Original Research Article

Activity level of ^{238}U, ^{232}Th, ^{40}K and resultant dose rates in soil and some common cultivated vegetables

Abstract

The aim of this present study is to determine the level of natural radionuclides of ^{40}K, ^{238}U and ^{232}Th in soil samples and in (Potato, *Solanum tuberosum* and Carrot, *Daucus carota*) samples and vegetables (Tomato, *Solanum hycopersicum* and Eggplant *Solanum melongena*) in Al-Mada'in district 30 km south east of Baghdad, Iraq. High purity germanium (HPGe) detector was used for measurement. The transfer factors, annual absorbed dose rate and the annual effective dose in the samples collected were determined. The results showed that the mean level of measured natural radionuclides were 362.6 ± 41.6 $Bqkg^{-1}$, 184.7 ± 17.4 $Bqkg^{-1}$, 191.9 ± 13.5 $Bqkg^{-1}$, 120.3 ± 10.6 $Bqkg^{-1}$ and 126.1 ± 11.7 $Bqkg^{-1}$ for ^{40}K; 19.67 ± 2.00 $Bqkg^{-1}$, 4.70 ± 0.609 $Bqkg^{-1}$, 5.43 ± 0.977 $Bqkg^{-1}$, 3.30 ± 0.460 $Bqkg^{-1}$ and 2.40 ± 0.701 $Bqkg^{-1}$ for ^{238}U and 12.34 ± 4.12 $Bqkg^{-1}$, 3.77 ± 0.904 $Bqkg^{-1}$, 4.54 ± 0.709 $Bqkg^{-1}$, 3.51 ± 0.721 and 3.81 ± 0.796 $Bqkg^{-1}$ for ^{232}Th for soil, tomato, eggplant, potato and carrot samples respectively. The soil-to-tomato transfer factors were found to be 0.512, 0.242 and 0.344 for ^{40}K, ^{238}U and ^{232}Th and soil-to-eggplant transfer factors were found to be 0.534, 0.279 and 0.408 for ^{40}K, ^{238}U and ^{232}Th respectively. The soil-to-potato transfer factors were found to be 0.336, 0.170 and 0.320 for ^{40}K, ^{238}U and ^{232}Th while the soil-to-carrot transfer factors were found to be 0.348, 0.122 and 0.309 for ^{40}K, ^{238}U and ^{232}Th respectively. The mean absorbed dose rate was 30.0 ± 0.57 $nGyh^{-1}$ and the mean annual outdoor effective dose was 55.2 $mSvy^{-1}$. The annual effective dose report for this present study 91.6% of the world average value of 70.00 $msvy^{-1}$ and 87.3% of Thi-Qar government, south Iraq state value of 39.9 $msvy^{-1}$.

