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Radionuclide Uptake and Soil-to-Plant Transfer Factor of Naturally Occurring Radionuclides (^{238}U, ^{232}Th and ^{40}K) in Leafy Vegetables from Farming Areas in Sohag, Upper Egypt

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ABSTRACT

This study quantified the activity concentrations of naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) in 25 soil and 25 leafy vegetable samples. These were taken from farming areas in the Sohag Governorate, Upper Egypt, during both the summer and winter months. Gamma spectroscopy, utilizing a calibrated High Purity Germanium (HPGe) detector, was employed for radionuclide analysis. The radium equivalent activity (Ra_{eq}) and soil-to-plant transfer factors (TF) were calculated to assess radiological hazard and radionuclide uptake, respectively. Results indicated that activity concentrations of ^{238}U (9.23-20.17 Bq/kg), ^{232}Th (12.69-23.76 Bq/kg) and ^{40}K (178.80-373.90 Bq/kg) in soil samples were below established global safety limits. In plant samples, activity concentrations were also within safe limits, with ^{40}K exhibiting the highest average concentration (126.5 Bq/kg). Ra_{eq} values for both soil (41.14-79.23 Bq/kg) and plant samples (10.43-34.38 Bq/kg) were significantly below the 370 Bq/kg safety threshold. TF values indicated differential radionuclide uptake by plants, with ^{40}K demonstrating the highest average TF (0.41), reflecting its biological significance.Overall, the measured radionuclide concentrations and transfer behaviors suggest that the cultivation and consumption of leafy vegetables in the studied region do not pose significant radiological health risks.

1. INTRODUCTION

Soil plays a fundamental role in supporting terrestrial ecosystems, acting not only as a medium for plant growth but also as a complex interface between the geosphere and biosphere. As the Earth's uppermost layer, soil is a dynamic mixture of minerals, rocks and organic matter, with its composition shaped by various environmental and anthropogenic factors, including climate, geology, vegetation and land use patterns [1, 2].

Among the natural constituents of soil are radionuclides, which originate from primordial radioactive elements within the Earth's crust. Notable naturally occurring radionuclides include uranium-238 (^{238}U), thorium-232 (^{232}Th), radium-226 (^{226}Ra) and potassium-40 (^{40}K) [3, 4]. The concentrations of these radionuclides vary significantly across different regions, primarily due to the underlying geological formations and soil characteristics [5-7]. These radionuclides are not confined to the soil matrix; rather, they establish pathways through which they may enter the food chain.

Plants can absorb radionuclides through several mechanisms: external irradiation, root uptake from contaminated soil and water and foliar absorption of airborne particles or gaseous radionuclides. Among these, root uptake is particularly influenced by factors such as soil pH, organic content, the presence of

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competing ions and plant-specific traits including root morphology and solute transport capacity. Importantly, radionuclides that share chemical properties with essential plant nutrients, such as potassium or calcium, exhibit higher biological mobility and are more readily absorbed by plants.

Understanding the behavior and mobility of radionuclides in the soil-plant system is crucial for assessing potential radiological health risks and for developing strategies to mitigate contamination in agricultural systems. This study investigates the concentrations and transfer dynamics of ^{238}U, ^{232}Th and ^{40}K in soil and leafy vegetables from farming areas in Sohag, Upper Egypt, aiming to provide a clearer picture of natural radioactivity exposure in this region.

2. Samples Collection, Preparation and Measurements

To prepare for radiological analysis, 25 leafy vegetable and 25 soil samples were taken from Sohag's farming areas during both summer and winter. The vegetable samples were thoroughly washed with water to remove surface contaminants, then dried in two stages, initially at room temperature, followed by oven drying at 50 °C. After complete drying, the samples were pulverized into a fine powder.

Soil samples were first cleared of stones, roots and other debris, then air-dried, crushed and sieved through a 2 mm mesh to ensure homogeneity. After weighing, all samples were placed in sealed plastic containers and stored for a minimum of four weeks to allow for secular equilibrium between thorium and radium progeny.

