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Radioactivity Concentrations in Soil and Transfer Factors of Radionuclides from Soil to Grass and Plants in the Chittagong City of Bangladesh

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Abstract: *The activity concentrations of naturally occurring and anthropogenic radionuclides in soil, grass and plant were measured in this work with an aim to determine the transfer factors of radionuclides from soil to grass and plant collected from Chittagong city in Bangladesh. The average activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs in soil were found to be 22.13 ± 2.30, 38.47 ± 2.72, 50.47 ± 4.75, 451.90 ± 24.89 and 2.41 ± 0.18 Bq kg^{-1} respectively while in grass, their values were 1.26 ± 0.11, 3.66 ± 0.31, 7.02 ± 0.49, 134.95 ± 3.68 and 0.17 ± 0.02 Bq kg^{-1} respectively. In branches of the plant, the concentration values of these radionuclides are higher than those for leaves. For soil to grass, the transfer factor values were found to be 0.056, 0.089, 0.137, 0.275 and 0.054 respectively for ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs. For plant, soil to branch transfer factor values (0.062, 0.098, 0.136, 0.274 and 0.064 respectively for ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs) are higher than those for soil to leaves (0.054, 0.088, 0.127, 0.266 and 0.061 respectively).*

Keywords: Soil-to-plant transfer factor, natural and anthropogenic radionuclides, activity concentration, tropical environment

1. INTRODUCTION

Both routine and accidental releases of nuclear wastes result in radionuclides sipping into the environment and ground. The plants take in deposited radionuclides from soil, commonly expressed as soil-to-plant transfer factor (TF), which is widely used for calculating radiological human dose via the ingestion pathway. The soil-to-plant TF is regarded as one of the most important parameters in environmental safety assessment for nuclear facilities.[1] This parameter is necessary for environmental transfer models, which are useful in the prediction of radionuclide concentration in agricultural crops for estimating dose impact to human being.

Generally, the soil-to-plant transfer of radionuclides depends on soil type, pH, solid/liquid distribution coefficient, exchangeable K^+ and organic matter contents. Absalom et al. presented a model which predicts the soil-to-plant TF of radionuclides (clay content, organic carbon content, exchangeable potassium and pH).[2] The Absalom model has been tested in Europe with successful prediction of the fate of Chernobyl and weapons fallout of ^{137}Cs.[3,4] However, testing and validation of this model for the tropical food chains in many countries in South Asia is very limited. As countries in the South Asian region like Bangladesh is expanding applications of nuclear technology, a comparable model is required to predict the impact of deposited radionuclides based on the regional parameters derived for wet-dry tropical environments. In order to apply the Absalom model and/or to modify the model, regional databases for model validation need to be developed for the tropical environments of Bangladesh. Nevertheless, very few data for Bangladesh are available in the open literature.[5–7]

As rice and vegetables are the main foods of the people of Bangladesh, in the present work, the activity concentrations of naturally occurring and anthropogenic radionuclides deposited in the soil and plant and soil-to-plant TF are measured in the Prabartak hill in Chittagong city of Bangladesh. A total of 60 soil samples (15 from each of 4 different depths), 10 grass (*Allium cepa, Amaranthus spinosis*, *Chenopodium album*, *Cynodon dactylon*, *Cyperus rotundas*, *Echinochloa crussgali*, *Eleusine indica*, *Mimosa pudica, Murdnnia nudiflora* and *Portulaca oleracea*) and 5 plant (*Acalypha indica*, *Bacopa monniera*, *Lantana camera*, *Solanum nigram* and *Syndrella nodiflora*) species were selected to investigate the concentration of radionuclides and TF values of natural radionuclides and ^{137}Cs in the soil-plant system. The radionuclides ^{232}Th, ^{238}U and their daughter are of great importance in the fuel cycle. Radium radionuclide is of radiological importance to human; water and aquatic lives and plants contain radium radionuclides taken from soil and water.

2. EXPERIMENTAL

2.1 Study Area

Chittagong city is situated on the banks of river Karnaphuli in the southern part of Bangladesh. It is the largest seaport of Bangladesh and is located at latitude 22°22'N and longitude 91°51'E. The city covers an area of about 160.7 km^2. It is bound by hills with closed canopy forest nurtured by heavy seasonal precipitation. The average annual rainfall in the area is about 2870 mm and mean annual temperature is about 26°C. The total duration of rainy season is about 5 months, from May to September. The south-west monsoon causes heavy rainfall between June and July. The soil in the study area is predominantly ultisols, brown hilly, sandy textured and low in organic matter.

2.2 Sample Collection

An area of about 3 m^2 was marked and the top layer of the soil which contained vegetation and root was removed. A total of 60 soil samples, 10 grass samples and 5 plant samples were collected for the present study. Soil samples were collected from different depths viz. 0–5, 5–10, 10–15 and 15–20 cm using a core sampler as tabulated in Table 1. In each case of plant samples, leaves and branches well exposed to the atmosphere were collected separately. In the case of grass, whole plant was collected. Soil samples were collected from the same location from where vegetation samples were collected. The category of soil samples at different depths are given below:

Table 1: Category of soil.

