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Transfer Factor of Radionuclides from Soil to Leafy Vegetables in Iraq Using Gamma Ray Spectroscopy

Athraa Naji Jameel
Physics Department, College of Education, Mustansiriyah University, Baghdad, Iraq

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Abstract:
The activity concentration of natural radioactivity levels, of artificial cesium and transfer factor from soil to plants in agricultural areas at Al- Yusiefya region were determined by using NaI (Tl) detector spectrometer. Ten species of leafy plants have been selected: Spinach, Parsley, Watercress, Lettuce, Rashad, Radish, Green onion, Turnip green, Green beet and Mint. The mean activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in leafy vegetable samples were 12.4±3.8, 14.8±4.7, 283±93 and 1.06±0.99 Bg/kg, and in soil samples were 15.9±4.3, 16.1±5.2, 298.5±3.9, and 1.11±0.37 Bq/kg. The radiation hazard indices were evaluated (radium equivalent, external hazard index, annual effective dose, absorbed dose rate) were within the permissible values except for excess lifetime cancer risk. The mean transfer factor values of ^{226} Ra, ^{232}Th, ^{40}K, and ^{137}Cs were 0.89±0.2, 0.9±0.2 , 1.02±0.3, and 0.77±0.25. The leafy vegetable are safe for consumption and the studied area does not pose a considerable radiological threat .

Keywords: Natural radioactivity, Radiological hazards, leafy vegetables, Transfer factor.

عامل نقل النويدات المشعة من التربة إلى الخضروات الورقية في العراق باستخدام التحليل الطيفي بأشعة كاما

عذراء ناجي جميل
قسم الفيزياء ، كلية التربية ، الجامعة المستنصرية ، بغداد ، العراق

الخلاصة:
تم تحديد مستويات النشاط الإشعاعي الطبيعي والسيزيوم الاصطناعي وعامل الانتقال من التربة إلى النباتات في المناطق الزراعية بمنطقة اليوسفية باستخدام مطياف NaI (Tl) لعشرة انواع من الخضروات الورقية : السبانخ، البقدونس، الجرجير، الخس، الرشاد، الفجل، البصل الأخضر ، اللفت الأخضر ، البنجر الأخضر والنعناع حيث كان متوسط تركيز النشاط , ^{238}U, ^{232}Th , ^{40}K و^{137}Cs في عينات الخضار الورقية 12.4±3.8، 4.7 ± 14.8 ، 93± 283 ، 1.06±0.99 بكرل /كغم وكان تركيزها في عينات التربة 15.9±4.3 ، 5.2 ± 16.1 ، 298.5±3.9 ، 1.11±0.37 . تم تقييم مؤشرات مخاطر الإشعاع (مكافئ الراديوم ، مؤشر الخطر ، الجرعة الفعالة السنوية ، معدل الجرعة الممتصة) كانت ضمن الحدود العالمية الموصى بها باستثناء الاصابة بالسرطان مدى العمر . حيث كانت قيم معامل النقل المتوسطة لـ ^{40}K

*Email: athraanaje@gmail.com

^{4226}Ra, ^{232}Th و ^{137}Cs هي 0.2 ± 0.89، 0.2 ±9.0 ، 0.3 ± 0.2 و0.77± 0.25 من خلال
الدراسة تبين ان الخضروات الورقية والمنطقة المدروسة لا تشكل اي تهديد اشعاعي.

Introduction:

Natural radioactivity origin comes from the uranium and thorium series, from ^{40}K, and from cosmic radiation interacting with matter. The man-made radioactive sources include those used in the different applications in medicine, industry, consumer products, and nuclear weapons testing [1]. humans are inevitably exposed to radioactivity nuclides through day by day meals and water intake, inhalation, absorption, and then move it transport from plants, fodder animals and animal products to human in biological cycle, both through the polluted plants and animal products can be affected [2,3].