A Canberra GR-4020 model High Purity Germanium (HPGe) detector, with 40% relative efficiency and 2.00 energy resolution, was used to analyze the natural radionuclides ^{238}U, ^{232}Th and ^{40}K. The detector was calibrated using standard gamma sources (^{226}Ra, ^{137}Ce, ^{60}Co, ^{22}Na, ^{133}Ba, ^{137}Cs and ^{232}Th). Each sample's gamma spectrum was collected for 24 hours and gamma transition energies were referenced from established tables [8, 9]. To find the activity concentration (A_s), the net count rate was adjusted for counting time (N_P), detector efficiency (ε_T), gamma-ray intensity (P_γ) and sample mass (M) in kg, using the provided equation [10-12]

$$A_{S\,(Bq/kg)} = \frac{(N_p)}{(M)\times(\varepsilon_T)\times(P_y)} \quad \textbf{(1)}$$

Table (1): Gamma-ray energies and emission probabilities used for the determination of activity concentrations of ^{238}U, ^{232}Th and ^{40}K.

Nuclide	Daughter	γ-ray's (Kev)	Probability (%)
^{238}U	^{226}Ra	186.2	3.29
	^{214}Pb	295.2	18.7
	^{214}Pb	351.9	35.8
	^{214}Bi	609.3	45.0
	^{214}Bi	1120.3	14.9
	^{214}Bi	1764.5	16.0
	^{214}Bi	2204.1	5.0
^{232}Th	^{212}Pb	238.6	45.0
	^{208}Ti	583.1	30.0
	^{228}Ac	911.1	29.0
	^{228}Ac	968.6	17.5
	^{208}Ti	2614.7	36.0
^{40}K		1460.9	10.67

2.1. Radium equivalent (Ra_{eq})

To evaluate the radiological safety of materials, the radium equivalent activity (Ra_{eq}) is commonly used as a unified index that consolidates the gamma radiation contributions of ^{226}Ra, ^{232}Th and ^{40}K into a single metric. This facilitates a straightforward assessment of external gamma radiation hazards and ensures compliance with internationally recommended safety thresholds [13, 14]. Ra_{eq} is calculated using the following empirical formula:

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

In the radium equivalent formula, A_{Ra}, A_{Th} and A_K stand for the activity concentrations (in Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The ^{232}Th contribution is weighted by a factor of 1.43 and the ^{40}K contribution by 0.077, to accurately reflect their respective radiation hazards.

According to international guidelines, Ra_{eq} values should not exceed 370 Bq/kg, a limit that corresponds to a maximum annual external gamma dose of 1 mSv for the general public.

2.2. Transfer Factor

The soil-to-plant transfer factor (TF), also referred to as the concentration ratio, measures the efficiency with which plants absorb radionuclides from soil [15]. It is calculated by dividing the activity concentration of a radionuclide in dry plant matter by its corresponding activity concentration in dry soil, both expressed in Bq/kg:

$$TF = (A_{Plant}) / (A_{\text{Soil}}) \quad \textbf{(3)}$$

Where A_{plant} is the activity concentration of the radionuclide in the dry plant sample (Bq/kg) and A_{Soil} is the activity concentration in the corresponding dry soil sample (Bq/kg). This factor reflects the degree of radionuclide accumulation in plants and serves as a key indicator of radionuclide mobility and bioavailability in the environment. The TF is influenced by various factors, including plant species, soil physicochemical characteristics, agricultural practices, climatic conditions and the chemical form of the radionuclide [16].

3. RESULTS AND DISCUSSIONS

Analysis of data presented in Table 2 and Figure 1 reveals that all soil samples contained measurable levels of ^{232}Th, ^{238}U and ^{40}K, with concentrations falling within internationally accepted safety limits. Specifically, the activity concentrations ranged from 12.69 to 23.76 Bq/kg for ^{232}Th, 9.23 to 20.17 Bq/kg for ^{238}U and 178.80 to 373.90 Bq/kg for ^{40}K.

Among these, ^{40}K exhibited significantly higher concentrations in soil samples. This elevated presence is likely attributed to the use of phosphate-based fertilizers and the inherent properties of the soil, which consists primarily of muddy sand enriched with calcium carbonate and potassium. The high calcium carbonate content in the soil likely acts as a sorbent, reducing the mobility and thus the bioavailability of ^{238}U and ^{232}Th. This sorption behavior may explain their relatively lower concentrations compared to ^{40}K.

Table 3 presents the average activity concentrations of ^{238}U in the soil samples analyzed in this study. The measured values were consistent with previously reported data for Egyptian soils (17 Bq/kg) and remained below the global average of 35 Bq/kg [6]. These findings are in line with results from several countries, including Vietnam, Cuba, Canada and various Mediterranean and Asian nations.

