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ASSESSMENT OF DOSES AND RISK DUE TO NATURAL RADIONUCLIDES IN EDIBLE BIOTA OF DOMIASIAT, MEGHALAYA

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A radiation dose assessment exercise was carried out for the edible biota *Solanum nigrum*, *Carica papaya*, *Raphnus sativum* and *Phaseolus domesticus* due to naturally available radionuclides ^{40}K, ^{238}U and ^{232}Th in the Domiasiat area in Meghalaya, India. The concentration of radionuclides in biota and corresponding soil was measured by the NaI(Tl) detector having a minimum detection limit (efficiency, 32.4 %) and machine counting time of 3000 s. The obtained transfer factor for ^{40}K was 0.3061, 0.7163, 0.1988 and 0.1279, for ^{232}Th 0.0003, 2.22E−05, 2.71E−05 and 3.45E−05 and for ^{238}U 1.46E−05, 9.73E−05, 1.46E−05 and 3.11E−05 (ratio) in each biota, respectively. The detailed physiological and morphological study of the biota was carried out. The point source dose distribution (source↔target) hypothesis was applied for the radiation absorbed fraction. The generated data were modelled using FASSET and obtained un-weighted total dose was 1.78E−04, 6.84E−03, 8.46E−03 and 1.73E−04μGy h^{-1}, respectively, finally compared with the IAEA and UNSCEAR data set for screening level dose risk assessment.

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 substantially at the global level and the associated activities of the power generation exercise impact biota adversely. A developing nation like India needs nuclear power generation for its growing energy requirements and so the radiation dose assessment to the biota as well as humans is a matter of concern from the environmental health safety point of view. This study examines incorporation of radiation dose to the locally cultivated green leafy vegetables *Solanum nigrum*, *Phaseolus domesticus*, *Raphnus sativum* and *Carica papaya* 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 Government of India has reported the range of (uranium oxide) U_3O_8 from 0.061 to 0.128 % with an average of 0.104 %.These ore are amenable for open cast mining in (lower proterozoic) Shillong group of rocks in Domiasiat (Figure 1) in India[1]. So it is of utmost importance to think about the radiation level to the different non-human biota in the area due to the naturally occurring radionuclide. Here the existence of sand-stone type of uranium ore has been reported by the Atomic Minerals Division North Eastern Region, Government of India. For health safety and environment points of view of the radiation level the estimation of doses to the non-human biota is now of wide concern for the radioprotection and for the radiologist. Traditionally, radiological protection has focused on the protection of man. The limitation to human health protection is being increasingly questioned and the requirement for an internationally agreed rationale for the protection of the environment to ionising radiation has been recognised.

An independent body, the Atomic Energy Regulatory Board (AERB) monitors safety. The safety standards formulated by AREB are at par with those recommended by the international bodies such as the International Atomic Energy Agency (IAEA) and the International Commission on Radiological Protection. The regulatory authority of AERB is derived from the rules and notifications promulgated under the Atomic Energy Act, 1962 and the Environmental (Protection) Act, 1986.

The major sources of radioactivity in the natural environment include natural phenomena like inter-compartmental interaction (ecosystem) from the atmosphere and runoff from watersheds that have received atmospheric deposition. Depending upon the element and the chemical form, radionuclides

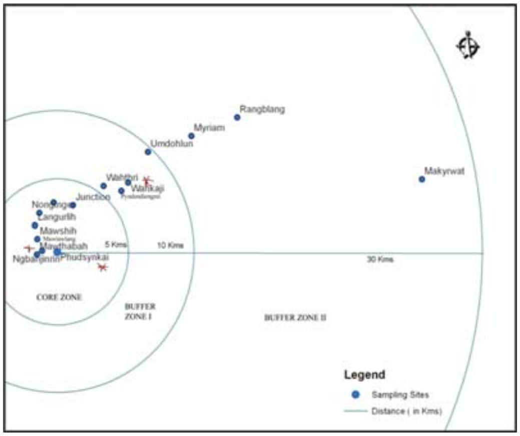

Figure 1. The zone-wise sampling location.

may accumulate in the bottom sediment or remain in the water column in the dissolved state[2]. The three naturally occurring radionuclides ^{40}K, ^{238}U and ^{232}Th are predominant in the study area; they can subsequently accumulate in biota and be transferred through food chain contamination of the environment by radionuclides, which inevitably results in an increase in the radiation exposure of natural populations of organisms that inhibit the area[3].

