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

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ABSTRACT

Knowledge of radionuclides concentrations in environmental media (such as common plants species) plays an important role in environmental protection and monitoring of any release of radioactivity to the environment. The activity concentrations and distribution of natural radionuclides in plants samples grown at scrap yard (A) (Al-Tuwaitha Nuclear Site) were investigated in this study. The measurements were carried out using gamma-ray spectrometry system (high purity germanium detector). The average and range of the activity concentrations of ^{226}Ra and ^{40}K were 0.19 (BDL to 2.92 Bq/kg) and 660.86 (510 to 796.49 Bq/kg). The radium equivalent activity, absorbed dose rate, annual effective dose equivalent, external and internal hazard indices were estimated and compared with internationally recommended values. The results of radiological hazards assessment obtained in this study indicated that the investigated plants species grown at the studied area have natural radioactivity levels well within internationally recommended limits.

Keywords: Natural radioactivity, radiological hazards, plants species, Al-Tuwaitha Nuclear Site

1. INTRODUCTION

Natural radionuclides are present in every human environment; earth material, water, air, foods and even our own body contain naturally occurring radioactive materials (NORM). The radionuclides present in the environment are normally in low activity concentrations.

The sources of these radionuclides are natural as well as man-made. The natural radioactive background originates from uranium and thorium series, from potassium - 40 and from the interaction of cosmic radiation with matter, while man-made sources include various applications of radionuclides in medicine, industries, consumer products and nuclear weapon tests [1-3]. Weathering of the earth's crust is the ultimate mechanism for the release of primordial radionuclides into the soil, which constitutes the principal source of natural background radiation. Plants acquire these radionuclides via their roots or leaves, and animals acquire them through consumption of plants, phosphate-based mineral food supplements and soils. These radionuclides are ultimately transferred to man by eating animal meat or milk or directly from plants by using them as food. Radionuclides ingested in food and to a lesser extent, water, account for a substantial part of the average radiation doses received by various organs of the human body, especially the skeleton [4]. Analysis of these radionuclides in foodstuff is an important part of the environmental monitoring program.

These natural radioactive sources are the largest contributor of the radiation doses received by mankind. In natural sources, the most important are ^{40}K and the member of ^{238}U and ^{232}Th decay series. Naturally occurring potassium (^{40}K) is present virtually in all foodstuff as an essential constituent of cellular material. The general public receives about 180 μSv/y from ^{40}K, an essential cellular constituent. The total potassium content in an average human being is about 0.14 kg of natural potassium, so ^{40}K is a predominant natural radioactive substance in our own body. Such natural background is considered as a constant source of radioactivity to human and, therefore, its adverse consequences cannot be ignored [5,6].

There are two mechanisms for the contamination of vegetables, i.e., by root uptake or directly by aerial deposition of fallout radionuclides on plants. It is necessary to carry out accurate assessment of these radionuclides in the daily used food materials in order to ascertain the degree of risk and deleterious effects to the public health [7-9]. Various radionuclides are always present in food samples from natural sources or as a result of discharges of radioactivity from industries, hospitals, research laboratories or from nuclear weapon tests fallout. Most of the internal radiation doses received by human beings are due to the consumption of food contaminated with different radionuclides. The aim of the present study is to determine the activity of various radionuclides present in different plant samples grown at scrap Yard (A) at Al-Tuwaitha Nuclear Site and estimate relevant radiation hazards.

2. MATERIALS AND METHODS

2. 1. Studied Area

The studied area, scrap yard (A), occupies a surface area of approximately 7705 m^2 (115 m × 67 m), located inside the earthen berms of Al-Tuwaitha Nuclear Site, surrounded to the south by earthen berms, to the east by damaged structure, to the north and west by vacant lands. The site is located within the latitudes 33°12'10.28" to 33°12'13.89" North and within

the longitudes 44°30'33.54" to 44°30'38.44" East. The site boundaries and the precise location of the studied area in relation to the nearby areas are shown in Figure 1.

