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Article

Ingestion of U(nat), ^{226}Ra, ^{230}Th and ^{210}Po in vegetables by adult inhabitants of Bagjata uranium mining area, Jharkhand, India

S. GIRI[1], G. SINGH[1], V.N. JHA[2], R.M. TRIPATHI[2]

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ABSTRACT **Ingestion of radionuclides through food intake accounts for a substantial part of radiation doses and vegetables constitute essential components of the diet, by contributing protein, vitamins, iron, calcium and other nutrients. Radionuclides can be apprehended in the ecosystem of the East Singhbhum region which is known for its viable grades of uranium. In the present study, vegetables were collected from the villages around the proposed Bagjata mining area and analysed for U(nat), ^{226}Ra, ^{230}Th and ^{210}Po. The geometric mean concentration of U(nat), ^{226}Ra, ^{230}Th, and ^{210}Po were 0.05, 0.09, 0.17 and 1.12 Bq kg^{-1} fresh weight, respectively. The intake of the radionuclides from vegetables was found to be 49.58 Bq y^{-1}while the ingestion dose was calculated to be 11.51 µSv y^{-1}, respectively. The estimated doses are reflecting the natural background dose *via* the route of ingestion, which is much below the 1 mSv limit set in the new ICRP recommendations. It is lower than the global average annual radiation dose of 2 400 µSv to man from the natural radiation sources as proposed by UNSCEAR. The total cancer risk due to the consumption of vegetables was calculated to be 6.65 × 10^{-9} which is negligible and much lower than the threshold risk value of 10^{-6}. The study also reveals that water is more conducive for high radioactivity occurrence in vegetables compared to soil systems.**

Keywords: vegetables / radionuclides / ingestion dose / cancer risk / intake

RÉSUMÉ **Ingestion d'U (naturel), de ^{226}Ra, de ^{230}Th et de ^{210}Po dans les légumes par les habitants adultes de la région minière d'uranium de Bagjata, Jharkhand, Inde.**

L'incorporation de radionucléides par ingestion de nourriture explique une partie substantielle des doses reçues de rayonnement et les légumes constituent les composants essentiels du régime, en contribuant à l'apport de protéines, vitamines, de fer, de calcium et d'autres nutriments. Des radionucléides sont présents dans l'écosystème de la région est de Singhbhum, connue pour ses teneurs en uranium. Dans la présente étude, des légumes ont été rassemblés dans les villages autour de la région minière de Bagjata et l'uranium naturel U, ^{226}Ra, ^{230}Th et ^{210}Po ont été mesurés. La concentration moyenne (moyenne géométrique) d'uranium naturel, ^{226}Ra, ^{230}Th, et ^{210}Po étaient en poids de 0,05, 0,09, 0,17 et 1,12 Bq kg^{-1} de poids frais, respectivement. L'incorporation des radionucléides des légumes est de 49,58 Bq par an et la dose qui en découle a été calculée comme étant de 11,51 µSv par an. Les doses estimées reflètent la dose liée au bruit de fond naturel du à l'ingestion et reste inférieure à la limite de 1 mSv recommandée par la CIPR. Elle est inférieure à la dose moyenne annuelle de rayonnement de 2 400 µSv estimée par l'UNSCEAR. Le risque de cancer dû à la consommation des légumes a été calculé comme étant de

[1] Dept. of Environmental Science and Engineering, Indian School of Mines, Dhanbad-826004, India.
[2] Environmental Assessment Division, Bhabha Atomic Research Centre, Mumbai-400085, India.

6,65 × 10^{-9}, et bien inférieur à la valeur de risque de seuil de 10^{-6}. L'étude indique également que l'eau est un vecteur plus favorable pour le transfert aux légumes que les composants du sol.

1. Introduction

Natural radioactivity arises mainly from the primordial radionuclides, such as ^{40}K, and the radionuclides from the ^{238}U and ^{232}Th and their decay products, which are present at trace levels in all ground formations (Tzortzis *et al.*, 2004). The knowledge on the levels of the naturally occurring radionuclides is important because they contribute a substantial portion of the radiation dose to the living organisms (NCRP, 1975; UNSCEAR, 1993).

The eco-regions mainly in the vicinity of the nuclear facilities, which are involved in mining, milling, ore separation, purification, etc., increase the radionuclides accumulation at different trophic levels in the food chains. The radionuclides enter the human body mainly by two routes namely: inhalation and ingestion. The intake through ingestion depends on the food habits that may lead to the increased dose to the public (Tripathi *et al.*, 1997).

Vegetables constitute essential components of the diet, by contributing protein, vitamins, iron, calcium and other nutrients which are usually in short supply (Thompson and Kelly, 1990). It is well-known that plants take up metals and radionuclides by absorbing them from the soil as well as from deposits on the parts of the plants exposed to the air. The contamination may also occur due to irrigation with contaminated water (Khairiah *et al.*, 2004; Chojnacha *et al.*, 2005). Vegetables may be subjected to direct and indirect contamination of uranium series radionuclides. The direct contamination of vegetables occurs by the deposition of radioactive particles from the atmosphere onto the above-ground parts. Primary direct deposition involves three processes: deposition, interception and retention. Indirect contamination refers to the sorption of radionuclides from the soil by the root system. In addition, activity already deposited on the ground may be re-deposited on vegetables by the wind, and then transferred to vegetables (Pietrzak-Flis and Skowronska-Smolak, 1995; Santos *et al.*, 1993).