Keywords: Thallium; HPGe; Radon; Transfer Factors; Annual Outdoor; Radioactivity

Introduction

Radionuclides are found naturally in soil, water and food. In general, any environment contains different materials and different amounts of natural radionuclides and their decay products. The isotopes of Potassium (^{40}K), Uranium (^{238}U), Thorium (^{232}Th) and the results of their decay can be found abundantly in the outer layers of the Earth [1]. Soils with above average level of radiation can be found in multiple regions due to exposure to cosmic rays from outer space [2]. Knowing the level of radiation in the environment is important to be able to develop and implement appropriate control programs to protect large numbers of people from exposure to radiation at a dose of about 1.5 Sv, which increases the incidence of cancerous diseases and deaths [3]. It is reported that all foods that contain few radionuclides be part of the resources where it collects leads to exposure of people to about 0.4 mSv annually [3]. Plant tubers and vegetables are a very important bio-source in the human diet, and the presence of natural radionuclides (^{40}K, ^{238}U and ^{232}Th) in which it may lead to radiological effects not only in the food but also on the population that consumes such foods. Plant Tubers are almost grown in all tropical regions of the world where to provide food rich with essential carbohydrates for 80 million people and an important source of income [4]. Humans are always exposed to ionizing radiation of natural origin, that is, to cosmic radiation from outside the Earth. The origin of cosmic radiation from outside the Earth is from high-energy cosmic ray particles at sea level about 30 nGyh-1 [3], while the cosmic radiation from the Earth is due to the presence of naturally occurring radionuclides; mainly Potassium, Rubidium and radionuclides in the decay chains of Thorium and Uranium [5]. These radionuclides have a half-life similar to the age of the Earth [6]. Agriculture has been the backbone of the economies of many developing countries. Many countries in Asia have developed policies on providing and sustaining food security. When people have enough food to eat, many problems related to nutrition are avoided and the citizen is healthy and able to work for the development of these countries. It is expected that developing countries not only focus on providing adequate food for their citizens, but also on chemically and radiologically safe foods [3]. This constitutes an important part of the goals of the United Nations, which is related to the sustainability of food security and to assist Member States to ensure that people have access to nutritionally adequate food, and very safe for human consumption [7]. The presence of radionuclides in the soil above certain levels leads to the pollution of agricultural crops because these crops derive their nutrients from the soil on which they are grown. The radionuclides present in the soil solution can then be transmitted through the root hairs to the roots of vegetables to transfer them to the vegetative plant and fruits that humans feed on. The uptake of the radionuclides associated with particles can be entry in the form of food directly or indirectly as the processes of weathering of the particles and their transfer from the soil - plants - animals. This depends on the pH of the soil solution, organic matter, microbial activities and the presence of vegetation [8]. Therefore, it is very important to evaluate the radiological safety of these plant tubers and vegetables that humans consume, because eating food contaminated with radionuclides leads to the possibility of human exposure to a high level of radiation doses. Moreover, radionuclides with long half-lives are considered dangerous to human health because they can enter the human body system through the food chain and thus increase the risk of radiation for many years [2]. The levels of radioactivity in vegetables and plant tubers which grown in such soils can enhance the accumulation of natural radionuclides in the body through nutrition of these food products as well as the concentration of many radioactive pollutants including Uranium, Thorium and Potassium may increase over the past few decades. [9]. These primary pollutants are already present in the environment where there is a threat to many living beings. Due to the lack of physical and biological studies that focus their attention on the effects and dangers of pollution with these radionuclides on humans. Therefore, it was necessary to measure the concentration of the radioactivity of naturally occurring radionuclides in soil samples and plant which grown in the contaminated study area. The aim of this study is to collect soil samples and common consumed foods (Tomatoes, Eggplant, Potatoes and Carrots) from some sites in Al- Mada'in area of Baghdad governorate in Iraq in order to determine the levels of natural radioactivity in these samples and to measure the concentration of radionuclides activity of ^{40}K, ^{238}U and ^{232}Th and determine the Transfer Factor (TFs) and estimation of the annual absorbed dose rate and annual effective dose in all samples collected for the study. Al- Mada'in area was chosen for this study due to its locations is close to most of the former Iraqi nuclear facilities.

Materials and Methods

Geographical description of the study area

Al- Mada'in is located within the administrative boundaries of Baghdad Governorate and on the banks of the Tigris River in a wide alluvial plain, 112 feet (34 meters) above sea level. Baghdad's climate is hot and dry in summer, from June to the end of August. The average temperature reaches 44 °C. Although the humidity is very low (usually less than 10%), dust storms from deserts in the west are normal. In the winter, from December to February, the average temperature in Baghdad is 15°C to 16°C. Annual rainfall is usually within the period from November to March, with an average around 140 mm, but the highest reaches 575 mm and decreases to the lowest 23 mm. The most important economic crops grown in the region are date palms, orange trees and apples. Potatoes, Carrots, Peppers, Eggplant, Tomatoes and other vegetables are also grown. In addition to the cultivation of the main crops, for example, bread wheat, barley and corn. Milk and its derivatives such as cheese and yoghurt are also produced in the city, date juice (molasses) is also manufactured. The area of Al-Mada'in covers 803 Km^2. Within the coordinates 33.1002983, 44.5831393. it has population of 434000 people.

