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Measurement of Radioactivity Levels and Assessment of Radiation Hazards for Plants Species Grown at Scrap Yard (B) at Al-Tuwaitha Nuclear Site (Iraq)

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Abstract: Samples of flowered grasses, herbs and jungles were collected from scrap yard (B) at Al-Tuwaitha Nuclear Site and analyzed in the laboratory using gamma-ray spectroscopy system. The activity concentrations for radionuclides grown on the studied area were found to be ranged from 1.05 to 5.45 Bq/kg (average 2.86 Bq/kg) for ^{226}Ra, below detection limit (BDL) to 1.4 Bq/kg (average 0.16 Bq/kg) for ^{232}Th, 483.2 to 595.7 Bq/kg (average 528.33 Bq/kg) for ^{40}K, and BDL to 1.15 Bq/kg (average 0.35 Bq/kg) for ^{235}U. No radionuclides of artificial origin (such as ^{137}Cs) were detected in any of the analyzed samples. Gamma absorbed dose rates (D), radium equivalent activities (Ra_{eq}), external hazard index (H_{ex}), and internal hazard index (H_{in}) were calculated and found to be considerably lower than their corresponding allowable limits and worldwide average values. Accordingly, it was found that natural radioactivity levels for the investigated plants species grown at the studied area pose no significant radiological threat to human health or the environment.

Keywords: Radiation Hazards, Plants Species, Al-Tuwaitha Nuclear Site

1. Introduction

From the beginning of life, all living creatures have been exposed to radiation. Estimates of the total radiation dose to the world population have shown that approximately 96% can be attributed to natural sources while the remaining 4% comes from artificial sources. The concentrations of natural radionuclides (^{238}U, ^{232}Th, their daughter products and ^{40}K) in the soil and rocks, which depend upon the local geology of each region, cause dose variation [1]. The most vital sources to the environment are the shipment of radioactive materials, as well as the residual fallout from nuclear weapon testing and nuclear accidents that continually spread a huge amount of radioactivity in the environment. Consequently, radionuclides in soil and plants have been monitored since their discovery and have increased as a result of the raise in nuclear power plant accidents.

Any radiological or nuclear accident at Al-Tuwaitha Nuclear Site may raise the radionuclides concentrations in soil and plants, and consequently, increasing health risk. Therefore, it is necessary to study the natural and artificial radioactivity in soil and plants in order to have baseline data for evaluating the radiological impact of any abnormal event or accident that may occur at Al-Tuwaitha Nuclear Site. The aims of the present study were:

- To investigate the radioactivity levels for common plants species grown at scrap yard (B), and
- To assess associated radiation hazards.

2. Area of the Study

The targeted area (scrap yard (B)) is an open area lying outside the earthen berms (located approximately 500 m away from the north border of Al-Tuwaitha Nuclear Site), used after 1991 as a vast scrap yard of damaged equipment, occupies a surface area of approximately 37800 m^2 (216 m × 175 m), bounded by vacant (disused) areas in the four directions, with some palm orchards located about 0.6 km distance to the north of the site. The site is located in the northeastern part of Al-Tuwaitha Nuclear Site (see Figure 1),

within the latitudes 33°214462 to 33°216890 North and longitudes 44°511627 to 44°514555 East. This site was known to be radioactively contaminated by uranium nuclides (^{235}U and ^{238}U) in localized area.

Figure 1. *Aerial satellite image for Al-Tuwaitha Nuclear Site shows location of the studied area.*

2.1. Plants Sampling and Preparation for Analysis

Herbs and jungles

Flowered grass

Figure 2. *Common plants species grown at the studied areas.*

Jungles, herbs and flowered grasses are the most popular plants species grown at the studied area (Figure (2)). Nine samples of these plants species were collected from the studied area. Similar three plants samples were sampled from the background area in order to be able to assess possible radiological impacts resulting from onsite operations. About 1 kg plants samples were collected in the field at 5 cm distance from the ground surface using plant clipper. The samples were then placed in polyethylene bags and sent to the analytical laboratory for analysis.

At the analytical laboratory, the collected plants samples were dried for 6 hours at 105°C, homogenization, milled using grinder and sieved using a fine-aperture mesh (0.75 mm mesh size) to obtain a fine-grained sample that would present a uniform matrix to the detector. Later, 0.17 – 0.2 kg of each dry sample was put into 0.5 ml polyethylene plastic Marinelli beakers to reach a geometric homogeneity around the detector. The Marinelli beakers were then sealed tightly, wrapped with thick tape around the screw necks, and tagged with the location, date of collection, weight and sample number, etc. The samples were stored for at least 4 weeks to reach secular equilibrium between the ^{238}U and ^{232}Th series and their respective progenies [2-4].