Key questions that have been arising throughout the international arena and now in India as well include why should one protect the environment, what should one protect and how can one 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 (FASSET, 2003)[4]. FASSET thus supports decision-making mechanisms for regulating approaches to protecting the environment from the effects of ionising radiation. The European Commission Ecological risk assessment (ERICA) and European commission co-ordinated action (PROTECT) are currently to have projects dealing with the *in situ* radiation impact study on the various biota for the derivation and assessment of the screening level dose. The programme involves 15 organisations in seven countries[5]. For the estimation of the concentration of energy or the radiation (internal or external) of the biota within the biotopes of interest are of much concern and importance in radiological impact assessment. The first concrete and universal approaches had been developed by Lovinger and Bernan (USA, 1968), of IAEA, to calculate the energy (external) irrespective of the characteristics of the radiation and the source release and it fits in the entire model for the assessment. It is also regarded as the 'point source dose distribution' and is advantageous in many ways[6]. The Lovinger general dose equation imposes no limitations on size or uniformity of source and target regions, source activity or the absorbing material. To meet this upcoming regulation in biota safety the Department of Atomic Energy, India has decided to start a research programme in this direction. This will lead to a total commitment to the environmental surveillance around the nuclear facilities[3]. As ERICA[7] had suggested, separating uncertainty and variability is necessary to provide greater accountability and transparency for the risk assessment and management exercise. Risk assessment has some sorts of uncertainty related to all the available methodology and could be based on parameters-based uncertainty, scenario-based uncertainty, model-based uncertainty, etc.

SELECTED SPECIES OF LOCALLY GROWN GREEN LEAFY VEGETABLE

Solanum nigrum

Black nightshade is a fairly common herb or short-lived perennial shrub[8]. The flowers have petals that are greenish to whitish, re-curved when aged and surround prominent bright yellow anthers. The edible and sampled berry (fruit) was mostly 6–8 mm in diameter and purple-black. In this area, the berries are casually grown and eaten, but not cultivated for commercial use. The berries are referred to as 'fragrant tomato' and mostly eaten raw by the local people. The leaves contain riboflavin and vitamin C and are commonly used as a medicinal plants for the treatment of many ailments like eczema, syphilis, etc.[8, 9]

Carica papaya

It is a large tree-like plant, with a single stem growing 5 m tall, with spirally arranged leaves confined to the top of the trunk. The lower trunk is conspicuously scarred where leaves and fruit were borne and it is normally consumed as fruit salad and vegetable in this area. It is the most common medicinal plants grown in India and is used for the remedy of various ailments[9]. The measured body dimension of the papaya (edible fruits) confirming ellipsoidal body geometry and was like first major (axis) 10 cm, first minor 6 cm and second minor 2.5 cm, respectively.

Raphnus sativus

Raphanus sativus is an edible root vegetable. The most commonly eaten portion is the napiform taproot, although the entire plant is edible and the

Table 1. Taxonomy of the locally grown vegetable.

Local Khasi Name	Shohgong	Sokhynpor	Muli	Persbin
English name	Black night shade	Papaya	Radish	French beans
Order	Solananles	Brassicales	Brassicales	Fabacae
Family	Solanancae	Cariacacae	Barssicace	Phaseoloe
Genus	*Solanum*	*Carica*	*Raphnus*	*Phaseolus*
Species	*nigrum*	*papaya*	*sativus*	*domesticus*

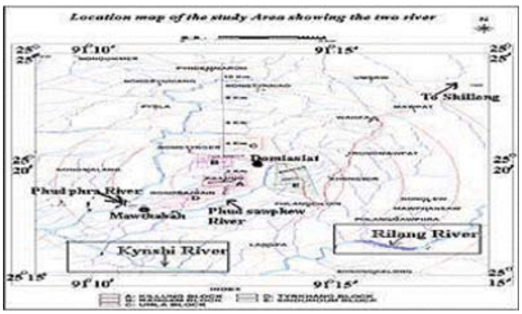

Figure 2. Area location.