Since the decay chains of both uranium and thorium involve radioactive progeny, with radon invariably being released into the environment through the air, all life forms are continuously exposed to such radionuclides by inhalation or other means [4]. Plant contamination occurs through two ways: from radionuclides that fall on plants and absorbed by roots or from radionuclides accumulated directly on the plant from the atmosphere. As a result, food contamination with various radionuclides, whether from natural, industrial sources, or ambient radioactive pollution, account for the vast majority of radiation doses received by people [5,6]. Interactions between radionuclides and plants are very complicated and depend on many factors such as type and shape of plants, soil characteristics, behavior of radionuclides, climatic conditions, etc. [7]. The quantity of primordial radionuclides depends on the geological and geographical formations of naturally occurring radioactive materials [8,9]. One of the most essential parameters in environmental safety is the soil-to-plant transfer factor which is the ratio of plant radioactivity concentrations to that of the soil. This factor is used to evaluate the amount of radiation that has been released from the soil to the plant. Many studies have been done on transfer factor from soil to food crops which showed a considerable disparity in values [10,11]. The type of vegetation, soil qualities, climatic circumstances, and radionuclide type all influence the transfer factor [12].
The aim of this research is to assess radionuclides activity in plants and their transfer factor from soil to plants in Al-Yusiefya region in Baghdad ,Iraq.

Materials and methods

1-2Samples collection and preparation

Ten samples of different leafy vegetables and its soil were collected from the agricultural locations located in Al-Yusiefya districts. The leafy vegetables studied were spinach, parsley, watercress, lettuce, rashad, radish, green onion, turnip green, green beet and mint. Following collection, the leaves of the vegetables were washed to remove dust, dried at 80˚Ccrushed and placed in Marinelli beakers for 30 days to reach radioactive equilibrium between parent and daughter radionuclides.

2.2 Radioactivity measurement

Radioactivity of the samples was measured with a 3"×3" NaI (Tl) detector for gamma spectrometry. Made in USA, measurement. the detector exhibited a relative performance of 90% and energy resolution of 28.74 keV at ^{60}Co gamma ray energy of 1332 KeV. This analyzer can be controlled and changing the characteristics and number of channels through by a specific computer program (bMCA). It features a red light indicator for intermittent gamma-rays reaching the detector, and it coupled to a computer by USB cable to transmit the signal to bMCA program . The radionuclides with their corresponding energies are ^{241}Am (59.5 keV), ^{60}Co (1173.24 and 1332.50 keV),^{137}Cs (661.66 keV). To measure the radiological background, the activity of ^{238}U was given through the gamma line of its product decay of

^{214}Bi(1764.5 keV). The activity of ^{232}Th was given by the product of ^{208}Tl (583.19 and 2614.5 keV, The ^{40}K(1460.8 keV) and ^{137}Cs (661.61 keV) Gamma lines of their energies were used to measure concentrations.

3. Calculations

3-1 Specific activity

The specific activity of ^{40}K, ^{226}Ra and ^{232}Th can be calculated in the fronds of palm samples [13,14]by the following relation:

$$A\,(E_\gamma) = \frac{N}{\varepsilon\,(E_\gamma)\times\, I_\gamma(E_\gamma)\times t\times m} \quad (1)$$

Where: N is the area under the image peaks, $\varepsilon\,(E_\gamma)$ is the efficiency of energy detection at E_γ, $I(E_\gamma)$ is the abundance of energy, m is the sample weight (kg) and t is the time of measurement (2 hour).

3-2Radiometric Parameters Radiation

3-2-1 Radium Equivalent Activity (Ra_{eq})

The Ra_{eq} is defined through the following equation [15]:

$$Ra_{eq}\,(Bq/kg) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

Where: A_{Ra}, A_{Th} and A_k are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K, respectively.

3-2-2 Absorbed Dose Rate (D_γ)

The absorbed dose rate can be calculated using the following formula [16]:

$$D_\gamma\,(nGy/h) = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_K \quad (3)$$

3--2-3 External Hazard Index(H_{ex})

The external hazard index is given as [17]:

$$H_{ex} = \frac{A_U}{370\,Bq/kg} + \frac{A_{Th}}{259\,Bq/kg} + \frac{A_K}{4810\,Bq/kg} \quad (4)$$

3-2-4 Annual Effective Dose Equivalent (AEDE)

Annual effective dose equivalent is given by the following equation[18,19]:

$$(AEDE)\,(\mu Sv/y) = D_\gamma \times 10^{-6} \times 0.80 \times 8760\ h/y \times 0.7\ Sv/Gy \quad (5)$$

3-2-5 Excess Life-time cancer risk (ELCR)

Radionuclides may be envisioned in terms of extra lifetime cancer risk. It is calculated by the following equation[20,21]:

$$ELCR = AEDE \times DL \times RF \quad (6)$$

Where AEDE is the annual effective dose equivalent, DL is the duration of life (70yrs), RF is the risk factor. For stochastic effects, ICRP 60 makes use of values of 0.05/Sv for the risk factor.