2.2. Samples Counting

A high-purity germanium (HPGe) semiconductor detector was used in the present work for measuring activity concentrations for gamma-ray emitting radionuclides in the plants samples. Samples measurements were performed using a gamma-ray spectrometer with a coaxial HPGe detector supplied by Canberra Instruments Inc. (USA) with a relative efficiency of 40% and 2 keV resolution for the ^{60}Co 1332 keV gamma-ray energy. The activity concentrations (A_C) of the radionuclides of concern for peak at energy (E_γ) were calculated in Bq/kg using the detected peaks in the spectra and the following equation [5-7]:

$$A_C = \frac{A_{net}}{I_\gamma(E_\gamma) \times E_{ff}(E_\gamma) \times T \times M} \quad (1)$$

where A_{net} is the net peak counts (detector background subtracted), I_γ (E_γ) is the absolute gamma decay intensity (emission probability) for the specific energy peak, also known as abundance at energy E_γ, E_{ff} (E_γ) is the efficiency of the detector at energy E_γ, T is the counting time (3600 sec) and M is the mass of the sample in kg. The activity concentrations of ^{226}Ra were determined from the gamma-ray energies of its daughters ^{214}Pb (352.92 and 295.21 keV) and ^{214}Bi (609.31, 1120.30 and 1764.50 keV), while the activity concentrations of ^{232}Th were determined from the gamma-ray energies of its daughter ^{228}Ac (911.07 and 969.11 keV). The activity concentrations of ^{40}K were determined from its gamma-ray energy of 1460.81 keV. The peaks corresponding to the gamma lines at 89.96, 93.35, 105, 109.14, 143.76, 163.35, 202.12 and 205.31 keV were used in the quantification of the activity concentrations of ^{235}U.

2.3. Radiological Hazards Assessment

2.3.1. Absorbed Dose Rate in Air (D)

According to the guidelines provided by UNSCEAR [8], the absorbed gamma dose rate D (nGy/h) in air was

determined at 1 m above the ground surface. The absorbed dose rate was calculated using the following formula [9]:

$$D\ (nGy/h) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/kg), respectively. The absorbed dose rate (D) indicates the received dose from radiation emitted by radionuclides in environmental materials. Determination of this parameter is the main step for evaluating health risk.

2.3.2. Radium Equivalent Activity

The Radium Equivalent Activity (Raeq) index provides guideline for regulating the safety standards of radiation protection for the general public residing in the investigated area. The Raeq index represents a weighted sum of the activities of the aforementioned natural radionuclides. This index is given by the following formula [10]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (3)$$

2.3.3. External and Internal Hazard Indices

The external radiation hazard index (H_{ex}) due to natural gamma radiation in plants samples was calculated using the following formula [3, 4]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (4)$$

There is also a radiation hazard to respiratory organs due to the ^{226}Ra decay product (^{222}Rn) and its short-lived decay products. To account for this hazard, the internal hazard index (H_{in}) was calculated using the following formula [3, 4]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

3. Results and Discussion

Table 1 presents the results of radiometric analysis for plants samples collected from scrap yard (B). Table 1 shows that plants species growing on the background area soil (labeled by the sample code BG) and on the studied area (labeled by the sample code BP) concentrate more ^{40}K than other radionuclides, as it is the most abundant natural radioactive element considered. The activity concentrations for radionuclides grown on the studied area were found to be ranged from 1.05 to 5.45 Bq/kg (average 2.86 Bq/kg) for ^{226}Ra (estimated from the average activity concentrations of ^{214}Pb and ^{214}Bi in each sample), below detection limit (BDL) to 1.4 Bq/kg (average 0.16 Bq/kg) for ^{232}Th, 483.2 to 595.7 Bq/kg (average 528.33 Bq/kg) for ^{40}K, and BDL to 1.15 Bq/kg (average 0.35 Bq/kg) for ^{235}U. Within the reported uncertainties, the average of radiometric analysis results for ^{40}K in plants samples collected from the studied area might be considered to be approximately within the normal background levels. No radionuclides of artificial origin (such as ^{137}Cs) were detected in any of the analyzed samples.

