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Determination of Transfer Factor for Some Crops in Selected Cultivated Soils, Khidir City, Iraq

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The current study dealt with the activity concentrations of some radionuclides in several common plants and corresponding soils in Khidir City, Iraq. The radioactivity measurements are carried out for ^{226}Ra, ^{232}Th, and ^{40}K in some consumable crops and their soils using gamma spectrometry with an HP germanium detector. The sampling process included 8 crops, averaging 7 samples for each plant and surrounding soils equally. The studied crops consisting of okra, onions, cucumber, tomatoes, eggplant, sweet potato, zucchini, and organic pepper showed obvious variability as follows: the activity levels of ^{226}Ra varied from 0.16±0.1 Bq/kg (in eggplant) to 3.984±0.19 Bq/kg (in tomato), with an average of 1.57±0.14 Bq/kg. ^{232}Th were found to be within the range of (0.023±0.01 - 2.93±0.19 Bq/kg) (in onions – in cucumber), and an average value of 0.80±0.12

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Bq/kg. For ^{40}K ranged between 87.801±2.24 Bq/kg (in cucumber) and 409.45±2.94 Bq/kg (in tomato), with an average of (273.53±2.43 Bq/kg). On the other hand, the radionuclides activity concentrations in the corresponding soils ranged between 4.644±0.24 Bq/kg, with an average of 16.124±0.50 Bq/kg for ^{226}Ra, and from 1.315±0.11 Bq/kg to 22.783±0.61 Bq/kg, with a mean value of 8.32±0.32 Bq/kg for ^{232}Th, and from 284.482±2.48 Bq/kg to 451.468±3.93 Bq/kg, with a mean value of 406.53±2.77 for 40K. The concentrations of ^{226}Ra and ^{232}Th in the plants and soil samples were lower than the permissible values reported by UNSCEAR. In contrast, the activity level of ^{40}K exceeded the allowed level suggested by UNSCEAR. Moreover, the obtained data were statistically analyzed and discussed in detail. Furthermore, the soil-to-plant transfer factors were calculated for the crops under study. TF of ^{226}Ra was found to be within the range of (0.056-0.143), with an average of 0.095, for ^{232}Th ranged between 0.056 and 0.192, with an average of 0.101, while for ^{40}K, it is found to be varied from 0.933 to 0.216, with an average of 0.669. transfer factors of all crops were lower than the unity value conducted by IAEA.

Keywords: Pollution; soil pollution; plant pollution; transfer factor; food; health hazards; Iraq.

1. INTRODUCTION

The radiation in our environment is contributed to by two major sources: artificial and natural; anthropogenic sources comprise the radiation from civil and military human activities, such as reactors and accelerator-driven processes, while natural sources are derived from cosmogenic and primordial background activity [1]. The main external sources of irradiation of the human body are thought to be the background radiation that originated as a result of the decay of naturally occurring radionuclides materials (NORM). NORM is “Materials which may contain any primordial radionuclides or radioactive elements as they occur in nature, such as potassium, uranium, and thorium, that are undisturbed by human activities” [2]. Terrestrial radionuclides are common in the soil, rocks, water, and building material used for dwellings. Only those primordial radionuclides with half-lives large enough (larger than or equal to the age of the earth) and their progenies present in sufficient amounts to contribute significantly to population exposure [3]. These radionuclides existed at the creation of the planet. Since some of these radionuclides have long half-lives, significant quantities are still on Earth today. However, the level of radiation in the soil varies widely depending on the geological conditions involved in the rock formation and soil. These radionuclides can be categorized into two types [4]: Singly Occurring Radionuclides, such as ^{40}K, and Decay Chains, such as ^{238}U, ^{232}Th. In general, terrestrial radionuclides are present in the soil in varying amounts depending on the nature of the bedrock accumulated during the soil formation and the soil properties. Besides several other factors, these radionuclides may present in soil with high or low concentrations, but their presence in any quantity is threatening. As mentioned, various sources transfer radiation into the human body in several ways. The radionuclides deposited on soils and different parts of crop plants, and their uptake by plants and water contamination, are the major sources of exposure that should be taken seriously. Generally, it was discovered that terrestrial pathways were more significant than aquatic ones [5]. Moreover, the soil-plant-man pathway is one of the main environmental processes that result in radioactive intake by humans [6]. Hence, understanding NORMs in soil systems is essential for improving radioactivity determination, enhancing the estimation of radiation hazards [7], and establishing appropriate scientific knowledge of the levels of radionuclides in the soil and their relationship with the uptake rate of the cultivated plants [8].