3-3Transfer Factor

The transfer factor is the ratio of plant radioactivity concentrations to the soil radioactivity concentrations. It is used in calculating radionuclide concentrations in agriculture crops in order to estimate dose intake by man [22,23]:

$$TF = \frac{Activity\ of\ radinuclides\ in\ plant\,(\,dry\ weight)}{Activty\ of\ radionuclides\ in\ soil\,(\,dry\ weight)} \quad (7)$$

RESULTS AND DISCUSSION

The results showed that (Table 1) natural activity concentrations of the leafy vegetable samples of spinach, parsley, watercress, lettuce, rashad, radish, green onion, turnip green,

green beet and mint. The activity concentrations of ^{238}U ranged from 9.1 to 15.5 Bq/kg with mean value 12.4±3.8 Bq/kg and from 11.1 to 19.4 Bq/kg with mean value 14.8±4.7 Bq/kg for ^{232}Th, and the activity concentrations of ^{40}K ranged from 214 to 393 Bq/kg with mean of 283±93Bq/kg, and 0.61 to 1.78 Bq/kg with mean value 1.06±0.99 Bq/kg for ^{137}Cs in leafy vegetables samples. Table 2 shows the mean values for the activity concentrations for soil samples of ^{238}U, ^{223}Th, ^{40}K and ^{137}Cs which were 15.9±4.3, 16.1±5.2, 298.5±3.9 and 1.11±0.37 Bq/kg, respectively. From both tables, it can be seen that activity concentrations were lower than the allowable values proposed by UNSCEAR [24]. Figure 1 displays the specific activity for the different radioactive isotopes uptake in the leafy vegetables and the soil.

Table 1: The activities of ^{238}U, Th^{232}, K^{40} and ^{137}Cs in (Bq/kg) for the leafy vegetables

Sample	leafy vegetables					
	K^{40}	^{238}U			Th^{232}	Cs^{137}
		Ra^{226}	^{214}Pb	^{214}Bi		
Spinach	323	13.2	6.96	11.2	13.4	**0.83**
Parsley	214	9.1	5.20	10.3	11.1	**0.61**
Watercress	240	12.4	9.071	11.5	14.4	**1.03**
Lettuce	371	13.5	12.07	11.2	16.4	**1.59**
Rashad	343	14.1	8.796	13.4	15.8	**0.61**
Radish	393	15.5	6.409	16	19.4	**1.15**
Green onion	324	9.7	7.123	11.3	15.1	**0.10**
Turnip green	322	10.8	6.44	12.3	12.9	**1.2**
Green beet	227	13.3	10.44	12.4	14.7	**1.06**
Mint	234	12.3	5.03	13	13.2	**1.78**
Average ± S.D	283± 93	12.4± 3.8	8.1± 1.28	11.1± 2.6	14.8± 4.7	**1.06 ±0.99**
Limit UNSCEAR, 2010[24]	**400**		**33**		**45**	**2**

Table 2: The activities of ^{238}U, Th^{232}, K^{40} and ^{137}Cs in (Bq/kg) for the soil of leafy vegetables

Sample	Soil					
	K^{40}	^{238}U			Th^{232}	Cs^{137}
		Ra^{226}	^{214}Pb	^{214}Bi		
Spinach	310	17.7	8.16	13.5	14	**0.93**
Parsley	215.3	10	6.20	12.3	14.3	**0.81**
Watercress	251.4	14.5	6.1	13.5	16.6	**1.25**
Lettuce	362	17.2	13.27	17	17	**1.85**
Rashad	273.6	12.3	9.6	11.3	16	**0.89**
Radish	343	17	7.409	14.4	20.8	**1.3**
Green onion	332	9.9	6.3	10.3	16.8	**0.7**
Turnip green	341.2	11.3	8.34	12.4	13.7	**1.32**
Green beet	222	15.3	9.44	13.3	16.41	**1.2**
Mint	213	12 .1	6.31	13.1	15.2	**1.89**
Average ± S.D	298.5± 3.9	15.9± 4.3	9.2± 1.4	13.3± 5.3	16.1± 2.3	**1.11± ±0.37**
Limit UNSCEAR 2010[24]	**400**		**33**		**45**	**2**