A significant part of the total dose contribution in the form of natural sources comes from terrestrial gamma radionuclides (UNSCEAR, 2000). Only nuclides with half-lives comparable with the age of the earth or their corresponding decay products, existing in terrestrial materials, such as ^{40}K, ^{238}U and ^{232}Th are of great interest. Abnormal occurrences of uranium and its decay products in rocks and soils and thorium in monazite sands are the main sources of high natural background areas that have been identified in several areas of the world (Al-Jundi *et al.*, 2003). One

such area is the Singhbhum Thrust Belt which is E-W trending 160 km long belt known for Cu-apatite-magnetite and kyanite deposits. Low-grade uranium deposits are found in Singhbhum region of Jharkhand. Following the discovery, mining and processing of uranium ore has been started in several parts of eastern Singhbhum (Jadugoda, Bhatin and Narwapahar). However, with increasing requirement of nuclear energy, by 2020, new sites of mining has been proposed to be excavated for uranium. One such proposed new site is at Bagjata which is an underground mine. The mining at Bagjata may lead to affect the pre-existing environmental status of the area. In this connection, the present study is being carried out to generate baseline data for biotic and abiotic components of the proposed Bagjata uranium mining area. As a part of this baseline study, naturally growing vegetables of the adjoining areas were also analysed for their radionuclides content.

2. Materials and methods

2.1. Description of the study area

Bagjata mining area is situated at latitude of 22°26'07"N to 22°28'34"N and longitude of 86°25'16"E to 86°31'29"E in Dalbhum sub division of East Singhbhum district in Jharkhand State. In the Singhbhum thrust belt, uranium mineralization is ascribed to the intrusive soda granite, providing the source of hydrothermal solutions, which found an easy passage through the shear planes. Studies of mineral paragenesis indicate that mineralization along the thrust belt took place over a long period, the minerals being deposited in two stages, the first to form being apatite and magnetite, closely followed by uranium mineralization and the sulphides including chalcopyrites were the last to be deposited. Uranium-copper mineralization coexists in the area, however depending upon the viability, Cu or U is mined and processed. The Bagjata mining area is situated in the Bhalki-Kanyaluka deposit (Bhola *et al*., 1964). The primary uranium minerals in the area are uraninite and pitchblende. The common secondary uranium mineral is autonite. The uranium minerals are associated with a wide variety of sulphides of copper, nickel, cobalt, molybdenum, arsenic, bismuth (Sarangi and Singh, 2006).The location detail of the study area is shown in the map of the study area (Fig. 1).

2.2. Sampling and analysis

Samples of locally growing vegetables were collected from the surrounding villages within 5 km of the Bagjata mining area during the month of January 2007 and October 2007. The vegetable samples were repeatedly washed in tap water to remove soil and other materials adhering to them. The samples were finally rinsed

