SJSS
SPANISH JOURNAL OF SOIL SCIENCE

Transfer of natural radionuclides from soil to plants in Savar Dhaka

Transferencia de radionucleidos naturales del suelo a plantas en Savar Dhaka
Transferência de radionuclídeos naturais do solo para as plantas em Savar Dhaka

AUTHORS

Haque M.[@,1]
munima.haque@gmail.com

Ferdous M. J.[2]

[@] Corresponding Author

[1] Department of Electrical and Electronic Engineering, Southeast University, Permanent Campus, 251/A & 252. Tejgaon Industrial Area, Dhaka-1208, Bangladesh.

[2] Health Physics Division, Atomic Energy Centre. Dhaka, Bangladesh.

Received: 17.07.2016 | **Revised:** 03.05.2017 | **Accepted:** 30.05.2017

ABSTRACT

The radioactivity of environmental samples from nuclear reactor sites must be analyzed before the public is given free access to the plants grown in these soils. Plant and corresponding soil samples were collected from a sample site around the Savar research reactor near Dhaka (Bangladesh) and the activity concentrations of natural radionuclides ^{226}Ra (^{238}U-chain), ^{228}Ra (^{232}Th-chain) and non-chained ^{40}K were measured using gamma ray spectrometry. Soils of Savar contained more radioactive ^{40}K than ^{226}Ra and ^{228}Ra. The influence of certain soil properties on the activity concentrations and transfer factors (TF) of natural radionuclides were investigated by correlating the observed data with those of soil properties. The activity concentrations of ^{40}K were much higher than those of ^{226}Ra and ^{228}Ra in plants due to higher uptake from soils. The transfer factors for ^{226}Ra, ^{228}Ra and ^{40}K were found to range from 0.04 to 0.10, 0.12 to 0.32, and 0.24 to 0.72, respectively. The soil to plant transfer factors for ^{40}K was found to be much higher in plants, which might be due to this element being vital in plants. This study showed that activity concentrations of these radionuclides in plants and their plant transfer factors seem to depend on the activity concentrations of the same radionuclides in soil.

RESUMEN

Es necesario analizar la radioactividad de muestras medioambientales procedentes de emplazamientos de reactores nucleares antes de que el público en general tenga libre acceso a las plantas que crecen en sus suelos. Se muestrearon plantas y sus correspondientes suelos en los alrededores del reactor Savar, cerca de Dhaka (Bangladesh), y se midieron las concentraciones de actividad de los radionucleidos naturales ^{226}Ra (de la cadena del ^{238}U), ^{228}Ra (de la cadena del ^{232}Th) y ^{40}K utilizando espectrometría de rayos gamma. Los suelos de Savar contenían más ^{40}K radioactivo que ^{226}Ra y ^{228}Ra. Se investigó la influencia de algunas propiedades del suelo sobre las concentraciones de actividad y los factores de transferencia (TF) de estos radionucleidos naturales. Las concentraciones de actividad de ^{40}K en plantas fueron mucho más elevadas que las de ^{226}Ra y ^{228}Ra debido a su mayor absorción por las plantas a partir del suelo. Los factores de transferencia para ^{226}Ra, ^{228}Ra y ^{40}K variaron entre 0,04 y 0,10, entre 0.12 y 0.32, y entre 0.24 y 0.72, respectivamente. Se encontró que los factores de transferencia de suelo a planta para el ^{40}K eran mucho más elevados en plantas, lo que puede ser atribuido a que este elemento es esencial para las plantas. Este estudio mostró que las concentraciones de actividad de estos radionucleidos en plantas y sus factores de transferencia a las mismas parecían depender de sus concentraciones de actividad en el suelo.

RESUMO

A radioatividade de amostras ambientais provenientes de áreas onde se localizam reatores nucleares deve ser analisada antes que o público tenha livre acesso às plantas que crescem nos solos dessas áreas. Colheram-se amostras de plantas e de solos onde estas crescem na envolvente do reator Savar localizado perto de Dhaka (Bangladesh) e

DOI: 10.3232/SJSS.2017.V7.N2.05

foi medida a concentração da atividade dos radionuclídeos naturais ^{226}Ra (cadeia do ^{238}U), ^{228}Ra (cadeia do ^{232}Th) e do ^{40}K por espetrometria de raios gama. Os solos de Savar contêm mais ^{40}K radioativo do que ^{226}Ra e ^{228}Ra. Foi investigada a influência de algumas propriedades do solo na concentração da atividade e fatores de transferência (TF) dos radionuclídeos naturais. Nas plantas, a concentração da atividade do ^{40}K foi muito mais alta do que a do ^{226}Ra e do ^{228}Ra devido à sua maior capacidade de absorção pelas plantas a partir dos solos. Os fatores de transferência para ^{226}Ra, ^{228}Ra e ^{40}K variaram entre 0,04 e 0,10, 0,12 e 0,32, e 0,24 e 0,72, respetivamente. Os fatores de transferência solo-planta para o ^{40}K são muito mais altos, pelo facto de este elemento ser essencial para as plantas. Este estudo mostrou que as concentrações da atividade destes radionuclídeos nas plantas e os seus fatores de transferência parecem depender da concentração da atividade dos mesmos radionuclídeos nos solos.

KEY WORDS
Radioactivity concentrations, soil parameters, transfer factors.

PALABRAS CLAVE
Concentraciones de radioactividad, parámetros del suelo, factores de transferencia.

PALAVRAS-CHAVE
Concentrações da atividade dos radionuclídeos, propriedades do solo, fatores de transferência.

