Radiation hazards and transfer factors of radionuclides from soil to plant and cancer risk at Al-Taji city-Iraq

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Abstract. The concentrations of natural radionuclides in various common plant species grown in the city of Al-Taji in the capital, Baghdad, were examined using NaI(Tl) gamma spectroscopy. The measurements were made on three parts of each plant sample which included roots, stalk, and leaves in addition to soil. The assessing of transport factors shows the K-40 transfer coefficients were lower than those values mentioned in other previous studies. The mean concentrations of specific activity for U-238, Th-232 and K-40 in the basil plant were 4.455±2.944, 18.774±14.998 and 123.767±23.047 Bq/kg respectively. For celery it was 3.904±3.326 Bq/kg, 32.899±6.739 Bq/kg, 85.032±35.650 Bq/kg. As for mint, it was 2.233±4.337 Bq/kg, 25.354±8.696 Bq/kg and 92.115±33.070 Bq/kg. The results showed that the concentration of uranium, thorium and cesium did not exceed the permissible limit. Potassium concentrations will not exceed the internationally permitted level in all parts of plants under study. The radium equivalent activity was 70.527 Bq/kg less than 370 Bq/kg recommended by UNSCEAR. The maximum absorbed dose rate in soil samples was 58.205 nGy/h, which is less than 84 nGy/h. Whereas the average annual effective dose equivalent in soil samples was 285.535 mSv/y which are less than the 290 mSv/y recommended by UNSCEAR, Respectively. The maximum hazard risk index was 0.214 in soil samples and is less than ≤1 recommended by UNSCEAR. The lifetime cancer risk (ECLR) ranged from 142.620×10^{-3} to 999.372×10^{-3}. This value is above the global average of 0.29×10^{-3} and 1.16×10^{-3} reported by UNSCEAR. The lifetime cancer risk is a function of environmental geology and the K-40 soil transfer factor to the plant is very high compared to other radionuclides in the samples. Therefore, there is a risk from its management.

Keywords: Natural radioactivity, Transfer Factor, soil, plant, radiological hazards, Al-Taji

1. Introduction
An assessment of the impact of radioactivity on the environment is important for protecting the general health of humans, especially if the radioactivity released could enter the food chain. Contamination of edible parts of the plant is the result of a series of closely coordinated steps after soil contamination, then absorption of the root, transport through the root to the stalk, and transportation from the stalk to the leaves, i.e. the aerial parts of the plant. The chemical and physical properties of the soil pass through the roots, and their ions are absorbed by the roots. The transfer of ions, the
refilling of mineral nutrients, and the perfusion of the root are some of the factors that influence the transport of radionuclides from soil to plants. This is called the soil-to-plant transfer factor (TF). The transfer factors relate the concentration of radionuclides in edible products with those in the soil. Transfer factor can be expressed as the ratio of dry weight of plant to dry weight soil [1]. To facilitate the comparison process and reduce the differences that occur due to the different environmental conditions, crop contamination is calculated on the basis of dry weight.

In Iraq, increased interest and control in measuring radioactive activity in the field of the environment after the Gulf War due to the exposure of many areas of the bombing. Some of these works have evaluated the measurements of natural nuclear radionuclides in soil, water, ground water, building materials, milk, wheat, river, laboratories [2,3,4,5,6,7,8,9].

2. Materials and methods

2.1. Collection and preparation of samples

A total of three samples were collected from the same site for basil, celery, mint and their soil. Each of these plants was separated into three parts (root, stalk, and leaves) in addition to the soil that permeated the roots. This is to prepare them to measure natural radioactivity to determine the risks from their consumption by citizens. All various parts of plants were dried and crushed with mill to obtain a homogeneous powder. After the grinding process, the powder was sifted through a sieve of 630 microns. After that, the samples were filled in Marinelli Becker and sealed with provisions. The code name for each sample was installed on Marinelli Becker's. Marinelli Beckers were closed for 30 days prior to the screening process in order to achieve a secular equilibrium.