Sample collection

Twelve (12) samples were collected for each of the soil, Tomatoes, Eggplant, Potatoes and Carrots. The locations of these samples were determined using the Global Positioning System (GPS). Soil samples were collected from depths of 0-15 cm for different locations, while all vegetables samples were collected directly from the agricultural lands in the study area. The samples were transported to the laboratory for preparation. The soil samples were mixed well after removing other external materials such as roots and stones. The samples were then weighed and dried in an electric oven at 100°C until a constant dry weight was obtained. Then the dried samples were ground using a mortar and pestle. After grinding and mixing well, the soil samples were sieved using a 2-mm sieve. 1 kg of each soil was weighed and placed in a closed container that does not allow the exchange of the Radon element, and kept for 28 days in order to ensure the required balance between radon and its offspring (what is generated from it during radioactive decay) before measuring the radioactivity. Vegetable samples were thoroughly washed to remove dust and contamination from the surface. It was dried under the sun and then dried in the oven at a temperature of 65 °C until a constant weight was reached. The dried samples were cooled to room temperature. Each sample was ground and sieved using a sieve (2mm) in size. Homogeneous samples (1 kg) were kept in a marked Marinelli beaker and then closed well with plastic tape to prevent airflow from the sample, these samples were stored for 30 days to allow the Bismuth ^{214}B and Thallium ^{208}Tl isotopes to reach equilibrium with Uranium ^{238}U and Thorium ^{232}Th and their offspring, moreover the plastic containers are kept tightly closed with plastic containers to ensure the retention of radon ^{220}Rn, ^{222}Rn. Subsequently, the samples were placed in a container weighing 1 kg per sample. Then 1 Kg was weighed with an accurate balance and placed in a closed box that do not allow radon exchange and kept for 28 days in order to reach the balance between radon and its radioactive decay products, and then the radioactivity was measured in the sample using the geometric shape of the Marnelly container to measure. The containers of the Marnelly were placed on the top of the detector for counting [4].

Determination of Specific Radioactivity

The specific radioactivity concentration of soil samples was measured using a gamma ray spectroscopy with a Germanic detector (HPGe) 40% efficiency, connected with a multi-channel analyzer (MCA) for radioactivity measurement and the results were analyzed using Analytical Giene-2000 software for the studied samples. To avoid the radiative effect of cosmic rays, the HPGe detector was placed in a protective shield with a thickness of 4.7 cm. The energy of the gamma spectrometer was calibrated using a standard multi-isotope radioactive source ^{152}Eu and ^{60}CO, and a Marnelly geometric container was used for measurement. Marnelly containers were placed on the top of the detector for counting. the required counting time was 72000 seconds for all samples in order to reduce the possible error in the radiometric counting (Probable counting error). The ^{40}K activity was estimated directly by the peak gamma radiation of 1461 keV while the ^{232}Th and ^{238}U were estimated by the gamma radiation emitted from the product of their offspring such as ^{214}Bi (1764 keV) and ^{208}Tl (2614.6 keV) respectively while ^{238}U and ^{232}Th were estimated by the gamma radiation emitted by the products of radionuclides such as ^{214}Bi (1764 keV) and ^{208}Tl (2614.6 keV) respectively, the Below detectable limits (BDL) for ^{214}Bi were 2.03 $Bqkg^{-1}$, Thallium ^{208}Tl 4.7 $Bqkg^{-1}$ and 18.9 $Bqkg^{-1}$ for Potassium [10]. These values were calculated using the formula suggested by [11]

$$A\ (Bqkg^{-1}) = \frac{N}{M \times I\gamma\ (E\gamma) \times eff \times T}$$

A: Specific activity concentration
N: net counts per second (CPS) = (sample CPS – background CPS) for the sample in the peak range
M: mass of the soil sample (kg)
$I\gamma$ ($E\gamma$): is the abundance at energy $E\gamma$
Eff : is the detection efficiency of crystal
T: The time of measurement which was equal to (72000 s)

Transfer Factor

Soil-to-crop transfer factor (TFs) is a measure of the transfer of radionuclides from soil to crops. Each radioactive element in the soil follows a complex dynamic in which part of its concentration is transferred to the soil solution, while the other part of it gradually binds strongly to soil particles. The part in the soil solution can be transmitted to the plant through the roots [12]. From the activity concentration of radionuclides observed in agricultural crops and their corresponding in soil, the values of transport factors (TFs) are calculated according to the equation.

$$TF = \frac{\text{Activity of radionuclides in crops (BqKg-1 dry weight}}{\text{Activity of radionuclides in soil (BqKg}-1\text{ dry weight)}}$$

Dry weight is preferred in the measurement because the amount of radioactivity per Kg of dry weight is much less variable than its quantity in wet weight. The soil-to-crop transfer factor TF can be used as an indicator of the accumulation of trace elements for crops or the transfer of elements from the soil to the crop.