1. Introduction

Soil-plant-man is recognized as a major pathway for the transfer of radionuclides to human beings (IAEA 1982). The radioactivity of environmental samples from sites and products suspected of contamination must be investigated before free access to them is given to the public (Owono 2010). Both routine and accidental release of nuclear waste can result in radionuclides moving into the environment and ground. The plants acquires deposited radionuclides from soil, named as soil -to-plant transfer factor (TF), which is extensively 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 (IAEA 1994). This TF is essential for environmental transfer models, which are useful in the prediction of radionuclide concentration in agricultural crops for estimating dose impact to human being (Chakraborty et al. 2013). Radionuclides in soils are frequently transferred to different plant tissues by direct transfer via the root system, or by fallout of radionuclides and re-suspension of contaminated soil followed by deposition on plant leaves (Noordijk et al. 1992). The uptake of radionuclides from soil to plant is characterized by the Transfer Factor (TF): the ratio of radionuclide concentration in plant to soil per unit mass (Staven et al. 2003; Yassine et al. 2003). The TF is usually used for assessing the impact of radionuclide releases into the environment. Due to a predicted long term transfer of radionuclides in the environment due to longevity of these radionuclides, knowledge of the geochemical and ecological cycles is also needed as they relate to the behavior of not only radionuclides but also associated elements. In general, transfer factors show a wide range of variations depending upon several factors including soil properties such as pH, clay mineral, Ca, K and organic matter content, species of plants and other environmental conditions (IAEA 1990). Maintaining reference-data records will assist in ascertaining possible changes in environmental radioactivity due to nuclear, industrial, and other human activities.

Natural radioactivity in various soil and plant samples has been collected and analyzed in different countries using various techniques. Soil and food crop samples were collected and tested for radioactivity concentrations of ^{226}Ra, ^{228}Th, and ^{40}K in Nigeria (Jibiri et al. 2007). In Saudi Arabia, the natural radiation levels in soil and sediment samples were collected and tested for activity concentrations of ^{214}Pb, ^{214}Bi, ^{228}Ac, ^{208}Tl, ^{40}K, ^{226}Ra and ^{228}Ra (Mohery et al. 2014). Also in India, the activity concentrations and the gamma-absorbed dose rates of the terrestrial naturally occurring radio nuclides ^{226}Ra, ^{232}Th and ^{40}K were determined in soil samples collected from some areas of Punjab and Himachal Pradesh, using gamma ray spectrometry (Singha et al. 2005). The activity concentrations of naturally occurring radionuclides (^{238}U, ^{226}Ra, ^{228}Ra, ^{210}Pb and ^{40}K) in Jordanian phosphate ore, fertilizer material and phosphogypsum piles were investigated (Al-Jundi et al. 2008). Natural radioactivity was tested in foods and drinks in Hong Kong (Yu and Mao 1999). Air, water and soil samples were tested for natural radioactivity for Sanliurfa province of southeastern Turkey (Bozkurt et al. 2007). The concentrations of the natural radionuclides (^{226}Ra, ^{228}Ra, and ^{40}K) and the artificial radionuclide (^{137}Cs) in leek and parsley in Tehran province-Iran were determined using HPGe (Changizi et al. 2010). The activity concentrations of ^{238}U, ^{232}Th and ^{40}K were surveyed and analyzed in granitoid samples from all over the region of Kestanbol Granitoid, Turkey by HPGe gamma spectrometry (Canbaz et al. 2010). Natural radioactivity in Spanish soils was also analyzed (Quindos et al. 1994). The activity concentration of ^{226}Ra (^{238}U) series, ^{232}Th series and ^{40}K were measured using a gamma-ray spectrometer. The activities of uranium isotopes (^{238}U, ^{235}U and ^{234}U) and ^{210}Pb were measured using an alpha spectrometer and a low-background proportional gas counting system, respectively, after radiochemical separation (Khatera et al. 2001). Annual intakes of ^{226}Ra, ^{228}Ra and ^{40}K in staple foodstuffs from a high background radiation area in the southwest region of Cameroon were studied by Abiama group (Ele Abiama et al. 2012).

As countries in the South Asian region like Bangladesh expand applications of nuclear technology, the Transfer Factors of the radionuclides in soil to the crops are viewed as one of the most significant parameters in environmental safety estimation of nuclear facilities (Chibowski 2000). To know that it is safe to have the reactor active and the soil to plant transfer factor is within limit is important for the plant to function long term for the safety of the living systems living around the nuclear reactor. Over the years, some work on the transfer or pathway mechanism of naturally occurring radionuclides to plants and human population have been reported but data are still very scarce in this area particularly in Bangladesh. The radioactivity of soils and plants were analyzed in Bangladesh (Gaffar et al. 2014). As not all soils have the same amount of natural radionuclides present, the uptake in plants also differs resulting in diverse public dose rates. This is a simplified way to explain the situation. The aim of the present investigation was to measure activity concentrations of naturally occurring radionuclides present in the soil and plant and to determine the soil-to-plant Transfer Factors of ^{226}Ra, ^{228}Ra and ^{40}K of some plants consumed as staple by the populations in the north-western parts of Dhaka, mainly Savar. This is an area around the nuclear research reactor in Savar, Dhaka. An investigation of this nature is useful for both the assessment of public dose rates and the performance of epidemiological studies.

2. Materials and methods

2.1. Location

Bangladesh is located at 23.6850° N, 90.3563° E. It is lower lying than India and so it is highly possible that Bangladesh is suffering from radioactivity due to the situation of the source of the rivers in India (Chabaux et al. 2001). There are also some rivers that are situated in Nepal, Bhutan and flow through India. Therefore its land might be contaminated by radioactive sources from upstream. In this present research, the soil samples are collected from one of the most significant regions Savar in Bangladesh. It is located at the latitude and longitude coordinates of 23°58' N and 90°20' E. The water from coal mines runs off into agricultural fields and rivers. This coal mixed water is used for various purposes in these regions. Coal is a major source of radioactive materials released to the environment and coal combustion is more hazardous to health. Coal is mixed with the oxides of silicon, aluminum, iron, calcium, magnesium, titanium, sodium, potassium, arsenic, mercury, and sulfur plus small quantities of uranium and thorium. As there are radioactive elements of uranium and thorium groups mixed in coal, so coal can become a concern.