2.2. Radioactivity measurement

Detection of natural radioactivity for U-238, Th-232, and K-40 in basil-root, basil-stalk, basil-leave, celery-root, celery-stalk, celery-leave, mint-root, mint-stalk, mint-leave, and soil of each plant samples were carried out with gamma spectrometry technique using 3×3 inch NaI(Tl) detector, Alpha Spectra Inc., scintillation detectors, Model 12/12/3, Serial (031215G), Made in United States of America (USA). The detector had 90% relative efficiency and energy resolution of 28.74 keV at 1332 keV of Co-60 gamma ray. The multichannel analyzer used is a digital analyzer of type Bright SPEC model bMCA (blug-on Multi-channel analyzer. It analyzes the gamma spectrum for gamma rays at 4096 channels. Note that this analyzer can be controlled and changing the characteristics and number of channels through a specialized computer program (bMCA). It contains a red light indicator for the intermittent gamma-rays to the detector and it coupled to a computer by USB cable to transmit the signal to bMCA program and finally, display the analyzed spectrum on the screen. The quality assured standard samples for the calibration and the absolute efficiency of the detector (obtained from the International Atomic Energy Agency) was used for the calibration and the absolute efficiency of the detector. The mixture of radionuclides (with corresponding energies) included Am-241 (59.5keV), Co-60 (1173.24 and 1332.50 keV), Cs-137 (661.66 keV). To measure the environmental gamma background, an empty identical Marinelli Beaker was used. All samples and the background were counted for 7200sec. After measurement, the activity concentrations were calculated by subtraction of the background values. The activity of U-238 was given by the line of gamma of its product decay Bi-214 (1764.5 keV). The activity of Th-232 was inferred from the weighted mean activities of the gamma peaks of Tl-208 (583.19 and 2614.5 keV). The K-40 and Cs-137 concentrations were measured by determining their characteristic gamma lines of energies, 1460.8 and 661.61 keV respectively. In addition, the minimum average detectable activity concentrations, in Bq/kg, of U-238, Th-232, K-40, and Cs-137 using NaI(Tl) detector, respectively.

3. Calculations

3.1. Specific activity
The activity specified is the activity per unit block, the unit used is either Ci/kg or Bq/g. It can be calculated from the following equation [10]:

$$A_i(E, \gamma) = \frac{N}{\varepsilon(E_{\gamma}) \times f_{\varepsilon}(E_{\gamma}) \times \tau \times m} \quad (1)$$

Where $N$ is the counting of gamma rays (i.e. area under the photo peaks) and $m$ is the sample mass in kg.

### 3.2. Absorbed dose rate $D$

According to the United Nations Scientific Committee on the Effects of Atomic Radiation, the outdoor absorbed dose rate can be calculated using the following equation [11, 12]:

$$D_{\text{out}}(\text{nGy/h}) = 0.427 A_U + 0.662 A_{\text{Th}} + 0.043 A_K \quad (2)$$

Where $A_U$, $A_{\text{Th}}$, and $A_K$ are the activity concentrations in ($\text{Bq/kg}$) of uranium, thorium and potassium respectively. The indoor gamma ray dose imparted by U-238, Th-232, and K-40 radionuclides present indoor can be calculated by converting the absorbed dose rate to effective dose, the following equation is used to calculate the indoor dose rate, given by (UC European Commission, 1999) [13]:

$$D_{\text{in}}(\text{nGy/h}) = 0.92 A_U + 1.1 A_{\text{Th}} + 0.081 A_K \quad (3)$$

### 3.3. Radium equivalent activity $R_{aeq}$

For uniformly distributed with respect to the exposure to radiation has defined the radium equivalent activity expressed by the following equation [14]:

$$R_{aeq}(\text{Bq/kg}) = A_U + 1.43 A_{\text{Th}} + 0.077 A_K \quad (4)$$

### 3.4. Hazard index $H$

The external ($H_{\text{ex}}$) and internal ($H_{\text{in}}$) hazard indices are due to external exposure to gamma ray. The external hazard index can be calculated from the following equation [14]:

$$H_{\text{ex}} = \frac{A_U}{370 \text{ Bq/kg}^{-1}} + \frac{A_{\text{Th}}}{259 \text{ Bq/kg}^{-1}} + \frac{A_K}{4810 \text{ Bq/kg}^{-1}} \quad (5)$$