Figure 1. Aerial satellite image for scrap yard (A) at Al-Tuwaitha Nuclear Site shows location of the studied area

2. 2. Samples Collection and Preparation

A total of 15 herbs and flowered grasses samples grown at the studied area were collected for radiometric analysis. These plants species might provide a food for calves, cattle and sheep graze onsite. The collected samples were dried at 105 °C to ensure that moisture is completely removed, homogenized, pulverized using crushing machine and sieved using 0.75 mm mesh size. Weighted samples were placed in Marinelli beakers, of 500 ml volume.

The beakers were completely sealed for more than one month to allow radioactive equilibrium to be reached between ^{226}Ra and its decay progeny. This step was necessary to ensure that radon gas is confined within the volume and that the daughters will also remain in the sample [10-12]. The samples were marked and brought to radioanalytical laboratory at Al-Tuwaitha Nuclear Research Site.

2. 3. Samples Counting

The radionuclides considered in the present study are: ^{214}Pb (at energies 74.81, 77.11, 89.8, 295.21, 351.92 and 785.91 keV), ^{214}Bi (at energies 609.31, 1120.29 and 1764.49 keV), ^{228}Ac (at energies 338.32 keV, 911.6 keV and 969.11 keV), ^{212}Pb (at energies 74.81, 77.11, 87.2, 89.8, 238.63 and 300.09 keV), and ^{40}K (at energy 1460.81 keV). Under the assumption that secular equilibrium was reached between ^{232}Th and ^{238}U and their decay products, the concentration of ^{232}Th was determined from the average concentrations of ^{228}Ac in the samples, and that of ^{226}Ra was determined from the average concentrations of the ^{214}Pb and ^{214}Bi decay products [13-16]. Gamma-spectrometric measurements were performed using high purity germanium (HPGe) detector. The measuring time for gamma-ray spectra was 3600 second. In order to determine the background distribution due to naturally occurring radionuclides in the environment around the detector, an empty Marinelli beaker was counted in the same manner as the samples. The activity concentrations of the radionuclides of concern were calculated using equation below [17-19,25]:

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

where A_{net} is the net peak counts (detector background subtracted), $I_\gamma(E_\gamma)$ is the absolute gamma decay intensity (emission probability) for the specific energy peak, also known as abundance at energy E_γ, $E_{ff}(E_\gamma)$ 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.

2. 4. Radiological Hazards Assessment

2. 4. 1. Radium Equivalent Activity

The radium equivalent activity (Ra_{eq}) is a radiation hazard index used for the evaluation of the radiation hazards of the gamma rays due to the naturally occurring radionuclides. It is given by the following relation [20]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad \ldots (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2. 4. 2. External and Internal Hazard Indices (H_{ex} and H_{in})

Plants grown on the studied area may contribute to the external gamma dose rates. To limit the external gamma-radiation dose due to naturally occurring radionuclides, the following criteria must be satisfied [21-23]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \ldots (3)$$

where H_{ex} represent the external hazard index.

In addition to external hazard index, radon and its short-lived products are also hazardous to the respiratory organs. The hazards associated with internal exposure to radon and its daughter progenies were quantified by the internal hazard index (H_{in}), which is given by the equation [21-23]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \ldots (4)$$

2. 4. 3. Absorbed Dose Rate in Air (D) and Annual Effective Dose Equivalent (AEDE)

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 [24]:

$$D\ (nGy/h) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad \ldots (5)$$

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. Annual effective dose equivalent was calculated to assess the health effects of the absorbed dose by using a conversion coefficient (0.7 Sv/Gy) to transform absorbed dose in air into effective dose received by humans, with an outdoor occupancy factor (0.2), which is equivalent to an outdoor occupancy of 20% and 80% for the indoors.