Naturally occurring radionuclides such as ^{238}U, ^{232}Th and ^{40}K and their progeny present in soil causes radiation exposure for the population. The activity concentrations of these nuclides are measured in many countries of the world including Bangladesh in order to monitor radiation level in the environment. Several studies have been carried out to determine the activity of naturally occurring radionuclides in the soil samples throughout Bangladesh and to derive the radiation hazard parameters to establish the radiation background database. There has not been much study of the northern part of Bangladesh. Along with natural radionuclides, we planned to detect ^{226}Ra, ^{228}Ra and ^{40}K in the soil samples near the Savar Research Reactor regions. There are many principles, methods and techniques used to determine the amount of radioactivity in the environment. One of the widely used techniques is gamma-ray spectrometry (Ebaid 2010) which is common to all low-level radioanalysis and can be applicable to other environment contaminants. We planned to carry out the measurements using high resolution γ-ray spectroscopy with an HPGe detector in a low background configuration in Health Physics Division, Atomic Energy Centre (AEC), Dhaka.

2.2. Sample collection

Sampling site was selected in the North-western part of Dhaka for the collection of plants (vegetables) and soil samples. **Figure 1** shows the sampling sites of Savar (latitude 23°58' N and longitude 90°20' E). Plant and soil samples were collected in February 2016 from location in the selected sites of North-western part of Dhaka, Savar nuclear research reactor. The geographical representations of the locations are shown in **Figure 1**. All the locations selected for plant and soil sample collection were on agriculture land. Plants commonly grown and consumed were collected in the harvesting season. To ensure sufficient representation, ten plants from the different sampling sites near Savar Research Reactor were collected. Crops from Savar included pointed gourd (*Trichosanthes dioica*; P_1), carrot (*Daucus carota*; P_2), papaya (*Carica papaya*; P_3), green banana (*Musa acuminata*; P_4), radish (*Raphanus sativus*; P_5), brinjal (*Solanum melongena*; P_6), bitter gourd (*Momordica charantia*; P_7), cauliflower (*Brassica oleracea var botrytis*; P_8), potato (*Solanum tuberosum*, P_9) and okra (*Abelmoschus esculentus*, P_{10}). About 5-7 kg (on fresh weight basis) of edible parts of the plants was collected.

Approximately 1 kg of soil surrounding the roots of corresponding plants was collected at a depth of 0 to 15 cm from each sampling site in Savar. All soil samples were carefully collected by using a shovel. The collected soil samples depict the major soil category of the area. The samples were packed in dried acetone-cleaned polyethylene bags. The bags were then labeled with sample codes and sealed.

Figure 1. Map showing sampling sites at Savar (left map). The right map is of Bangladesh.

The labels included soil sample ID and location. Finally, the samples were transferred to the radiation detection laboratories of the Health Physics division, Atomic Energy Centre (AEC), Bangladesh.

2.3. Sample preparation

Plant samples were cut into small pieces and primarily dried in air by spreading on separate sheets of brown paper. The samples were then dried in an electric oven at 70 ºC until friable. Then the samples were ground to powder by a grinder. Each of the collected soil samples were air dried by spreading on separate sheets of paper after it was transported to the laboratory. After air drying, the larger aggregates were broken by gentle crushing with a hammer. The soil samples were then dried in an electric oven at 105 ºC and sieved through a 2 mm sieve. The properties of soil were determined by standard methods as used by BAEC, Dhaka (Gaffar et al. 2014). The soil samples contained sand, silt and clay. The pH (H_2O) values ranged from 5.0-8.0. Organic matter (%) of the soil samples ranged from 1-2.5. Each of the plant and soil samples was transferred to cylindrical plastic containers of approximately equal size and shape. In order to maximize counting efficiency and precision and to minimize self-absorption for that specific geometry, containers of identical size and shape were used. The containers were then sealed tightly, wrapped with thick vinyl tapes around their screw necks, and stored for at least four weeks to reach equilibrium between the ^{238}U (^{226}Ra) and ^{232}Th (^{228}Ra) their respective progenies prior to measurement (Kabir et al. 2009).

2.4. Radioactivity measurements

Radioactivity in soil and plant samples was measured by a gamma ray spectrometry system consisting of a High Purity Germanium (HPGe) detector, a detector shield (lead and steel), a preamplifier, a linear amplifier, high voltage power supply, a multichannel analyzer system and a printer. A picture of the whole detector system is shown in **Figure 2**. The mass of the samples varied because of the varying density of the sample material but the counting time was 5000 s for each sample. Different masses gave the same geometry (depth) across all the samples. Direct determination of 226Ra and 228Ra in the samples without any chemical treatment using semiconductor γ-ray spectrometer is difficult because radionuclides do not emit any intensive γ-rays (lines) of their own. They have several progenies which have more intensive lines and activities equal to their parents in the state of equilibrium (Bunzl and Trautmannsheimer 1999). As a result, the measurements of the radionuclides relied on detecting emissions from their progenies. The radioactivity concentration of the natural radionuclides in these samples was determined from the following peaks: ^{226}Ra was determined from γ-ray energies of its daughter ^{214}Bi (609.31 keV) while the ^{228}Ra was determined from γ-ray energies of its daughter ^{228}Ac (911.07 keV). The radioactivity concentration of ^{40}K was determined from the γ-ray energy of 1460.80 keV. The efficiency calibration of the detector was performed by using standard sources. Having established the efficiency curve, the measurements of radioactivity in plant and soil samples were carried out. Prior to sample counting, two background counts (owing to naturally occurring radionuclides in the environment around the detector) were taken twice during weekends for 5000 s each, and the average of this background was then subtracted from the samples counted during that week. Having determined the integral counts under the interested gamma-energy peaks, the gamma activity was calculated based on the measured efficiency of the detector from the following equation (Sheppard and Evenden 1988):

$$A = \frac{C}{\varepsilon(E) \times P\gamma(E) \times W}$$

where, A is the activity in Bq/kg; C is the net gamma counting rate in count per second (cps); ε(E) is the efficiency of the detector at energy E (keV); Pγ is the photon emission probability at energy E (keV) intensity of the radionuclide and W is the dry mass of the sample.

Figure 2. A coaxial high purity germanium (HPGe) detector and a set of shielding (a) door closed tightly against shield body (b) liquid nitrogen cryostat (c) detector located near center of shield volume (d) cylindrical lead material and (e) an inner layer of copper.