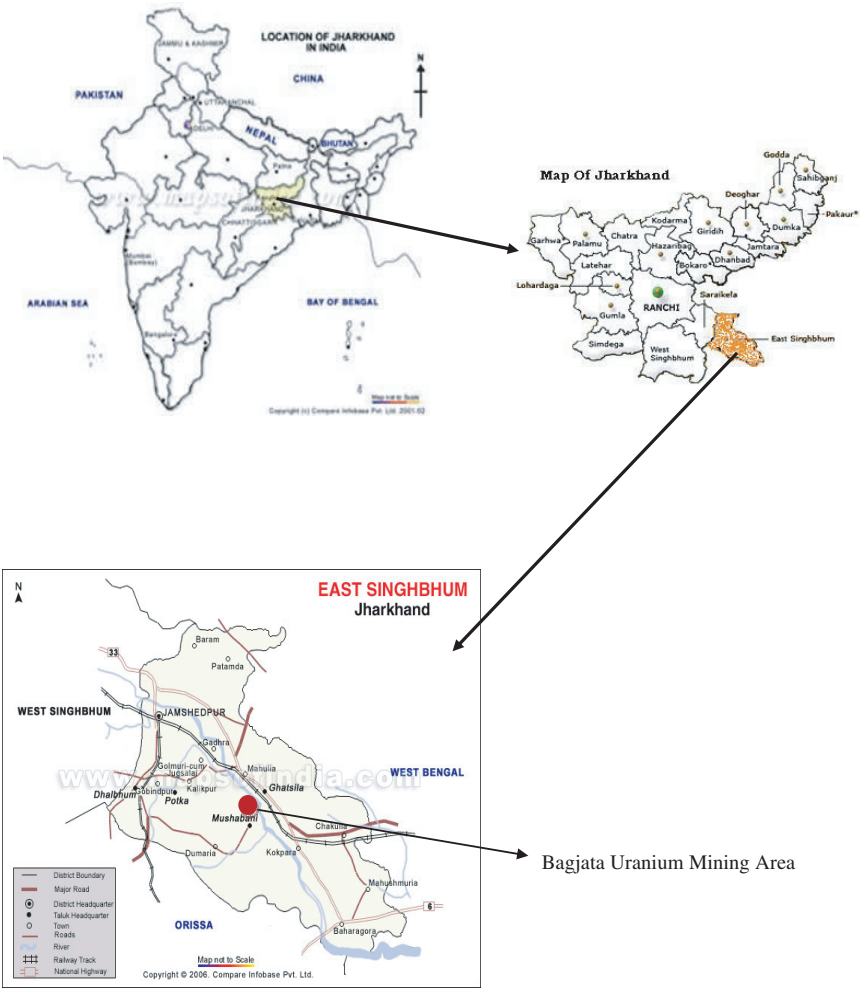

Figure1 – ***Location map of the study area.***
Carte de la zone étudiée.

with distilled water. Then the edible parts of the samples were separated for analysis. The fresh weights of the samples were recorded and then dried in the oven for 48 hours it 110 °C to obtain the dry weights. For radionuclide analysis, the dried samples were subjected to wet ashing. After removal of organic matter (mixture of nitric and perchloric acid), samples were leached repeatedly with 8N HNO_3, filtered and the volume was made up to 100 ml.

The samples of ground water, which is mostly used for irrigation, and soil samples from the root zone of the vegetables were also collected from all the locations. Water samples were preserved by lowering the pH to <2 by addition of 6N ultrapure nitric acid after filtration.

Soil samples after air-drying, were subjected to acid digestion. Soil and vegetable samples were analysed for U(nat), ^{226}Ra, ^{230}Th and ^{210}Po. ^{226}Ra and U(nat) have been estimated in the water samples. The activity of ^{230}Th and ^{210}Po in water is found to be negligible so these radionuclides have not been estimated for water.

Since U(nat) is recovered during mining and processed, U(nat) has been considered. This includes ^{238}U, ^{235}U and ^{234}U in their natural composition. Around the uranium mining areas, the ^{238}U is the major health and safety concern owing to its high abundance in the natural uranium. All the decay products (also called progeny) of ^{238}U isotopes are found in the ore as well as in the nearby environment. Thus, the 4 long lived α emitters including uranium have been considered. ^{230}Th is the next long lived α emitter, which has significant multi-compartmental deposition in the body. All other are short lived progenies (maximum being 24.5 days). Next important nuclide is ^{226}Ra which is a high energy α emitter, bone seeker and a known carcinogen. ^{210}Po is last of the decay chain and an important health hazard and potential carcinogen. These four nuclides almost represent the decay chain.

The ^{210}Po was analysed by electrochemical exchange technique followed by alpha counting (Figgins, 1961) while estimation of Uranium was carried out florimetrically (Kolthoff and Elving, 1962). ^{226}Ra was estimated using radon emanation technique (Raghavayya *et al.*, 1980) and the analysis of thorium was carried out by separating it through anion exchange resin followed by alpha counting (Hyde, 1960).

2.3. Analysis of the data

For each radionuclide, the distribution of the combined data of the vegetable category was verified by the curve of accumulated frequency (Miller and Miller, 1989). As usually observed in environmental samples, the concentrations of the radionuclides were better represented by the log-normal distribution, and the central tendency thus is represented by the geometric average (Wayne, 1990).

2.4. Intake and ingestion dose of the radionuclides

In order to calculate the ingestion dose of these radionuclides, per day consumption of 95 g of vegetables by reference Indian man (Dang *et al.*, 1994) is

used to calculate the intake. Ingestion dose of these radionuclides is evaluated using dose conversion factors of 0.045 μSv Bq^{-1} for uranium, 0.28 μSv Bq^{-1} for radium, 0.21 μSv Bq^{-1} for thorium and 0.24 μSv Bq^{-1} for polonium (ICRP, 1994).

2.5. Risk from the intake of radionuclides through ingestion: cancer risk

Carcinogenic risk can be estimated by multiplying ADD with slope factor (SF). The sum of the risks from all radionuclides and pathways yields the lifetime risk from the overall exposure. A lower limit lifetime cancer risk of 10^{-6} is used as the risk threshold below which it can be inferred that cancer risk is negligible (USEPA, 1993).

The basic equation for calculating excess lifetime cancer risk is:

$$\text{Risk} = \text{ADD} \times \text{SF}_o$$

where:
Risk = a unitless probability of an individual developing cancer over a lifetime; ADD = average daily dose [pCi]; SF_o = slope factor, expressed in [pCi/risk].

The risk is related to doses but since USEPA-IRIS database has provided slope factors (SF_o) in unit activity/risk which is specific for each radionuclide, the same procedure is adopted for the assessment. The slope factors are given in the unit of pCi/risk so the activities are converted from Bq to pCi.