Annual effective dose equivalent (AEDE, in mSv/y) received by the population can be calculated using the following equation [24]:

$$AEDE\ (mSv/y) = D\ (nGy/h) \times 8760\ h/yr \times 0.7\ Sv/Gy \times 10^{-6} \times 0.2 \quad \ldots (6)$$

where D (nGy/h) is the absorbed dose rate in air; 8760 h is the number of hours in one year; 0.2 is the outdoor occupancy factor; 0.7 Sv/Gy is the conversion coefficient from absorbed dose in air to effective dose received by adults; 10^{-6} is the conversion factor between nano (n) (10^{-9}) and milli (m) (10^{-3}).

3. RESULTS AND DISCUSSION

Table 1 presents the concentrations of ^{238}U, ^{232}Th and ^{40}K in plants samples collected from the studied area. The average of the activity concentrations of ^{226}Ra and ^{40}K were 0.19 (range from below detection limit (BDL) to 2.92 Bq/kg) and 660.86 (range from 510 to 796.49) Bq/kg. The results presented in Table 1 also showed that the activities of ^{232}Th in all analyzed plants samples were below detection limit. The contents of natural radionuclides were found to be dependent on the plant species. Also, the radioactivity contents in plants species varied over relatively narrow ranges except in some cases.

The calculated Ra_{eq} is shown in Figure 2. The average value (51.08 Bq/kg) and range of the Ra_{eq} (39.72 to 61.33 Bq/kg) were far below the maximum permissible value of 370 Bq/kg [12].

The average value of the absorbed dose rate was 27.65 nGy/h (range from 21.27 to 33.21 nGy/h) (see Figure 3), which were below the internationally recommended value of 59 nGy/h [1,12]. The estimated annual effective dose equivalent (AEDE) for the plants samples

(see Figure 4) was found to be ranged from 0.026 to 0.041 mSv/y, with an average value of 0.034 mSv/y. The worldwide average annual effective dose is 0.5 mSv/y [1]. Thus, the present average annual effective dose rates do not exceed the worldwide average value.

Figure 5 shows that the estimated H_{ex} and H_{in} values for collected plants samples were found to be ranged from 0.11 to 0.17, with an average value of 0.14, which was considerably lower than the recommended value of 1 [12].

Table 1. Results of radiometric analysis performed for samples of common plant species growing on scrap yard (A).

Sample code	Plant species	Activity concentration (Bq/kg)				
		^{40}K	^{238}U Series		^{232}Th Series	
			^{214}Bi	^{214}Pb	^{228}Ac	^{212}Pb
AP1	Herbs	562.2 ± 58.9	*BDL	BDL	BDL	BDL
AP2	Herbs and flowered grasses	596.5 ± 66.1	BDL	BDL	BDL	BDL
AP3	Herbs	689.8 ± 71.6	BDL	BDL	BDL	BDL
AP4	Herbs	610.9 ± 41.3	BDL	BDL	BDL	BDL
AP5	Herbs	770 ± 59	BDL	BDL	BDL	BDL
AP6	Herbs and flowered grasses	510 ± 56.7	BDL	BDL	BDL	BDL
AP7	Herbs and flowered grasses	796.49 ± 11.64	BDL	BDL	BDL	BDL
AP8	Herbs	716.4 ± 61.9	BDL	BDL	BDL	BDL
AP9	Herbs	570.38 ± 66.85	BDL	BDL	BDL	BDL
AP10	Herbs	675.89 ± 40	BDL	BDL	BDL	BDL
AP11	Herbs and flowered grasses	697.39±69.61	2.05 ± 0.2	3.79 ± 0.9	BDL	BDL
AP12	Herbs	586.87±74.72	BDL	BDL	BDL	BDL
AP13	Herbs	787.3±55.8	BDL	BDL	BDL	BDL
AP14	Herbs	654.2±68.3	BDL	BDL	BDL	BDL
AP15	Herbs	688.7±50.4	BDL	BDL	BDL	BDL
Average		660.86	0.13	0.25	BDL	BDL
Minimum		510	BDL	BDL	-	-
Maximum		796.49	2.05	3.79	-	-