The present study reports the concentrations of radium-226, thorium-232, and potassium-40 isotopes in some consumable crops collected from different cultivated soil. In addition, the transfer of these radionuclides from soil to plants was estimated by calculating the transfer factor (TF) value.

2. LITERATURE REVIEW

Mustafa Y. A. Mustafa et al. conducted the TF of the radionuclides ^{238}U, ^{232}Th, and ^{40}K using an HPGe detector for several crops collected from some farms in the suburbs of Baghdad and Najaf City, Iraq [9]. The results showed that the value of TF for ^{238}U, ^{232}Th, and ^{40}K are (0.32, 0.70, and 3.44), respectively. The average value of TF for ^{238}U and ^{232}Th were (0.23) and (0.2), which are lower than the allowed value, but the (1.85) reported for ^{40}K was higher than that.

The activities of ^{238}U, ^{232}Th, and ^{40}K were carried out for some crops and corresponding soils in Erbil City, north of Iraq, by Hiwa A. Azeez et al. using an HP germanium detector [10]. The results showed that the activity levels range for ^{226}Ra, ^{232}Th, and ^{40}K in cultivated soils ranged from 11.94 $Bq.kg^{-1}$ to 18.24 $Bq.kg^{-1}$, and from 8.80 $Bq.kg^{-1}$ to 12.36 $Bq.kg^{-1}$ and from 247.65 $Bq.kg^{-1}$ to 338.26 $Bq.kg^{-1}$, respectively. While for plant crops were (0.20–1.45) $Bq.kg^{-1}$ for ^{226}Ra, (0.11–0.48) $Bq.kg^{-1}$ for ^{232}Th, and (68.07–1355.36) $Bq.kg^{-1}$ for ^{40}K. The transfer factor values were found to be in the ranges of (0.011-0.087), (0.011–0.046), and (0.201–5.130) for ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

The radiation levels and transfer factors have been assessed using NaI(Tl) gamma spectroscopy in various plant species grown at Al-Tuwaitha City in Baghdad, Iraq, by Iman Tarik Al-Alawy et al. [11]. The mean specific activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in green pepper plant were 8.064±4.22 Bg/kg, 1212.774 Bq/kg, and 202.541±151.911 Bq/kg, respectively. Cucumbers were 11.563±6.971 Bq/kg, 6.965±4.222 Bq/kg, and 205.248±138.356 Bq/kg. for celery were 7.847±10.500, 24.895±14.705, 172.003±149.272. The mean soil-to-plant TFs were 0.0919, 1.0673, 0.7944, and 0.038 for ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs, respectively.

Transfer factors of ^{238}U, ^{232}Th, and ^{40}K for several crops in some cultivated soils in The Nahrawan region, Baghdad, Iraq, were evaluated by Saja S. Kadim et al. using a high-purity germanium detector [12]. TF for ^{238}U, ^{232}Th, and ^{40}K were found within the range of (0.00019-0.24), (0.09-1.24), and (0.9-5.1), respectively.

Transfer factor and the specific activity of some radionuclides from soil to sesame and cowpea plants at Minia Governorate, Egypt, were determined by Elsaman et al. using gamma-ray spectrometry [13]. The activity concentrations of Ra-226, Th-232, and K-40 were 12.75 $Bq.kg^{-1}$, 10.20 $Bq.kg^{-1}$, and 131.75 $Bq.kg^{-1}$, respectively. For the corresponding soil were 5.20 $Bq.kg^{-1}$, 4.15 $Bq.kg^{-1}$, and 171.00 for sesame, and 6.70 $Bq.kg^{-1}$, 5.60 $Bq.kg^{-1}$, and 182.90 $Bq.kg^{-1}$ for cowpea. On the other hand, the transfer factors from soil to plants were calculated, and their mean values were found to be (0.42, 0.43, and 1.33) for sesame, (0.51, 0.53, and 1.36) for cowpea, respectively.