Absorbed Dose Rate

The estimation of the absorbed dose rate ($nGyh^{-1}$ units) due to the concentration of radionuclides was determined based on the following equation [13].

$$D = 0.042C_K + 0.429C_U + 0.666C_{Th}$$

Whereas: D is the absorbed dose rate in $nGyh^{-1}$ due to the specific radionuclide concentration C_K, C_U and C_{Th} for ^{40}K, ^{232}Th and ^{238}U respectively in $Bqkg^{-1}$ at 1m above the ground.

Annual Outdoor Effective Dose

Effective dose is a measure of the random effects of health risks due to radiation dose, whether internal or external, on all or part of the body. The equivalent annual effective dose was estimated using the outdoor Occupancy factor of 0.2 and the conversion factor of 0.7 $SvGy^{-1}$ for adults referred to [3] to convert the absorbed dose rate in the air to the effective dose in humans.

Conversion Factor 0.7 $SvGy^{-1}$.

$$E_x = D_x * N(h) * O_f * K_f$$

E_x is the annual outdoor effective dose ($mSvy^{-1}$),
$N(h)$ is the number of hours in a year (24 hours x 365.24 days),
D_x is absorbed dose rate in the air ($nGyh^{-1}$),
O_f is outdoor occupancy factor,

K_f is conversion factor ($SvGy^{-1}$).

Results and discussion

Activity Concentrations in the Soil Samples

In this study, the level of radioactivity in soil samples (Table 1) ranged from 298.4 to 419.2 $Bqkg^{-1}$ with a rate of 362.6±41.6 $Bqkg^{-1}$ for ^{40}K and a range of (16.62 to 22.078) $Bqkg^{-1}$ with a rate of 19.67±2.00 $Bqkg^{-1}$ for ^{238}U, (6.38 to 18.93) $Bqkg^{-1}$ with an average of 12.34±4.12 $Bqkg^{-1}$ for ^{232}Th. The activity concentration of the radionuclides of ^{40}K, ^{238}U and ^{232}Th in soil samples was higher than the corresponding values in vegetable samples, and this supports what is scientifically known, that only a small part of the radionuclides in the soil can be transferred to plants [14]. The activity concentration for ^{40}K, ^{238}U, and ^{232}Th was lower than the global average values of 410, 35.0 and 28.0 $Bqkg^{-1}$ for the ^{40}K, ^{238}U and ^{232}Th, respectively [3]. The values were also lower than the average activity concentration values of 632.74 ± 14.86 and 20.66 ± 1.41 $Bqkg^{-1}$ for ^{40}K and ^{238}U and higher than the average activity concentration values of 6.73 ± 0.885 for the ^{232}Th $Bqkg^{-1}$ respectively, as previously recorded for some agricultural crops grown in different areas of the soil of Nineveh Governorate, northern Iraq [14], but higher than the average values of 98.39 ± 4.46, 7.67 ± 0.24 and 5.75 ± 0.320 $Bqkg^{-1}$ for ^{40}K, ^{226}Ra and ^{232}Th for some agricultural crops cultivated in the soil of Diwaniyah governorate, southern Iraq [15].

Table 1. The radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th in soil samples.

