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ARTICLE

Comparing of the Natural Radioactivity in Soil Samples of University at Al-Husseineya and Al-Mothafeen Sites of Kerbala, Iraq

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Abstract: Radioactivity must be studied in soil to see the changes in the doses of human exposure. In this study, natural radioactivity and radiological hazard indices in soil samples of the Faculty of Agriculture (Al-Husseineya site) and the Faculty of Medicine (Al-Mothafeen site) in Kerbala Governorate were determined using gamma-ray spectroscopy. The results showed that the mean values of specific activity (in units of Bq/kg) and standard errors of: ^{238}U, ^{232}Th and ^{40}K at Al-Husseineya site was 21.7±7.2, 9.43±3.2 and 335.8±82.2, respectively, while at Al-Mothafeen site, the mean values and standard errors were 22.4±8.8, 11.2±3.3 and 333.1±70.7, respectively. Radiation maps of natural radioactivity (^{238}U, ^{232}Th and ^{40}K) at Al-Husseineya and Al-Mothafeen sites were mapped using geographic information system (GIS) technology. Moreover, most results in the present study fall within the acceptable levels, as defined by OCDE, UNSCEAR and ICRP. Therefore, there is no significant radiological hazard at the sites which were studied.

Keywords: Radiological hazard, Natural radioactivity, Soil, NaI (Tl), Gamma-ray, Karbela University.

Introduction

Background radiation reaches us everywhere and at all times. It is an important part of our lives, where all aspects of earth's life are being subjected to ionizing radiation. Both human-made and natural radionuclides release background radiation. Natural radionuclides arise from the atmosphere due to the outer space radiation, crusts of earth including mineral rock ores and soil; or even from our bodies due to radionuclides in water and food that we intake and air that we breathe [1]. The term "NORM" indicates a material that is naturally occurring radioactive. In addition, human-made radiation comes into the environment every day from nuclear power plants, medical processes and consumer products. In general, the main radiation types are: alpha particles, beta particles and gamma rays; They often come from radionuclides [2, 3]. NORMs are divided into two major groups. The first group is the naturally occurring radioactive materials with very long half-lives (hundreds of millions of years). These materials existed around 4.5 billion years ago; i.e., when the earth was born. These materials are called primordial radionuclides [2, 3]. They can be found in sedimentary igneous rocks and can transfer into soil, water and even through air [4]. However, the NORM of the second group is cosmogenical; it comes from the interactions between the outer atmosphere and the cosmic rays [2, 3]. It is important to investigate natural radioactivity, as the NORM can work as a good geochemical and biochemical tracer within the environment having geological events like eruptions, volcanoes and earthquakes [4]. It is well known that the biologically harmful effects occur even from exposing the body to a small amount of gamma-ray from these radionuclides

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and the lung tissue irradiation from radon and its daughters' inhalation [5]. Therefore, it is very important to know the exposure dose limits for measuring the radiation level provided by air, land, food, water, buildings … etc., in order to assess exposure and human protection regarding natural sources of radiation [6, 7]. As the soil is considered as the leading contributor to background radiation, the knowledge of its radioactivity content worldwide is quite important. The main soil's natural radioactivity arises from ^{238}U, ^{232}Th series and ^{40}K during earth creation. In Iraq and other countries, these natural radioactivities were studied utilizing various techniques, such as gamma spectroscopy [6, 7].

The main purpose of this work is to evaluate the specific activity of natural radioactivity in soil samples from the Faculty of Agriculture (Al-Husseineya site) and the Faculty of Medicine (Al-Mothafeen site) in Kerbala Governorate. Moreover, ten radiological hazard parameters were estimated, which include: Radium Equivalent Activity (Ra_{eq}), External Hazard Index (H_{ex}), Internal Hazard Index (H_{in}), Representation Level Index (I_γ), Alpha Index (I_α), exposure rate ($\dot{x}$), absorbed dose rate in the air (d), equivalent gonad dose (AGED), annual equivalent outdoor active dose and lifelong cancer risks calculated (ELCR). Finally, map of ^{238}U, ^{232}Th and ^{40}K concentrations in the present study area using GIS technique was drawn as a reference to be a base for any future studies.