The internal radiation exposure is quantified by the internal hazard index ($H_{\text{in}}$) given by [14]:

$$H_{\text{in}} = \frac{A_U}{185 \text{ Bq/kg}^{-1}} + \frac{A_{\text{Th}}}{259 \text{ Bq/kg}^{-1}} + \frac{A_K}{4810 \text{ Bq/kg}^{-1}} \quad (6)$$

Provided that for safety consume the upper limit of the above indexes should be less than unity for the radiation hazard to be regarded as insignificant, as reported by UNSCEAR, 2000 [14] and ICRP, 2007 [15].

### 3.5. Annual effective dose equivalent ($A\text{EDE}$)

The outdoor annual effective dose equivalent ($A\text{EDE}_{\text{out}}$) was estimated to convert the outdoor absorbed dose in air to effective dose. While the indoor annual effective dose equivalent ($A\text{EDE}_{\text{in}}$) is estimated from indoor absorbed dose in air to convert it to the effective dose reported the value 0.7 SvGy-1 as conversion coefficient from absorbed dose in the air to the effective dose received by adults [14]. While 0.2 and 0.8 represent the outdoor and indoor occupancy factors respectively. The annual effective dose equivalent can be calculated from the following equations as reported by [14]:

$$A\text{EDE}_{\text{out}}(\mu\text{Sv/yr}) = D_{\text{out}}(\text{nGy/h}) \times 8760(\text{h/yr}) \times 0.20 \times 0.7(\text{Sv/Gy}) \times 10^{-3} \quad (7)$$

$$A\text{EDE}_{\text{in}}(\mu\text{Sv/yr}) = D_{\text{in}}(\text{nGy/h}) \times 8760(\text{h/yr}) \times 0.80 \times 0.7(\text{Sv/Gy}) \times 10^{-3} \quad (8)$$

### 3.6. Life-time cancer risk ($ELCR$)

The excess life-time cancer risk ($ELCR$) was estimated from annual effective dose equivalent using the equation [16]:

$$ELCR_{\text{out}} = A\text{EDE}_{\text{out}} \times DL \times RF \quad (9)$$
\[ ELCR_{in} = AEDE_{in} \times DL \times RF \]  
(10)

Where \( DL \) and \( RF \) are the duration of life (70 years), and risk factor \((0.05/Sv)\), respectively. Defined the risk factor as fatal cancer risk per Sievert is assigned a value of 0.05 for the public for random effects, for low-level radiations, as reported by ICRP, 2012 [17].

3.7. Transfer factor (TF)

The transfer factor represents the absorption of radionuclides by plants from contaminated soil to enter the human food chain. It is defined as the ratio between the plant's specific activity and the soil activity. Plants are the main recipients of radioactive contamination in the food chain. One of the most important criteria in assessing the environmental safety needed for nuclear installations is the soil to plant transfer factor. Its usefulness lies in predicting the concentrations of radionuclides in agricultural crops to estimate the dose a person takes. The transport factor (TF) is defined as the ratio of the concentrations of radionuclides in the plants and soil by relationship [18]:

\[ TF = \frac{\text{dry crops Bq.kg}^{-1}}{\text{dry soil Bq.kg}^{-1}} \]  
(11)

4. Results and discussion

The activity concentrations of U-238, Th-232 and K-40 in basil, celery and mint are summarized in Table 1. As tabulated in Table 1, for basil the activity concentrations of U-238 varied from 2.088 to 8.739 Bq/kg with an average value of 4.455±2.944 Bq/kg and from 1.137 to 36.687 Bq/kg for Th-232, respectively. Additionally, concentrations of K-40 activity ranged from 97.237 to 153.472 Bq/kg with an average of 123.767±23.047 Bq/kg and from 0.014 to 0.085 Bq/kg with an average value of 0.050±0.033 Bq/kg, Cs-137. For celery, the mean activity concentrations for U-238, Th-232 and K-40 were 3.904±3.326, 32.899±6.739, 85.032±35.650, and 0.030±0.037 Bq/kg. For mint it was 2.233±4.337, 25.354±8.696, 92.115±33.070 and 0.042±0.029 Bq/kg, respectively.