2.6. Quality control

As a part of quality control, spike recovery for matrix elimination was also carried out for the samples. The recovery of U(nat), ^{226}Ra, ^{230}Th and ^{210}Po was found to be 88%, 90%, 85% and 96%, respectively. Results are provided in Table I. Four Certified Reference Materials supplied from BAS, U.K., were analysed for their uranium content. The results are presented in Table II.

TABLE I

Matrix elimination analysis of radionuclides.
Analyse prédictive des radionucléides.

S. No	Radionuclide	Activity of soil/ml of aliquot (Bq)	Predicted activity	Actual activity	% Recovery
1	U(nat)	0.024	0.0104	0.0091	88
2	^{226}Ra	0.0006	0.008	0.0072	90
3	^{230}Th	0.008	0.056	0.0475	85
4	^{210}Po	0.0055	0.383	0.368	96

TABLE II

Analysis of certified reference material for uranium U(nat): µg g^{-1}.
Analyse des matériaux de référence pour l'uranium naturel µg g^{-1}.

Certified reference material	[1]BARC Mumbai	[2]HPU Jadugoda	BAS certified concentration
TILL-1(Soil)	1.95	1.89	2.2
TILL-3(Soil)	1.87	1.80	2.1
STSD-1 (Stream Sediment)	7.95	8.16	8.0
LKSD-1(Lake Sediment)	9.20	9.30	9.7

[1] Bhabha Atomic Research Centre, [2] Health Physics Unit.

3. Results and discussion

3.1. Distribution of radionuclides

The results of radiochemical analysis of vegetables of Bagjata mining area are displayed in Table III. The ranges of U(nat), ^{226}Ra, ^{230}Th, and ^{210}Po in the vegetable samples were < 0.017–0.213, < 0.02–1.45, < 0.01–2.16 and < 0.2–35.56 Bq kg$^{-1}_{\text{fresh}}$ weight, respectively. The geometric mean concentration of U(nat), ^{226}Ra, ^{230}Th, and ^{210}Po were 0.05, 0.09, 0.17 and 1.12 Bq kg$^{-1}_{\text{fresh}}$ weight, respectively. Highest activity for Th(α) and ^{226}Ra was found in *Moringa sps*, whereas that of U(nat) and ^{210}Po was found in *Musa paradisica* and *Amorphophllaus sp*., respectively. Among the radionuclides, activity of ^{210}Po was highest for samples analysed for the same specimen. This may be attributed to the derivation of the radionuclide from soil and air. The secondary decay of ^{210}Pb present in the soil may also be a reason of the high ^{210}Po content in the plant foodstuffs (Moore *et al.*, 1976; Shacklette *et al.*, 1978; Kabata-Pendias, 2001). Actual root uptake and translocation into edible portions of plants used as human food has been observed to equal < 1%. The dominant mechanism is considered to be surface deposition of particulate matter on which Pb-210 and Po-210, originating as decay daughters of Rn-222 gas, are adsorbed (Hill, 1960; Berger *et al.*, 1965). The overwhelming source of plant Po-210 is the deposition of its precursor, Pb-210, on plant surfaces during rainfall events (Francis *et al.,* 1968).

It is also evident that all the radionuclides were significantly higher in the leafy vegetables and in the underground vegetables. This indicates the partitioning of the elements with accumulation of greater concentrations in the edible portions of leafy or root crops than the storage organs or fruits (Lehoczky *et al.*, 1998; Sharma and Agrawal, 2006; Sharma *et al.*, 2008). Moreover, this is in accordance with the studies from different parts of the world revealed the high accumulation of elements in leafy vegetables which may be attributed to atmospheric deposition (Markose, 1990; Khairiah *et al.,* 2004; Chojnacha *et al.*, 2005).

TABLE III

Radiochemical analysis of vegetables of Bagjata mining area.
Analyse radiochimique des légumes de la région minière de Bagjata.