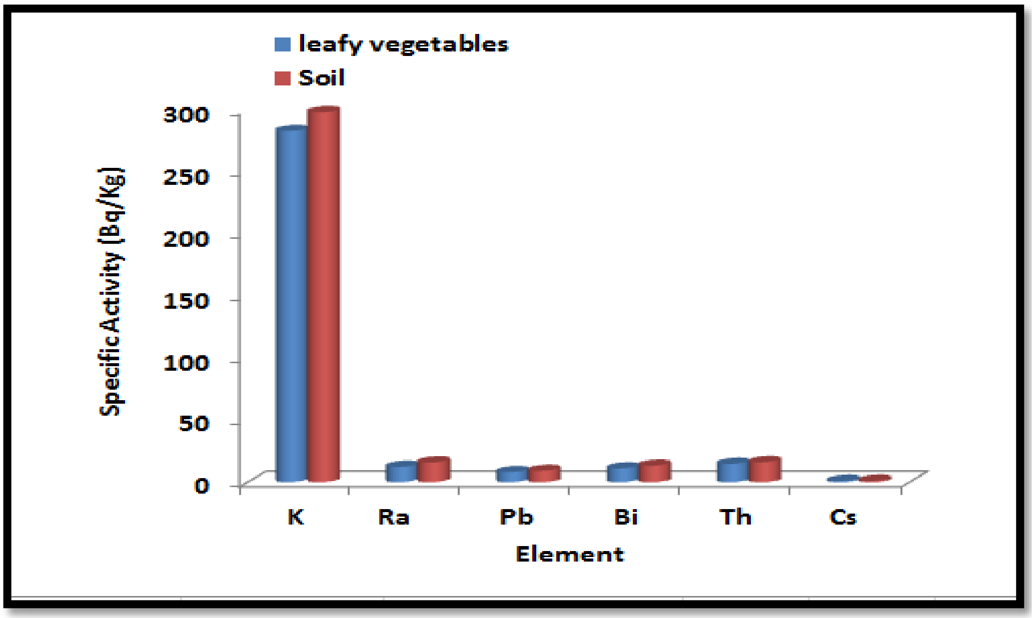

Figure 1: The mean specific activity of the leafy vegetable samples and its soil.

Table 3 shows the radiometric parameters (radium equivalent, externa hazard index, annual effective dose equivalent, absorbed dose rate and extra life-time cancer factor) for the leafy vegetable which are less than the permissible limits recommended by UNSCEAR, only the ELCR values were slightly higher than the permissible limit.

The maximum value of Ra_{eq} was 65.519 Bq/kg in lettuce and the minimum value of Ra_{eq} was 41.451Bq/kg in parsley with an average of 56.4±25.7 Bq/kg. These values are less than the 370 Bq/kg recommended by UNSCEAR[24] as shown in Figure 2. The maximum value of D_{γ} was 31.058 nGy/h in lettuce and the minimum value was 20.021 nGy/h in parsley with an average of 27.3±8.9 nGy/h. This value is less that recommended by the UNSCEAR, as shown in Figure 3.

The highest values for H_{ex}, AEDE and ELCR, were 0.1, 152.2 µ/Svy, and 0.56, with an average value of 0.091±0.02, 133.5±0.04 µ/Svy and 0.27.2±0.5 for H_{ex}, AEDE and ELCR, respectively. These average values are lower than the recommended values of UNSCEAR, 2008 [25]. Figures 4, 5 and 6 show the radiological hazard parameters(external hazard index, annual effective dose equivalent, and excess lifetime cancer risk) for the investigated leafy vegetables.