Category of soil	Depth (cm)
Soil A	0–5
Soil B	5–10
Soil C	10–15
Soil D	15–20

2.3 Sample Preparation

Grass and plant samples were cleared by fresh water for removing the dust and mud. All the samples were then dried under direct sun and humidity condition for 2 days. Soils were well mixed after removing extraneous materials such as roots, mat portions, pieces of stone and gravel. Samples were weighed and dried into an electric oven at 110°C for 4 days until a constant dry weight was obtained. After crushing and mixing thoroughly, soil samples were shaken in a sieve shaker and were scaled in a plastic cylindrical container of about 250 cm^3. Plant and grass samples were individually dried for 4 days in an electrical oven of 110°C to obtain a constant dry weight. The samples were charred and then ashed, and finally ground into fine power. The ash was then stored tightly in a 250 cm^3 container with a cap and wrapped with thick vinyl tapes. These samples were a stored for about 30 days to allow ^{214}Bi and ^{208}Tl to reach a secular equilibrium with ^{238}U and ^{232}Th and their respective daughters. Further, the containers were preserved airtight by plastic packets to ensure that ^{222}Rn and ^{220}Rn is confined within the volume.[8]

2.4 Activity Determination (Gamma-ray Spectrometry)

A 344cc P-type coaxial HPGe detector with a relative efficiency of 35% and a resolution (FWHM) of 1.81 keV at 1.33 MeV (with associated electronics) was employed for the measurement of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs activity. The following classical formula:

$$A = \frac{CPS \times 100 \times 100}{E \times I \times W(gm)} \tag{1}$$

where

CPS = net count per second,
E = counter efficiency,
I = Intensity of gamma ray, and
W = weight of the sample

was used to determine the activities in the prepared samples of the soil, grass and plant by the mentioned detector and eventually to determine the TFs due to natural and anthropogenic radionuclides from soil to plant. The detector was enclosed in a 5.08 cm thick graded lead shield. The counting of the samples were obtained by analysing the spectra acquired (by the detector) by employing a PC-based 8K multichannel analyser and associated software (Assayer 3.80). International Atomic Energy Agency (IAEA) standard reference samples RGU-1, RGTh-1 and RGK-1 were used for efficiency calibration. The energy efficiency calibration curve is shown in Figure 1. The standard materials and samples were taken using containers of same size (having a diameter of 6.5 cm and a height of 7.5 cm) and type so that the detector geometry remained identical. The counting time sample was kept enough to minimise the counting error. After adjustment of necessary parameters, the airtight containers contained the standard, soil and ashed samples were placed on the top of the detector and counted for 20,000–80,000 s. The gamma spectrum of the soil, grass and plant samples were taken. Most prominent gamma energy peaks of 238.63 and 300.09 keV (for ^{212}Pb); 241.98, 295.21 and 351.92 keV (for ^{214}Pb); 338.40, 911.07 and 969.11 keV (for ^{228}Ac); 583.19, 860.56 and 2614.53 keV (for ^{208}Tl); 609.31, 1120.29, 1238.11, 1377.82, 1764.49 and 2204.22 keV (for ^{214}Bi); 727.17 keV (for ^{212}Bi); 1406.75 keV (for ^{40}K); 661.66 keV (for ^{137}Cs) and 795.85 keV (for ^{134}Cs) respectively were considered for our calculation.

The lower limit of the detector (LLD) ^{212}Pb, ^{214}Pb, ^{228}Ac, ^{208}Tl, ^{214}Bi, ^{137}Cs and ^{40}K were 0.0293, 0.0187, 0.2018, 0.1145, 0.0140, 0.0545 and 1.9050 Bq kg^{-1} respectively (at 95% confidence level) for a counting time of 68,000 s and the sample was kept in a 250 cc cylindrical container.

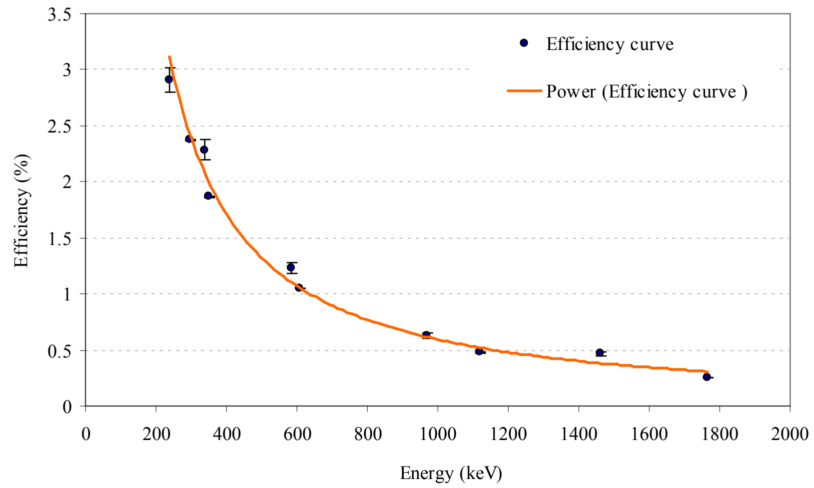

Figure 1: Energy Efficiency curve of the detector.

2.5 Transfer Factor (TF)

The soil-to-plant TF measured the transfer of radionuclides from soil to plant taken through the plant roots. From observed activity concentrations of the radionuclide in the plant and in the corresponding soil, the TF values were calculated according to the equation:[9]

$$TF = \frac{Activity\ of\ radoinuclides\ in\ plant\ (Bq\ kg^{-1} dry\ weight)}{Activity\ of\ radionuclides\ in\ soil\ (Bq\ kg^{-1} dry\ weight)} \quad (2)$$

Grass, grass/root vegetation and small plant grown in tropical Bangladesh are selected to measure TF values.