2.5. Transfer Factors

The soil-to-plant transfer factor (TF) of radionuclides was calculated as the ratio of the activity concentration in the edible part of the plant (in Bq/kg dry weight) to the activity concentration in the soil (in Bq/kg dry weight) according to the equation (Noordijk et al. 1992):

$$TF = \frac{\text{Activity concentration in plant } (Bq/kg \text{ dry weight of plant})}{\text{Activity concentration in soil } (Bq/kg \text{ dry weight of soil})}$$

The radioactivity measurements and transfer factor were calculated and given in **Table 1**.

3. Results

3.1. Radioactivity concentration of ^{226}Ra, ^{228}Ra and ^{40}K

The activity concentrations of ^{226}Ra (^{238}U Chain) for soils of Savar were found to be within the range of 42.43±0.05 to 65.39±0.05 Bq/kg (**Table 1**). The average value for ^{226}Ra of the Savar soils was found to be 52.07±0.05 Bq/kg which is higher than the range of the world average of 35 Bq/kg (UNSCEAR 2000). The average activity concentration of ^{228}Ra (^{232}Th Chain) in soils from Savar was 77.35±0.10 Bq/kg with a range of 52.23±0.10 to 104.13±0.16 Bq/kg. All of the soils contained relatively high levels of ^{228}Ra compared to the world average value of 40 Bq/kg (UNSCEAR 2000). The radioactivity concentration of ^{40}K (non-chained) ranged from 742.18±0.87 to 1025.40±0.92 Bq/kg with an average value of 892.65±0.90 Bq/kg which is relatively much higher than the world average of 400 Bq/kg (UNSCEAR 2000).

Radioactivity of ^{226}Ra, ^{228}Ra and ^{40}K was also measured in edible parts of plants corresponding to the soils collected from Savar, Dhaka and given in **Table 1**. Results revealed that the concentration of ^{226}Ra in the vegetable samples varied between 2.01±0.03 and 4.57±0.04 Bq/kg with an average value of 3.34±0.04 Bq/kg. The maximum activity was found in Carrot (*Daucus carota*; P_2) (4.57±0.04) and minimum ^{226}Ra was found in Bitter gourd (*Momordica charantia*; P_7) (2.01±0.03). The activity of ^{228}Ra ranged from 9.38±0.08 to 23.10±0.09 Bq/kg with an average value of 13.36±0.08 Bq/kg. The activity concentrations of ^{228}Ra in vegetables were higher than those of ^{226}Ra. Of all the plants, the lowest accumulator of ^{228}Ra was Okra (*Abelmoschus esculentus*; P_{10}) (9.38±0.08 Bq/kg) and the highest as Green banana (*Musa acuminata*; P_4) (23.10±0.09) (**Table 1**). Activity concentrations of ^{40}K varied widely depending on plant type. Concentration of ^{40}K in plants ranged from 207.70±0.78 to 537.39±0.84 Bq/kg with an average value of 329.26±0.78 Bq/kg. Papaya (*Carica papaya*; P_3) was the highest (537±0.84 Bq/kg) accumulator of ^{40}K and the lowest was in Bitter gourd (*Momordica charantia*; P_7) (207.70±0.78 Bq/kg). Among the investigated radionuclides, ^{40}K was found to accumulate in large amounts in different vegetables. This higher activity of ^{40}K might be attributed to the higher biological requirement of plants for potassium as it is a major essential nutrient element.

At 95% confidence interval, in soils it ranged from 51.87-52.27 Bq/kg for ^{226}Ra, 77.15-77.55 Bq/kg for ^{228}Ra, and 890.89-894.89 Bq/kg for ^{40}K. Also for plants, at 95% confidence interval, it ranged from 3.26-3.42 Bq/kg for ^{226}Ra, 13.20-13.52 Bq/kg for ^{228}Ra, and 327.73-330.79 Bq/kg for ^{40}K.

Figure 3 shows that the activity of ^{228}Ra (^{232}Th chain) was higher than that of ^{226}Ra (^{238}U Chain) in soils of Savar, which is evident from the fact that thorium is 1.5 times higher than that of uranium in the Earth's crust (Kabir et al. 2009). It was also observed that the measured activity of ^{40}K (non-chained) markedly exceeded the values of both ^{228}Ra and ^{226}Ra as it is the most abundant radioactive element present in the environment. It can be seen from **Figure 4** that ^{40}K activity in plants was much higher than the activity of ^{226}Ra and ^{228}Ra in Savar. This high accumulation may be due to higher biological requirements of ^{40}K; also plants have the tendency to take up soluble potassium far in excess of their needs if sufficiently large quantities are present, termed

Table 1. Activity concentration of natural radionuclides in vegetable and corresponding soil samples and transfer factors from Savar, Dhaka

Sample Code	Activity concentration in plants (Bq/kg)			Activity concentration in soil (Bq/kg)			Transfer Factor (TF)		
	^{226}Ra	^{228}Ra	^{40}K	^{226}Ra	^{228}Ra	^{40}K	^{226}Ra	^{228}Ra	^{40}K
Pointed gourd (*Trichosanthes dioica*; P_1)	3.63±0.04	11.72±0.08	261.43±0.79	42.43±0.05	74.33±0.11	929.54±0.90	0.09	0.16	0.28
Carrot (*Daucus carota*; P_2)	4.57±0.04	13.39±0.08	376.18±0.81	48.07±0.05	78.02±0.11	907.76±0.90	0.09	0.17	0.41
Papaya (*Carica papaya*; P_3)	2.28±0.03	16.07±0.09	537.39±0.84	65.39±0.05	88.40±0.11	742.18±0.87	0.03	0.18	0.72
Green banana (*Musa acuminata*; P_4)	3.76±0.04	23.10±0.09	344.22±0.81	49.01±0.05	71.32±0.11	1025.40±0.92	0.08	0.32	0.34
Radish (*Raphanus sativus*; P_5)	3.36±0.04	12.39±0.08	251.27±0.79	58.28±0.05	99.45±0.11	913.57±0.90	0.06	0.12	0.28
Brinjal (*Solanum melongena*; P6)	3.22±0.04	12.05±0.08	238.20±0.79	59.22±0.05	67.64±0.10	931.00±0.90	0.05	0.18	0.26
Bitter gourd (*Momordica charantia*; P_7)	2.01±0.03	10.72±0.08	207.70±0.78	48.61±0.05	57.26±0.10	874.35±0.90	0.04	0.19	0.24
Cauliflower (*Brassica oleracea var botrytis*; P_8)	3.89±0.04	12.72±0.08	416.84±0.82	59.62±0.05	104.13±0.16	798.83±0.88	0.07	0.12	0.52
Potato (*Solanum tuberosum*, P_9)	4.16±0.04	12.05±0.08	434.27±0.82	43.78±0.05	80.70±0.11	931.00±0.90	0.10	0.15	0.47
Okra (*Abelmoschus esculentus*, P_{10})	2.55±0.04	9.38±0.08	225.12±0.78	46.33±0.05	52.23±0.10	872.90±0.90	0.06	0.18	0.26
Average	3.34±0.04	13.36±0.08	329.26±0.78	52.07±0.10	77.35±0.10	892.65±0.90	0.07	0.18	0.38
95% confidence interval	3.26-3.42	13.20-13.52	327.73-330.79	51.87-52.27	77.15-77.55	890.89-894.89			