*BDL: Below detection limit

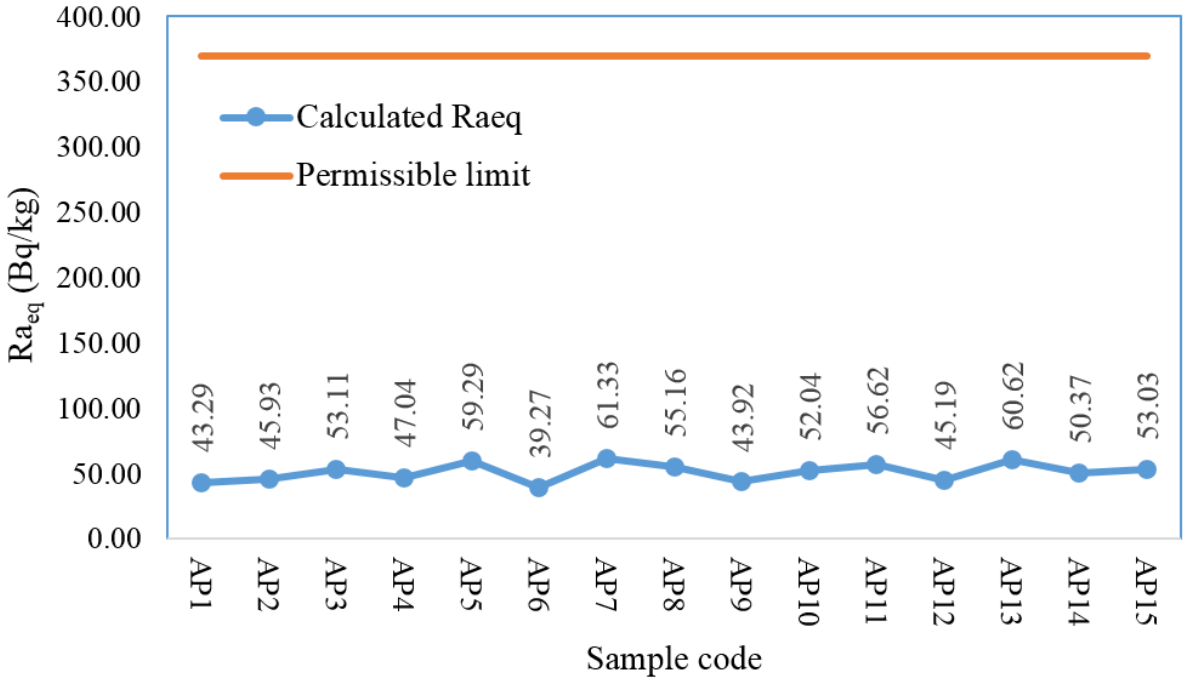

Figure 2. The calculated Ra_{eq} for collected plants samples

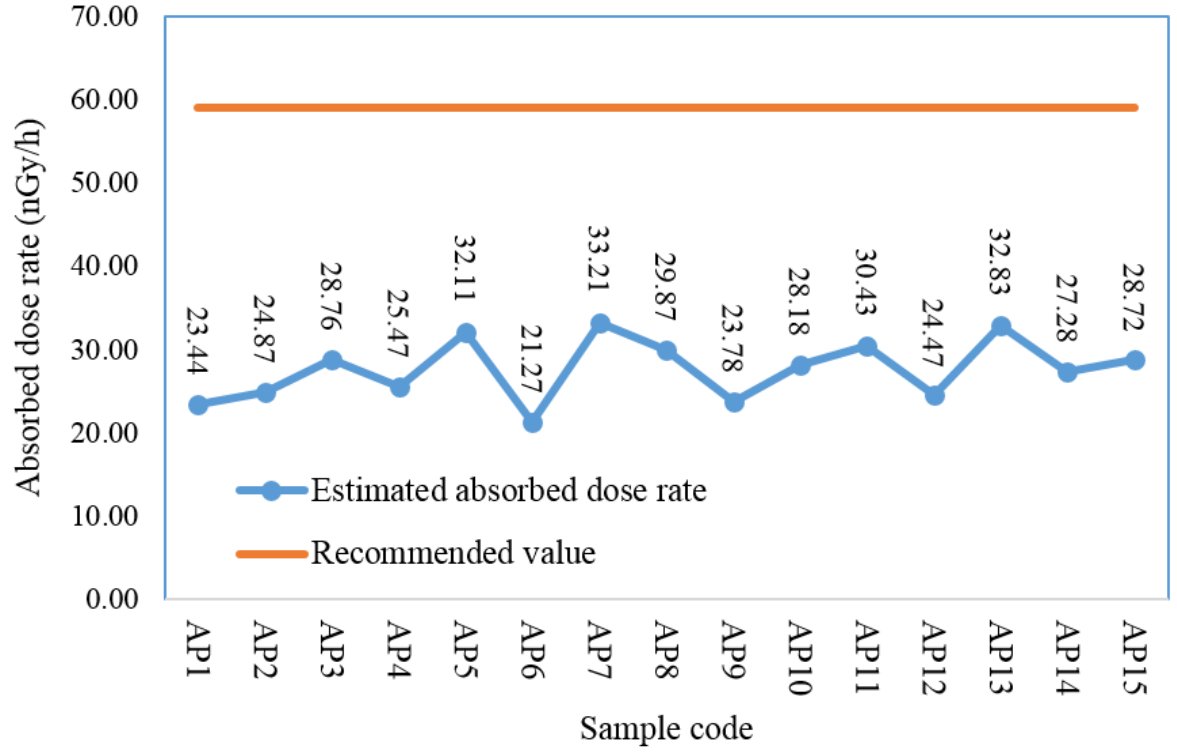

Figure 3. The calculated absorbed dose rates for collected plants samples

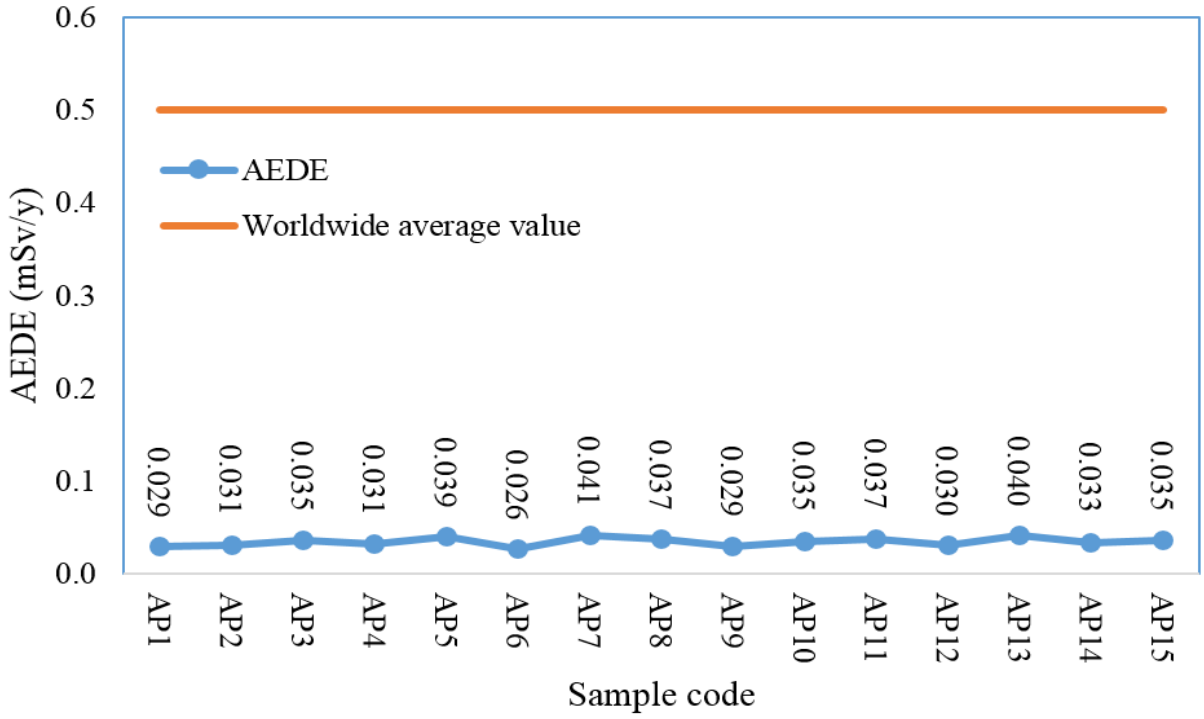

Figure 4. The calculated AEDE for collected plants samples

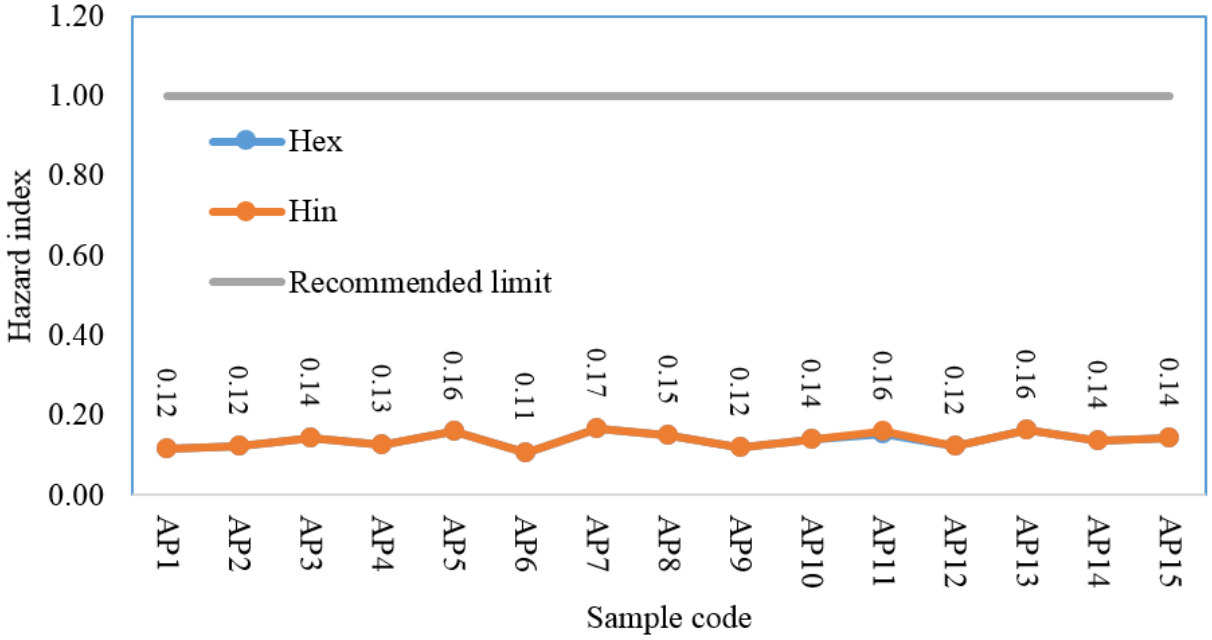

Figure 5. The calculated radiation hazard indices for collected plants samples

4. CONCLUSIONS

The levels of naturally occurring radioactivity in plants samples collected from scrap yard (A) at Al-Tuwaitha Nuclear Research Site were investigated using gamma-ray spectrometry system (HPGe detector). The average and range of the activity concentrations of ^{226}Ra and ^{40}K were 0.19 (BDL to 2.92 Bq/kg) and 660.86 (510 to 796.49 Bq/kg). ^{232}Th had no detectable activity in all analyzed samples. The radium equivalent activity (Ra_{eq}), absorbed dose rate (D), annual effective dose equivalent (AEDE), external (H_{ex}) and internal (H_{in}) hazard indices were evaluated. The results of radiological hazards assessment obtained in this study indicated that the investigated plants species grown at the studied area have natural radioactivity levels well within internationally recommended limits. The results presented in this study would be useful for establishing database in the area under consideration and represent a basis to assess any future changes in the environmental radioactivity levels due to various artificial influences on or around the studied area.

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