Table 3: Radiometric parameters for the leafy vegetables

Sample	Ra_{eq} (Bq/Kg)	D_{γ} (nGy/h)	H_{ex}	AEDE (µSv/y)	ELCR $\times 10^{-3}$
Spinach	57.233	27.889	0.08	136.8	0.47
Parsley	41.451	20.021	0.068	98.2	0.34
Watercress	51.472	24.679	0.089	121.06	0.42
Lettuce	65.519	31.058	0.1	152.2	0.56
Rashad	63.105	30.629	0.099	150	0.52
Radish	56.105	26.329	0.087	143.3	0.47

Green onion	56.241	27.369	0.085	134.6	0. 45
Turnip green	54.041	26.428	0.079	135	0.42
Green beet	51.8	24.739	0.093	121.6	0.43
Mint	42.8	20.6	0.017	105.7	0.41
Average ± S.D	56.4±25.7	27.3±8.9	0.091±0.02	133.5±0.04	0.47.2±0.5
Limit UNSCEAR, 2010[24].	**370**	**55**	**1**	**290 UNSCEAR, 2008[25].**	**0.29×10^{-3}**

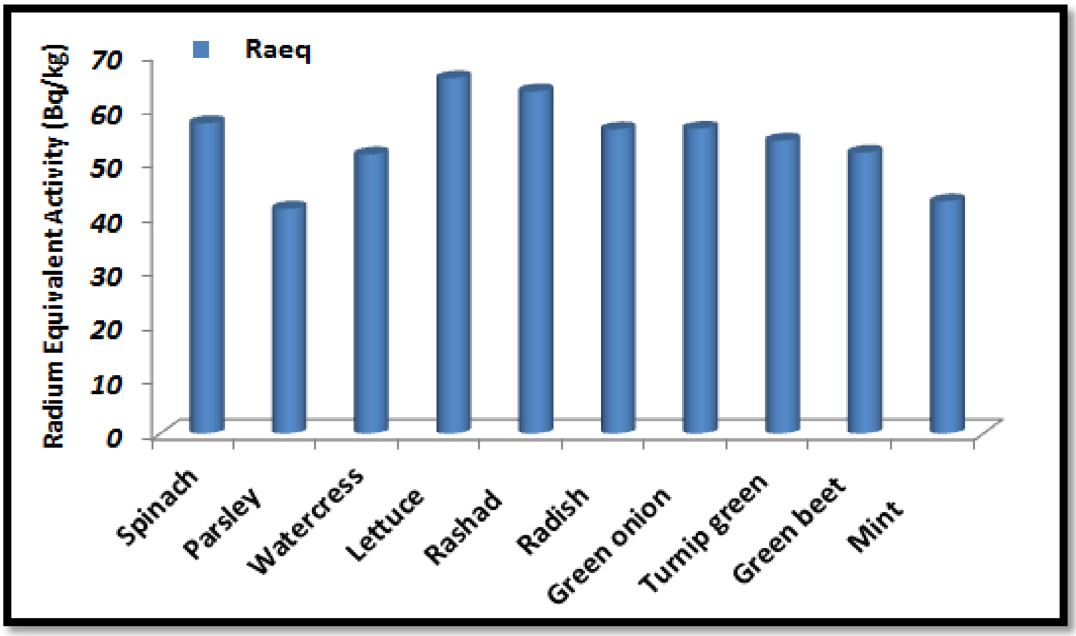

Figure 2: Radium equivalent activity of the leafy vegetable samples.