Figure 3. The semi-natural disturb ecosystem.

tops can be used as a leafy vegetable. People consume radish as a raw salad or in a mixture with other green vegetable as a local recipe in the study area. The leaf is also consumed as a *Saag* or in a preparation of vegetable soup. It is mostly grown in this area during the winter season and the harvesting period is 45–75 days and it thrives well in free draining loamy and sandy soil[10, 11]. The body geometry of the radish was ellipsoidal and the dimension was first major 15 cm, first minor 3 cm and second minor 2.5 cm.

Phaseolus domesticus

Phaseolus domesticus is a locally grown vine which is widely used as a vegetable or eaten raw in the study area. The elongated beans are used as a vegetable. The sampled species at Nongbajynrin (Figure 1, Table 1) have ellipsoidal body geometry[11].

STUDY AREA

Domiasiat is located in south western part of West Khasi Hills District Meghalaya at latitude of N25^{0}16′30″ and longitude of E91^{0}16′15″), India. The sampling site is very close to Domiasiat-Mawthabah area approximately at a distance of 2–4 km which was identified as having a heavy deposit of uranium ore. The corezone and buffre zone 1 (Figure 1), scarcely populated rural area (Figure 2) having a semi-natural disturbed agriculture ecosystem (Figure 3) and (Whakaji) was the periphery of the dense forest ecosystem.The area receives heavy rainfall, being about 1000 cm per annum, and the temperature ranges between 3 and 33°C. The soil in this area has good deposits of organic contents and nitrogen because of the alluvial low lands and is highly fertile[12]. The hills of the study area are very old and formed 135 millions years ago and the chief rocks include sandstone, shale and limestone and the formation is of Mahdek type[12, 13].

MATERIALS AND METHODS

Sampling and terresterial environment

The selected edible biota are commonly cultivable and heavily consumbable by the different animals including human beings in a various ways. All the selected edible biota are from the semi-natural disturbed agriculture ecosytem within the study area and mostly grown to meet their daily demand and at some extent for commercial purposes. The sampling had been done in the cultivable season of the particlar vegetable species directly from agriculture land and biota available in the local market supplied from the rural area. The concentration of the three available radionuclies ^{40}K, ^{238}U and ^{232}Th is measured by NaI(T1) detector method and mentioned in Table 2.

The apical tissue bud and fruits were sampled and processed as per the Indian Protocol and USEPA Guideline[25]. All the considered plant species complete their entire life cycle within the mentioned ecosystem. The frequency of soil sampling was on a monthly basis and carried out for 12 months,

Table 2. Measured concentration calculated activity, calculated TF and obtained DPUC.

Biota	Measured concentration (Kharbuli *et al.* 2007)[26]			Activity calculated (Bq kg^{-1})			TF obtained (Bq kg^{-1} per Bq kg^{-1} dry-weight basis) (calculated)			$DPUC_{ext}$ (μGy h^{-1} per Bq kg^{-1}) (FASSET)			$DPUC_{int}$ (μGy h^{-1} per Bq kg^{-1})			pH of soil
	^{40}K (ppm)	^{232}Th (ppm)	^{238}U (ppb)	^{40}K (SD ± 74.55)	^{232}Th (SD ± 0.02)	^{238}U(SD ± 0.091)	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U	^{40}K	^{232}Th	^{238}U	
Solanum nigrum	2692.5	12	15	86.75	0.0488	0.1833	3.06E−05	3.00E−05	1.46E−05	3.00E−07	1.70E−10	4.40E−10	2.90E−04	2.40E−03	2.30E−03	4.0–6.3
Carica papaya	1125	0.9	1	36.25	0.0036	0.0122	1.27E−05	2.22E−05	9.73E−05	2.40E−05	4.00E−09	1.90E−08	2.90E−04	2.40E−03	2.30E−03	
Raphnus sativum	6300	1.1	15	203.00	0.0044	0.1833	7.1E−05	2.71E−05	1.46E−05	2.90E−05	8.90E−08	9.60E−08	2.90E−04	2.40E−03	2.30E−03	
Phaseolus domesticus	1749	14	3.2	56.35	0.0570	0.0391	1.9E−05	3.45E−05	3.11E−05	4.00E−07	1.50E−09	1.50E−09	2.90E−04	2.40E−03	2.30E−03	