Area of Study

University of Kerbala consists of many faculties distributed over three sites; namely, Frariha site, Al-Husseineya site and Al-Mothafeen site. In this work, the natural gamma radioactivity for (^{238}U, ^{232}Th and ^{40}K) was measured in soil samples that have been distributed across residency quarters that are belonging to the University of Kerbala at Al-Husseineya site and Al-Mothafeen site.

Al-Husseineya site is located between 3240'33.37"N north latitude and 4409'50.98"E east longitude. It consists of five faculties; Medicine, Dentistry, Pharmacy, Applied Medical Sciences and Nursing. Al-Mothafeen site is located between 3236'31.36"N north latitude and 4400'15.1"E east longitude. It consists of two faculties; Agriculture and Veterinary Medicine.

Materials and Methods

Sample Collection and Preparation

Forty soil samples were collected from different locations in Kerbala Governorate (Al-Husseineya site and Al-Mothafeen site) during the past year from October-November 2019 at a depth equal to (10 to 15 cm) from the earth's surface. Locations were determined using Global Positioning System (GPS) coordinates (GARMIN, Model: 010-00779-00, SKU: ETREXLEGEND) (2017) and drawn using GIS technique, as shown in Figs. 1 and 2. After collecting the soil samples, they were placed in a plastic bag and marked with the sample codes and symbols. Samples were then transferred to the laboratory of nuclear physics in the department of physics, Faculty of Science, University of Kufa. Samples were crushed and then dried inside the oven at (120) °C for (60) minutes to ensure removing any significant moisture. Then, a sieve of (500 μm) pores was used to obtain homogeneous soil samples of 0.750 kg each. Samples were then packed using one-liter plastic Marinelli cups to ensure uniformity around the detector. Plastic Marinelli cups were kept close using a proper tape and then stored for about a month prior to the counting time to permit a secular equilibrium between ^{222}Rn and ^{226}Ra in the uranium chain [8].

Experimental Setting and Measurement of Samples

The detection system (see Fig. 3) used in this work consists of a sodium iodide detector (Alpha Spectra, Inc.-12I12 / 3) with dimensions "3x3" connected to an MCA (ORTEC-Digi Base) "4096" with a high-voltage measurement scale from 0 to 1500 volts. The detector operating voltage is 787 volts. The protective cover (i.e., shielding) contains two parts: the upper one is made of lead with a thickness equal to 5 cm and 20 cm length which surrounds the crystal with a circular cover having a thickness of 5 cm and a diameter of 22 cm, while the lower part forms the base. The detector was located at the center of the chamber to minimize the influence of scattered radiation from the shield. NaI(Tl) detector was calibrated by obtaining a spectrum from radioactive standard sources of gamma-ray ^{137}Cs, ^{54}Mn, ^{60}Co, ^{22}Na and ^{152}Eu. All samples were measured for a period of 18000 sec. The MAESTRO-32 data analysis package was used to estimate the sample specific activity which is equal to the net area below the corresponding peaks within the energy spectrum. This area was calculated by subtracting the counts owing to background sources from the area under a certain peak. An empty (1-liter) polyethylene plastic Marinelli cup was placed on the detector to measure the background spectrum for the same period of time as for the soil samples. For low gamma energies which had not well-separated photo-peaks and poor resolution of NaI(Tl) detector, activity concentration measurements are possible if well-separated photo-peaks at elevated energies have been used, as shown in Fig. 4. In this study, the results obtained from the gamma rays emitted by the progenies of ^{232}Th and ^{238}U are in secular equilibrium with them; however, estimation of ^{40}K was direct using its gamma-line of 1460 keV. Therefore, the ^{238}U specific activity was found using the gamma-lines 1765 keV (^{214}Bi). The corresponding ^{232}Th results were estimated *via* the gamma-ray lines 2614 keV (^{208}Tl) [9].