Samples	GPS location		Soil		
	North	East	^{40}K ($Bqkg^{-1}$)	^{238}U($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)
S1	33.081586	44.569323	419.2±14.16	21.41±1.25	11.68±0.619
S2	33.083887	44.570696	298.4±6.04	16.62±1.40	16.71±1.07
S3	33.078421	44.570954	400.1±10.29	19.99±2.17	10.64±0.705
S4	33.066122	44.567177	375.48± 7.82	22.78±1.33	14.42±0.385
S5	33.068568	44.566405	324.9± 3.70	18.03±3.08	8.12±0.200
S6	33.065834	44.565890	408.2±11.41	17.57±2.00	15.28±2.70
S7	33.080363	44.578936	368.3± 4.35	20.19±1.07	9.06±0.926
S8	33.076407	44.577906	394.2±8.81	18.37±2.65	12.07±1.12
S9	33.070653	44.581253	318.7±2.67	19.84±1.06	18.93±2.06
S10	33.063892	44.574816	309.5±6.8	22.25±2.91	6.38±1.47
S11	33.062957	44.583399	346.3±3.71	17.74±1.68	7.74±1.29
S12	33.059648	44.574644	387.6±8.24	21.26±2.09	17.07±2.59
Range			298.4 – 419.2	16.62–22.78	6.38–18.93
Mean			362.6±41.6	19.67±2.00	12.34±4.12

Radioactivity concentrations in Tomato (*Solanum hycopersicum*) and Eggplant (*Solanum melongena*) samples.

The level of radioactivity in Tomato samples ranged from 153.6 to 216.2 $Bqkg^{-1}$, an average of 184.7±17.4 $Bqkg^{-1}$ for ^{40}K, and 3.84 to 5.46 $Bqkg^{-1}$, with an average. 7.0±609 $Bqkg^{-1}$ for ^{238}U and 2.46 to 4.97 $Bqkg^{-1}$ with an average value of 3.77±0.904 $Bqkg^{-1}$ for ^{232}Th. The highest value for radionuclides was for ^{40}K among other measured radionuclides for all samples and this may be due to the fact that Potassium is present in high levels. It is also added to agricultural soils in the form of chemical fertilizers. In this study, the values of ^{232}Th were higher than the values of 2.22±0.05 $Bqkg^{-1}$ while the values of ^{40}K and ^{238}U were lower than the values of 219.99+1.29 $Bqkg^{-1}$ and 5.12+0.22 $Bqkg^{-1}$ which were recorded for Tomato samples in Iraq. (Kufa city) [16].

The level of radioactivity in Eggplant samples in the study area ranged from 167.3 to 217.2 $Bqkg^{-1}$ and with an average value of 191.9 ± 13.5 $Bqkg^{-1}$ for ^{40}K and 4.06 to 7.14 $Bqkg^{-1}$ with an average value of 5.43 ± 0.977 $Bqkg^{-1}$ for ^{238}U and 3.27 to 5.50 $Bqkg^{-1}$ with average value of 4.54±0.709 $Bqkg^{-1}$ for ^{232}Th. The concentration of radioactivity in Tomato samples was lower compared to its concentration in Eggplant samples. The high concentration of ^{40}K in vegetable samples may be attributed to the use of fertilizers on farmland. The overall average concentration of radioactivity for ^{40}K, ^{238}U and ^{232}Th in the Eggplant samples was 3.89%, 15.5% and 20.4%, respectively, higher than the overall average values in the Tomato samples mentioned in this study. The high percentage of radioactive Potassium nuclides compared to Thorium and Uranium nuclides is attributed to the fact that Potassium is one of the essential elements needed by the plant to complete its life cycle.

Table 2. The radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th in Tomato and Eggplant samples.