N. M. Yussuf et al. measured the soil-to-plant transfer factor of some radionuclides (^{238}U, ^{232}Th, and ^{40}K) using instrumental activation analysis techniques in different locations in Malaysia [14]. The TF's values were found to be in the range of (0.003-0.473), (0.003-0.548), and (0.430-1.479) for 238U, 232Th, and 40K, respectively.

Kiadtisak Seanboonruang et al. conducted ^{226}Ra and ^{40}K concentrations in selected medicinal plants in Thailand using a high-purity germanium detector [15]. The activity concentrations were 4.8 ± 2.6 Bq/kg and 610 ± 260 Bq/kg for ^{226}Ra and ^{40}K, respectively. Furthermore, the TF has been estimated for both radionuclides, which were 2.0 for ^{226}Ra and 0.17 for ^{40}K.

M. M. Orosun et al. estimated the activity concentration of ^{238}U, ^{232}Th, and ^{40}K in the corn grain samples from granite mining fields in Asa, Nigeria, using gamma-ray spectroscopy [16]. The concentrations were (441.06 Bq/kg) for ^{40}K, (11.51 Bq/kg) for ^{238}U, and (15.42 Bq/kg) for ^{232}Th. Further, the transfer factor has been determined and was 0.49, 0.46, and 0.58 for ^{40}K, ^{238}U, and ^{232}Th, respectively.

3. MATERIALS AND METHODS

3.1 Study Aria Description

The current study dealt with radioactivity levels in the agricultural lands in Khidir City (25 km) to the south of Samawa City, the capital of Muthanna Province, Iraq. The city is located on the western edge of the alluvial plain, which extends along (650 km) from northwestern to southeastern Iraq, which makes the city a link between the alluvial plain and the western plateau. Therefore, it is certain that this location significantly impacts the city's climate and, thus, the agriculture situation and production. Based on that, the study area is divided into two main parts: the eastern side, which occupies the lands on both sides of the Ephorate River and represents the densely populated area, and the second part, which is an extension of the western desert of Iraq, which is positioned far from Ephorate River or any close surface water. Hence, agriculture in the study area depends on two main sources of irrigation water: surface water provided by the Ephorate River on the eastern side and groundwater supplied by hundreds of wells dug for that purpose on the western side. This natural diversity overshadows the methodology of this study in terms of sample classification and the discussion of obtained results. As an extension of the Mesopotamia plain, the soil of the eastern side is characterised by high salinity, clay nature, and the relatively high depth of the bedrock [17,18] While The western side is a part of the plateau, so it is normal for the soil there to be different where it is characterised by sandy nature, high porosity, and the short distance between the soil surface and the bedrock [19]. Furthermore, due to the semi-desert nature of the city and the high salinity of the soil and irrigation water, the diversity of crops is limited and on a small scale. So, agriculture in the region is limited to some types of vegetables and grains. Map 1 shows the location and borders of the study area.