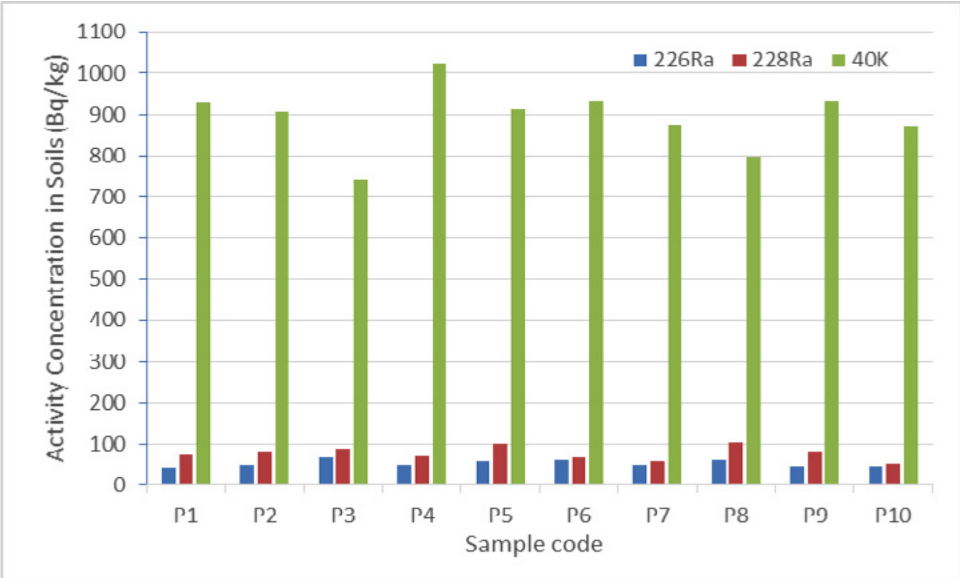

Figure 3. A Statistical representation of the activity concentration of ^{226}Ra, ^{228}Ra and ^{40}K in different soil samples as measured in Savar.

Figure 4. A bar diagram of radioactivity levels of natural radionuclides ^{226}Ra, ^{228}Ra, and ^{40}K of different plant samples of Savar.

as luxury consumption (Brady and Weil 2002). Radioactive potassium is also taken along with non-radioactive potassium. Hence, the activity of ^{40}K in vegetables tested was very much higher. Mobility of potassium in soil is high (Nutrient 2017).

The radioactivity levels of natural radionuclides ^{226}Ra, ^{228}Ra, and ^{40}K of different plant samples are shown in **Figure 4**. In all P1-P10 plants, the ^{40}K levels are much higher than ^{226}Ra or ^{228}Ra.

The TF of ^{226}Ra of plants collected in Savar ranged from 0.03 to 0.10 with an average of

0.07 (**Table 1**). The highest and the lowest TF of ^{226}Ra was found in potato (*Solanum tuberosum*, P_9) (0.10 Bq/kg) and papaya (*Carica papaya*; P_3) (0.03 Bq/kg) respectively. The results of ^{228}Ra showed that the TF of ^{228}Ra in different plants collected from Savar ranged from 0.12 to 0.32 with an average of 0.18. Green banana (*Musa acuminata*; P_4) showed the highest value (0.32 Bq/kg) while the lowest value (0.12 Bq/kg) was found both in radish (*Raphanus sativus*; P_5) and cauliflower (*Brassica oleracea var botrytis*; P_8). The TF of ^{40}K in different plants of Savar ranged from 0.24 to 0.72 with an average of 0.38. Bitter gourd (*Momordica charantia*; P_7) showed the lowest TF (0.24) whereas papaya (*Carica papaya*; P_3) had the highest TF (0.72) (**Table 1**).

TF value of ^{40}K in different plants of Savar was higher than those of other radionuclides (**Figure 5**). The high TF of ^{40}K was probably due to its high mobility in soil and its subsequent uptake by plants. High TF values ranging from 5 to 8 for ^{40}K have also been reported by Ababneh group (Ababneh et al. 2009).