3. RESULTS AND DISCUSSION

3.1 Radionuclides Concentration in Soil

The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and anthropogenic radionuclide ^{137}Cs in soil samples collected from the Prabartak hill in Chittagong city of Bangladesh are shown in Table 2. The ± values are shown because of the 2σ variation due to counting errors. The activity concentration of ^{226}Ra ranges from 15.27 to 27.52 Bq kg^{-1} with an average of 22.13 ± 2.30 Bq kg^{-1}, ^{232}Th ranges from 26.75 to 57.62 Bq kg^{-1} with an average of 38.47 ± 2.72 Bq kg^{-1}, ^{228}Th ranges from 26.75 to 57.62 Bq kg^{-1} with an average of 50.47 ± 4.75 Bq kg^{-1} and ^{40}K ranges from 279.02 to 647.82 Bq kg^{-1} with an average of 451.90 ± 24.89 Bq kg^{-1}. The worldwide average concentrations of these radionuclides as reported by UNSCEAR are 35, 30 and 400 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively.[10] Therefore, the obtained results for ^{232}Th, ^{228}Th and ^{40}K have high values of activity concentrations, as compared to the worldwide average values. However, for ^{226}Ra, these values are less than the worldwide median values. The anthropogenic radionuclide ^{137}Cs was found in all samples with an average of 2.41 ± 0.18 Bq kg^{-1} and ranges from 0.18 to 5.07 Bq kg^{-1} which is lower than the worldwide average value.[10]

Figure 2 shows the distributions of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs in the surface (Soil A) soil samples. The natural radioactivities did not have a uniform distribution as the soil of the study area is ultisols and sand textured. The sample numbers of high activity concentrations for each of four radionuclides are 5, 7 and 4; particularly for sample 5, which had a very high concentration of ^{40}K (Table 2). Conversely, low activity concentrations were detected in samples 8, 11 and 10. In all samples, the activity concentrations of Thorium are higher than those of Uranium, as Uranium is relatively more susceptible to be soluble whereas Thorium is easily absorbed by the soil.

Table 2: Activity concentrations of radionuclides in soil samples.

Sample no.	Activity (Bq kg^{-1} dry wt)				
	^{226}Ra	^{232}Th	^{228}Th	^{40}K	^{137}Cs
1	19.99 ± 1.98	45.13 ± 2.01	49.09 ± 3.43	550.29 ± 20.16	1.43 ± 0.08
2	23.41 ± 2.29	44.14 ± 2.32	56.63 ± 4.73	544.45 ± 23.99	0.77 ± 0.07
3	20.74 ± 2.30	38.83 ± 2.29	50.69 ± 4.62	480.05 ± 23.61	2.07 ± 0.12
4	26.87 ± 3.33	48.37 ± 3.18	57.14 ± 6.90	594.08 ± 33.24	4.45 ± 0.29
5	27.52 ± 2.86	57.62 ± 3.36	73.76 ± 6.78	647.82 ± 32.13	3.14 ± 0.21
6	20.41 ± 2.25	37.03 ± 2.77	46.54 ± 5.48	418.51 ± 25.74	5.07 ± 0.29
7	26.84 ± 3.06	41.99 ± 3.12	56.60 ± 6.77	599.87 ± 33.74	2.26 ± 0.21
8	18.78 ± 2.59	33.41 ± 2.76	42.27 ± 5.13	279.02 ± 21.50	1.01 ± 0.12
9	23.98 ± 2.23	38.78 ± 2.71	53.84 ± 4.52	443.95 ± 18.75	3.64 ± 0.23
10	15.27 ± 2.03	26.80 ± 3.39	33.88 ± 3.13	318.12 ± 17.27	1.93 ± 0.20
11	20.50 ± 1.62	36.82 ± 2.59	54.13 ± 3.54	300.82 ± 21.05	2.17 ± 0.17
12	16.49 ± 1.62	33.57 ± 2.62	45.11 ± 4.30	348.30 ± 24.42	2.37 ± 0.20
13	24.97 ± 2.46	35.46 ± 3.01	53.70 ± 5.01	447.11 ± 27.34	3.10 ± 0.24
14	21.04 ± 1.96	26.75 ± 2.09	35.21 ± 3.28	370.25 ± 25.84	0.18 ± 0.06
15	25.21 ± 1.97	32.35 ± 2.58	48.48 ± 3.62	435.94 ± 24.52	2.72 ± 0.20
Average	22.13 ± 2.30	38.47 ± 2.72	50.47 ± 4.75	451.90 ± 24.89	2.41 ± 0.18
Range	15.27–27.52	26.75–57.62	33.88–73.76	279.02–647.82	0.18–5.07