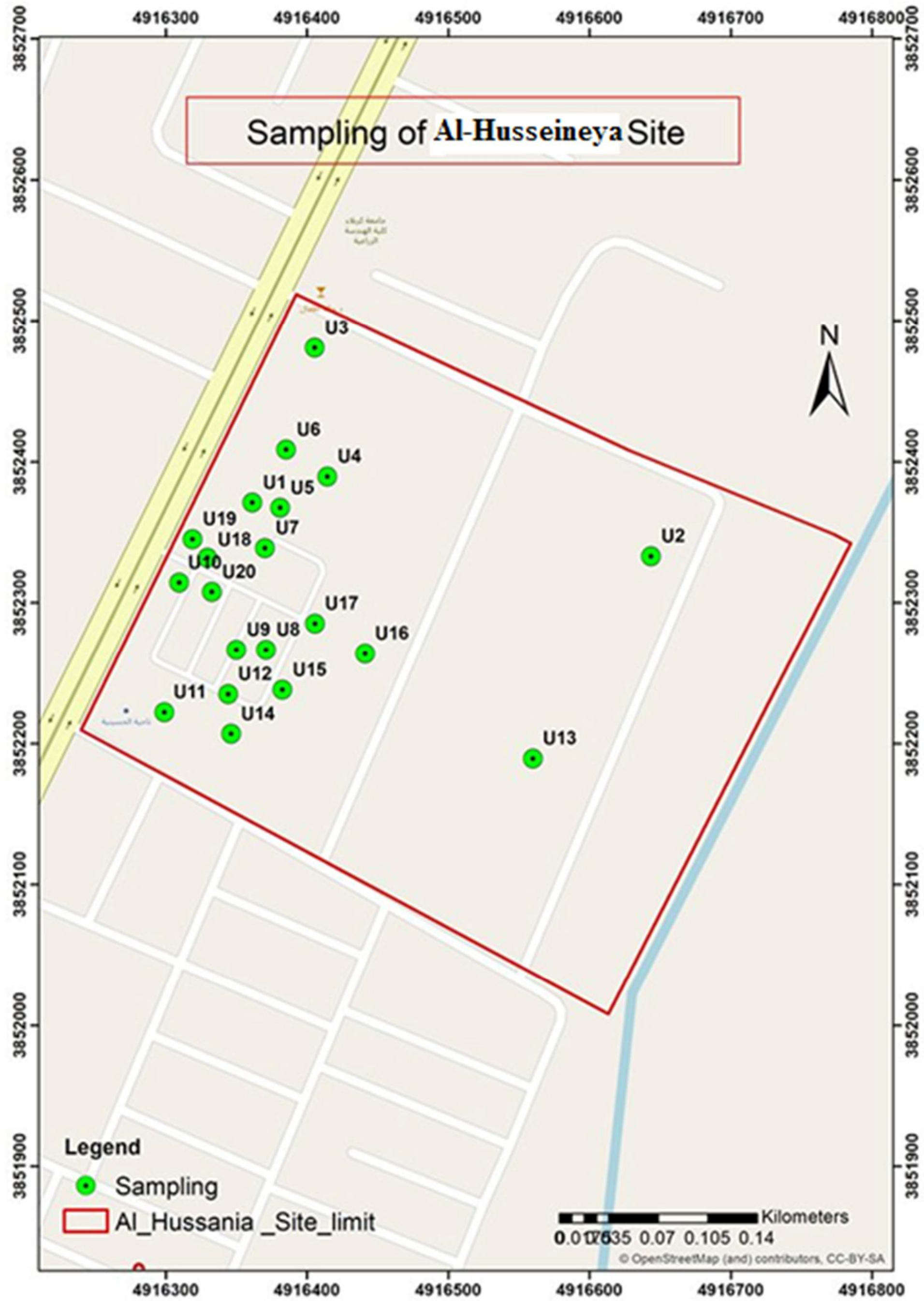

FIG. 1. Map of samples' location for Al-Husseineya site.