	Sample	Location	U(nat) Bq kg^{-1}	^{226}Ra Bq kg^{-1}	^{230}Th Bq kg^{-1}	^{210}Po Bq kg^{-1}
Leafy vegetables						
1	*Amaranthus lividus*	Bagjata	0.165	0.75	0.62	2.4
2	*Moringa sps*	Bagjata	0.098	1.45	2.16	6.18
3	*Amaranthus lividus*	Bhaduya	0.080	0.61	0.51	1.42
4	*Amaranthus lividus*	Manajhari	0.026	0.21	1.05	1.54
5	*Amaranthus lividus*	Surda	0.031	0.12	0.94	1.42
6	*Amaranthus lividus*	Bakra	0.018	0.32	0.4	0.37
7	*Amaranthus lividus*	Phuljhari	0.030	0.09	1.15	2.59
Vegetables (fruits)						
8	*Lycopersicum esculantum*	Bagjata	0.031	0.15	0.05	0.76
9	*Abelmoschus esculantus*	Bagjata	< 0.017	0.12	0.3	0.27
10	*Trichosanthes sps.*	Bagjata	< 0.017	0.03	0.16	< 0.2
11	*Carica papaya*	Bagjata	< 0.017	0.04	0.32	0.34
12	*Lagenaria siceraria*	Bagjata	< 0.017	0.031	0.08	0.65
13	*Solanum melongena*	Bagjata	0.029	0.06	0.24	2.15
14	*Solanum melongena*	Bhaduya	0.032	0.07	0.29	1.61
15	*Musa paradisica*	Bhaduya	0.213	0.11	0.19	0.38
16	*Abelmoschus esculantus*	Bhaduya	0.064	0.09	1.6	0.89
17	*Trichosanthes sps.*	Bhaduya	< 0.017	0.05	0.07	< 0.2
18	*Lycopersicum esculantum*	Bhaduya	< 0.017	0.07	0.11	0.63
19	*Trichosanthes sps.*	Latia	< 0.017	0.03	0.08	< 0.2
20	*Lycopersicum esculantum*	Latia	< 0.017	0.04	0.15	0.61
21	*Lagenaria siceraria*	Latia	0.020	< 0.02	0.06	0.48
22	*Solanum melongena*	Latia	0.028	0.038	0.11	3.24
23	*Trichosanthes sps.*	Latia	0.086	0.2	0.33	< 0.2
24	*Momordica charancia*	Latia	0.051	0.06	0.04	< 0.2
25	*Lagenaria siceraria*	Manajhari	< 0.017	0.057	0.02	1.24
26	*Trichosanthes sps.*	Manajhari	< 0.017	0.082	0.03	< 0.2

Table III. Continued.

	Sample	Location	U(nat) Bq kg^{-1}	^{226}Ra Bq kg^{-1}	^{230}Th Bq kg^{-1}	^{210}Po Bq kg^{-1}
27	*Lycopersicum esculantum*	Manajhari	< 0.017	0.06	0.14	0.63
28	*Abelmoschus esculantus*	Manajhari	0.036	0.1	0.71	0.65
29	*Luffa acutangula*	Surda	0.025	0.056	0.2	0.61
30	*Lagenaria siceraria*	Surda	< 0.017	0.023	< 0.01	1.22
31	*Trichosanthes sps.*	Surda	< 0.017	0.072	0.05	< 0.2
32	*Lycopersicum esculantum*	Surda	< 0.017	0.12	0.11	0.63
33	*Abelmoschus esculantus*	Surda	0.031	0.11	0.54	0.71
34	*Carica papaya*	Bakra	< 0.017	0.05	0.25	< 0.2
35	*Trichosanthes sps.*	Bakra	< 0.017	0.34	0.11	0.34
36	*Lagenaria siceraria*	Bakra	< 0.017	< 0.02	0.11	0.4
37	*Cucurbita sps.*	Bakra	< 0.017	0.047	0.14	2.67
38	*Abelmoschus esculantus*	Phuljhari	0.034	0.09	0.41	0.64
39	*Lycopersicum esculantum*	Phuljhari	< 0.017	0.09	0.13	0.52
40	*Luffa acutangula*	Phuljhari	< 0.017	0.08	0.02	0.44
41	*Trichosanthes sps.*	Phuljhari	< 0.017	0.02	0.05	0.44
42	*Lagenaria siceraria*	Phuljhari	< 0.017	< 0.02	0.04	< 0.2
Underground vegetables						
43	*Amorphophallus campanulatus*	Bakra	0.072	< 0.02	0.26	35.56
44	*Colocasia sps.*	Bakra	0.077	0.116	0.36	2.22
45	*Amorphophallus campanulatus*	Latia	0.059	0.062	0.05	2.61
46	*Colocasia sps.*	Latia	0.066	0.138	0.09	6.84
47	*Colocasia sps.*	Latia	0.054	0.12	0.24	2.45
48	*Colocasia sps.*	Manajhari	0.030	0.1	0.1	3.99
	Geomean		**0.05**	**0.09**	**0.17**	**1.12**
	GSD		**1.88**	**2.42**	**3.10**	**2.79**
	Intake (Bq y^{-1})		**1.73**	**3.12**	**5.89**	**38.84**
	Ingestion dose (μSv y^{-1})		**0.08**	**0.87**	**1.24**	**9.32**

There are variation in the concentration of radionuclides in the fruits and vegetables according to species and locations. This can be ascribed to various factors: (i) direct deposition to fruit surfaces, absorption by the fruit skin and transport to the interior; (ii) deposition to the above-ground parts of the plant, absorption to interior and transfer to the various plant parts; and, (iii) deposition to

soil, root uptake and transfer to fruit. The relative significance of each pathway after an accidental release depends upon the radionuclide, the kind of crop, the stage of plant development, the season at time of deposition and the timescale for dose assessment (Carini, 2000). If the plant is originally contaminated *via* direct deposition, then storage and translocation are likely to be important in terms of transfer to the crop in later years (Carini, 2001).