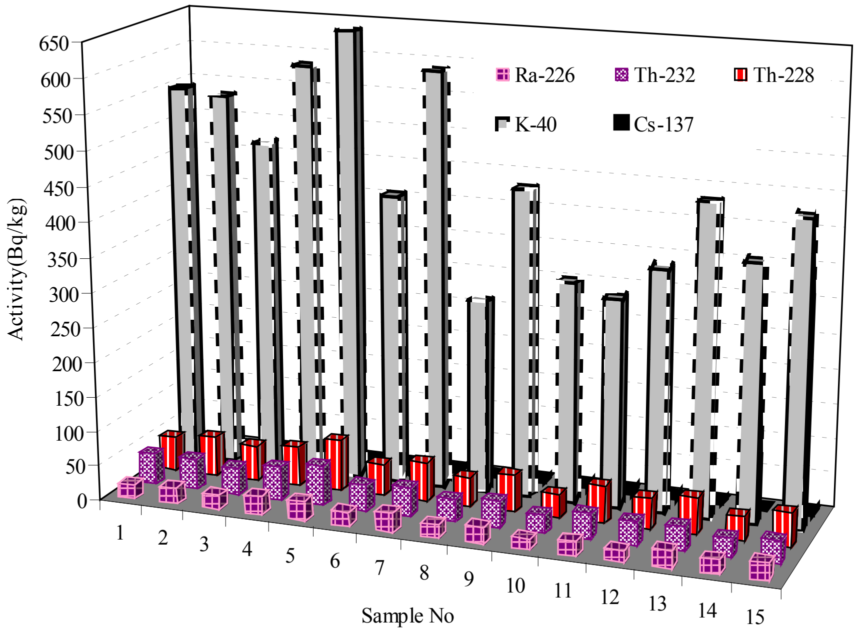

Figure 2: Activity concentrations of radionuclide in different soil samples.

The ^{137}Cs activities were found to vary from 0.18 ± 0.06 to 5.07 ± 0.29 Bq kg^{-1} in different samples, which were very small compared to the specific activities of the other radionuclides. Notably, ^{137}Cs does not exist in soil naturally; the man-made radionuclide deposited in the soil was presumably a result of a nuclear power plant accident and atmospheric nuclear weapon tests around the world. The ^{137}Cs was readily mixed with soil and by rain. However, the potential radiological impact on humans from such low levels of ^{137}Cs is insignificant.[11,12]

Table 3 compares the activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in soil samples observed in the present study with those by other investigators in different locations of the world. In comparison, it was found that the range of ^{226}Ra is lower compared to worldwide values. However, the values for ^{232}Th and ^{40}K were almost matching those of other countries. It was also observed that, the measured ^{137}Cs activity concentration range is below the reported range in Cairo (Egypt), Louisiana (USA), Aoh in Rila Mountain (Bulgaria), Patras Harbour (Greece), Majorca (Spain), Kocaeli Basin (Turkey) and northern Jordan rift valley (Jordan), but is higher than Tamilnadu (India).

Table 3: Comparison of activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs in Bq kg^{-1} in the soil samples of the different parts of the world with the present study.

Region/Country	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	References
Cairo, Egypt	5.3–66.8	5–37.3	41.5–418	0–35.7	13
Taiwan	44.7-10.6	12.2–44.2	195.3-640	0–12.1	14
Louisiana, USA	34-95	4–130	43–719	5–58	15
Argentina	–	–	540–750	–	10
China	2–440	1–360	9–1800	–	10
Hong Kong SAR	20–110	16–200	80–1100	–	10
India	7–81	14–160	38–760	≤1–2.88*	10,16*
Japan	6–98	2–88	15–990	–	10
Korea, Rep. of	–	–	17–1500	–	10
Iran	8–55	5–42	250–980	–	10
Savar, Bangladesh	32–49	19-29	129-527	2–3	17
Denmark	9–29	8–30	240–610	–	10
Belgium	5–50	5–50	70–900	–	10
Luxembourg	6–52	7–70	80–1800	–	10
Switzerland	10–900	4–70	40–1000	–	10
Bulgaria	12–210	7–160	40–800	287.9–827.1*	10;17*
Poland	5–120	4–77	110–970	–	10
Romania	8–60	11–75	250–1100	–	10
Greece	1–240	1–190	12–1570	1.8–11.1*	10, 19*
Portugal	8–65	22–100	220–1230	–	10
Spain	6–250	2–210	25–1650	10–60*	10, 20*
Kocaeli, Turkey	10–58	–	161–964	2–25	21
Jordan	16.3–57.3	7.6–16.2	121.8–244.8	1.9–5.3	22
Present study	15.27–27.52	26.75–57.62	279.02–647.82	0.18–5.07	–
World Average	35	30	400		10

3.2 Variation of Concentration with Depth of the Soil

Table 4 presents the concentrations of radionuclides at different depths. The results are shown in Figure 3 reveals that for all nuclides, the activity concentrations decreases with depth up to 10 cm which support the results of Copplestone et al. After 10 cm, an increase in activity concentrations was observed which contradicts the distribution expected based on earlier studies of undistributed soils collected away from coast.[23] This equate to a variation in activity concentrations (Bq kg^{-1}) from 23.55 (0–5 cm) to 22.94 (15–20 cm) for ^{226}Ra, from 40.07 (0–5 cm) to 40.64 (15–20 cm) for ^{232}Th, from 51.25 (0–5 cm) to 54.74 (15–20 cm) for ^{228}Th, from 472.61 (0–5 cm) to 461.85 (15–20 cm) for ^{40}K and from 2.6 (0–5 cm) to 1.9 (15–20 cm) for ^{137}Cs. Therefore, it can be concluded that the radionuclide distribution at different soil depths is independent of the soil's mineral content and is due to the rapid percolation of water through channels between sand grains which support the results obtained by Copplestone et al.[23]

Table 4: Activity concentrations (Bq kg^{-1}) of radionuclides in different depth of soil sample.