Appendix II. The sample collection for both soil and biota was in triplicate from the different sampling sites, particularly Wahakaj, Domiasiat and Syngkai) to keep the uniformity of the radiation level (source)[14, 15]. Analysis of variance was applied for the statistical anlysis of the generated data and the standard deviation was ±0.02 (concentration measurement) DPUC (dose per unit concentrations) values for each of the selected biota species was obtained from FASSET by considering them either as herbs or shrubs (Table 2). The external DPUC was considered at the 10 cm below the soil having 4 mm of surface roughness. The apical meristem and the bud were sampled for measuring the concentration and activity of ^{40}K, ^{232}Th and ^{238}U in the studied biota by the NaI(Tl) detector method (Table 2). The DPUC values were considerd by assuming the target entirely exposed under the soil ecosystem and having ellepsoidal body geometry of source and target, respectively. The calculated un-weighted dose to the biota is of chronic type by the low LET (linear energy transfer) and is in micro Gray per hour.

Estimation of radionuclides

Radionuclide concentrations of ^{40}K, ^{226}Ra and ^{232}Th in *Solanum nigrum*, *Carica papaya*, *Raphnus sativum* and *Phaseolus domesticus* had been measured by using a gamma-ray spectrometer. Activity concentrations in the corresponding soil samples are also measured using gamma-ray spectrometer consisting of NaI(T1) detector housed in 7.5-cm thick lead shielding, PC coupled 8K MCA card and associated electronics and was calibrated using high-purity germanium detector. Minimum detection limit for 300 g of soil for ^{40}K and ^{232}Th are 7.7, 3.4 Bq kg^{-1}, respectively. Minimum detection limit for 100 g plant sample for ^{40}K and ^{232}Th are 0.016 and 0.008 Bq g^{-1}, respectively[16].

Energy calibration and efficiency evaluation of the gamma spectrometer was done by using standards obtained from IAEA in the appropriate matrix[17]. 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 ^{232}Th was estimated from 2614.53 keV.

Assumption for calculating the dose using FASSET

As for the radiation level assessment of the biota of interest (selected), FASSET is used as *a priori* tool because it has a study a range of biota of the different ecosystems. It was assumed that source radiation is uniformly distributed within the study zone and the radiation emerges from the source colloid uniformly and homogeneously on the target body (surface area) which has uniformly distributed molecular structure (packing fraction) by which the external radiation would irradiate uniformly on the body surface. All the biota have a shape of ellipsoidal body geometry (3:2:1) ratio of all three axis. The transfer factor (TF) of the different radionuclide involves the consideration of detail study of the physiology and morphology and the life history of the different biota, and after that it is considered that the obtained TF value is constant in particular radiation zone overtime. The calculation of DPUC has taken into account the average alpha beta and gamma energy for the particular nuclide and the absorbed fraction within the particular biota. The DPUC is calculated in μGy h^{-1} per Bq kg^{-1}. The overall dose is the total sum of dose incorporated externally and internally separately to the biota by the each type of radionuclide having each type of (alpha, beta and gamma) radiation. The internal and external DPUC by the naturally available radionuclides ^{238}U, ^{232}Th and ^{40}K to the biota is calculated using equations A and B of Appendix I.

RESULTS AND DISCUSSION

Calculation

Calculation of TF

The site-specific TF values were obtained for all these three radionuclides in all the species as follows, e.g. *solanum nigrum*

By ^{40}K (Table 2):

$$\text{Measured concentration} = \frac{2692.5\ \text{ppm} = (2692.5 \times 0.00087 \times 1000)}{27} = 86.75\ \text{Bq kg}^{-1},$$

$$\text{TF} = \frac{\text{Biota activity}}{\text{Soil activity}} = \frac{86.75}{283.4} = 0.3069$$

where the measured activity of ^{40}K in soil=283.4; the factor for ^{40}K for changing concentration in activity=0.00087 and 1000 is for per kilogram (see Appendix II, measured activity of the soil at the sites).