3.2 Sampling and Processing

In the current study, plants and soil samples were collected from different agricultural fields within the study area, representing a large contributor to food in the region. The samples of soil were collected from the area with a diameter of (20 cm) surrounding the plant roots at a depth of (5-15 cm) with an average of (1 kg) for each one using an iron shovel. Crop samples, including Okra, onions, cucumber, tomatoes, eggplant, sweet potato, zucchini, and organic pepper, were collected from the same sampling points of the soil by gathering edible parts of vegetables equivalent to about 2 kg weight for each sample. The collected soil and corresponding vegetable samples were packed in labelled polyethylene bags (every bag carries a sample code and location), sealed, and transferred to the lab for treatment. The first step of processing is preparing the samples for counting; plant samples were cut into small parts and dried in room air for a few days, then in an electric oven at (60 ^{o}C) for (4 hours) to get rid of water. After drying, the samples were ground to a fine powder using a manual grinder. On the other hand, soil samples were firstly air dried, then genteelly smashed by a hummer before putting in the oven to remove any remaining moisture. The drying process took (8 hours) at (80 ^{o}C), and then sieved through a 2 mm sieve. Finally, both crops and soil samples of (500 g) dry-weight were placed into cylindrical plastic containers, and the containers were selected to be identical in size and shape to increase counting accuracy and to reduce self-absorption for that specific geometry [20]. The containers were then tightly sealed using silicon and adhesive tape and left for four weeks to reach the secular equilibrium between the radionuclides and their progenies.

Map 1. Geographical location of Khuder city

3.3 Samples Analysis

The radioactivity measurements were performed using a high-resolution gamma spectroscopy system, the system consisting of an HP Ge detector "crystal diameter of 65.4 mm, thickness of 52.3 mm, the operating voltage of 2500 V" with an efficiency of 50 % and 2.2 keV-FWHM energy resolution at the 1332 keV photons at 60 ^{o}C, surrounded by a cylindrical shield of lead with a thickness of 10 cm, with the inner surface covered by three layers of aluminium, cadmium, and iron with 1 mm thickness for each to reduce the background. The detector was connected to an ICS-PCI card with a (1024-4096) channel analyser, amplifier, and analogue-to-digital converter. The detector's energy and efficiency were performed using standard multi-gamma reference sources. The curves were obtained by fitting the experimental efficiencies for each sampling density and corrected for attenuation and self-absorption [21]. The radioactivity levels of the radionuclides in the investigated samples were conducted from the following gamma-ray lines: (351.93) keV (35.6%) from ^{214}Pb, and (609.32) keV (45.49%) and (1120.294) keV (14.92 %) from ^{214}Bi were used for determination of ^{226}Ra, ^{232}Th concentration was obtained using (238.632) keV (43.6 %) from ^{212}Pb, (583.19) keV (85 %) from ^{208} Tl, and (911.204) keV (25.8 %) from ^{228}Ac. In comparison, the content of ^{40}K was estimated using the gamma-ray line (1460.822) keV (10.66 %) [22,23]. To evaluate the specific activity of the samples, each sample was counted for (12000) s, and the net activity was obtained by deducting the background and calculated using the following equation [24,25]:

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

Where N is the peak area, t is the measurements time, $\varepsilon\,(E_\gamma)$ is the efficiency of detection, I_γ is the abundance of energy E_γ, and m is the sample weight.

3.4 Transfer Factor

Transfer factor (TF) is a steady-state concentration between two different physical conditions, an important factor for radiological evaluation [1]. The ratio of the activity concentration in the plants in (Bq.kg^{-1}) to the concentration in the corresponding soil in (Bq.kg^{-1}) was used to calculate the transfer factor as follows [26,27]:

$$TF = \frac{C_v\ (Bq\ kg^{-1}, dry\ weight)}{C_s\ (Bq\ kg^{-1}, dry\ weight)}$$

Where TF is the transfer factor, C_v is the radionuclide concentration in the dry weight of vegetables (Bq/kg), and C_s is the concentration of the radionuclides in the dry weight of soil (Bq/kg).

3.5 Statistical Aspect

Statistical analysis of obtained data was carried out using IBM SPSS software; significant differences among the crops for ^{226}Ra, ^{232}Th, and ^{40}K concentrations are estimated according to a one-way ANOVA test. The post hoc (Duncan) test was applied to detect the source of significant differences. Further, a box-and-whisker plot was established to provide an accurate understanding of the differences between radionuclides activity distribution in plants and the soil, on the other hand, to make the distribution of radionuclides among the plants and soil clear and understandable.