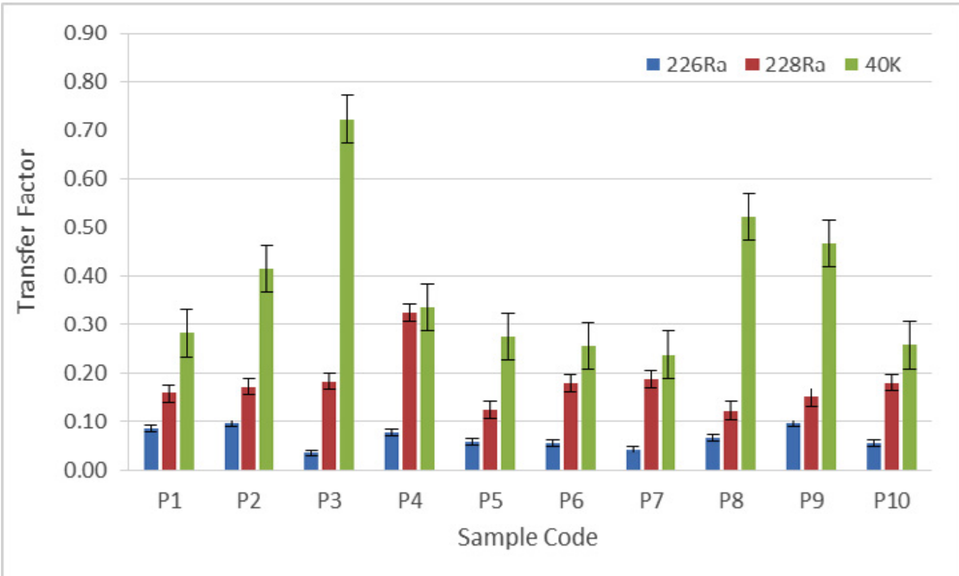

Figure 5. Transfer Factor (TF) of the radionuclides (^{226}Ra, ^{228}Ra and ^{40}K) in different plant samples of Savar. The symbols for plants P1-P10 are given in **Table 1**.

4. Discussion

4.1. TF link to nuclear industry

Human are exposed to both natural and artificial radionuclides amongst which on an average, 79% of the radiation is from natural sources, 19% from medical application and the rest of 2% from fallout of weapons testing and the nuclear power industry (Wild 1993). Most of the public concern has been due to the global fallout from atmospheric nuclear weapons testing and the operation of nuclear facilities. Both of these activities have introduced a substantial amount of manmade radionuclides into the environment and have produced radionuclide contamination of large areas of land worldwide. Radionuclides in soil are taken up by plants and are available for further redistribution within food chains. As radionuclides ultimately will pass on to human beings through food chains, it may represent an environmental threat to the health of local populations (Howard et al. 1991). Although atmospheric testing of nuclear bombs has been banned globally, the nuclear power industry will continue to make an increasing contribution to power consumption. As accidental and routine releases of radionuclides from the nuclear industry are unavoidable, and can even cause global environmental contamination, remediation of soils contaminated with radionuclides is becoming an increasingly important part of radiological protection (Zhu and Shaw 2000). Once radionuclides enter the soil environment, their endpoint is determined by their own and the physio-chemical properties of the soil, also by other factors (e.g. climate and vegetation). Understanding their geochemical behavior in soil-plant systems is of vital importance for the modelling of their transport and retention in soils, transfer from soil to plants and later into the food chain, and phytoremediation (Cremers et al. 1988). Consumption of agricultural produce contaminated with radionuclides signifies the principal route of internal intake of radionuclides in humans (Shaw and Bell 1994). Due to this, plant uptake of radionuclides has been widely studied from the early 1940s (Collander 1941). Buildup of radionuclides has been investigated on a wide array of plant species and has been shown to vary greatly among different habitats and plant species (Broadley and Willey 1997; Zhu and Shaw 2000).

4.2. TF dependence on parameters

The relationship between activity, TF and soil parameters can be obtained by analyzing their effects. Among the soil properties sand content, K content and Ca content in the soils can have significant positive or negative correlation with the activity concentration of radionuclides in soil. Radiocaesium bioavailability is strongly influenced by soil properties (e.g. K status and clay content) (Absalom et al. 1995). Three soil parameters required to determine radioactive bioavailability in soils can be estimated. These can be determined as functions of soil clay content, exchangeable K^+ status, pH, NH_4^+ concentration and organic matter content (Absalom et al. 2001).

4.3. Limitations of TF

Soil-to-plant TFs are commonly used to estimate the food chain transfer of radionuclides, which assumes that the concentration of a radionuclide in a plant relates linearly only to its average concentration in the rooting zone of the soil. Numerous observations show that for a number of long-lived radionuclides, soil-to-plant TFs show variations which may exceed three orders of magnitude (Frissel 1992). This extreme variability of soil-to-plant TFs indicates that a general relationship between the soil and plant concentrations of a radionuclide does not exist. This macroscopic parameter integrates a number of soil chemical, soil biological, hydrological, physical and plant physiological processes, each of which shows its own variability and may be influenced by external factors. Evaluation of the influence of these processes has been attempted by statistical inference from soil-to-plant TF data bases (Nisbet and Woodman 2000) but with moderate success. As the data bases were collected from individual observations made by various researchers linking a large number of parameters, it is not possible to represent a statistically well-defined sample of the population. Another limitation is, even a statistically valid correlation of soil-to-plant TFs with a soil or plant specific parameter does not necessarily reflect a cause-effect relationship or provide insight into the mechanisms governing plant uptake. The main application of soil-to-plant TFs is in food chain models used for calculating radiological outcomes from routine or accidental release of radioactive elements into the environment are usually designed to give conservative assessments (Peterson 1995). Radioecological research more works in clarifying the chemical, biological and physical mechanisms governing the root uptake and translocation of radionuclides from soils (Ehlken and Kirchner 2002).