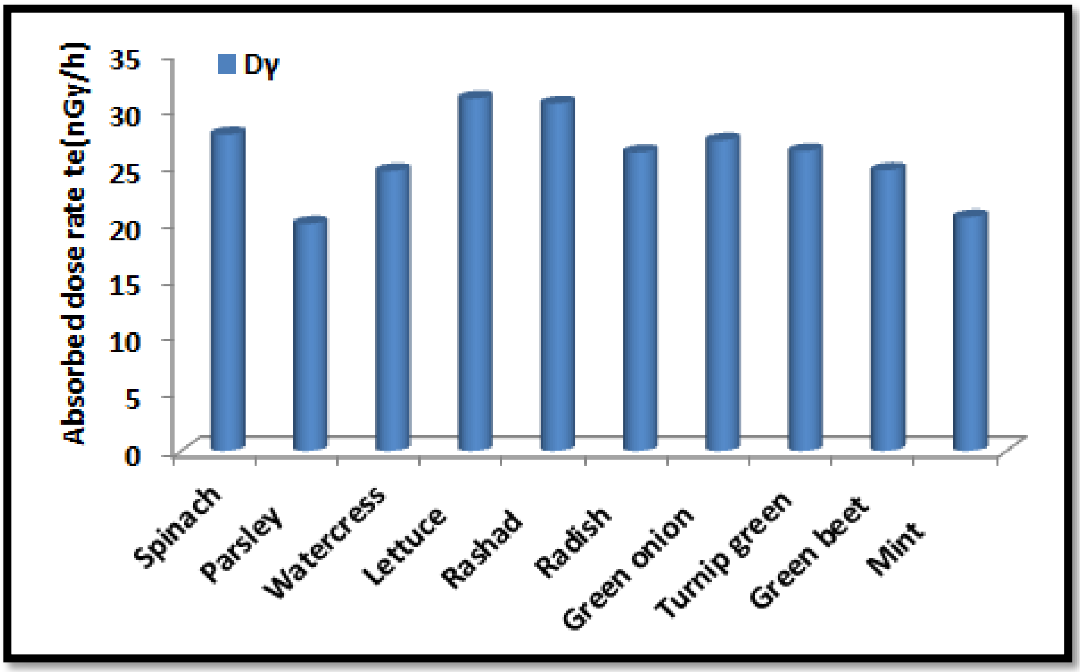

Figure 3: Absorbed dose rate of leafy vegetable samples.

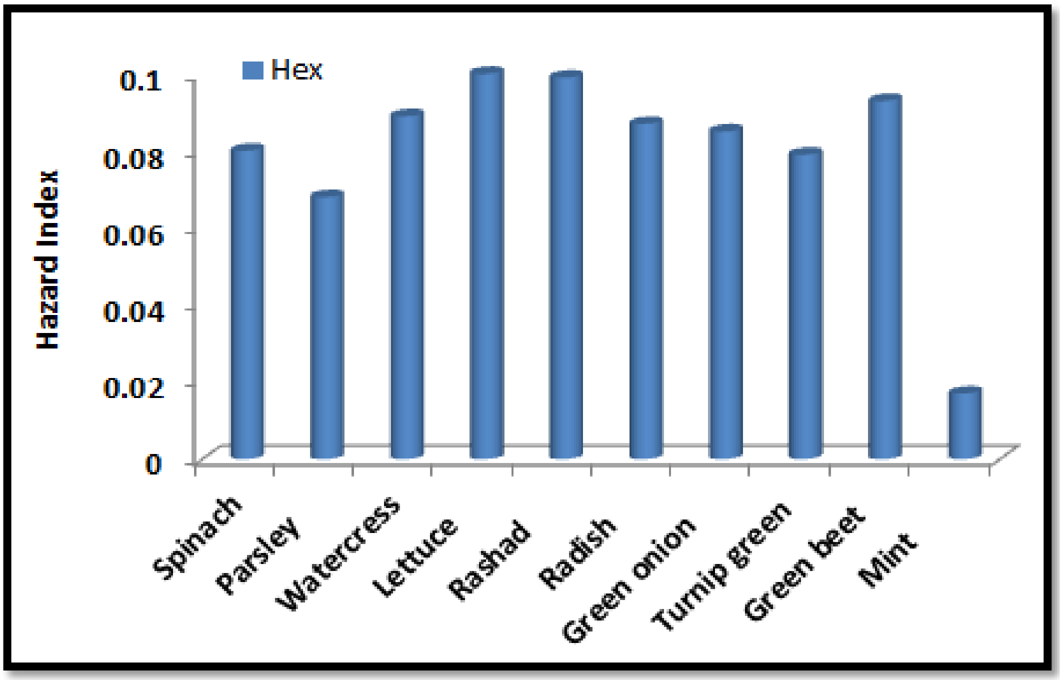

Figure 4: External hazard index of leafy vegetable samples.