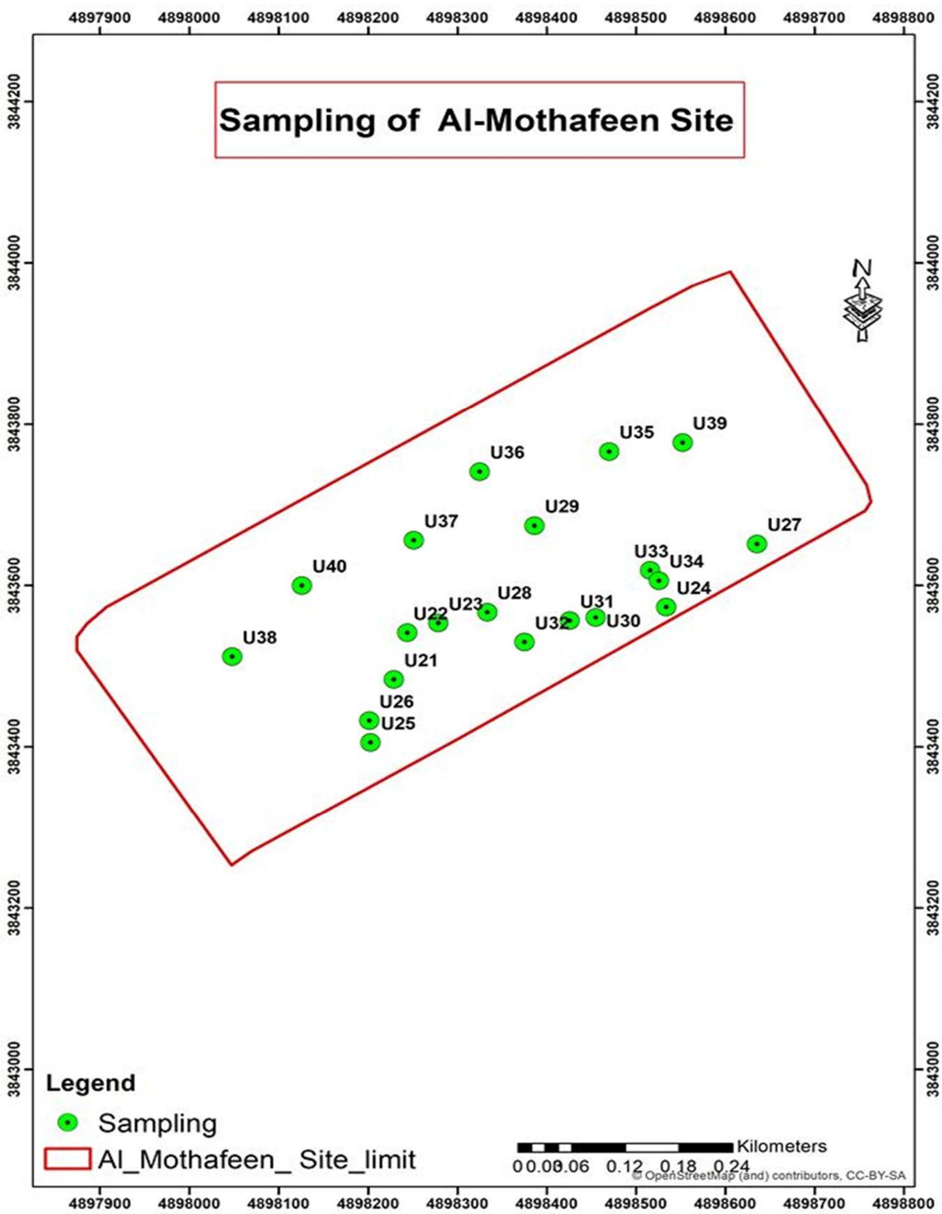

FIG. 2. Map of samples' location for Al-Mothafeen site.