However, the ^{238}U concentrations observed in this study were lower than those reported in Bangladesh, the United States, Pakistan and several other countries, while higher than those documented in the Netherlands and in some studies conducted in Cameroon and Cyprus. Overall, the ^{238}U levels in Sohag soils fall within the typical global range, reflecting expected regional variations influenced by geological characteristics, soil composition and local agricultural practices.

Table 3 also presents the activity concentrations of ^{232}Th in the analyzed soil samples. The measured values were below the global average of 30 Bq/kg but consistent with the reported average for Egyptian soils, which is approximately 18 Bq/kg [6]. These findings are comparable to those from several countries, including Cuba, Syria, Greece, Egypt, Taiwan and the United States.

However, the ^{232}Th concentrations in this study were higher than those reported in certain studies conducted in Cuba, the Netherlands, Cyprus and Canada, while lower than values recorded in Yugoslavia, Vietnam, India, Pakistan and various other regions. Overall, the measured ^{232}Th levels fall within a typical global range, with the observed variation likely influenced by differences in local geology, mineral content and land-use practices across different geographic locations.

Table 3 further presents the activity concentrations of ^{40}K in the analyzed soil samples. The measured levels were below the global average of 400 Bq/kg but were consistent with the reported average for Egyptian soils, approximately 320 Bq/kg [6]. These values are in agreement with findings from several countries, including Jordan, Turkey, the United States and others.

However, the ^{40}K concentrations in this study were higher than those reported in Vietnam, the Netherlands, Cuba, Cyprus, Nigeria and Syria, yet lower than those observed in Yugoslavia, Pakistan, India, Italy and several other nations. Overall, the ^{40}K levels recorded in this study fall within a typical global range, reflecting expected geographical variability due to differences in soil mineralogy, fertilizer application and environmental conditions.

As shown in Table 2 and Figure 2, the radium equivalent activity (Ra_{eq}) in the analyzed soil samples ranged from 41.14 to 79.23 Bq/kg, with an average value of 66.94 Bq/kg. This average is substantially below the internationally recommended safety limit of 370 Bq/kg, as established by UNSCEAR guidelines [6]. The low Ra_{eq} values indicate minimal external gamma radiation hazard in the studied agricultural areas, suggesting that the natural radioactivity levels in the soil do not pose a significant radiological risk to human health or the surrounding environment.

Table 4 and Figure 3 illustrate the activity concentrations (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K in the collected plant samples. The average concentration of ^{238}U was 9.74 ± 1.80 Bq/kg, with a range of 5.91 ± 1.02 to 19.60 ± 3.50 Bq/kg. For ^{40}K, the average activity was 126.5 ± 1.90 Bq/kg, ranging from 56.00 ± 1.30 to 211.10 ± 3.50 Bq/kg. The average concentration of ^{232}Th was 2.20 ± 0.80 Bq/kg, with a range from 1.50 ± 0.76 to 5.00 ± 2.40 Bq/kg.

Among the three radionuclides, ^{40}K exhibited the highest concentrations in plant tissues. This is primarily due to its natural abundance in the soil and its essential role in plant physiology, where it contributes to various biochemical and metabolic functions such as enzyme activation, osmoregulation and nutrient transport. In contrast, the lower levels of ^{238}U and ^{232}Th can be attributed to their limited mobility and lower bioavailability, as these radionuclides tend to bind strongly to soil particles, reducing their uptake by plants.

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K were relatively consistent across the seven analyzed plant species, with only minor variations observed. These slight differences are likely attributable to factors such as the type and timing of fertilizer application, irrigation practices and subtle variations in the physicochemical properties of the soil in which the plants were cultivated.

This interpretation is supported by the relatively uniform activity concentrations recorded in the corresponding soil samples, as shown in Table 2, indicating that local environmental conditions and agricultural inputs were broadly similar across the sampling sites.

As detailed in Table 5, the average ^{238}U concentration in this study's vegetables was similar to those in Nigeria, Indonesia and Iraq. However, it was much lower than Malaysia's and significantly higher than China, Iran, Italy, India, Egypt, other Malaysian studies and Korea.

Referring to Table 5, the average activity concentration of ^{232}Th in the analyzed vegetable samples was comparable to values reported in studies from Malaysia, Italy, and India. However, it was higher than those recorded in some regions of India, Iran, Korea and China and lower than the concentrations reported in Nigeria, other Malaysian studies, Indonesia and Iraq. These variations reflect regional differences in soil composition, agricultural practices and environmental conditions that influence radionuclide uptake by plants.