3.2. Intake and ingestion dose of radionuclides

The intake of U(nat), ^{226}Ra, ^{230}Th and ^{210}Po through the consumption of vegetables by the local inhabitants was computed to be 1.73, 3.12, 5.89 and 38.84 Bq y^{-1}, respectively. The total ingestion dose was estimated to be 11.51 μSv y^{-1}, with a contribution of 0.08, 0.87, 1.24 and 9.32 μSv y^{-1}, respectively from U(nat), ^{226}Ra, ^{230}Th and ^{210}Po. The doses have been calculated based on Publication 68 of ICRP (1994), for all the radionuclides. However, using a dose conversion factor of 1.2 μSv Bq^{-1} for ^{210}Po (Publication 72 of ICRP, 1996), the total ingestion dose was estimated to be 48.79 μSv y^{-1}, with a contribution of 46.6 μSv y^{-1} from ^{210}Po. The added radiation doses likely to result from eating these vegetables are a small fraction of the radiation dose that normally results from radionuclides present in the body from natural sources. It is lower than the global average annual radiation dose of 2 400 μSv to man from the natural radiation sources as proposed by UNSCEAR (2000). The contributions from these natural radionuclides were much below the 1 mSv limit set in the new ICRP recommendations (ICRP, 2007). Therefore, it is concluded that current levels of radioactivity do not pose a significant radiological risk to the inhabitants.

3.3. Cancer risk due to intake of radionuclides

The data has been used for the cancer risk assessment by USEPA method. The total cancer risk due to the consumption of vegetables was calculated to be 6.65×10^{-9} (Tab. IV) which is negligible and much lower than the threshold risk value of 10^{-6}. However, the risk was more due to Po than other radionuclides (Fig. 2).

3.4. Radionuclides in soil and water

The uptake of radionuclides by plants is mainly from the soil and the water used for the irrigation. The results of soil analysis from the root zone of the vegetables are given in Table V. At the Latia village which is in close vicinity to the abandoned copper mine, Badia, the mean ^{226}Ra (65.2 Bq kg^{-1}) and mean ^{210}Po (136.7 Bq kg^{-1}) showed highest activity. The Bagjata village also experienced high Th(α) activity (106.7 Bq kg^{-1}). The mean U(nat) varied from 0.5 mg kg^{-1} to 34.4 mg kg^{-1}.

TABLE IV

Cancer risk due to intake of vegetables.
Risque de cancer dû à la consomation des légumes.

Radionuclide	SF_o[1] (Slope Factor oral)	Intake[2]	Cancer risk
U(nat)	8.66×10^{-11}	0.13	1.11×10^{-11}
^{226}Ra	5.14×10^{-10}	0.23	1.19×10^{-10}
^{230}Th	1.19×10^{-10}	0.44	5.19×10^{-11}
^{210}Po	2.25×10^{-9}	2.88	6.47×10^{-9}
Total risk			6.65×10^{-9}

[1] SF_o in Risk/pCi, [2] Daily Intake in pCi.

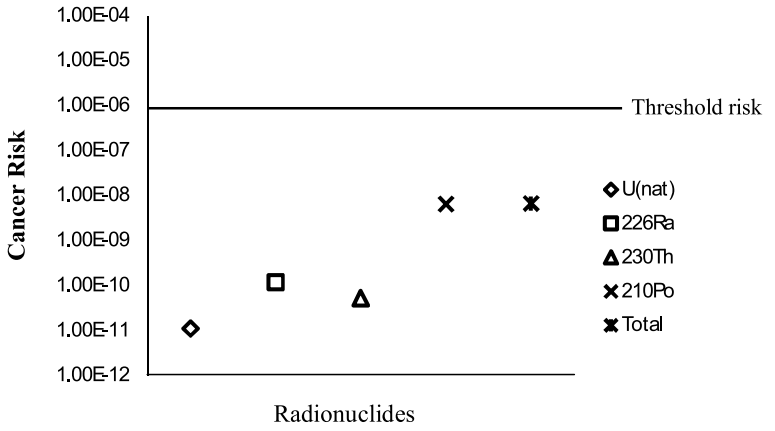

Figure 2 – ***Cancer risk due to ingestion of radionuclides through vegetables.***
Risque de cancer dû à l'ingestion des radionucléides par des légumes.

The results of ground water (used for irrigation) analysis are given in the Table VI. The mean U(nat) concentration was found in the range of 0.5 µg l^{-1} to 10.14 µg l^{-1} while the mean ^{226}Ra activity varied from 3.5 mBq l^{-1} to 40.78 mBq l^{-1}. Comparing with the drinking water standards of USEPA and WHO, it can be inferred that none of the samples exceeded the permissible limits.

Considering the uranium concentration in water, the radiological and chemical risks have been assessed using USEPA method. The intake was calculated using average water consumption of 1.48 m^3/y by an Indian adult (Dang *et al.,* 1994). The average daily dose was calculated by dividing the intake by the body weight of an average Indian man *i.e*. 52 kg (Jain *et al.,* 1995; Dang *et al.,* 1996). For the radiological risk, cancer risk assessment has been done (Tab. VII). The risk has been calculated from 8.96×10^{-11} to 1.78×10^{-9} for various locations with an

TABLE V

Radiochemical analysis (Bq kg^{-1}) of soil around Bagjata mining area.
Analyse radiochimique (Bq kg^{-1}) des sols autour de région minière de Bagjata.