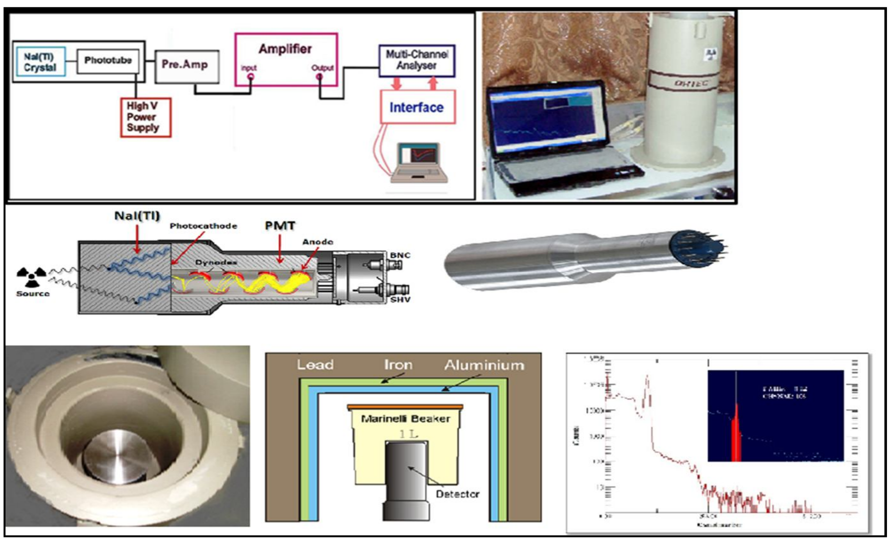

FIG. 3. Diagram of NaI(Tl) system.