As shown in Table 5, the average activity concentration of ^{40}K in the vegetable samples was comparable to levels reported in Nigeria, Egypt, Italy, Iraq and Spain. However, it was higher than those observed in Korea, Iran, Indonesia, Lebanon, Syria, and India and lower than the values reported in several studies conducted in Malaysia. These differences are likely due to variations in soil potassium content, crop type, fertilizer use and environmental conditions influencing potassium uptake in plants.

As presented in Table 3 and illustrated in Figure 4, the radium equivalent activity (Ra_{eq}) in the analyzed plant samples ranged from 10.43 to 34.38 Bq/kg, with an average value of 22.61 Bq/kg. All measured Ra_{eq} values were significantly below the internationally recommended safety threshold of 370 Bq/kg, indicating that the consumption of these vegetables poses no significant external gamma radiation hazard.

Table 6, supported by Figure 5, presents the transfer factor (TF) values for ^{238}U, ^{232}Th and ^{40}K in the analyzed plant samples. The TF values for ^{238}U ranged from 0.36 to 1.15, with an average of 0.60; for ^{232}Th, they ranged from 0.07 to 0.28, averaging 0.12; and for ^{40}K, the values ranged from 0.20 to 0.78, with an average of 0.41.

These TF values reflect the extent to which each radionuclide was transferred from soil to plant tissue. The higher average TF for ^{238}U suggests greater bioavailability or plant uptake potential compared to ^{232}Th, which exhibited the lowest TF values, likely due to its low mobility and strong affinity for soil particles. The moderate TF for ^{40}K aligns with its essential role in plant physiology, despite its widespread presence in the soil.

4. CONCLUSION

Based on the comprehensive analysis conducted, this study demonstrates that the activity concentrations of naturally occurring radionuclides ^{232}Th, ^{238}U and ^{40}K in both soil and plant samples from agricultural areas in Sohag Governorate, Upper Egypt, fall within or below internationally recognized safety limits. Among the radionuclides, ^{40}K consistently exhibited the highest activity levels, particularly in soil samples, a trend attributed to agricultural inputs and the inherent soil composition. In contrast, the presence of calcium carbonate likely contributed to the reduced mobility and lower uptake of ^{238}U and ^{232}Th.

The calculated radium equivalent activity (Ra_{eq}) values for both soil and plant samples were substantially below the recommended safety threshold of 370 Bq/kg, indicating minimal external gamma radiation hazard. Comparative analysis with data from other countries showed that the radionuclide concentrations observed in this study generally fall within the typical global range, with expected regional variations linked to local geological and environmental conditions.

The transfer factor (TF) analysis revealed varying degrees of radionuclide uptake by plants, with ^{40}K demonstrating the highest transfer efficiency, likely due to its essential physiological role in plant growth and metabolism. Lower TF values for ^{232}Th reflect its strong soil retention and limited bioavailability.

In summary, the findings confirm that soils and vegetables from the studied region pose no significant radiological risk to consumers. The study provides important baseline data for future environmental monitoring and enhances our understanding of radionuclide behavior and transfer within agricultural ecosystems. Moreover, it underscores the importance of local environmental and agricultural factors in influencing natural radioactivity levels in food crops.

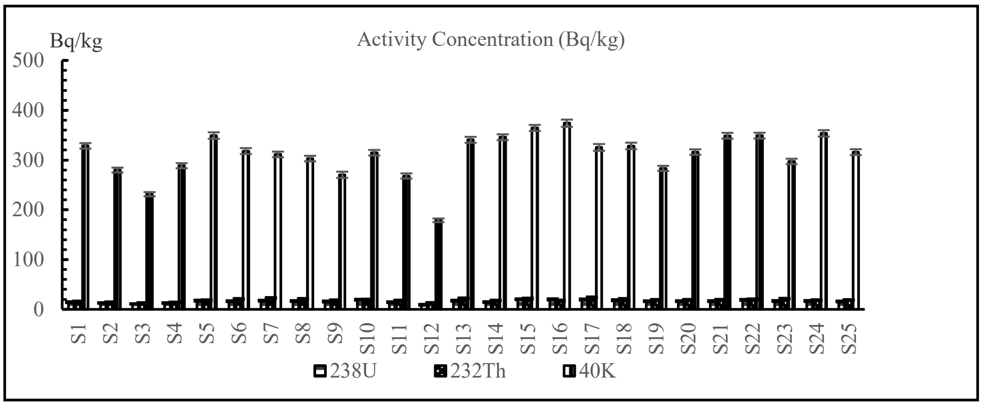

Fig (1): Activity concentrations (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K in different soil samples collected from the study area.