By ^{232}Th:

$$\text{Measured concentration} = 12\ \text{ppm} = \frac{(12\times0.00011\times1000)}{27} = 0.0488\ \text{Bq kg}^{-1},$$

$$\text{TF} = \frac{\text{Biota activity}}{\text{Soil activity}} = \frac{0.015074}{165.4} = 0.0003$$

where the measured activity of ^{232}Th in soil=165.4; the factor for ^{232}Th for changing concentration in activity=0.00011 and 1000 is for per kilogram (see Appendix II, measured activity of the soil at the sites).

By ^{238}U:

$$\text{Measured concentration} = 15\ \text{ppb} = \frac{(15\times0.00033\times1000)}{27} = 0.011\ \text{Bq kg}^{-1},$$

$$\text{TF} = \frac{\text{Biota activity}}{\text{Soil activity}} = \frac{0.011}{125.6} = 1.46\text{E}-05$$

where the measured activity of ^{238}U in soil=15; the factor for ^{238}U for changing concentration in activity=0.00033 and 1000 is for per kilogram (see Appendix II, measured activity of the soil at the sites).

Similarly for all the species TF is calculated (Table 2).

Calculation of dose

External dose

The external dose is calculated by using the following equation for each radionuclide separately, e.g. *solanum nigrum* (5.1).

$$\text{Dose} = \Sigma\text{Soil activity}\times\text{DPUC}_{ext} = (283.4 \times 3.00\text{E}-07 + 165.4 \times 1.70\text{E}-10 + 4.40\text{E}-10 \times 125.6) = 8.51\text{E}-05\ \mu\text{Gy h}^{-1}.$$

where 3.00E−07, 1.70E−10 and 4.40E−10 are the DPUC value, respectively, for ^{40}K, ^{232}Th and ^{238}U (Table 2).

Internal dose

$$\text{Dose} = \sum_{n=1}^{12}\text{TF}\times\text{DPUC}_{int} = (0.3061 \times 2.90\text{E}-04) + (0.0003 \times 2.40\text{E}-03) + (2.30\text{E}-03 \times 1.46\text{E}-05) = 9.28\text{E}-05\ \mu\text{Gy h}^{-1}$$

where 0.3061, 0.0003 and 2.30E−03 are the TF values for ^{40}K, ^{232}Th and ^{238}U, respectively (see Table 2).

$$\text{Total dose} = \text{External} + \text{Internal}$$

$$9.28\text{E}-05 + 8.51\text{E}-05 = 1.78\text{E}-04\ \mu\text{Gy h}^{-1}$$

Discussion

The result had shown that the obtained TFs (soil to plant transfer) for ^{40}K are in the range of 0.1376–0.7706 Bq kg^{-1} per Bq kg^{-1} on dry mass basis in all the studied biota. The highest TF value was in *Raphnus sativum*, while the lowest was in *Carica papaya.* While for ^{232}Th the range was 2.22E−05 to 3.415E−05 and for ^{238}U the range is in 9.73E−05 to 1.46E−03. The highest TF due to ^{238}U was in *Raphnus sativum* and *Solanum nigrum* among all the four biota (Table 2). The result also depicted that the TF was in direct proportion to the calculated background radiation level and it was also found that the values for TF could easily differ from the recommended defaults by an order of magnitude or more in either direction. The major contribution of radionuclides in the study area is due to the natural biogeochemical cycling and it is observed that the weathering of igneous rocks gives rise to ^{232}Th, ^{235}U and ^{238}U, long-lived radionuclide remaining from the primordial nucleosynthesis. In igneous rocks, both thorium and uranium exist in the 4^{+} oxidation state. Uranium, unlike thorium, however, can be oxidised to the 5^{+} and 6^{+} oxidation states in the near-surface environment. Among all these four biota, the maixmum total background radiation doses was in *Raphnus Sativum* and it was 8.46E−03 μGy h^{-1} and the minimum was in *Phaseolus domesticus* and was 1.73E−05 μGy h^{-1} (Table 2). *Solanum nigrum* and *Phaseolus domesticus* receive almost same total doses. And it was because of the physiological and morphological characteristics, as both of these species (berries and persian, edible product) do not have the direct contact with soil of semi-natural disturbed agricultural type ecosystem of the study area (Figure 3). The ecosystem has the only intake of radionuclide because of the natural disturbance and cycling like runoff, atmospheric exchange (by weathering of rocks and dust deposition) and by evapotranspiration and only sustained by the natural biogeochemical cycle in the ecosystem. As it was studied that most natural, or semi-natural, ecosystems the soil is undisturbed (e.g. not ploughed) and the bulk of the radioactivity remains in the soil upper of 10–15 cm (Figure 4)[18].