Depth (cm)	Activity (Bq kg^{-1} dry wt)				
	^{226}Ra	^{232}Th	^{228}Th	^{40}K	^{137}Cs
0–5	23.55	40.07	51.25	472.61	2.6
5–10	21.64	35.34	46.83	434.38	1.87
10–15	20.42	37.85	49.07	417.61	2.78
15–20	22.94	40.64	54.74	461.85	1.9

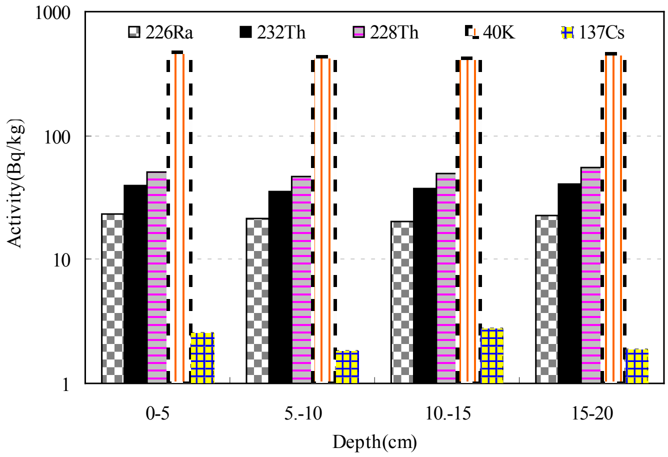

Figure 3: Variation of activity of radionuclides with depth of soil.

3.3 Radionuclide Concentrations in Grass and Transfer Factor (TF)

The results of the activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs radionuclides in 10 grass samples collected from the site of the present study area as well as their TFs are presented in Table 5. It was observed that, the activity concentration varies with grass species and it is different for different radionuclides. For all the species, ^{40}K showed a higher concentration than the other radionuclides which were similar to the results obtained by Karunakar et al.[24] The averages concentration of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs were 1.26 ± 0.11, 3.66 ± 0.31, 7.02 ± 0.49, 134.95 ± 3.68 and 0.17 ± 0.02 Bq kg^{-1} respectively having the order $^{40}K > ^{228}Th > ^{232}Th > ^{226}Ra > ^{137}Cs$.

At 95% confidence level, and considering all the sampling points, the TF values obtained for the two thorium isotopes (^{232}Th and ^{228}Th) are distinguishable statistically, with average values of 0.089 and 0.137 respectively. For grass growing in a hilly area, TF values had been reported three order magnitude lower than those obtained in the present work.[25] Other authors studied the uptake of thorium by thyme, forage and barley stems around a thorium ore deposit, and obtained TF values one order of magnitude lower for washed plants.[26] TF values of between 0.048 and 0.089 for ^{232}Th, and between 1.07 and 2.63 for ^{228}Th were found in a uranium mine for grass-pasture.[27] For different vegetable crops grown on a contaminated lake bed, for ^{232}Th the TF value found by Whicker et al. was in the range of 0.000021 to 0.0023.[28] Finally, the published TF mean value for thorium in grass is 0.011, with a range between 0.0011 and 0.11, compatible with the results obtained in the present work.[9] Almost for all grass, it was seen that the TF values for ^{228}Th is higher by one order of magnitude than that for ^{232}Th. The excess of ^{228}Th in vegetation versus ^{232}Th must be explained by the higher absorption of radium, in particular ^{228}Ra. Therefore, the excess of ^{228}Th arises from ^{228}Ra decay in the plant and the uptake of ^{228}Th itself.[29]

The TF average value for ^{226}Ra in grass was 0.056, which is lower than the value reported in the work by Vera Tomé et al.[27] Similar results were obtained for radium in grass with a TF mean value of 0.08, and a range between 0.016 and 0.4.[30] Lower mean values are usually found for this element both in vegetables and rice (about 0.001).[31] However, the TF values for radium in native plants growing in a uranium mine are in the range 0.07 to 0.15 which is higher than the results obtained in this work.[32]

From the TF values comparison, we can conclude that the uptake of ^{228}Th is higher than those for the other two radionuclides.

Table 5: Activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs radionuclides in grass and their transfer factors.