Samples	Tomato			Eggplant		
	^{40}K ($Bqkg^{-1}$)	^{238}U($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	^{40}K ($Bqkg^{-1}$)	^{238}U($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)
S1	201.4±3.27	4.98±0.381	2.46±0.144	217.2±3.60	5.63±0.732	4.18±0.194
S2	186.5±2.93	4.77±0.308	2.58±0.227	190.6±4.00	6.27±0.468	3.27±0.613
S3	191.8±4.10	4.57±0.642	3.04±0.357	209.5±1.05	6.01±0.930	4.64±0.209
S4	187.3±2.05	4.69±0.255	4.24±0.924	191.0±6.02	7.41±1.09	5.33±1.73
S5	153.6±4.27	3.84±0.272	3.19±0.610	167.3±5.83	4.26±0.830	3.84±1.02
S6	202.1±3.09	3.96±0.107	4.83±0.476	181.9±4.91	5.73±0.507	5.47±1.46
S7	173.7±4.69	5.07±0.215	4.97±0.382	198.4±3.78	5.23±0.446	4.23±1.15
S8	184.9±1.49	5.22±0.236	4.73±0.814	190.3±2.62	5.48±0.866	5.01±1.28
S9	170.0±3.81	5.18±0.300	3.58±0.348	178.9±4.29	5.92±0.780	4.42±0.831
S10	164.9±2.64	3.57±0.284	3.38±0.730	185.4±5.07	4.06±0.408	3.83±0.384
S11	183.7±3.32	5.46±0.462	4.76±0.661	201.4±6.68	4.97±0.714	5.50±0.368
S12	216.2±2.17	5.14±0.336	3.42±0.543	190.7±5.42	4.14±0.635	4.74±0.404
Range	153.6-216.2	3.84-5.46	2.46-4.97	167.3-217.2	4.06-7.41	3.27-5.50
Mean	184.7±17.4	4.70±0.609	3.77±0.904	191.9±13.5	5.43±0.977	4.54±0.709

Radioactivity concentrations in Potato (*Solanum tuberosum*) and Carrot (*Daucus Carota*) samples.

In this study, the level of radioactivity in Potato samples ranged from 107.3 to 137.0 $Bqkg^{-1}$ with an average value of 120.3±13.5 $Bqkg^{-1}$ for ^{40}K and 2.38 to 4.12 $Bqkg^{-1}$ with an average value of 3.30±0.460 $Bqkg^{-1}$ for ^{238}U and 2.71 to 5.31 $Bqkg^{-1}$ with an average value of 4.07±0.969 $Bqkg^{-1}$ for ^{232}Th. The results showed that the concentration of the radioactivity of ^{40}K is the highest among the other radionuclides that were measured for all samples because it is one of the elements needed by the plant in large quantities (Macroelements essential plant nutrients). In this study, the values of ^{40}K and ^{232}Th were higher than the values of 116.9 $Bqkg^{-1}$ and 3.11 $Bqkg^{-1}$, while the values of ^{238}U were less than the value of 4.24 $Bqkg^{-1}$. Which recorded in Potato samples in Iraq (Kufa city) [16]. The level of radioactivity in the carrot samples ranged from 111.6 to 158.1 $Bqkg^{-1}$, with an average value of 126.1±13.7 $Bqkg^{-1}$ for ^{40}K and 1.39 to 3.38 $Bqkg^{-1}$, with an average value of 2.40±0.701 $Bqkg^{-1}$ for the ^{238}U and 3.60 to 6.72 $Bqkg^{-1}$ with an average value of 5.03±0.902 $Bqkg^{-1}$ for the ^{232}Th. The radioactivity concentration of ^{40}K and ^{232}Th in Potato samples was lower at 4.6% and 7.9%, respectively compared to their concentrations in carrot samples, while the radioactivity concentration of ^{238}U in carrot samples was lower at 27.7% compared with its concentration in the Potato samples mentioned in this study. The reason for the high concentration of ^{40}K in vegetable samples may be attributed to the use of Potassium fertilizers on agricultural land.

Table 3. The radioactivity concentrations of ^{40}K, ^{238}U and ^{232}Th in Potato and Carrot samples.