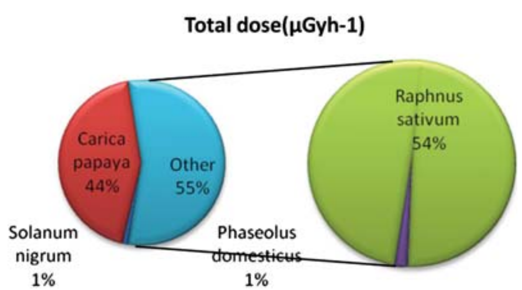

Figure 4. *Raphnus sativm* showing a maximum dose accumulation.

Solanum nigrum receives almost the same dose per hour of its internal dose incorporation and are 8.51E−05 (external) and 9.28E−05 (internal) μGy h^{-1}. Among all these biota major dose incorporation was due to the primordial radionuclide ^{40}K having the highest energy level of photons and electrons. In all the biota normally the external dose is lower than the internal dose incorporation and the difference is significant and had shown almost similar trends except *Solanum nigrum* and on this ground it could be predicted that rest of the three species have almost same exposure time depending upon physiology to the chronic type radiation. The major dose incorporation was due to the internal uptake and accumulation of the radionuclied to the tissue in all four species. External energy deposition was comparatively low. But in case of *Raphnus sativum* the differences was highest between external and internal energy dposition.

The internal contribution of doses due to ^{232}Th and ^{238}U is almost the same in all the species except *Raphnus sativus* (Table 3). It was because the study says that when uranium is separated from its ores, the decay chain is broken. Only thorium ^{234}Th and protactinium ^{234}Pa reach equilibrium with ^{238}U within 1 y and are the major contributors to the radioactivity[19]. The dose incorporation due to

Table 3. The external and internal dose due to natural radionuclides seperately.

Species	Calculated external and internal dose						Total dose (SD ± 0.0014)
	External (SD ± 0.002)			Internal (SD ± 0.002)			
	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	
Solanum nigrum	8.50E−05	2.81E−08	5.53E−08	8.88E−05	7.09E−07	3.36E−06	1.78E−04
Carica papaya	6.80E−03	6.62E−07	2.39E−06	3.71E−05	5.32E−08	2.24E−07	6.84E−03
Raphnus sativum	8.22E−03	1.47E−05	1.21E−05	2.08E−04	6.50E−08	3.36E−06	8.46E−03
Phaseolus domesticus	1.13E−04	2.48E−07	1.88E−07	5.77E−05	8.28E−07	7.16E−07	1.73E−04

Table 4. Dose rate (μGy h^{-1}) to wild terrestrial biota from the natural background, from Woodhead (2002), based on the reviews of IAEA (1976) and UNSCEAR (1996).

	Radiation type(LET)	Cosmic radiation	External radionuclide	Internal radionuclide	Total
Plants	Low	0.032	0.008–0.34	0.050–0.24	0.09–0.71
	High	<0.001	NA	0.020–0.56	0.02–0.56

Source: EA R&D 128 (2002).