Some other limitations of TF (Ehlken and Kirchner 2002) are: (a) Competing ions: The most important limitation of the TF is that it does not take into account competition between ions. Soil-to-plant transfer factors are most often measured for trace substances whose behavior in the soil–plant system largely depends on the concentrations of macro-nutrients present; (b) Bioavailability: A major fraction of a trace element present in the rooting zone may be fixed to soil constituents. Bioavailability of trace substances in soil does not account for the effects of competition of the substance studied with other elements; (c) Soil/soil solution interactions: The concentration of an ion in solution in most soils is determined by cation exchange reactions with the soil matrix which by their nature are competitive but other processes (e.g. co-precipitation) also depend on the concentrations of competing substances in solution; (d) Time trends: TFs of Cs and Sr in Lysimeter and field tests were often seen to decrease slowly with time for some years after contamination of the soils. Usually this time dependency is credited to a slow irreversible fixation of the radionuclides to the soil medium (IAEA 1994); (e) Rhizosphere effects: TF is related to the chemistry of the trace substance in the bulk soil but ignores rhizosphere effects. Roots excrete a variety of substances including organic acids, sugars, amino acids, H^+ and HCO_3^-, creating micro-environments with accessibilities which may significantly vary from those in the bulk soil (Courchesne and Gobran 1997). By release of H^+ or HCO_3^-, roots actively impact the pH in their surrounding environment, increasing the availability of K and P, respectively (Jungk and Claassen 1986). Root-induced mobilization of non-exchangeable K fixed in clay mineral interlayers may significantly contribute to the K nutrition of plants (Mitsios and Rowell 1987). As a consequence of the K removal, clay minerals are altered (Courchesne and Gobran 1997). Compared to the bulk soil, the rhizosphere is populated by large concentrations of micro-organisms (Russell 1973) which mainly composed of bacteria and mycorrhizal fungi (Richards 1987). The combined effects of roots and rhizosphere organisms in a small amount of soil create bioavailabilities which may be completely different to those of the bulk soil; (f) Transport to roots: Solutes are transported to plant roots by mass flow and diffusion. But if root uptake rates of a solute exceed mass flow rates, reduction of the solute at the root–soil interface produces a concentration gradient which initiates additional diffusional transport of the solute towards the roots resulting in a depletion zone around the absorbing root develops, which in the long-term reduces uptake rates of the solute. Future research should be performed in detailed quantification of the effect of these methods on soil-to-plant transfer (Ehlken and Kirchner 2002).

5. Conclusions

The level of activity concentrations of natural radionuclides in the soils under investigation were close to the range of the world average and some cases a bit higher than the world average, which might not pose any major radiation hazard to the population. But continuous intake of radionuclides through the food-chain may have some serious health effects on individuals in the long term. It is important to understand the behavior of radionuclides with variable elements within the soil, availability for plant uptake with time and different agricultural practices. As a higher concentration of radioactive substances in the environment is undesirable, investigations should be undertaken to detect the concentration of radionuclides in soil and their transfer to plants in order to take necessary radiological and dosimetric measures with the aim of minimizing the harmful effects of ionizing radiation. It is hoped that the data presented here will help establish a baseline for radioactivity concentrations and TFs of various plants in the Savar area of Dhaka, Bangladesh.

REFERENCES

• Ababneh AM, Maisoun S, Masa'deh MS, Abaneh ZQ, Mufeed MA, Alyassin AM. 2009. Radioactivity concentration in soil and vegetable from the Northern Jordan Rift Valley and the corresponding dose estimates. Radiation Protection Dosimetry 134(1):30-37.

• Absalom JP, Young SD, Crout NMJ. 1995. Radiocaesium fixation dynamics: Measurement in six Cumbrian soils. European Journal of Soil Science 46:461-469.

• Absalom JP, Young SD, Crout NMJ, Sánchez A, Wright SM, Smolders E, Nisbet AF, Gillett AG. 2001. Predicting the transfer of radiocaesium from organic soils to plants using soil characteristics. Journal of Environmental Radioactivity 52:31-43.

• Al-Jundi J, Al-Ahmad N, Shehadeh H, Afaneh F, Maghrabi M, Gerstmann U, Ilriegl VH, Oeh U. 2008. Investigations on the Activity Concentrations of ^{238}U, ^{226}Ra, ^{228}Ra, ^{210}Pb and ^{40}K in Jordan Phosphogypsum and Fertilizers. Radiation Protection Dosimetry 131(4):449-454.

• Bozkurt A, Yorulmaz N, Kam E, Karahan G, Osmanlioglu AE. 2007. Assessment of environmental radioactivity for Sanliurfa region of southeastern Turkey. Radiation Measurements 42(8):1387-1391.

• Brady NC, Weil RP. 2002. The Nature and Properties of Soils. 13 edn. Upper Saddle River, New Jersey, USA: Prentice Hall.

• Broadley MR, Willey NJ. 1997. Differences in root uptake of radiocaesium by 30 plant taxa. Environmental Pollution 97:11-15.

• Bunzl K, Trautmannsheimer M. 1999. Transfer of ^{238}U, ^{226}Ra, and ^{210}Po from slag-contaminated soils to vegetables under field conditions. Science of the Total Environment 231:91-99.

• Canbaz B, Çam N F, Yaprak G, Candan O. 2010. Natural radioactivity (^{226}Ra, ^{232}Th and ^{40}K) and Assessment of Radiological Hazards in the Kestanbol Granitoid, Turkey. Radiation Protection Dosimetry 141(2):192-198.

• Chabaux F, Riotte J, Clauer N, France-Lanord C. 2001. Isotopic tracing of the dissolved U fluxes of Himalayan rivers: Implications for present and past U budgets of the Ganges-Brahmaputra system. Geochimica et Cosmochimica Acta 65(19):3201-3217.

• Chakraborty SR, Azim R, Rahman AKMR, Sarker R. 2013. Radioactivity Concentrations in Soil and Transfer Factors of Radionuclides from Soil to Grass and Plants in the Chittagong City of Bangladesh. Journal of Physical Science 24(1): 95-113.

• Changizi V, Jafarpoor Z, Naseri M. 2010. Measurement of ^{226}Ra, ^{228}Ra, ^{137}Cs and ^{40}K in edible parts of two types of leafy vegetables cultivated in Tehran province-Iran and resultant annual ingestion radiation dose. Iran J Radiat Res. 8(2):103-110.

• Chibowski S. 2000. Studies of Radioactive Contaminations and Heavy Metal Contents in Vegetables and Fruit from Lublin, Poland. Polish Journal of Environmental Studies 9(4):249-253.

• Collander R. 1941. Selective absorption of cations by higher plants. Plant Physiology 16:691-720.

• Courchesne F, Gobran GR. 1997. Mineralogical variations of bulk and rhizosphere soils from a Norway spruce stand. Soil Science Society of America Journal 61:1245-1249.

• Cremers A, Elsen A, De Preter P, Maes A. 1988. Quantitative analysis of radiocaesium retention in soils. Nature 335:247-249.