Grass species	Activity (Bq kg^{-1} dry wt)				
	^{226}Ra	^{232}Th	^{228}Th	^{40}K	^{137}Cs
Allium cepa	0.70 ± 0.13	3.11 ± 0.24	6.14 ± 0.35	95.81 ± 2.04	0.08 ± 0.01
Amaranthus spinosis	1.42 ± 0.26	4.36 ± 0.34	8.08 ± 0.48	180.74 ± 4.26	0.24 ± 0.04
Chenopodium album	1.51 ± 0.15	4.60 ± 0.85	9.21 ± 0.74	205.03 ± 4.64	0.15 ± 0.03
Cynodon dactylon	1.55 ± 0.07	2.89 ± 0.17	6.31 ± 0.20	112.21 ± 2.87	0.32 ± 0.05
Cyperus rotundus	1.47 ± 0.05	2.45 ± 0.17	6.04 ± 0.33	74.28 ± 2.26	BDL
Echinochloa crussgali	1.01 ± 0.15	2.60 ± 0.05	6.82 ± 0.66	120.03 ± 3.01	0.23 ± 0.02
Eleusine indica	1.03 ± 0.06	5.15 ± 0.59	6.54 ± 0.84	146.49 ± 5.85	0.17 ± 0.02
Mimosa pudica	1.32 ± 0.11	3.71 ± 0.12	6.51 ± 0.54	148.47 ± 3.15	BDL
Murdannia nudiflora	1.38 ± 0.10	4.72 ± 0.42	7.48 ± 0.60	140.46 ± 4.08	0.05 ± 0.01
Portulaca oleracea	1.21 ± 0.10	3.08 ± 0.24	7.13 ± 0.21	126.02 ± 4.68	0.13 ± 0.03
Average	1.26 ± 0.11	3.66 ± 0.31	7.02 ± 0.49	134.95 ± 3.68	0.17 ± 0.02
			TF values		
Allium cepa	0.045	0.116	0.181	0.301	0.041
Amaranthus spinosis	0.052	0.090	0.141	0.304	0.053
Chenopodium album	0.054	0.079	0.124	0.316	0.047
Cynodon dactylon	0.075	0.078	0.135	0.268	0.063
Cyperus rotundus	0.078	0.073	0.142	0.266	NM
Echinochloa crussgali	0.042	0.067	0.126	0.270	0.063
Eleusine indica	0.038	0.122	0.115	0.244	0.075
Mimosa pudica	0.056	0.084	0.114	0.272	NM

(*continued on next page*)

Table 5: (*continued*)

Grass species	Activity (Bq kg^{-1} dry wt)				
	^{226}Ra	^{232}Th	^{228}Th	^{40}K	^{137}Cs
Murdannia nudiflora	0.069	0.104	0.152	0.255	0.034
Portulaca oleracea	0.058	0.079	0.140	0.262	0.062
Average	0.056	0.089	0.137	0.275	0.054

Note: BDL – Below detection limit, NM – Not measured

3.4 Radionuclide Concentrations in Plant and Transfer Factors (TF)

The activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs radionuclides in branches and leaves of different plant species are presented in Table 6. It can be observed from the results of ^{226}Ra that the concentration in branches of a particular plant species is higher than the leaves of the same plant except *Solanum nigram* which showed a higher concentration in leaves. Similar observation had also been reported by Karunakara et al.[24] The reported values of ^{226}Ra activity in stem and leaves of *Clerodendrum viscosum vent*. (Ittovu) from Kaiga region, India was 5.9 ± 0.9 and 4.6 ± 1.1 Bq kg^{-1} dry wt respectively.[24]

Continuous accumulation of ^{226}Ra through root uptake may be the reason for the higher concentration level in branches.

The actual concentration of radium in the part of the plant species depends on the radium content of soil, including its availability to the plant and the metabolic characteristics of the plant species. In view of the fact that the radium content of soil varies fairly widely, corresponding variations in radium levels in land crops may be expected. Chemical factors such as the amount of exchangeable calcium in the soil will determine the rate at which radium will be absorbed by plants.[33]

Table 6: Activity concentrations of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs radionuclides in plant and transfer factors.

Plant species	Plant part	Activity (Bq kg^{-1} dry wt)				
		^{226}Ra	^{232}Th	^{228}Th	^{40}K	^{137}Cs
Acalypha indica	Leaves	0.91 ± 0.11	3.02 ± 0.13	5.30 ± 0.26	92.51 ± 1.96	0.18 ± 0.05
	Branch	1.05 ± 0.15	3.29 ± 0.11	6.55 ± 0.29	94.66 ± 2.10	0.18 ± 0.04
Bacopa monniera	Leaves	1.02 ± 0.13	2.72 ± 0.14	4.51 ± 0.10	90.23 ± 2.03	BDL
	Branch	1.57 ± 0.15	2.89 ± 0.25	4.97 ± 0.18	94.12 ± 2.34	BDL
Lantana camera	Leaves	1.26 ± 0.16	3.71 ± 0.03	7.06 ± 0.22	92.38 ± 2.68	BDL
	Branch	1.44 ± 0.22	4.00 ± 0.14	7.76 ± 0.24	95.63 ± 3.06	BDL
Solanum nigram	Leaves	1.40 ± 0.20	2.29 ± 0.08	5.98 ± 0.51	104.59 ± 3.30	0.22 ± 0.02
	Branch	1.12 ± 0.17	3.03 ± 0.30	4.61 ± 0.40	107.30 ± 3.19	0.20 ± 0.05
Syndrella nodiflora	Leaves	1.35 ± 0.13	2.87 ± 0.19	7.45 ± 0.22	124.11 ± 4.76	0.11 ± 0.04
	Branch	1.54 ± 0.24	3.04 ± 0.24	8.14 ± 0.44	126.24 ± 5.06	0.15 ± 0.03
Average in leaves		1.18 ± 0.14	2.92 ± 0.11	6.06 ± 0.26	100.76 ± 2.04	0.17 ± 0.03
Average in branches		1.34 ± 0.18	3.25 ± 0.20	6.40 ± 0.31	103.59 ± 3.15	0.17 ± 0.04
TF values						
Acalypha indica	Leaves	0.055	0.089	0.117	0.265	0.075
	Branch	0.063	0.098	0.145	0.271	0.075
Bacopa monniera	Leaves	0.048	0.101	0.128	0.243	NM
	Branch	0.074	0.108	0.141	0.254	NM
Lantana camera	Leaves	0.061	0.100	0.130	0.037	NM
	Branch	0.070	0.108	0.143	0.317	NM
Solanum nigram	Leaves	0.056	0.064	0.111	0.233	0.070
	Branch	0.045	0.085	0.085	0.239	0.064
Syndrella nodiflora	Leaves	0.053	0.088	0.153	0.284	0.040
	Branch	0.061	0.093	0.167	0.289	0.055
Average in leaves		0.054	0.088	0.127	0.266	0.061
Average in branches		0.062	0.098	0.136	0.274	0.064