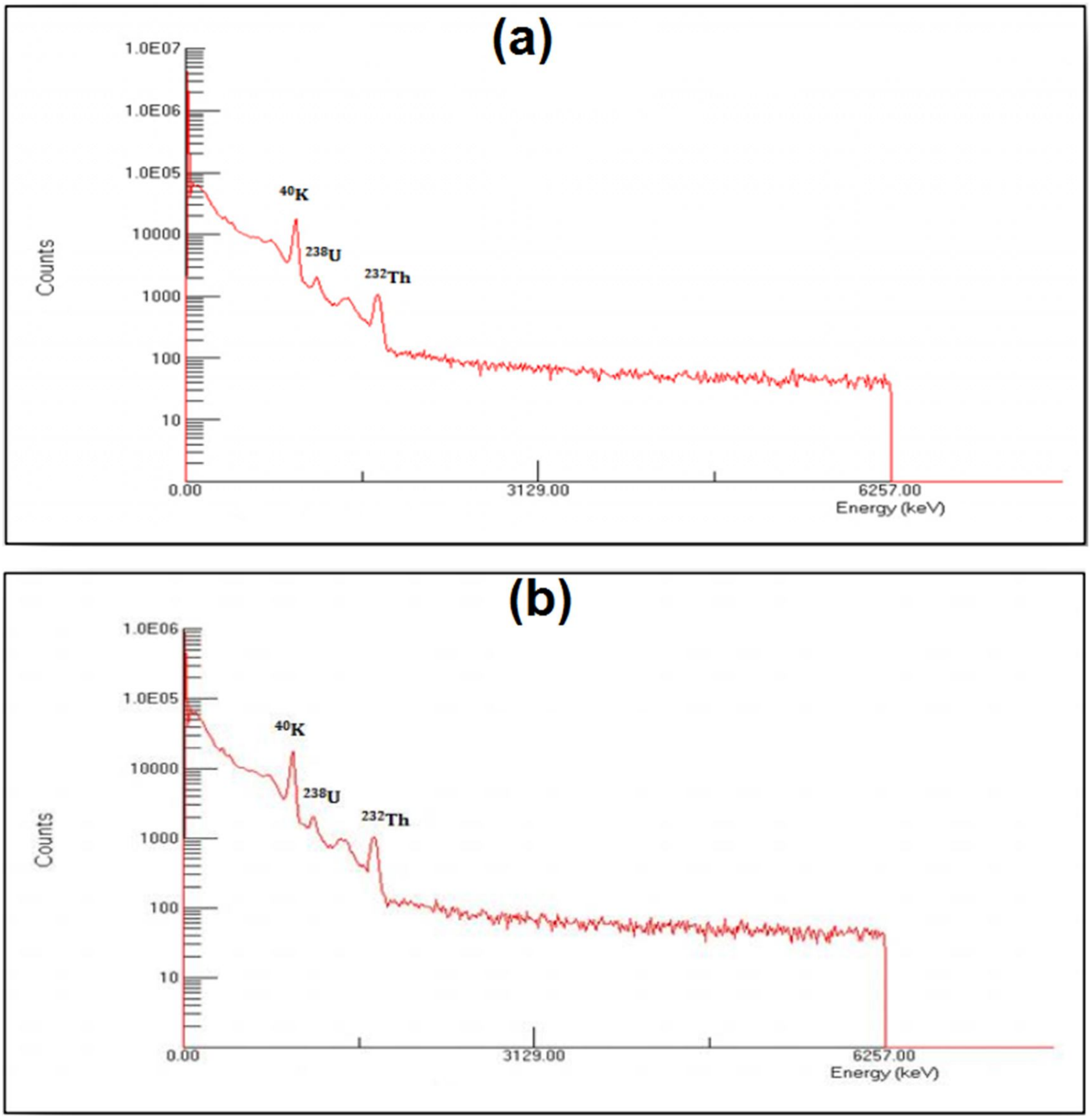

FIG. 4. Gamma-ray spectrum using MAESTRO-32 soft for NaI(Tl) NaI (Tl) (3"×3") for some samples: (a) Sample U1, (b) Sample U21.

Theoretical Equations

Specific Activity (A)

The gamma- ray emitting radionuclide specific activity or which is called the activity concentration within the sample is calculated as per Eq. (1) [10, 11]:

$$A\left(\frac{Bq}{kg}\right) = \frac{N}{I_\gamma\, \varepsilon\, T\, M} \tag{1}$$

where the symbol A denotes the radionuclide specific activity in the sample, N indicates the net area below the photopeak, I_γ denotes the gamma decay probability, ε denotes the gamma-ray detector efficiency, M is the measured sample weight (kg) and T indicates the live time for collecting the spectrum (seconds).

External Hazard Index (H_{ex})

The sample external hazard index can be calculated as per Eq. (2) [12]:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{2}$$

A_U, A_{Th} and A_k stand for the specific activity of ^{238}U, ^{232}Th and ^{40}K, respectively.

Internal Hazard Index (H_{in})

Internal exposure to ^{222}Rn and its radioactive progenies is controlled by the internal hazard index which is calculated as per Eq. (3) [13]:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{3}$$

Representative Level Index (I_γ)

Radiation dangers due to the predetermined radionuclides of $^{238}U(^{226}Ra)$, ^{232}Th, and ^{40}K were evaluated by another parameter called representative level index (I_γ). The following equation can be utilized to determine I_γ for soil samples under study[14]:

$$I_\gamma = \left(\frac{1}{150}\right) A_U + \left(\frac{1}{100}\right) A_{Th} + \left(\frac{1}{1500}\right) A_K \quad (4)$$

Alpha Index (I_α)

This index has been created to evaluate the impact of an excess of alpha radiation due to the inhaled radon emanating from building materials. This index was resolved utilizing Eq. (5) [12]:

$$I_\alpha = \frac{A_U}{200\ (\frac{Bq}{kg})} \quad (5)$$

Radium Equivalent Activity (Ra_{eq})

The radiological hazard that is accompanied by samples that normally contain radionuclides; namely, ^{238}U,^{232}Th and ^{40}K, can be evaluated by the radium equivalent activity [15]. It is described mathematically by the following equation:

$$Ra_{eq}\left(\frac{Bq}{kg}\right) = A_U + 1.43\ A_{Th} + 0.077A_K \quad (6)$$

Exposure Rate ($\dot{X}$)

The rate of gamma-ray exposure in the air, measured at one meter above a thick slab that is infinitely extended, due to ^{238}U, ^{232}Th series and ^{40}K that were uniformly distributed within the material, is equal to [13, 16]:

$$\dot{X}\left(\frac{\mu R}{h}\right) = 1.90\ A_U + 2.82\ A_{Th} + 0.197A_K \quad (7)$$

$\dot{X}$ is defined as the exposure rate (μR/h). Here, the concentrations of activity are usually given in pCi/g. For each radionuclide in the radioactive series, the average values of the gamma-ray energies are described by the constants presented on the right-hand side of Eq. (7).