4. RESULTS AND DISCUSSION

4.1 Radioactivity Measurements

Radioactivity levels in (8) types of vegetables and corresponding soils in Khidir City were carried out using HP(Ge) gamma spectroscopy. The activity of ^{226}Ra, ^{232}Th, and ^{40}K was estimated in 54 vegetable samples, including Okra, onions, cucumber, tomatoes, eggplant, sweet potato, zucchini, and organic pepper, with an average of (7) samples for each type. The activity concentration of ^{226}Ra in crop samples varied from the minimum value of (0.16 ± 0.10 Bq/kg) in zucchini to the maximum value of (3.98 ± 0.19 Bq/kg) in okra, with the mean value of (1.58 ± 0.14 Bq/kg), ^{232}Th content level is found to be within the range of (0.023 ± 0.10 – 2.93 ± 0.19 Bq/kg), with the mean value of (0.801 ± 0.12 Bq/kg), where the highest value was found in cucumber, The lowest was in onion. In contrast, ^{40}K concentration ranged between (87.801 ± 2.04 Bq/kg) in cucumber and (409.45 ± 2.94 Bq/kg) in tomatoes, with a mean value of (273.53 ± 2.43 Bq/kg). To provide a clear perception of the distribution of radionuclides within studied crops, the box-and-whisker diagram has been employed to show the variation among the sets of radioactivity in crops for each radionuclide separately. Figs. 1a, 1b, and 1c) illustrate ^{226}Ra, ^{232}Th, and 40K concentrations activity for the crops under study, where (P1, P2, P3….P8) stand for crops (okra, unions, cucumber, tomato, eggplant, sweet potato, zucchini, and organic paper) respectively, also, the figures show the minimum value, second quartile, median value, third quartile, and maximum value for each set of radionuclides within vegetable crops.

On the other hand, radionuclides activity levels in the corresponding soil were found as follows: the concentration of ^{226}Ra varied between (4.644 ± 0.24 Bq/kg) and (24.846 ± 0.68 Bq/kg) and the mean value was (16.124 ± 0.50 Bq/kg), which is lower than the allowed limit of (35 Bq/kg) that reported by UNSCEAR [28], the minimum value of ^{232}Th was (1.315 ± 0.11 Bq/kg), and the maximum value was (22.783 ± 0.61 Bq/kg) with a mean value of (8.320 ± 0.31 Bq/kg), all of the soils contained low levels of thorium-232 compared to (40 Bq/kg) referenced by UNSCEAR [29], 40K activity levels ranged from (284.482 ± 2.48 Bq/kg) to (451.468 ± 3.93 Bq/kg), and the mean value was (406.526 ± 2.77 Bq/kg), ^{40}K content for most samples was higher than the permissible value of (400 Bq/kg) proposed by UNSCEAR [24]. Figs. 2a, 2b, and 2c) show radionuclides contents in the corresponding soil, where (S1, S2, S3, …., S8) represent the soils corresponding to (okra, unions, cucumber, tomato, eggplant, sweet potato, zucchini, and organic paper), respectively.

The obtained results according to the ANOVA test (ρ =0.001) for 226Ra, 232The, and ^{40}K statically showed three different groups as follows: okra, onions, sweet potato, and eggplant for ^{226}Ra, okra, tomato, potato, cucumber, and zucchini for ^{232}Th, onions, tomato, sweet potato, and zucchini for ^{40}K

4.2 Transfer Factor Calculating

The calculated values of transfer factor (TF) of ^{226}Ra, ^{232}The, and ^{40}K from soil to vegetables are shown in Table 1.

The transfer factor of ^{226}Ra of collected crops is found to be ranged from 0.056 to 0.143 with an average value of 0.095 (Table 1). The highest and lowest TFs were found in tomatoes (P4) and sweet potatoes (P6). The results of ^{232}Th showed that TF varied between 0.056 and 0.192, with an average value of 0.101. The highest value of TF was found in cucumber (P3), while the lowest value was found in eggplant (P5) (Table 1). The obtained value of TF for ^{40}K was found within the range (0.54 – 0.933), with an average value of 0.669. Due to the high conducted concentrations, TF values of 40K were higher than other radionuclides. The variation in TF for different soils may be attributed to the difference in soil properties, such as "granulometric production, organic matter content, hydrological content, and pH, etc.," within the soil [26]. Besides, the biological variability inherent in plants and the difference between types and species is likely the source of the variations in transfer factors. Soil control, crop farming technologies, the growing period, and the properties of root distribution also have an effect. The above parameters may change soil features or cause the redistribution of radionuclides uptake in crops [9]. The kind of soil and farming data are significant factors because the sampling conditions and soil characteristics play a major role that heavily influences the behaviours of radionuclides. The soil's physiochemical features greatly affect the transfer of natural radionuclides from soil to plants, such as "Potassium content, cation exchange capacity (CEC), organic matter content, calcium content, etc." [9,25].