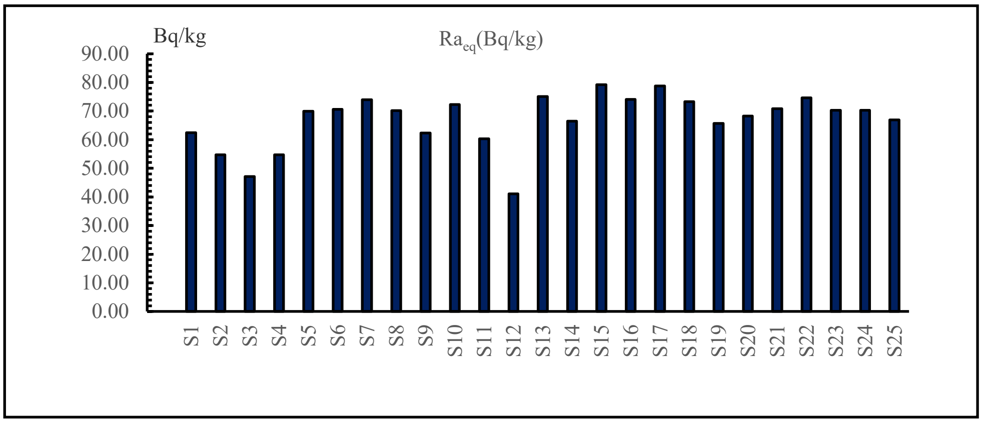

Fig. (2): Radium equivalent activity (Raeq) in Bq/kg for different soil samples collected from the study area.

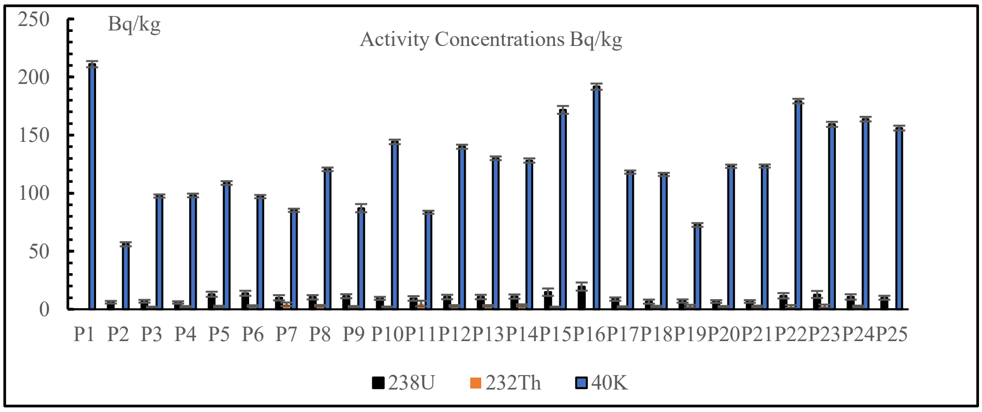

Fig. (3): Activity concentrations (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K in different plant samples collected from the study area.

Table (2): Activity concentrations of ^{238}U, ^{232}Th and ^{40}K and radium equivalent activity (Ra_{eq}) in Bq/kg for different soil samples collected from the study area.