Location	No. of samples	U(nat)	^{226}Ra	^{230}Th	^{210}Po
		(mean ± standard deviation)			
Bagjata	8	8.3 ± 1.2	36.5 ± 6.4	106.7 ± 20.7	75.6 ± 21.6
Bhaduya	6	1.5 ± 0.08	14.8 ± 2.6	96 ± 12.9	104 ± 16.7
Latia	7	7.3 ± 1.8	65.2 ± 5.3	57.8 ± 10.2	136.7 ± 19.4
Manajhari	5	0.9 ± 0.02	8.8 ± 3.1	57.8 ± 6.8	33.3 ± 9.6
Surda	5	0.5 ± 0.04	9.8 ± 2.7	34.4 ± 3.9	17.8 ± 3.9
Bakra	6	34.4 ± 6.3	62.2 ± 9.5	7.1 ± 1.8	1.2 ± 0.9
Phuljhari	6	3.6 ± 0.12	19 ± 2.9	42 ± 5.3	96 ± 8.3

TABLE VI

Radiochemical analysis of ground water around Bagjata mining area.
Analyse radiochimique des eaux souterraines autour de la région minière de Bagjata.

Location	No. of samples	U(nat) µgl^{-1}	^{226}Ra mBq l^{-1}
		(mean ± standard deviation)	
Bagjata	5	7.83 ± 1.2	40.78 ± 5.3
Bhaduya	4	10.14 ± 1.7	12.61 ± 2.8
Latia	6	3.45 ± 0.56	7.89 ± 3.1
Manajhari	4	2.32 ± 0.34	9.75 ± 1.8
Surda	4	0.5 ± 0.03	4.34 ± 1.0
Bakra	5	1.36 ± 0.4	7.2 ± 2.4
Phuljhari	5	5.0 ± 1.4	3.5 ± 1.6
US-EPA (1993)		**30**	**185**
WHO (drinking water standard)		**15**	**1000**

average risk of 7.62 × 10^{-10}. For the chemical risk, Hazard quotient has been calculated (Tab. VIII). The hazard quotient ranges from 0.01 to 0.26 with a mean value of 0.11. The concentration of Uranium does not pose any radiological or chemical threat as the cancer risk is below 10^{-6} and hazard quotient is below 1.

3.5. Regression analysis of the radionuclides

Regression analysis of the radionuclide activity between vegetables and water as well as between vegetables and soil reveals that water is more conducive for high

TABLE VII

Cancer Risk due to intake of uranium in drinking water.
Risque de cancer dû à l'incorporation d'uranium dans l'eau potable.

Location	SF_o[1] (Slope Factor oral)	Intake[2]	Cancer risk
Bagjata		21.4	1.37×10^{-9}
Bhaduya		27.8	1.78×10^{-9}
Latia		9.5	6.08×10^{-10}
Manajhari	6.4×10^{-11}	6.4	4.1×10^{-10}
Surda		1.4	8.96×10^{-11}
Bakra		3.8	2.43×10^{-10}
Phuljhari		13.8	8.83×10^{-10}
Mean		**11.9**	**7.62×10^{-10}**

[1] SF_o in Risk/pCi, [2] Daily Intake in pCi.

TABLE VIII

Hazard quotient of uranium due to intake of drinking water.
Coefficient de risque lié à l'incorporation d'uranium par l'eau potable.

Location	RfD_o[1] (Reference oral dose)	Intake[2]	ADD[3] (Average daily dose)	HQ (Hazard Quotient)
Bagjata		0.032	0.00061	0.20
Bhaduya		0.041	0.00079	0.26
Latia		0.014	0.00027	0.09
Manajhari	3.0×10^{-3}	0.009	0.00018	0.06
Surda		0.002	0.00004	0.01
Bakra		0.006	0.00011	0.04
Phuljhari		0.020	0.00039	0.13
Mean		**0.018**	**0.00034**	**0.11**

[1] RfD_o in mg kg^{-1} body weight/day, [2] Intake in mg day^{-1}, [3] ADD in mg kg^{-1} body weight/day.

radioactivity occurrence in vegetables compared to soil systems. High correlations were obtained between uranium in water and vegetables ($R^2 = 0.70$) (Fig. 3) and ^{226}Ra in water and vegetables ($R^2 = 0.87$) (Fig. 4). It is in accordance to the study by Alam *et al.* (1997) which stated that the decay products of the uranium series, dissolve in water and are first transported into plants and subsequently transported from plants to human. Poor regression values were obtained between the radionuclides in soil and vegetables except ^{230}Th. However, the regression value for ^{230}Th in soil and vegetables is 0.44 (Fig. 5). The regression values of the other radionuclides ranged from 0.013 to 0.184.