BDL-Below detection limit, NM- Not measured

The values of ^{232}Th activity concentration in branches and leaves of plant species varied from 2.89 ± 0.25 to 4.00 ± 0.14 Bq kg^{-1} and 2.29 ± 0.08 to 3.71 ± 0.03 Bq kg^{-1} respectively. In the present study, ^{232}Th activity was observed to be higher in plant branches than leaves. The maximum concentration of ^{232}Th activity was observed in *Lantana camera* branch and it is 4.00 ± 0.14 Bq kg^{-1}. In all plants species ^{228}Th activity concentrations were higher than thase of ^{232}Th. The highest concentration of 8.14 ± 0.44 Bq kg^{-1} was observed in *Syndrella nodiflora* branch.

The results of ^{40}K measurements in various plant species are presented in column 4, Table 6. All the species show a considerable amount of ^{40}K in branches and leaves and it varied from 90.23 ± 2.03 to 126.24 ± 5.06 Bq kg^{-1}. The ^{40}K content of branches is higher when compared to leaves. It is reported that the ^{40}K activity in banana leaves from Rawatbhata environment was 1220.9 Bq kg^{-1} and in Mango tree leaves from Kaiga environment it varied from 141.9–837.7 Bq kg^{-1}.[33,34] In the present study, maximum concentration of ^{40}K activity is observed in *Syndrella nodiflora* branches whereas minimum concentration is observed in *Bacopa monniera* leaves. As discussed in the case of ^{226}Ra, this may be due to the continuous accumulation of ^{40}K through root uptake over a period of time. It is well known that as an essential element of metabolism, plants take up potassium from soil in varied amounts depending upon their metabolism and ^{40}K respectively.[24]

Column 5, Table 6 presents the range of ^{137}Cs activity in leaves and branches of different plant species from Chittagong environment. ^{137}Cs activity in plant leaves is in the range of BDL to 0.22 ± 0.02 Bq kg^{-1} and for branches it varies from BDL to 0.20 ± 0.05 Bq kg^{-1}. Joshi et al. reported that ^{137}Cs activity in the leaves of *Mangifera indica* (Mango) and congress leaves was in the range of 0.4–2.8 Bq kg^{-1} and 2.5–5.8 Bq kg^{-1} at Kaiga, India. In the same area, the ^{137}Cs activity in the mango leaves was in the range of 0.7 to 1.2 Bq kg^{-1} and in the leaves of *Tectona grandis Lf*, it was in the range of 3.10–3.42 Bq kg^{-1}. In the present study, for different plant species, the TF for ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs were found to have the ranges of 4.5×10^{-2}–7.4×10^{-2}, 6.4×10^{-2}–10.8×10^{-2}, 8.5×10^{-2}–16.7×10^{-2}, 3.7×10^{-2}–31.7×10^{-2} and 4×10^{-2}–7.5×10^{-2} respectively.[33,35] The TF of ^{226}Ra for aerial part of pasture from Mediterranean grass land ecosystem was reported to be 0.11 ± 0.06.[36] It can be observed that the TF for plant branches are relatively higher when compared to that for leaves except for *Solanum nigram*. Further, the TF for ^{40}K was significantly higher than that the other radionuclides which suggests higher levels of uptake of ^{40}K. It is interesting to note that although all the plant species are grown in soils of similar characteristics, the TFs are different for different species. TFs of ^{226}Ra for plant leaves vary from 0.03 to 0.65 in the Kaiga region.[33]

Soil-to-plant TF of ^{226}Ra for crop plants were found to range from 0.009 to 0.276 and for grass pasture near a uranium mine area was reported to vary from 0.097 to 0.504.[27,37] IAEA has compiled soil-to-plant TF of ^{226}Ra for leaves of herbs from tropical environment and the mean value reported is 0.11 with a minimum of 1.1×10^{-2} and maximum of 1.0.[38] The observed values of soil-to-plant TF in the present study are within the range of reported values.

TFs corresponding to ^{232}Th and ^{228}Th are distinguishable with an average of 0.088 and 0.127 for plant leaves, and 0.098 and 0.136 for plant branches. The

TF values for soil to branch were slightly higher than those of soil to leaves for all species except *Solanum nigram*. TF of ^{232}Th was found at maximum in *Bacopa monniera* branches and minimum in *Solanum nigram* leaves while for ^{232}Th it was the highest in *Syndrella nodiflora* branches and the lowest in *Solanum nigram* branches. For edible vegetables growing in an area of enhanced natural radioactivity, TF values were reported three orders of magnitude lower than those obtained in this study (mean value of 6×10^{-5}).[25] TF values between 0.013 and 0.270 for ^{232}Th, and 0.0.517 to 4.31 for ^{228}Th were found in a uranium mine for grass-pasture.[27] The mean TF value for thorium in grass is 0.011, with a range between 0.0011 and 0.11, compatible with the results obtained in this present work.[9] The higher TF values of ^{228}Th in plant species versus ^{232}Th may be explained by the higher absorption of radium, in particular ^{226}Ra. Therefore, the excess of ^{228}Th arises from ^{226}Ra decay in the plant and the uptake of ^{228}Th itself.[27]