While the average activity concentration of Cs-137 for all samples was lower than the unit. All these values are significantly lower than the permissible limits (33, 45, and 412 Bq/kg for U-238, Th-232 and K-40 respectively) as reported by UNSCEAR, 2010 [12].

| Table 1. Specific activity concentrations for U-238, Th-232, K-40 and Cs-137, and Radium equivalent activity of samples. |
| --- | --- | --- | --- | --- |
| Sample | Sample parts | Specific activity concentration (Bq/kg) | Ra\(_{eq}\) (Bq/kg) |
| --- | --- | --- | --- |
| **Basil** | Soil | 8.739 | 9.695 | 22.417 | 36.687 | 0.085 | 121.103 | 70.527 |
| | Root | 3.834 | 10.753 | 5.229 | 23.265 | 0.068 | 153.472 | 48.921 |
| | Stalk | 3.160 | 5.326 | 4.730 | 14.006 | 0.031 | 123.257 | 32.679 |
| | Leaves | 2.088 | 0.428 | 0.378 | 1.137 | 0.014 | 97.237 | 11.202 |
| | Average | 4.455±6.551 | 22.417±6.739 | 5.229±14.006 | 23.265±14.998 | 0.068±0.031 | 121.103±23.047 | 70.527±25.110 |
| **Celery** | Soil | 8.739 | 9.695 | 22.417 | 36.687 | 0.085 | 127.110 | 70.527 |
| | Root | 3.254 | 0.096 | 0.774 | 38.945 | 0.120 | 109.368 | 67.365 |
| | Stalk | 2.384 | 0.071 | 0.155 | 32.286 | 0.011 | 61.722 | 53.307 |
| | Leaves | 1.241 | 0.063 | 0.093 | 23.680 | 0.010 | 47.934 | 38.795 |
| | Average | 3.904±2.481 | 38.945±36.687 | 0.030±0.010 | 32.286±14.998 | 0.011±0.003 | 85.032±14.998 | 57.498±14.998 |
| **Mint** | Soil | 8.739 | 9.674 | 22.347 | 36.687 | 0.085 | 121.103 | 70.527 |
| | Root | 0.141 | 1.200 | 0.433 | 26.571 | 0.032 | 113.656 | 46.889 |
| | Stalk | 0.039 | 0.907 | 0.684 | 22.096 | 0.029 | 85.561 | 38.225 |
| | Leaves | 0.015 | 0.684 | 0.204 | 16.062 | 0.020 | 48.141 | 26.690 |
As shown in figures 1, 2, and 3 the activity concentrations of K-40 in basil-root sample had the highest activity concentration 153.427 Bq/kg while celery-leaves sample had lowest value 47.934 Bq/kg. For all samples, the activity concentration values of K-40 were lower than the acceptable value 412 Bq/kg as recommended by UNSCEAR, 2010 [12].

Table 1 and figure 4 also show the calculated values for radium equivalent activity. The results showed that the average radium equivalent values were 42.832±25.110, 57.498±14.542, and 45.583±18.574 Bq/kg for basil, celery, and mint, respectively. These values are below the permissible limit of 370 Bq/kg recommended by UNSCEAR, 2000 [14].

| Limit UNSCEAR, 2010 [12] | Average 2.233±4.337 | 3.121±4.387 | 5.850±1.045 | 25.354±8.696 | 0.042±0.029 | 92.115±33.070 | 45.583±18.574 |
|--------------------------|----------------------|-------------|-------------|--------------|-------------|--------------|--------------|
| 33                       | 45                   | 412         | 370         |

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Figure 1. Specific activity of the basil sample in Al-Taji city.

Figure 2. Specific activity of the celery sample in Al-Taji city.
As shown in Table 2 and figure 5, the average rate of transition factor for basil sample from U-232, Th-232, K-40 and Cs-137 was 0.346±0.100, 0.260±0.326, 1.029±0.232 and 0.442±0.322. For celery sample it was 0.262±0.115, 0.862±0.208, 0.0602±0.266 and 0.131±0.010. Whereas, the average rate of the transition factors for mint plant samples was 0.007±0.0071, 0.588±0.143, 0.680±0.271 and 0.321±0.070 respectively.