^{232}Th and ^{238}U activity incorporation was very low, and it may be due to its presence being in the form of organic complexes or ligands in the soil[19]. As the area is acidic to slightly alkaline and the lateritic soil type has pH (4.0–6.3) it could be possible that these radionuclides were bounded with other alkali metal. As Awati *et al.*[13] had studied, sandstone type uranium mineralisation occurs mainly in the Cretaceous Mahadek sandstones in Meghalaya and the Siwalik formations along the northwest Sub-Himalayan foothills. Therefore, its mobility is reduced and because of that not much energy deposition was observed in the studied biota from the radiation dose point of view. David and Sheppard *et al.*[20] had also studied the sorption behaviour and its relation with the pH and found that sorption behaviour differences between UO_2^{2+} and UO_2^{2+}-carbonate complexes are so great that any other effect of soil properties hardly matter and mobility of the ^{232}Th and ^{238}U in the form of bio-available was reduced at the high pH[21, 22]. So its uptake was noticed comparatively less in biota, due to which background radiation level was low in baseline study. Regarding the stochastic or deterministic effect of radiation on all these biota there was not much sufficient data or evidences available yet, but based on the review from the different literature dose limited cited for the wild biota by different radiation protection body is in Table 4. The per hour dose incorporation to the studied biota was comparatively lesser. It can be due to its semi-natural ecosystem representation. As usually the biota of ecosystems having tremendous anthropogenic changes have high background radiation levels like Chernobyl and some parts of India like Kerala state, where the coastal biota naturally had high background radiation levels. If we compare the obtained dose range to the wild grass (worldwide), it could be said that there can be a potential negative impact on the growth of the plants. Dmitriev *et al.*[23] had studied the mutation due to radiation and had predicted that it is a useful tool to know the chronic type radiation impact at certain dose ranges. The studies in an area contaminated as a result of the Chernobyl accident (1986–1988), seeds of timothy-grass (*Phleum pratense L.*) were additionally exposed to probing acute gamma radiation in different doses and it wound that 20 Gy (5 μGyd^{-1}) and 80 Gy (240 μGyd^{-1}) stimulation of growth processes was observed[23, 24].

CONCLUSION

It is concluded that the naturally occurring radionuclides ^{40}K, ^{232}Th and ^{238}U in the Whakaji study area incorporate radiation in the form of chronic (prolonged exposure of low-dose radiation) un-weighted doses to all these edible biota in the ranges of 1.73E−04 to 8.46 E−03 μGy h^{-1}. The main contributor to the doses is primordial radionuclide ^{40}K. The doses received by the biota are in the range of modelled doses by FASSET in the European country for the herbaceous and shrub plant of the similar biota. *Raphnus sativus* species is much prone to radiation absorption from the dose risk point of view. Although it is much less than the recommended chronic dose for the terrestrial biota it reveals that the area is still under the very pristine condition and biota sustainability is not much affected. This is the condition of the pre-mined, and there are fair chances of enhancement in the dose to the edible biota in the post-mining scenario when radionuclides will be exposed to the surface.

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APPENDIX I

Dose equation description

$$\mathrm{DPUC}_{\alpha\mathrm{int}} = 5.77 \times 10^{-4} \times \varphi_\alpha \times \Sigma(p_i E_i)_\alpha \qquad (A)$$

$$\mathrm{DPUC}_{\alpha\mathrm{ext}} = 5.77 \times 10^{-4} \times (1 - \varphi_\alpha) \times \Sigma(p_i E_i)_\alpha \qquad (B)$$

$$D = \Sigma\left(\left(C_{i\,\mathrm{soil}} \times \mathrm{CF}_{i\,\mathrm{soil}} \times \mathrm{DPUC}_{\mathrm{total\,int}i}\right) + \left(\begin{array}{c}\left(f_{\mathrm{sediment}} + 0.5 f_{\mathrm{surface}}\right) C_{i\,\mathrm{sediment}} \\ +(f_{\mathrm{water}} \times C_{i\,\mathrm{water}})\end{array}\right) \times \mathrm{DPUC}_{\mathrm{totalext}}i\right)$$

C_{water} and C_{sediment} are the radionuclide concentrations in water and sediment, respectively; $\mathrm{CF}_{\mathrm{water}}$ is the concentration factor for biota referenced to water; f_{sediment} is the fraction of time spent buried in sediment; f_{surface} the fraction of time spent on the sediment surface and f_{water} the fraction of time spent free swimming in the water column or on the water surface.

APPENDIX II

Average activity of the (soil, 12 months) in the Domiasiat study area (Figure 1) of three naturally occurring radionuclides (Bq kg^{-1})

Radionuclides	Whakaji			Domiasiat			Phud-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		