil and its primordial nature. Among these three cereals species *Brassica* spp. experienced highest soil to plant transfer ratio for ^{40}K while *Zea mays* has lowest ^{232}Th uptake (Table 2).

As TF vary considerably between species and also with environmental conditions, such as water chemistry and soil type. ^{232}Th and ^{238}U radionuclides uptake was less in *Oryza sativa* (Table 2). The result depicted that total external dose 6.90E−03 µGy h^{-1} (SD ± 0.003) was highest in *Zea mays* (Table 5) and lowest external dose was in *Oryza sativa* 1.28E−04 µGy h^{-1} which signifies *Zea mays* has higher foliar absorption of the radiation because of large surface area of leaf, while total internal dose was noticed highest in *Brassica* spp. and lowest in *Oryza sativa*. Shahandeh et al. [16] proved that Indian mustard *Brassica juncea* and sunflower accumulated more uranium (U) than any other plant species at pH range 4.7–8 and the measured soil (Tables 2, 4). Due to ^{40}K alone, highest internal dose was in *Brassica* spp. while lowest was in *Oryza* spp., although the latter has extensive water logging period and ^{40}K could be retain in soluble phase for extensive time period (Table 4). The previous study proved that the above-ground portions of plants (leaves, stem) accumulated more U than storage organs like seed, grain or roots and probably this can be the reason [17]. This indicated that uptake and translocation of radionuclide was plant species dependent in this area as well. Saric et al. [18], had demonstrated that plant species could be important for understanding radionuclide contamination within the food chain. The total external dose in *Oryza* spp. was 1.28E−04 µGy h^{-1} (SD ± 0.003) amongst which the incorporation due to the ^{232}Th and ^{238}U radionuclides were equal in proportion (Table 4). Indeed, when uranium is separated from its ores, the decay chain is broken and only thorium (^{234}Th) and protactinium (^{234}Pa) reaches equilibrium with ^{238}U within one year and was the major contributors to the natural radioactivity. Internal dose, 2.93E−05 µGy h^{-1}(SD ± 0.003) was due to ^{40}K in *Oryza* spp. and was highest

Table 3 Calculated external, and internal (μGy h^{-1}) to cereal species due to different radionuclides

External (μGy h^{-1})				Internal (μGy h^{-1})		
Species	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U
Oryza sativa var. shalum1	1.28E−04	4.80E−07	3.52E−07	2.93E−05	2.19E−07	2.01E−07
Brassica compesteries var. dichotoma.	1.28E−04	2.48E−07	1.88E−07	1.56E−04	7.09E−07	1.88E−06
Zea mays	6.80E−03	6.62E−07	2.39E−06	9.90E−05	2.13E−07	1.34E−07
Cumnis sativam	1.28E−04	4.80E−07	3.52E−07	3.34E−05	2.36E−08	2.01E−06
Lactuca indica	8.22E−03	1.59E−05	1.12E−05	6.08E−05	3.84E−07	8.28E−07
Clocasia esculanta	7.65E−03	5.79E−06	5.65E−06	1.23E−04	1.18E−06	8.95E−07

Table 4 Total dose, external dose, internal dose

Species	Total dose (μGy h^{-1})	External (μGy h^{-1})	Internal (μGy h^{-1})
Oryza sativa var. shalum1	1.58E−04	1.28E−04	2.97E−05
Brassica compesteries var.dichotoma	2.87E−04	1.28E−04	1.59E−05
Zea mays	6.90E−03	6.80E−03	9.94E−05
Cumunis sativum	1.64E−04	1.28E−04	3.54E−05
Latuca indica	8.31E−03	8.25E−03	6.2E−05
Clocasia esculanta	7.79E−03	7.76E−03	1.25E−05