Code.	Soil Activity Concentrations (Bq/kg)			Ra_{eq} (Bq/kg)
	^{238}U	^{232}Th	^{40}K	
S_1	14.45±1.22	15.85±1.09	328.36±5.52	62.40
S_2	12.72±0,95	14.34±1.00	279.77±4.89	54.76
S_3	10.98±0.69	12.83±.91	231.18±4.27	47.12
S_4	12.64±1.02	13.90±1.01	288.58±5.14	54.73
S_5	17.48±1.33	17.92±1.62	349.15±6.48	69.98
S_6	16.36±1.23	20.80±1.30	317.86±6.03	70.58
S_7	17.40±1.20	22.77±1.21	311.25±5.56	73.92
S_8	16.71±1.22	22.77±1.17	302.86±5.55	70.10
S_9	15.69±1.41	18.07±1.33	270.31±6.24	62.34
S_{10}	19.27±1.26	20.11±073	314.56±5.61	72.25
S_{11}	14.30±1.21	17.79±1.00	267.91±5.20	60.37
S_{12}	9.23±1.08	12.69±1.27	178.80±3.74	41.14
S_{13}	17.43±1.29	21.97±1.29	340.56±5.95	75.07
S_{14}	14.57±1.14	17.66±1.12	345.74±5.84	66.44
S_{15}	20.17±1.30	21.68±1.20	364.40±6.05	79.23
S_{16}	20.10±1.48	17.65±1.32	373.90±7.27	74.10
S_{17}	19.75±1.44	23.76±1.51	325.31±6.76	78.78
S_{18}	18.34±1.43	20.72±1.40	328.25±6.55	73.24
S_{19}	16.43±1.08	19.23±.95	283.22±5.09	65.73
S_{20}	16.49±1.15	19.22±1.06	315.99±5.45	68.31
S_{21}	16.55±1.21	19.21±1.17	348.75±5.80	70.88
S_{22}	19.03±1.29	20.10±1.22	348.89±5.92	74.65
S_{23}	16.82±1.18	21.41±1.09	297.13±5.42	70.31
S_{24}	16.79±1.24	18.34±1.27	353.58±6.44	70.25
S_{25}	15.87±1.25	18.71±1.21	315.79±5.93	66.94
Max.	20.17±1.48	23.76±1.62	373.90±7.27	79.23
Min.	9.23±0.69	12.69±0.73	178.80±3.74	41.14
Average	16.22±1.21	18.71±1.18	311.28±5.71	66.94

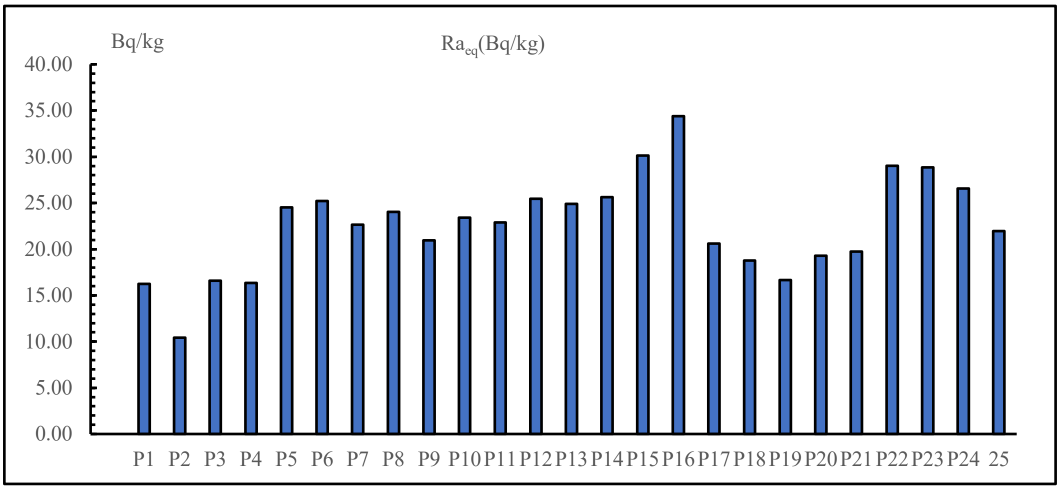

Fig. (4): Radium equivalent activity (Ra_{eq}) in Bq/kg for different plant samples collected from the study area.

Table (3): Measured activity concentrations (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K in soil samples from various countries, including data from the present study for comparison.