Finally, the values of transition factors from soil to root in the celery sample for U-232, Th-232, K-40, and Cs-137 was 0.016, 0.724, 0.938, and 0.377. The highest transfer factor rate was 1.029±0.232 in the basil sample with a concentration of K-40. The lowest rate of transfer factor from root to leaf in the mint sample for U-232 was 0.007±0.0071. We note from the results that the highest rate of transfer factor was for roots and the highest rate of uranium transfer factor was 0.438 in basil plant. The highest transfer rate for thorium was 1.061 at the root of celery. The highest transfer rate for potassium is 1,267 for basil roots. While the highest transfer factor for Cs-137 was 0.796 at the roots of basil. As for the highest average rate of K-40 for the root-to-leaf transform factor was 1.029 ± 0.232 in the basil sample. The lowest average transfer factor rate of U-232 concentration from the root-to-leaves was 0.007±0.0071 in the mint sample. Among them, the transition factor rates for the concentrations of Th-232 and Cs-137 were also for the basil sample.
Table 2. Soil-to-plant transfer factor (TF) of natural radionuclides and artificial Cs-137.

| Sample | Parts   | U-232 | Th-232 | K-40  | Cs-137 |
|--------|---------|-------|--------|-------|--------|
| Basil  | Root    | 0.438 | 0.624  | 1.267 | 0.796  |
|        | Stalk   | 0.361 | 0.115  | 1.017 | 0.365  |
|        | Leaves  | 0.238 | 0.031  | 0.802 | 0.166  |
|        | Average | 0.346±0.100 | 0.260±0.326 | 1.029±0.232 | 0.442±0.322 |
| Celery | Root    | 0.372 | 1.061  | 0.903 | 0.139  |
|        | Stalk   | 0.272 | 0.880  | 0.509 | 0.135  |
|        | Leaves  | 0.142 | 0.615  | 0.395 | 0.120  |
|        | Average | 0.262±0.115 | 0.862±0.208 | 0.602±0.266 | 0.131±0.010 |
| Mint   | Root    | 0.016 | 0.724  | 0.938 | 0.377  |
|        | Stalk   | 0.004 | 0.602  | 0.706 | 0.345  |
|        | Leaves  | 0.001 | 0.437  | 0.397 | 0.241  |
|        | Average | 0.007±0.0071 | 0.588±0.143 | 0.680±0.271 | 0.321±0.070 |

Figure 5. Transfer factor in the samples at Al-Taji city.

Table 3 shows calculated results for radiological risk indicators (absorbed dose, annual effective dose, hazard indices and risk cancer) for all samples. The values of all radiation hazard indices were below the permissible limits of 1 recommended by UNSCEAR, 2000 [14]. Figure 6 estimated mean values for the absorbed dose rate of basil and celery and mint ranged from 5.826 to 11.948 nGy/h in basil leaves to 33.638 to 58.205 nGy/h in soil according to UNSCEAR Recommendation, 2010 [12]. All results were below the recommended limit for the average exposure rate (84 nGy/h).

Table 3 and figure 7 show a lifetime risk assessment of cancer. The results show that there is a difference in the risk of developing cancer. The lifetime risk of developing cancer inside the body was higher than the risk of developing lifelong cancer outside the body. The highest lifetime risk of cancer,
both inside and outside the body, is found in the soil sample. The same standards were followed by the celery root sample. However, the lowest risk of cancer is in the basil leaf sample.