Absorbed Dose Rate in Air (D_r)

The major contribution to the rate of absorbed dose in the air arises from the radionuclides of the terrestrial gamma-ray that exist in soil trace amounts. The dose rate measurements are actually depending on measurements of concentrations of the specific activity of radionuclides, mainly ^{232}Th, ^{238}U and ^{40}K. The report of UNSCEAR 2008 shows that the rate of absorbed dose, 1 meter higher than the ground surface in the air, is described by Eq. (8) [17]:

$$D_r\left(\frac{nGy}{h}\right) = 0.462\ A_U + 0.604\ A_{Th} + 0.0417A_K \quad (8)$$

Annual Gonadal Equivalent Dose (AGED)

As per UNSCEAR [18], the gonads are viewed as intrigue organs. The yearly gonads' identical portions [AGED] for the occupants in the study site because of particular activities of ^{238}U, ^{232}Th and ^{40}K were determined by utilizing Eq. (9) [19, 20] as:

$$AGED\ (\frac{mSv}{y}) = 3.09\ A_U + 4.18\ A_{Th} + 0.314A_K \quad (9)$$

Annual Effective Dose Equivalent (AEDE)

The yearly successful portion equivalent (AEDE) is determined from the consumed portion using the portion transformation factor of 0.7 (Sv/Gy) with an outside inhabitance factor of 0.2 as in Eq. (10) [21]:

$$AEDE_{outdoor}\left(\frac{mSv}{y}\right) = [D_r(mGy/hr) \times 8760\ hr \times 0.2 \times 0.7Sv/Gy] \times 10^{-6} \quad (10)$$

Excess Lifetime Cancer Risk (ELCR)

This factor measures the cancer probability created over a lifetime span for a given level of exposure. In this factor, 70 years is considered as the normal life-span for an individual. This risk factor can be given by [10, 15]:

$$ELCR = AEDE\ \times DL\ \times RF \quad (11)$$

where $AEDE_{outdoor}$ is the outdoor Annual Effective Dose Equivalent, DL is the normal duration of life (70 years as mentioned previously), RF is the risk factor (1/Sv). For the stochastic impact, generally, ICRP utilizes RF as 0.05 for people.

Results and Discussion

The Specific Activity

The radionuclides' specific activities for ^{238}U, ^{232}Th and ^{40}K that were measured in the selected soil samples taken from various locations at the Faculty of Agriculture (Al-Husseineya site) in Kerbala Governorate are presented in Table (1). It is noted that the specific activity of ^{238}U ranged from 6.5±0.6 Bq/kg in sample U1 to 35.1±1.5 Bq/kg in sample U19, with a mean value of 21.7±7.2 Bq/kg, the specific activity of

^{232}Th varied from 3.1± 0.2 Bq/kg in sample U20 to 14.2± 0.5 Bq/kg in sample U1, with a mean value of 9.4±3.2 Bq/kg. Moreover, the values of ^{40}K were 115.5± 2.5 Bq/kg in sample U14 and 419.7±5.6 Bq/kg in sample U6, with a mean value of 335.8±82.2 Bq/kg. The comparison between the specific activities of ^{238}U, ^{232}Th and ^{40}K of Al-Husseineya site in Bq/kg for all the samples is shown in Figs. (5), (6) and (7) which are drawn by GIS technology. The specific activities of ^{40}K, ^{232}Th and ^{238}U that were measured in selected soil samples for different locations at the Faculty of Medicine (Al-Mothafeen site) belonging to Kerbala Governorate are recorded in Table (2). In Table (2), the specific activity in Bq/kg of ^{238}U ranged from11.0±0.7 in sample U38 to 41.5±1.4 in sample U34, with a mean value of 22.4±8.8, the specific activity in Bq/kg for ^{232}Th ranged from 6.1±0.3 in sample U28 to 17.3±0.5 in sample U35, with a mean value of 11.2±3.3 and for ^{40}K, the specific activity ranged from 207.1±3.2 in sample U35 to 448.4±6.0 in sample U27, with a mean value of 333.1±70.7. The comparison between the specific activities of ^{238}U, ^{232}Th and ^{40}K of Al-Mothafeen site in Bq/kg for all the samples is shown in Figs. (8), (9) and (10) which are drawn by GIS technology.

TABLE 1. Specific activity results at Al-Husseineya site.