Country	^{226}Ra	^{232}Th	^{40}K	Ref.
Egypt	5.3-66.8	5-37.3	41.5-418	[17]
Taiwan	10.6-44.7	12.2-44.2	195.3-640	[18]
USA	34-95	4-130	43-719	[19]
Argentina	--	--	540-750	[6]
China	2-440	1-360	9-1800	[6]
Hong Kong	20-110	16-200	80-1100	[6]
India	7-81	14-160	38-760	[20]
Japan	6-98	2-88	15-990	[6]
Korea	--	--	17-1500	[6]
Iran	8-55	5–42	250-980	[6]
Denmark	9-29	8-30	240-610	[6]
Belgium	5-50	5-50	70-900	[6]
Luxembourg	6-52	7-70	80-1800	[6]
Bulgaria	12-210	7-160	40-800	[6]
Poland	5-120	4-77	110-970	[6]
Romania	8-60	11-75	250-1100	[6]
Greece	18	17	367	[21]
Portugal	8-65	22-100	220-1230	[6]
Spain	6-250	2-210	25-1650	[6]
Turkey	10-58	--	161-964	[22]
Jordan	16.3-57.3	7.6-16.2	121.8-244.8	[23]
UNSCEAR	35	30	400	[6]
Egypt	17	18	320	[6]
Syrian	20	20	270	[6]
Nigeria	16.2	24.4	34.8	[24]
Canada	19	8	480	[25]
Bangladesh	42	81	833	[26]
Cyprus	7.1	5	104	[7]
Brazil	47	29	678	[27]
Saudi Arabia	23.4	29.7	380	[28]
Cameroon	14	31	586	[29]
Cuba	17	16	188	[30]
Mexico	22.8	22.8	----	[31]
Zambia	24	26	714	[32]
Malaysia	70.3	33.3	425.5	[33]
The Netherlands	8.1	10.6	200	[34]
Taiwan	26.3	--	398.3	[35]
Italy	24	27	528	[36]
Pakistan	24.5	43.2	508.8	[37]
Vietnam	19.6	31	34.6	[38]
Yugoslavia	39	53	454	[39]
Present Study	16.22	18.71	311.28	-----

Table (4): Activity concentrations of ^{238}U, ^{232}Th and ^{40}K and radium equivalent activity (Ra_{eq}) in Bq/kg for different plant samples collected from the study area.

Sample NO.	Vegetable Type	Plant Activity Concentrations (Bq/kg)			Ra_{eq} (Bq/kg)
		^{238}U	^{232}Th	^{40}K	
P_1	Molokhia	ND	ND	211.10±2.66	16.25
P_2	Molokhia	6.11±1.12	ND	56.00±1.76	10.43
P_3	Molokhia	6.91±1.19	1.52±0.78	97.52±1.38	16.60
P_4	Molokhia	5.91±1.02	2.02±0.78	98.02±1.58	16.35
P_5	Molokhia	12.97±2.20	2.23±0.83	108.76±1.56	24.53
P_6	Molokhia	13.79±2.16	2.75±0.72	97.06±1.39	25.20
P_7	Molokhia	9.92±2.27	4.32±1.55	85.26±1.39	22.66
P_8	Cabbage	10.34±1.86	3.09±0.62	120.55±1.55	24.04
P_9	Cabbage	11.27±1.74	2.09±0.75	87.09±3.55	20.97
P_{10}	Cabbage	9.43±1.29	2.01±0.38	144.16±1.95	23.39
P_{11}	Cabbage	9.34±1.96	4.97±2.41	83.56±1.29	22.88
P_{12}	Cabbage	10.60±1.90	2.85±0.76	140.01±1.74	25.46
P_{13}	Cabbage	10.60±1.90	2.99±0.61	130.05±1.57	24.89
P_{14}	Parsley	10.95±1.86	3.35±0.92	128.12±1.84	25.61
P_{15}	Spinach	14.76±3.18	1.50±0.76	171.72±3.38	30.13
P_{16}	Lettuce	19.61±3.48	ND	191.72±2.68	34.38
P_{17}	Lettuce	8.78±1.44	1.90±0.64	118.15±1.39	20.60
P_{18}	Watercress	6.62±1.76	2.25±0.76	116.17±1.37	18.78
P_{19}	Watercress	7.16±1.39	2.74±1.15	72.63±1.61	16.67
P_{20}	Watercress	6.68±1.19	2.17±0.68	123.18±1.41	19.28
P_{21}	Watercress	6.78±1.15	2.41±0.75	123.39±1.31	19.73
P_{22}	coriander	11.68±2.32	2.47±1.22	179.29±1.99	29.01
P_{23}	coriander	12.78±3.00	2.67±1.40	159.29±2.19	28.86
P_{24}	coriander	10.65±2.30	2.32±0.85	163.78±1.98	26.57
P_{25}	coriander	9.95±1.72	ND	156.06±2.10	21.96
Max.		19.6±3.50	5.00±2.4	211.10±3.50	34.38
Min.		5.91±1.02	1.50±0.76	56.00±1.30	10.43
Average		9.74±1.80	2.2±0.80	126.5±1.90	22.61