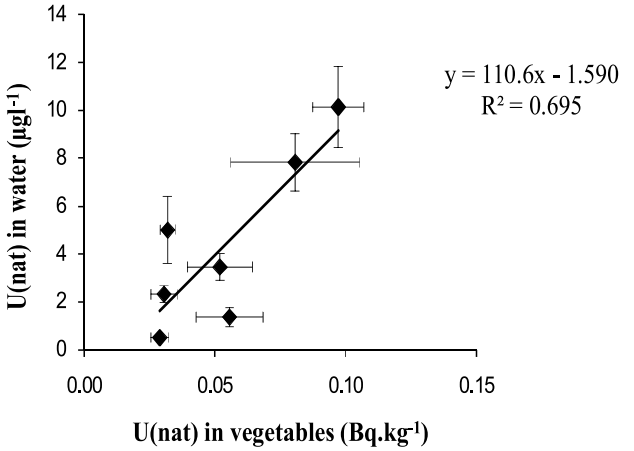

Figure 3 – ***Regression analysis between U(nat) in water and U(nat) in vegetables. † Error bars represent Standard deviation.***

Analyse de régression entre U (naturel) dans l'eau et U (naturel) dans les légumes.

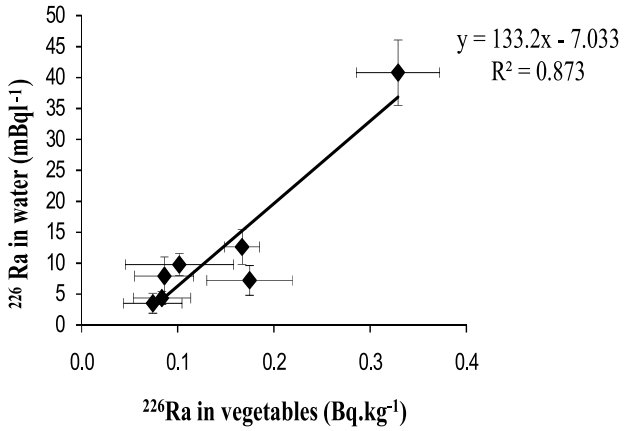

Figure 4 – ***Regression analysis between ^{226}Ra in water and ^{226}Ra in vegetables. † Error bars represent Standard deviation.***

Analyse de régression entre ^{226}Ra dans l'eau et ^{226}Ra dans les légumes.

The activity of ^{230}Th and ^{210}Po in water was found to be negligible. This is, in part, due to the fact that ^{210}Po is very insoluble in water (Tanaka *et al.*, 1983), therefore the majority of ^{210}Po in the water column is bound to suspended particulate material. Moreover, ^{210}Po is very strongly adsorbed by $Fe(OH)_3$ in the soil so the concentration in water is negligible (Wanty *et al.*, 1991; Navas *et al.*, 2005). ^{230}Th is also very insoluble in water so its activity in water is negligible. In

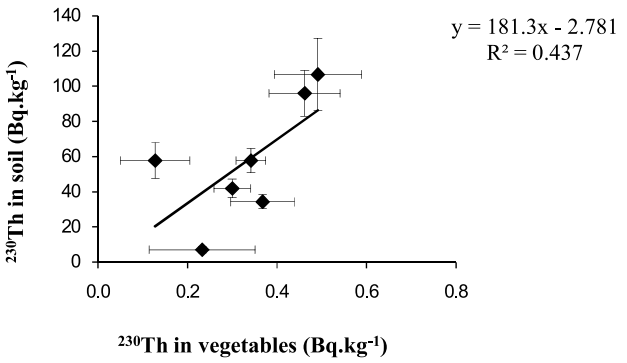

Figure 5 – ***Regression analysis between ^{230}Th in soil and ^{230}Th in vegetables. † Error bars represent Standard deviation.***

Analyse de régression entre la ^{230}Th dans le sol et ^{230}Th dans les légumes.

water, thorium will be present in suspended matters and sediment and the concentration of soluble thorium will be low (Platford and Joshi, 1986). Thus it can be suggested that the main source of ^{230}Th in the vegetables is the soil. In case of ^{210}Po, other than soil, the sources may be derivation of the radionuclide from air and the secondary decay of ^{210}Pb present in the soil.

4. Conclusions

Accumulation of above discussed radionuclides by different vegetable species around various locations of Bagjata mining site assumes importance due to large-scale industrial and mining activity in the region. The study will form a baseline data before the starting of the mining. The concentration levels of the radionuclides in the vegetables depict the natural background concentration. Among the radionuclides the activity of the ^{210}Po is greater than other radionuclides. The ingestion dose from these natural radionuclides were much below the 1 mSv limit set in the new ICRP recommendations. The total cancer risk due to the consumption of vegetables was calculated to be 6.65×10^{-9} which is negligible and much lower than the threshold risk value of 10^{-6}. Therefore, it is concluded that current levels of radioactivity do not pose a significant radiological risk to the local inhabitants. The results also suggest very strong association of the radionuclides between the vegetables and water and reveals that water is more conducive for high radioactivity occurrence in vegetables compared to soil systems.

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