• Ebaid YY. 2010. Use of Gamma-ray Spectromenter for Uranium Isotopic Analysis in Environmental Samples. Rom Journ Phys. 55(1-2):69-74.

• Ehlken S, Kirchner G. 2002. Environmental processes affecting plant root uptake of radioactive trace elements and variability of transfer factor data: a review. Journal of Environmental Radioactivity 58:97-112.

• Ele Abiama P, Ben-Bolie GH, Amechmachi N, Najib F, El Khoukhi T, Owono AP. 2012. Annual intakes of ^{226}Ra, ^{228}Ra and ^{40}K in staple foodstuffs from a high background radiation area in the southwest region of Cameroon. Journal of Environmental Radioactivity 110:59-63.

• Frissel MJ. 1992. An update of the recommended soil-to-plant transfer factors of Sr-90, Cs-137 and transuranics. In: International Union of Radioecologists, editors. VIIIth report of the working group soil to-plant transfer factors. IUR Pub R-9212-02. Balen, Belgium. p. 16-25.

• Gaffar S, Ferdous MJ, Begum A, Ullah SM. 2014. Transfer of Natural Radionuclides from Soil to Plants in North Western Parts of Dhaka. Malaysian Journal of Soil Science 18:61-74.

• Howard BJ, Beresford NA, Hove K. 1991. Transfer of radiocaesium to ruminants in natural and semi-natural ecosystems and appropriate countermeasures. Health Physics 61:715-725.

• International Atomic Energy Agency (IAEA). 1982. Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases. Exposure of Critical Groups. Safety Series, No. 57. Vienna, Austria: IAEA.

• International Atomic Energy Agency (IAEA). 1990. The Environmental Behavior of Radium. Technical Report Series No. 310. Vienna, Austria: IAEA.

• International Atomic Energy Agency (IAEA). 1994. Handbook of parameter values for predicting of radionuclide transfer in temperate environments. Technical report series no. 364. Vienna, Austria: IAEA.

• Jibiri NN, Farai IP, Alausa SK. 2007. Activity concentrations of ^{226}Ra, ^{228}Th, and ^{40}K in different food crops from a high background radiation area in Bitsichi, Jos Plateau, Nigeria. Radiat Environ Biophys. 46(1):53-59.

• Jungk A, Claassen N. 1986. Availability of phosphate and potassium as the result of interactions between root and soil in the rhizosphere. Zeitschrift für Pflanzenernährung und Bodenkunde 149:411-427.

• Kabir KA, Islam SMA, Rahman MM. 2009. Distribution of radionuclides on surface soil and bottom sediment in the district of Jessore, Bangladesh and evaluation of radiation hazard. Journal of Bangladesh Academy of Sciences 33(1):117-130.

• Khatera AE, Higgy RH, Pimpl M. 2001. Radiological impacts of natural radioactivity in Abu-Tartor phosphate deposits, Egypt. Journal of Environmental Radioactivity 55:255-267.

• Mitsios IK, Rowell DL. 1987. Plant uptake of exchangeable and non-exchangeable potassium. I. Measurement and modelling for onion roots in a Chalky Boulder clay soil. Journal of Soil Science 38:53-63.

• Mohery M, Baz S, Kelany AM, Abdallah AM. 2014. Environmental radiation levels in soil and sediment samples collected from floating water from a land runway resulting from heavy rains in the Jeddah region, KSA. Radiation Physics and Chemistry 97:16-24.

• Nisbet AF, Woodman RFM. 2000. Soil-to-plant transfer factors for radiocesium and radiostrontium in agricultural systems. Health Physics 78:279-288.

• Noordijk, H, Van KE, Lembrechts J, Frissel MJ. 1992. Impact of ageing and weather conditions on soil-to-plant transfer of radiocesium and radiostrontium. The Journal of Environmental Radioactivity 15:277-286.

• Nutrient. 2017. Nutrient Management. Competency Area 1: Basic Concepts of Plant Nutrition. Cornell University.

• Owono AP. 2010. Multi-group approximation, scattering and calibration coefficients, uncertainty estimates and detection limits of a NaI (Tl)-based gamma spectrometry setup for low-level activity analysis. The Journal of Environmental Radioactivity 101:692-699.

• Peterson SR. 1995. Testing the conservativeness of a screening model in a model validation exercise. Health Physics 68:539-545.

• Quindos LS, Fernández PL, Soto J, Ródenas C, Gómez J. 1994. Natural Radioactivity in Spanish Soils. Health Physics 66(2):194-200.

• Richards BN. 1987. The microbiology of terrestrial ecosystems. Harlow: Longman Scientific and Technical.

• Russell EW. 1973. Soil conditions and plant growth (10th ed.). London, UK: William Clowes and Sons.

• Shaw G, Bell JNB. 1991. Comparative effects of potassium and ammonium on caesium uptake kinetics in wheat. Journal of Environmental Radioactivity 13:283-296.

• Sheppard SC, Evenden WG. 1988. The assumption of linearity in soil and plant concentration ratio: an experimental evaluation. The Journal of Environmental Radioactivity 7:221-247.

• Singha S, Rani A, Mahajan RK. 2005. ^{226}Ra, ^{232}Th and ^{40}K analysis in soil samples from some areas of Punjab and Himachal Pradesh, India using gamma ray spectrometry. Radiation Measurements 39:431-439.

• Staven LH, Rhoads K, Napier BA, Strenge DL. 2003. A Compendium of Transfer Factors for Agricultural and Animal Products. Pacific Northwest National Laboratory. US Department of Energy.

• United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 2000. Sources and Effects of Ionizing Radiation. New York, USA: UNSCEAR.

• Wild A. 1993. Soil and the Environment. Cambridge: Cambridge University Press. 287 p.

• Yassine T, Al-Odat M, Othman I. 2003. Transfer of ^{137}Cs and ^{90}Sr from typical Syrian soils to crops. Journal of Food Engineering 16:73-79.

• Yu S, Mao Y. 1999. Assessment of Radionuclide Contents in Food in Hong Kong. Health Physics 77(6):686-696.

• Zhu YG, Shaw G. 2000. Soil contamination with radionuclides and potential remediation. Chemosphere 41:121-128.