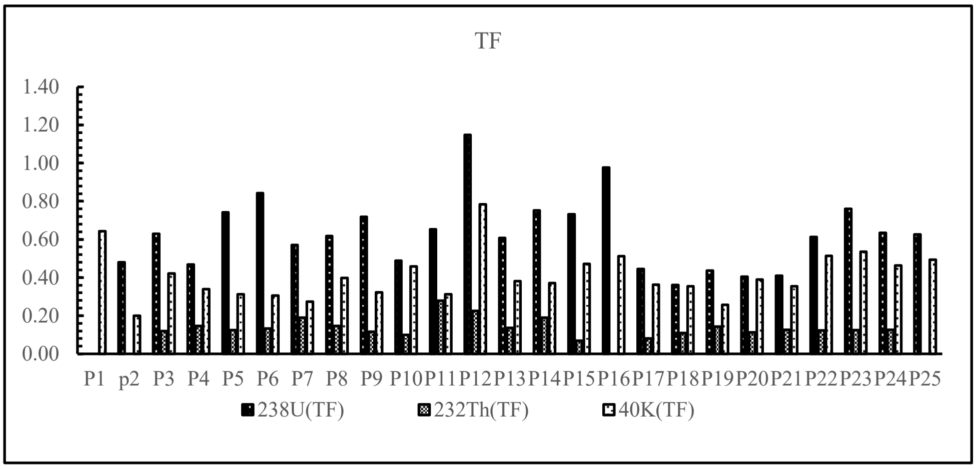

Fig. (5): Soil-to-plant transfer factors (TF) for ^{238}U, ^{232}Th and ^{40}K in different plant samples from the study area.

Table (5): Measured activity concentrations (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K in vegetable samples from various countries, including comparative data from the present study.

Country	^{238}U	^{232}Th	^{40}K	Ref.
Spain	----	---	93.29	[40]
Syria	-----	----	0.79	[41]
Iran	0.18	0.20	48.15	[42]
Egypt	1	---	116.04	[43]
China	0.075	0.012	---	[44]
Lebanon	----	----	74.30	[45]
Korea	0.049	0.001	68.39	[46]
India	0.51	1.33	57.64	[47]
India	1.90	2.40	80.30	[48]
Italy	2.60	2.92	163.40	[49]
Indonesia	7.67	20.24	75.47	[50]
Malaysia	1.22	1.95	1190.45	[51]
Malaysia	48.80	25.36	1017.94	[52]
Malaysia	2.07	2.12	791.51	[53]
Iraq	5.21	4.76	186.15	[54]
Nigeria	7.67	5.65	118.37	[55]
Malaysia	1.3-6.25	0.41-2.5	----	[56]
Present Study	9.74±1.80	2.2±0.80	126.5±1.90	-------

Table (6): Soil-to-plant transfer factors (TF) for ^{238}U, ^{232}Th and ^{40}K in different plant samples collected from the study area.

NO.	^{238}U (T_F)	^{232}Th (T_F)	^{40}K (TF)
P_1	ND	ND	0.64
p_2	0.48	ND	0.20
P_3	0.63	0.12	0.42
P_4	0.47	0.15	0.34
P_5	0.74	0.12	0.31
P_6	0.84	0.13	0.31
P_7	0.57	0.19	0.27
P_8	0.62	0.15	0.40
P_9	0.72	0.12	0.32
P_{10}	0.49	0.10	0.46
P_{11}	0.65	0.28	0.31
P_{12}	1.15	0.22	0.78
P_{13}	0.61	0.14	0.38
P_{14}	0.75	0.19	0.37
P_{15}	0.73	0.07	0.47
P_{16}	0.98	ND	0.51
P_{17}	0.44	0.08	0.36
P_{18}	0.36	0.11	0.35
P_{19}	0.44	0.14	0.26
P_{20}	0.41	0.11	0.39
P_{21}	0.41	0.13	0.35
P_{22}	0.61	0.12	0.51
P_{23}	0.76	0.12	0.54
P_{24}	0.63	0.13	0.46
P_{25}	0.63	ND	0.49
Min.	0.36	0.07	0.20
Max.	1.15	0.28	0.78
Average	0.60	0.12	0.41

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