Table 3. Absorbed dose rate, annual effective dose equivalent, hazard indices, and life-time cancer risk.

| Code          | D (nGy/h) | AEDE (µSv/y) | Hazard index | ELCR * 10^-3 |
|---------------|-----------|--------------|--------------|---------------|
|               | outside   | inside       | outside      | inside        | H_{ex} | H_{in} | outside | inside |
| Basil Soil    | 33.638    | 58.205       | 40.748       | 285.535       | 0.190  | 0.214  | 142.620 | 999.372 |
| Basil Root    | 23.638    | 41.551       | 28.990       | 203.834       | 0.132  | 0.035  | 101.466 | 713.420 |
| Basil Stalk   | 15.921    | 28.298       | 19.526       | 138.819       | 0.088  | 0.096  | 68.341  | 485.866 |
| Basil Leaves  | 5.826     | 11.948       | 7.145        | 54.201        | 0.030  | 0.035  | 25.007  | 189.706 |
| Celery Soil   | 33.638    | 58.205       | 40.748       | 285.535       | 0.190  | 0.214  | 142.620 | 999.372 |
| Celery Root   | 31.873    | 54.691       | 39.089       | 268.292       | 0.182  | 0.190  | 136.812 | 939.023 |
| Basil Stalk   | 25.046    | 42.708       | 30.716       | 209.511       | 0.144  | 0.150  | 107.507 | 733.29  |
| Celery Leaves | 18.267    | 31.073       | 22.403       | 152.433       | 0.104  | 0.108  | 78.412  | 533.515 |
| Mint Soil     | 33.638    | 58.205       | 40.748       | 285.535       | 0.190  | 0.214  | 142.620 | 999.372 |
| Mint Root     | 22.538    | 38.564       | 27.640       | 189.182       | 0.126  | 0.126  | 96.714  | 662.138 |
| Basil Stalk   | 18.323    | 31.272       | 22.472       | 153.409       | 0.103  | 0.104  | 78.652  | 536.934 |
| Mint Leaves   | 12.709    | 21.581       | 15.587       | 105.871       | 0.072  | 0.071  | 54.555  | 370.550 |
| Limit         | 84        | 290          | 1            | 0.29 x 10^-3  | 1.16 x 10^-3 |

Figure 6. Absorbed dose rate of samples in Al-Taji city.
Figure 7. Life-time cancer risk of samples in Al-Taji city.

5. Conclusions
In this study, radioactivity in basil, celery and mint, which was consumed by adults in Iraq, was measured regularly. Specific activity concentrations U-238, Th-232, and K-40, using the NaI (Tl) gamma ray spectrum detector, were comparable to those reported elsewhere. Very high K-40 soil-to-plant transfer factors (root) were found in most of the study samples as they were 1,267 in basil. The extremely high K-40 transfer factor values were observed in the cases where the K-40 concentration in the soil samples was too low. This may be due to the continuous accumulation of K-40 by absorbing through the root uptake over a period of time. The mean concentrations of activity of U-238, Th-232 and K-40 in basil samples were greater than those in celery and mint and were all less than the permissible value.

To assess radiological hazards, radium-equivalent equivalents, absorbed dose rate, annual effective dose rate, and hazard indices were all estimated below the permissible limits that are considered safe from radiological hazards.

Therefore, the analysis confirms that the studied samples did not have significant gamma radiation effects. Quality must be strictly controlled, and studying the radionuclide concentration in this field is of great importance. So in terms of the market, determining the radioactivity values of the commodity is important for the general population.

In this study K-40 transfer factors were found to be arranged at the roots. Gradually, descending from the roots to the stalk and then to the leaves in the selected basil, celery and mint plants under study. The highest K-40 transfer factors values were concentrated in the roots and were close to the limit recommended by UNSCEAR, 2010. This high absorption i.e. uptake of K-40 by the roots may be due to the essential nutrient characteristic of potassium in plants.

The transfer factors for U-238 differed in the average range from 0.007±0.0071 in mint to 0.346±0.100 in basil plant. The soil-to-root transfer factors of Th-232 were 0.031 in the basil leaves to 1.061 in the root of the celery sample, with an average range of 0.260±0.326 in the basil plant to 0.862±0.208 in celery plant. The transfer factors for Th-232 were higher than that obtained for U-238 in this study. The average soil-to-plant transfer factors for Cs-137 varied from 0.241 in mint plant to 0.796 in basil plant. These transfer factors for Cs-137 are not significant because of their low concentration in environmental samples which was obtained in this study.
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