Samples	Potato			Carrot		
	^{40}K ($Bqkg^{-1}$)	^{238}U($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	^{40}K ($Bqkg^{-1}$)	^{238}U($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)
S1	106.7±6.24	3.30±0.110	2.71±0.083	118.9±2.09	2.02±0.130	3.24±0.169
S2	117.4±10.4	3.16±0.134	3.52±0.476	121.0±3.75	3.16±0.209	3.86±0.551
S3	121.0±2.00	2.94±0.068	3.34±0.380	111.6±11.9	2.74±0.750	4.39±0.275
S4	118.2±18.2	3.64±0.540	4.59±0.590	121.7±3.22	3.04±1.04	5.18±0.778
S5	112.6±4.40	4.12±0.122	3.47±0.961	116.0±1.70	2.12±0.129	4.44±0.184
S6	127.5±7.38	2.73±0.731	2.09±0.148	131.3±2.32	1.73±0.077	2.72±0.226
S7	109.6±2.61	3.36±0.300	2.82±0.129	114.9±4.94	2.24±0.246	4.04±0.425
S8	116.7±5.16	3.42±0.422	4.53±1.12	120.2±3.20	3.27±0.200	3.72±0.636
S9	107.3±7.30	3.39±0.196	3.65±0.516	158.1±24.1	1.39±0.987	4.66±0.608
S10	137.0±12.0	2.38±0.163	3.71±0.304	141.1±1.10	2.28±1.28	3.47±0.332
S11	115.9±10.9	3.72±0.347	4.02±0.157	119.4±10.0	1.48±0.230	3.60±0.849
S12	153.5±3.54	3.41±0.361	3.68±0.842	138.9±4.85	3.38±0.290	2.43±0.820
Range	107.3-137.0	2.38-4.12	2.09-4.59	111.6-158.1	1.39-3.38	3.60-6.72
Mean	120.3±10.6	3.30±0.460	3.51±0.721	126.1±11.7	2.40±0.701	3.81±0.796

Transfer Factors (TFs)

The radionuclide transport coefficient depends on soil type, pH, solid/liquid distribution coefficient, replaceable K^+ ions, and organic matter content. The transport factor (TFs) for ^{40}K, ^{238}U, and ^{232}Th were determined and the results are in Table (4). The average values of the transport factor for Tomato samples were 0.512 ± 0.046, 0.242 ± 0.040 and 0.344 ± 0.154 for ^{40}K, ^{238}U and ^{232}Th respectively, while the average values of the transport factors for the Eggplant samples, they were 0.534±0.054, 0.279±0.056, and 0.408±0.146 for ^{40}K, ^{238}U, and ^{232}Th, respectively. The TFs values of ^{40}K were higher in the samples compared to the values of ^{238}U and ^{232}Th. The average values of transfer factor of ^{40}K, ^{238}U and ^{232}Th for Eggplant samples were higher than for Tomato samples. The mean values of the transfer factors for Potato samples were 0.336 ± 0.052, 0.170 ± 0.031 and 0.320 ± 0.136 for ^{40}K, ^{238}U and ^{232}Th, respectively, while the mean values of the transfer factors for Carrot samples were 0.354 ± 0.067, 0.123 ± 0.038 and 0.346 ± 0.137 for ^{40}K and ^{238}U and ^{232}Th, respectively. The TFs values of ^{40}K were higher in the samples compared to the values of ^{238}U and ^{232}Th. The values of the transfer factors of ^{40}K and ^{232}Th in the Potato samples were lower than those of the Carrot samples, while the values of the transfer factor of ^{238}U in the Carrot samples were lower than those of the Potato samples.

Table 4. The Transport Factor (TFs) from soil to Tomato, Eggplant, Potato and Carrot

Sample	TF (Tomato)			TF (Eggplant)			TF (Potato)			TF (Carrot)		
	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th
S1	0.480	0.233	0.211	0.518	0.263	0.358	0.255	0.154	0.232	0.284	0.094	0.277
S2	0.625	0.287	0.154	0.639	0.377	0.196	0.393	0.190	0.211	0.405	0.190	0.231
S3	0.479	0.229	0.286	0.524	0.301	0.436	0.302	0.147	0.314	0.279	0.137	0.413
S4	0.499	0.206	0.294	0.509	0.325	0.370	0.315	0.160	0.318	0.324	0.133	0.359
S5	0.473	0.213	0.393	0.515	0.236	0.473	0.347	0.229	0.427	0.357	0.118	0.547
S6	0.495	0.225	0.316	0.446	0.332	0.358	0.312	0.155	0.137	0.322	0.098	0.178
S7	0.472	0.251	0.549	0.539	0.259	0.467	0.298	0.166	0.311	0.312	0.111	0.446
S8	0.469	0.284	0.392	0.483	0.298	0.415	0.296	0.186	0.375	0.305	0.178	0.308
S9	0.533	0.261	0.189	0.561	0.293	0.233	0.337	0.171	0.193	0.496	0.070	0.246
S10	0.533	0.160	0.530	0.599	0.182	0.600	0.443	0.107	0.582	0.456	0.102	0.544