Samples of herbs, flowered grasses and jungles grown near the contaminated zone at the studied area (labeled by the codes BP2, BP3, BP5 and BP8) showed slightly elevated levels of ^{235}U in comparison with the locality background samples. Relatively elevated ^{235}U activity concentrations in these plants samples were not surprising, since the roots of these plants reside in contaminated soil with elevated ^{235}U activity concentrations. However, these relatively low plants contamination levels do not indicate a threat to public health and safety or threat to the environment. It might indicate unexpected radiation levels detected in plants samples.

The results of absorbed dose rates calculations (D) are presented in Figure 3. In the present study, the absorbed dose rate due to ^{226}Ra, ^{232}Th and ^{40}K in plants samples were found to be varied from 20.68 to 25.81 nGy/h (average 23.45 nGy/h). The estimated D values are considerably lower than the worldwide average value of 55 nGy/h [3, 10].

The calculated Ra_{eq} values are presented in Figure 4. The Ra_{eq} for plants samples were found to be varied in the range of 38.36 to 47.97 Bq/kg (average 43.77 Bq/kg). These values are far below the allowable limit recommended in the literature (370 Bq/kg) [3, 4, 10].

The calculated external hazard index (H_{ex}) values for plants samples (see Figure 5) were found to be ranged from 0.1 to 0.13 (average 0.12). The calculated H_{ex} values for all plants samples were considerably below the allowable limit of unity [3, 10]. In this study, the estimated plants samples internal hazard index (H_{in}) values (see Figure 5) were found to be ranged from 0.11 to 0.14 (average 0.13), considerably below the allowable limit of unity [3, 10]. These results clearly indicate that there are no harm to the populations of the investigated site due to ^{226}Ra, ^{232}Th and ^{40}K in plants samples.

Table 1. *Activity concentration for radionuclides in plants samples collected from scrap yard (B).*

Sample code	Plant species	Activity concentration (Bq/kg)				
		^{40}K	^{238}U Series		^{232}Th (^{228}Ac)	^{235}U
			^{214}Bi	^{214}Pb		
BG1	Herbs and flowered grasses	607.4 ± 30.3	BDL	BDL	*BDL	BDL
BG2	Herbs	521.2 ± 21.6	BDL	BDL	BDL	BDL
BG3	Jungles	467.9 ± 18.5	BDL	BDL	BDL	BDL
BP1	Jungles	530.2 ± 50.8	5.8 ± 1.1	4 ± 0.8	BDL	BDL
BP2	Herbs and Flowered grasses	517.1 ± 10.5	5 ± 0.7	3.8 ± 1.8	1.4 ± 0.5	1.15 ± 0.4
BP3	Jungles	501±26.6	6.4 ± 1.1	4.5 ± 0.9	BDL	0.6 ± 0.2
BP4	Jungles	483.2 ± 25.8	BDL	2.3 ± 0.8	BDL	BDL
BP5	Jungles	595.7 ± 27	BDL	4.2 ± 1.7	BDL	0.82 ± 0.2
BP6	Herbs	499.8 ± 15.8	2.1 ± 0.5	BDL	BDL	BDL

Sample code	Plant species	Activity concentration (Bq/kg)				
		^{40}K	^{238}U Series		^{232}Th (^{228}Ac)	^{235}U
			^{214}Bi	^{214}Pb		
BP7	Jungles	527.4 ± 11.2	BDL	3.1 ± 1.8	BDL	BDL
BP8	Jungles	523.7 ± 5.5	3.8 ± 0.1	2.4 ± 0.5	BDL	0.57 ± 0.17
BP9	Jungles	576.9 ± 9.5	4.1 ± 0.6	BDL	BDL	BDL
Average		528.33	3.02	2.70	0.16	0.35
Minimum		483.2	BDL	BDL	BDL	BDL
Maximum		595.7	6.4	4.5	1.4	1.15

*BDL: Below detection limit.