Table 1. Activity concentration of natural radionuclides in plants and soil and calculated TF

Sample code	Mean activity consent. in the plant (Bq/kg)			Mean activity consent. in soil (Bq/kg)			Transfer factor		
	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K	^{226}Ra	^{232}Th	^{40}K
P1	2.27± 0.15	0.96 ± 0.13	222.48 ± 2.49	20.95 ± 0.56	9.18 ± 0.40	411.43 ± 2.68	0.108	0.104	0.54
P2	1.16 ± 0.12	0.59 ± 0.11	145.03 ± 2.39	11.13 ± 0.44	7.80 ± 0.28	404.31 ± 2.66	0.104	0.075	0.358
P3	1.38 ± 0.13	1.54 ± 0.14	109.31 ±2.35	14.22 ± 0.48	8.02 ± 0.33	417.54 ± 2.85	0.097	0.192	0.216
P4	2.69 ± 0.17	1.2 ±0.14	301.56 ± 2.45	18.78 ± 0.53	11.99 ± 0.37	403.21 ± 2.65	0.143	0.1	0.747
P5	1.38 ± 0.14	0.54 ± 0.10	347.19 ± 2.51	15.98 ±0.49	9.5 ± 0.33	401.08 ± 2.67	0.086	0.056	0.865
P6	0.83 ± 0.11	0.56 ± 0.10	340.02 ± 2.43	14.72 ± 0.48	8.108 ± 0.31	412.92 ± 2.77	0.056	0.069	0.823
P7	1.59 ± 0.15	0.52 ± 0.11	351.34 ± 2.39	16.66 ± 0.52	3.4 ± 0.22	402.54 ± 2.95	0.095	0.152	0.872
P8	1.27 ± 0.14	0.59 ± 0.10	371.34 ± 2.44	16.24 ± 0.52	8.77 ± 0.36	397.9 ± 2.95	0.078	0.067	0.933
Mean	1.571 ± 0.13	0.812 ± 0.11	273.53 ± 2.43	16.085 ± 0.50	8.346 ± 0.32	406.36 ± 2.77	0.095	0.101	0.669