Soil-to-leaf TF of ^{40}K calculated for plant leaves were found to vary from 0.037 to 0.284 and in branches it varied from 0.271 to 0.317. The reported geometric mean value of transfer coefficient of ^{40}K for banana leaves from Rawatbhata environment[29] is 2.42. Soil-to-leaf TF for teak leaves from Kaiga, India[33] is reported as 1.95. The variation observed in TFs for the same species is due to various factors such as age of the plant/tissue and the environment in which the plant is grown. Patra reported that the extent of absorption of minerals and its distribution in the plant depends upon the bioavailability of the minerals in the soil, structure of root and shoot system.[19] The data compiled by IAEA[38] for soil to plant transfer factor of ^{40}K in leaves was in the range of 0.49–5.6 with a mean of 1.4. In the present study the mean values of TF for each plant species was found to be lower than IAEA value. TF value of ^{40}K activity in plant branches was found to be higher than that of plant leaves.

Soil-to-leaf and branch TF of ^{137}Cs for different plant species was calculated by using ^{137}Cs activity concentration in plant leaf and branch, and the mean value of ^{137}Cs activity in soil. As shown in Table 6, TF value for ^{137}Cs is in the range of 0.04–0.266. Al-Qudar et al. reported that geometric mean of the soil-to-branch TF of ^{137}Cs for Olive tree is 1.55 and for soil to leaves it is 2.06.[39] The reported average TF value of ^{137}Cs for rice[7] from Dhaka, Bangladesh is 1.9×10^{-2} and for tomato[5] it is 0.28. TF of ^{137}Cs for branches show slightly higher value of TF than leaves as shown in Figure 4. TF factor for ^{137}Cs is found to be less than that of ^{232}Th, ^{228}Th and ^{40}K in all plant species. This indicates that ^{137}Cs is less efficiently transported from soil to plants than ^{232}Th, ^{228}Th and ^{40}K. It was reported that soil-to-plant TF depends on soil properties such as nutrient standard, exchangeable K content, pH and moisture content.[40] In the present study, the average values of transfer factors plant parts was found to be in close agreement with IAEA[38] mean value of ^{137}Cs for leaves of herbs which was in the range of 0.02–3.2.

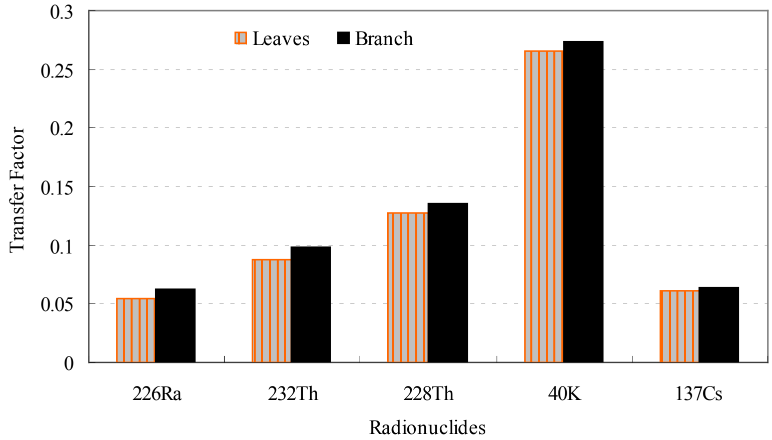

Figure 4: TF of radionuclides for different parts of plant.

4. CONCLUSION

The activity concentration of naturally occurring and anthropogenic radionuclides in soil, grass and plant, and TF for grass and plant were measured in Chittagong city of Bangladesh. ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs activity in soil sample are 22.13 ± 2.30, 38.47 ± 2.72, 50.47 ± 4.75, 451.90 ± 24.89 and 2.41 ± 0.18 Bq kg^{-1} respectively while in grass they have the values of 1.26 ± 0.11, 3.66 ± 0.31, 7.02 ± 0.49, 134.95 ± 3.68 and 0.17 ± 0.02 Bq kg^{-1} respectively. In branches of the plant, the average activity of ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs are 1.34 ± 0.18, 3.25 ± 0.20, 6.40 ± 0.31, 103.59 ± 3.15 and 0.17 ± 0.04 Bq kg^{-1} respectively which are higher than plant leaves. Soil-to-grass TF for ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs at the study area are 0.056, 0.089, 0.137, 0.275 and 0.054 respectively. Soil-to-leave TF for ^{226}Ra, ^{232}Th, ^{228}Th, ^{40}K and ^{137}Cs are 0.054, 0.088, 0.127, 0.266 and 0.061 respectively which are lower than the corresponding values of 0.062, 0.098, 0.136, 0.274 and 0.064 for branches. In grass, the TF varies in the order of ^{40}K > ^{228}Th > ^{232}Th > ^{226}Ra > ^{137}Cs and in all plant species it is in the order of ^{40}K > ^{228}Th > ^{232}Th > ^{137}Cs > ^{226}Ra. The studied radionuclides are of radiological importance to human; water and aquatic lives. Thus, the collected data from this study will help to develop a reference database on this important issue so that any change in this respect in future due to nuclear phenomenon can be ascertained and radiation safety measurements may be taken accordingly.

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