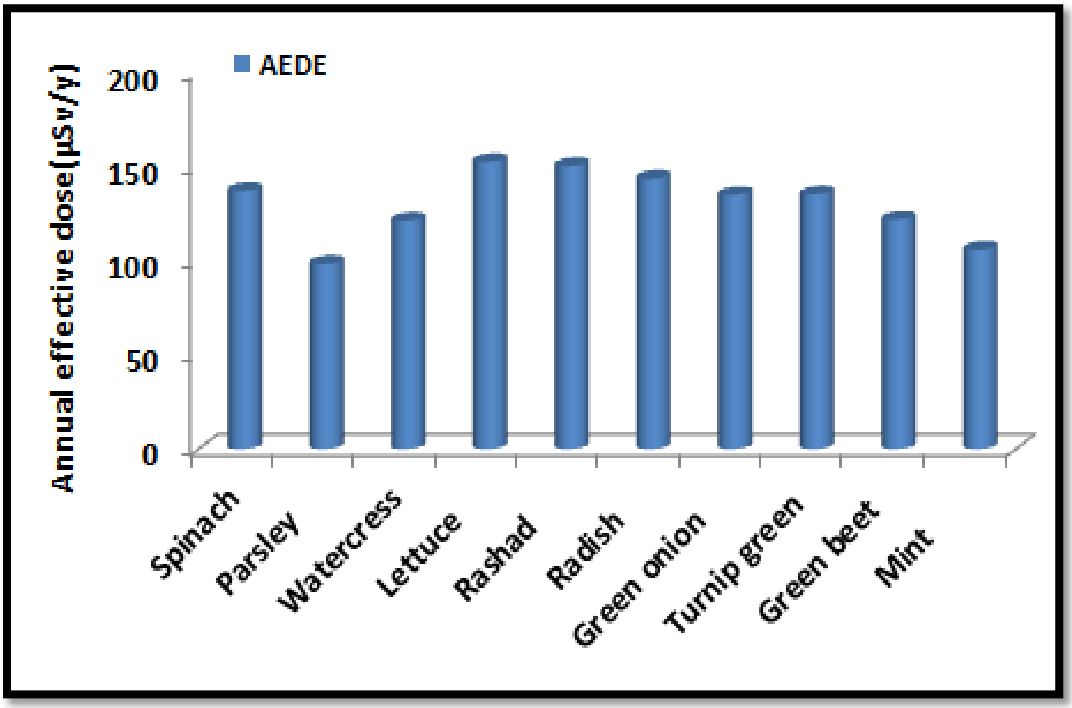

Figure 5: Annual effective dose equivalent of leafy vegetable samples.

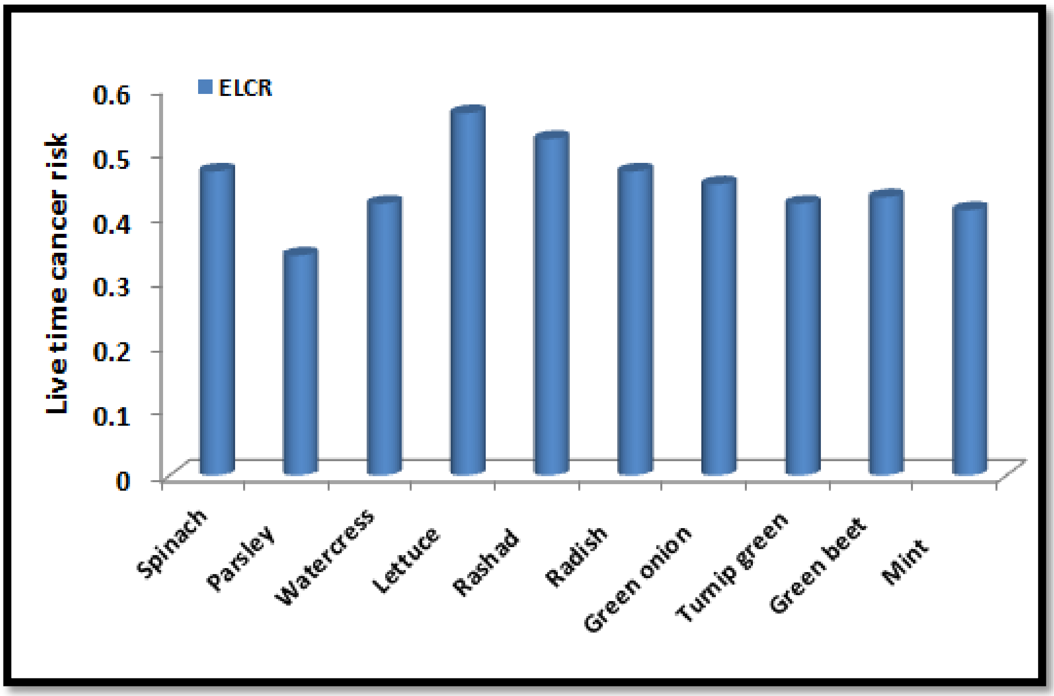

Figure 6: Excess life-time cancer risk of leafy vegetable samples.