S11	0.530	0.308	0.615	0.582	0.280	0.711	0.335	0.210	0.519	0.345	0.083	0.465
S12	0.558	0.242	0.200	0.492	0.195	0.278	0.396	0.160	0.216	0.358	0.159	0.142
Mean	0.512	0.242	0.344	0.534	0.279	0.408	0.336	0.170	0.320	0.354	0.123	0.346

Absorbed Dose Rate and Annual Outdoor Effective Dose

The outdoor dose ratio was estimated due to the concentration of radionuclides in the soil for this study. The health risks associated with exposure to radioactivity in the soil were estimated in the study area. The results are shown in Table (5). The mean values ranged from 30.0 to 38.1 nGyh^{-1}, and the average values were 34.8±2.49 nGyh^{-1} for the agricultural soils of the Al-Mada'in city. These values of the absorbed dose rate were recorded as 63.3% of the global average values of 55.0 (nGyh^{-1}). The values of the average absorbed dose recorded in this study are higher than the value of 29.3 ± 0.48 nGy□$^{-1}$ that was recorded for different areas in Nineveh Governorate [14] but it is lower than the values of 39.9 ± 4.50 nGyh^{-1} that were recorded in selected soil samples for Dhi Qar Governorate Southern Iraq [17]. The annual outdoor effective dose recorded in this study ranged from 36.8 to 46.8, with an average value of 43.1±3.07 µSvy^{-1}. It is lower than the value of 53.9 µSvy^{-1} that was recorded in Nineveh Governorate, northern Iraq [14]. The recorded value of the annual effective dose is 38.4% less than the global average value of 70.0 µSvy^{-1} [3], and 7.4% is higher than the average value of the annual effective dose recorded in Dhi Qar Governorate / Iraq 39.9 [17] µSvy^{-1}

Table 5. Average values of Absorbed Dose Rate and Annual Outdoor Effective Dose in the study area

Samples	Absorbed dose rate D (nGyh^{-1})	Annual outdoor effective dose E (µSvy^{-1})
S1	37.2	45.7
S2	31.5	38.7
S3	34.5	42.3
S4	36.5	44.8
S5	33.4	45.0
S6	34.9	42.9
S7	33.5	41.1
S8	37.8	46.4
S9	34.5	42.3
S10	36.1	44.3
S11	30.0	36.8
S12	38.1	46.8
Mean	34.8±2.49	43.1±3.07

Table 6. The average distribution of natural radionuclides in the soil

Location	^{40}K (Bqkg^{-1})	^{238}U(Bqkg^{-1})	^{232}Th (Bqkg^{-1})
Al- Mada'in, Baghdad State, Iraq present (study)	362.6	19.67	12.34
Nineveh state, Iraq	592.5	20.9	7.30
Thi-Qar governorate, Iraq	304.6	29.2	22.7
World Average (UNSCEAR, 2000) [3]	410	35.0	28.0

Table 7. Annual Outdoor Effective Dose (E)

Location	E (μSvy^{-1})
Al- Mada'in Baghdad State, Iraq present (study)	64.1
Nineveh state, Iraq	53.9
Thi-Qar governorate, Iraq	73.4
World Average (UNSCEAR, 2000) [3]	70.0

Conclusions

The radioactivity concentration of ^{40}K, ^{238}U and ^{232}Th radionuclides in Eggplant samples was higher than the concentration in Tomato, Carrot, and Potato samples, and the ^{40}K concentration in Eggplant increased by 3.70, 37.3 and 34.3% compared to Tomato, Potato and Carrot samples, respectively. ^{238}U increased by 13.4, 39.2 and 55.8%, on the other hand the ^{232}Th in Eggplant samples increased by 17.0, 22.7 and 16.1 compared with Tomato, Potato and Carrot samples, respectively. The values reported for this study were higher than the values reported for some regions in different studies and lower for the values in other regions. It is not probable that the values obtained in this study would cause radiological health risks to people living in the studied area.

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