(Table 3). Total internal dose incorporation in *Brassica* spp. was 1.59E−04 μGy h^{-1} and contribution of ^{238}U was significant. *Brassica* spp. was much susceptible to ^{238}U radionuclide. Internal dose received by *Zea mays* 9.94E−05 μGy h^{-1} was fairly higher than the dose received by *Oryza* spp. and was lower than dose received by *Brassica* spp. In *Zea mays* external dose was 6.80E−03 μGy h^{-1} while internally, the lowest incorporation was 1.34E−07 μGy h^{-1} due to ^{238}U (Table 4). The energy depositions in biota were due to low LET type radiation. The major background radiation dose incorporation was due to primordial radionuclide ^{40}K, and previous study has proved that the bioaccumulation rate of K is higher than other two radionuclides. Broadley et al. [19] had demonstrated that radionuclide uptake is plant specific because of different genetic makeup. In the Domiasiat ecosystem has the only intake of radionuclides occurred because of the natural biogeochemical process and because of the bulk of the radioactivity was in soil upper 10–15 cm [20]. The dose incorporation due to ^{232}Th and ^{238}U radionuclides was very low and it may be due to its presence in the form of ligands in the soil. Indeed, because of the high pH (5.5–8) (Table 2) radionuclides were bounded with other alkali metal. Awati et al. had shown that sandstone type uranium mineralization occurs mainly in the Cretaceous Mahadek sandstones (alkaline pH) in Meghalaya. Dresen et al. [20], Sheppard et al. [21] had advocated that the mobility and bio-availability of Uranium radionuclides get reduced at high pH. Among vegetables species *Clocasia* spp. was receiving highest total dose 7.79E−03 μGy h^{-1} while lowest was in *Cumunis sativam* 1.64E−04 μGy h^{-1}. Even in vegetable species external deposition was highest and on an average 120 times more than the internal deposition among all the vegetable biota (Tables 2, 5). Like the cereal species, the transfer factor was in direct proportion with the received dose. Regarding the chronic dose impact study to the plant, activity of proteinase enzyme inhibitors in grains of wheat and rye was decreased to 30–55% as compared to a control study [22]. Sparrow et al. [23] suggested[1] LD$_{50}$ values for cereals is in range of 16–22 Gy while Filipas et al. [24] suggested the[2] YD$_{50}$ values of *Oryza* spp. is 75 Gy. After the review of some worldwide studies regarding the irradiation impact on the *Brassica* spp., it could be says that, the significant impact could be observed on received chronic dose in this Domiasiat ecosystem's biota. Finally, it could be concluded that the external and internal dose deposition is mainly due to the low LET beta and gamma type just indicated that ^{40}K is the main contributor of energy in all these biota because of high TF values of ^{40}K. Real et al. [25], UNSCEAR [26] and ERICA [27] recommended the background weighted dose rate to such an ecosystem is between 0.1 and 0.7 Gyh^{-1} from low LET and it is also reported that the

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[1] LD50 the dose value that causes the 50% mortality of population of the organism tested.

[2] YD50 the dose values that cause the 50% reduction in total yield.

radio sensitivity is affected by vegetation structure and shrubs are less sensitive in comparison with tree. Eventually, there is no significant negative impact like deficit in yields, could be noticed to these biota at current baseline background radiation level although it is a matter of further detail research.

Conclusion

It could be concluded that the naturally occurring radionuclides ^{40}K, ^{232}Th and ^{238}U in Domiasiat study area emit radiation chronically and doses to all these studied edible biota were in the ranges of 2.87E−04–8.31E−03 μGy h^{-1}. The main contributor to the doses was primordial radionuclide ^{40}K. The doses received by the biota were in the range of modeled doses to cereal and vegetable by FASSET in European country for the herbaceous and shrub plant of the similar biota. Among cereals *Zea mays* and among vegetable species *Clocasia esculanta* was much prone to the radiation absorption in this area. Although it was very less than the recommended chronic dose for the terrestrial biota which reveals that the area was still under very pristine condition and biota sustainability was not much affected. This is the condition of the pre-mined and there are the fair chances of enhancement in the dose to the cereal crops in post-mining.

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Appendix 1

See Table 5

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Appendix 1 Average activity of the (Soil) (12 months) Whakaji and the adjacent area (Fig. 5) of three naturally occurring radionuclide BqKg^{-1}

Radionuclide	Whakaji			Domiasiat			Syngkai		
	Activity	Median	SD	Activity	Median	SD	Activity	Median	SD
^{40}K	370.80	338	136	189.5	188.4	93.02	237.54	96.67	66.14
^{232}Th	138.17	137	61.6	133.9	106.01	49.06	211.77	127.2	81.07
^{238}U	53.44	47.8	19.4	66.58	106.01	20.49	230.38	96.67	129.0
Location wise total activity	187.47			129.99			226.56		

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