From Table 4 and Figure 7, the average transfer factor values for the radionuclides (^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs) were 0.89±0.2, 0.9±0.2,1.02±0.3 and 0.77±0.25, respectively for the leafy vegetables. According to the results, the mint sample had transfer factor of uranium at its maximum rate of 0.93. Furthermore, the highest transfer factor for thorium was 0.98 in rashad sample, while the highest transfer factor for potassium was 1.09 in the mint. These values are comparable to those reported elsewhere. There was a considerable difference in radionuclide transfer factors, which could be attributable to the phosphate fertilizers utilized.

Table 4: Transfer factor for natural and artificial radionuclides in the leafy vegetable samples

Sample	**Transfer factor**			
	^{40}K	**^{226}Ra**	**^{232}Th**	**^{137}Cs**
Spinach	1.04	0.74	0.95	0.89
Parsley	0.99	0.91	0.77	0.75
Watercress	0.95	0.85	0.867	0.824
Lettuce	1.08	0.76	0.964	0.85
Rashad	1.2	1.14	0.98	0.68
Radish	1.05	0.90	0.93	0.88
Green onion	0.944	0.90	0.93	0.14
Turnip green	0.943	0.95	0.941	0.90
Green beet	1.02	0.86	0.89	0.88
Mint	1.09	0.93	0.86	0.94
Average± S.D	1.02±0.3	0.89±0.2	0.9±0.2	0.77±0.25

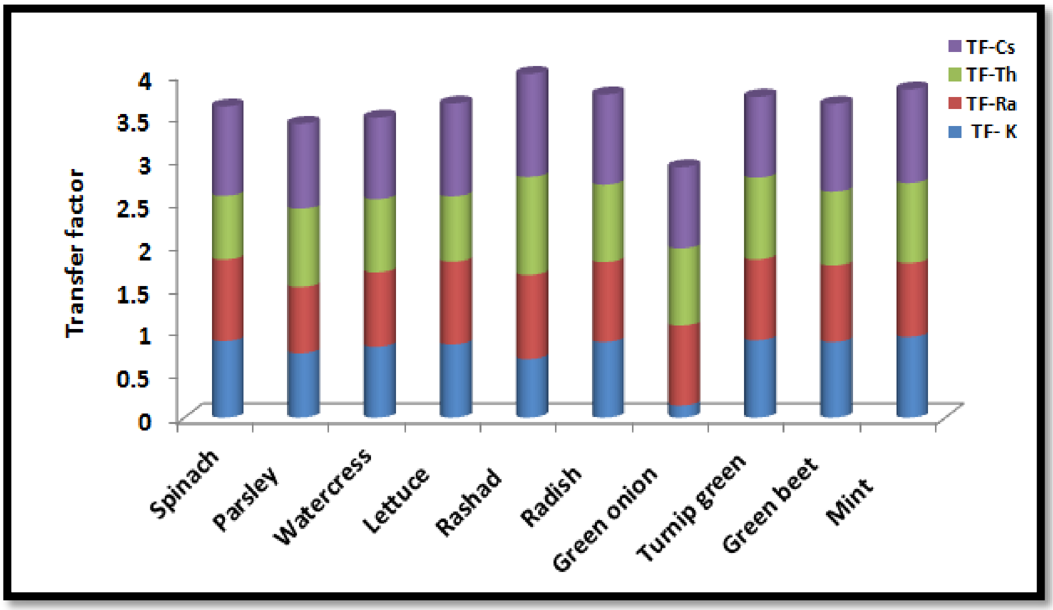

Figure 7: Transfer factor for the leafy vegetable samples.

Conclusions

The activity concentrations ^{238}U, ^{238}Ra, ^{40}K and ^{137}Cs and radiometric factors were less than the allowable limits for the leafy vegetable samples in spinach, parsley, watercress, lettuce, rashad, radish, green onion, turnip green, green beet and mint but the excess lifetime cancer risk were slightly higher than the permissible limits. While the transfer factors of ^{226}Ra,^{40}K and ^{137}Cs from soil to leafy vegetable were found to be higher in mint but the transfer factors of ^{232}Th were found to be the highest in Rashad sample. The Analytics established that the samples under investigation do not have any harmful radiological impacts.

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