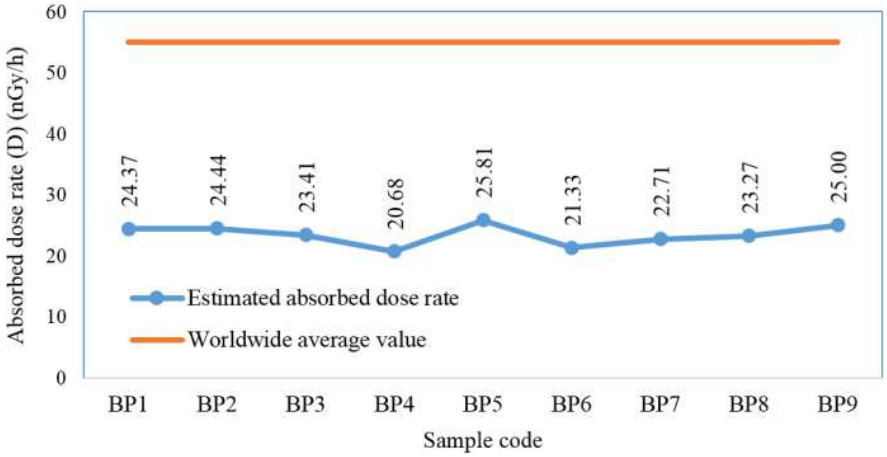

Figure 3. *Comparison between results of absorbed dose rates calculations with worldwide average value.*

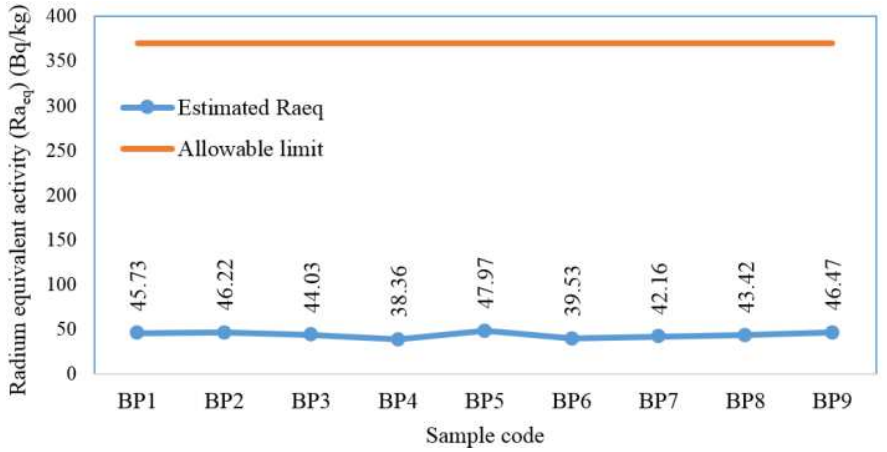

Figure 4. *Comparison between results of radium equivalent activity calculations with allowable limit.*

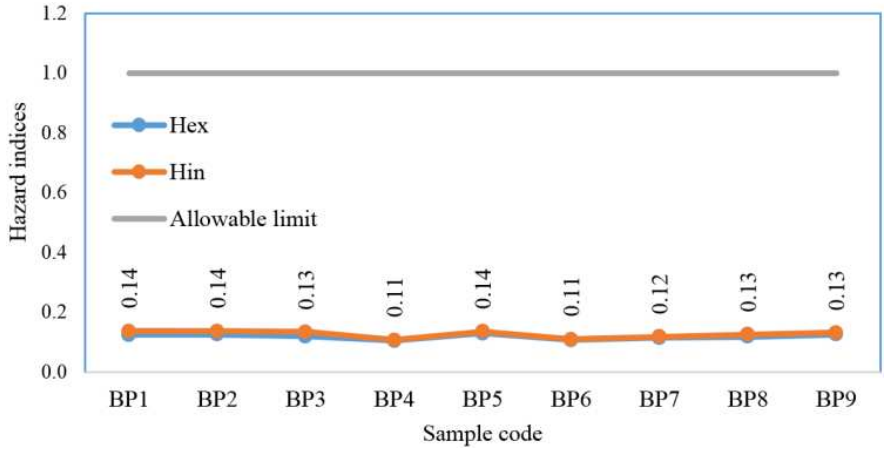

Figure 5. *Comparison between results of hazard indices calculations with allowable limit.*

4. Conclusions

The findings of this study have shown that the activity concentrations of ^{40}K in the plants samples were found to be higher than those for ^{226}Ra, which in turn were greater than those for ^{232}Th. The calculated values for gamma absorbed dose rates (D), radium equivalent activity (Ra_{eq}), and hazard indices (H_{ex} and H_{in}) of the naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in plants samples analyzed in current study were found to be well below corresponding allowable limits. No radionuclide of artificial origin (such as ^{137}Cs) was detected in any of the samples collected from the studied area.

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