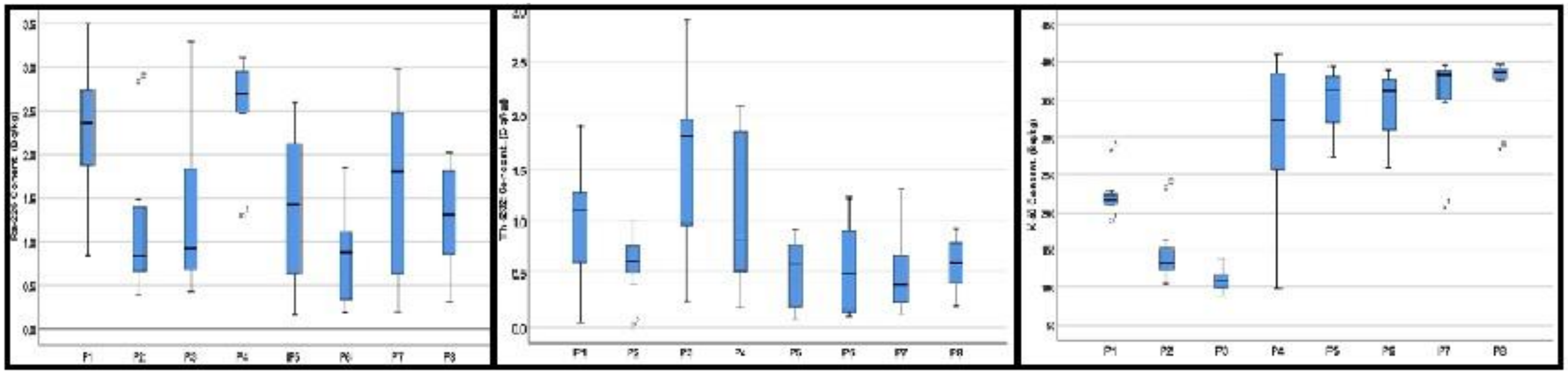

Fig. 1a **Fig. 1b** **Fig. 1c**

Fig. 1. variation among the sets of radioactivity in crops for each radionuclide

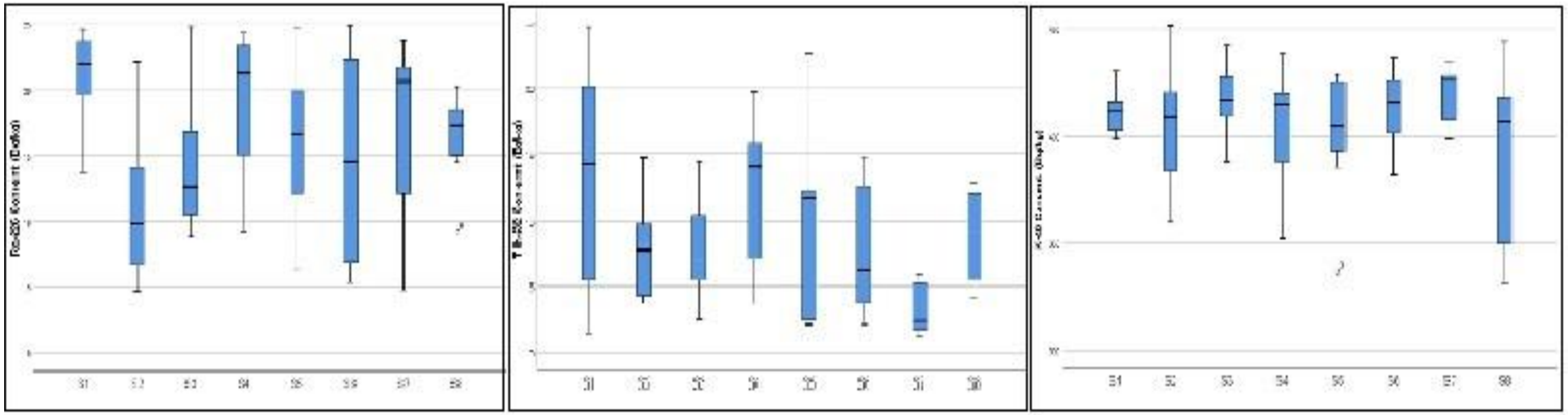

Fig. 2a **Fig. 2b** **Fig. 2c**

Fig. 2. Radionuclides contents in the corresponding soil

5. CONCLUSION

This study established radioactivity levels in several crops and corresponding soils. The study included the measurements of ^{226}Ra, ^{232}Th, and ^{40}K in Okra, onions, cucumber, tomatoes, eggplant, sweet potato, zucchini, and organic pepper, as well as the assessment of radionuclides activity concentrations in surrounding soils. The results indicate that the ^{226}Ra and ^{232}Th in plants and soil fall below the permissible value reported by UNSCEAR (35 Bq/kg for ^{226}Ra and 40 Bq/kg for ^{232}Th) [30], while ^{40}K exceeds the allowed level of 400 Bq/kg proposed by UNSCEAR [26]. Soil-to-plant transfer factors were calculated and were found to be less than the worldwide limit of (1.4) suggested by IAEA or a value of (TF=1) reported by ICRP [31]. Finally, it is possible to say that the crops are safe and don't pose a considerable amount of radionuclides which may lead to serious health hazards.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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