No.	Sample code	Specific activity (Bq/kg)					
		Uranium-238		Thorium-323		Potasium-40	
		Average	±S.D.	Average	±S.D.	Average	±S.D.
1	U1	6.5	0.6	14.2	0.5	407.8	4.9
2	U2	25.1	1.1	13.0	0.5	383.5	4.4
3	U3	13.6	0.8	5.8	0.3	294.7	3.8
4	U4	19.9	1.0	5.4	0.3	152.4	2.9
5	U5	27.6	1.3	9.6	0.4	329.1	4.5
6	U6	15.3	1.0	9.6	0.5	419.7	5.6
7	U7	27.1	1.2	11.5	0.5	373.4	4.5
8	U8	28.3	1.4	13.1	0.6	390.8	5.2
9	U9	21.6	1.0	4.7	0.3	246.0	3.6
10	U10	17.1	1.1	8.4	0.5	308.4	4.7
11	U11	23.9	1.2	11.4	0.5	417.1	5.2
12	U12	27.7	1.4	9.3	0.5	365.3	5.2
13	U13	30.1	1.4	9.9	0.5	329.9	4.7
14	U14	24.1	1.1	3.4	0.3	111.5	2.5
15	U15	18.8	0.9	13.4	0.5	290.8	3.9
16	U16	12.1	0.8	10.9	0.4	363.5	4.3
17	U17	20.7	1.1	10.5	0.5	391.2	5.2
18	U18	11.4	0.9	12.8	0.6	417.4	5.6
19	U19	35.1	1.5	8.7	0.4	376.9	5.0
20	U20	29.0	1.1	3.1	0.2	348.3	4.1
	Max.	35.1	1.5	14.2	0.5	419.7	5.6
	Min.	6.5	0.6	3.1	0.2	111.5	2.5
Average ±S.D.		21.7±7.2		9.4±3.2		335.8±82.2	
Worldwide average [11]		35		45		420	

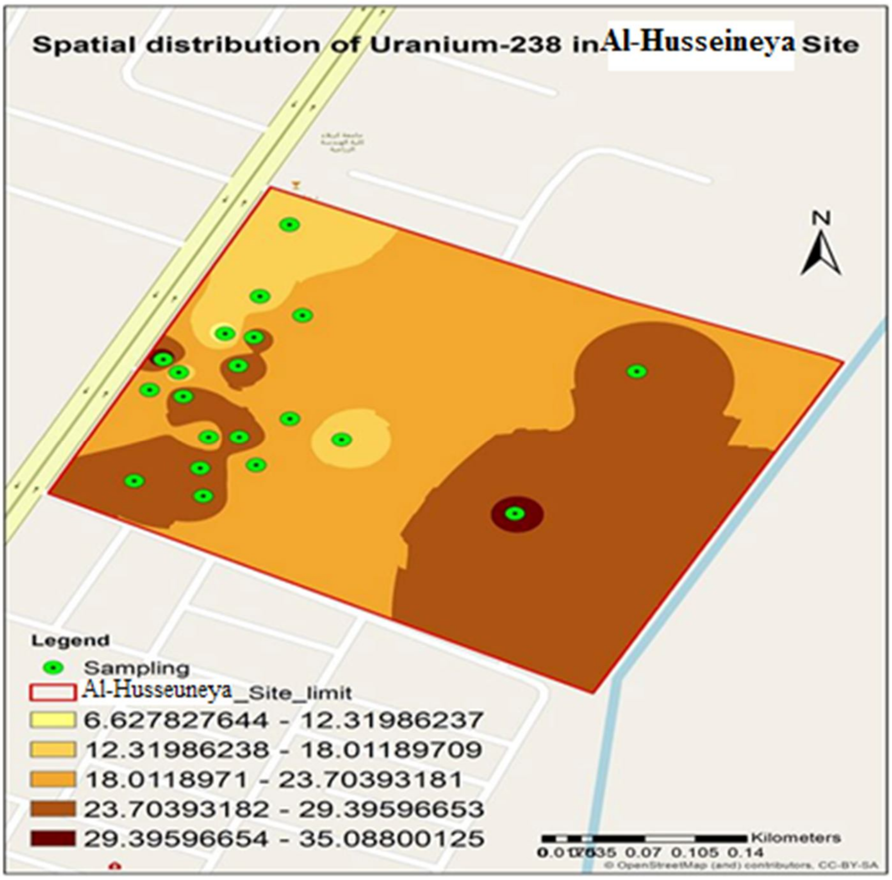

FIG. 5. Spatial distribution map of the specific activity values of ^{238}U using GIS technology.

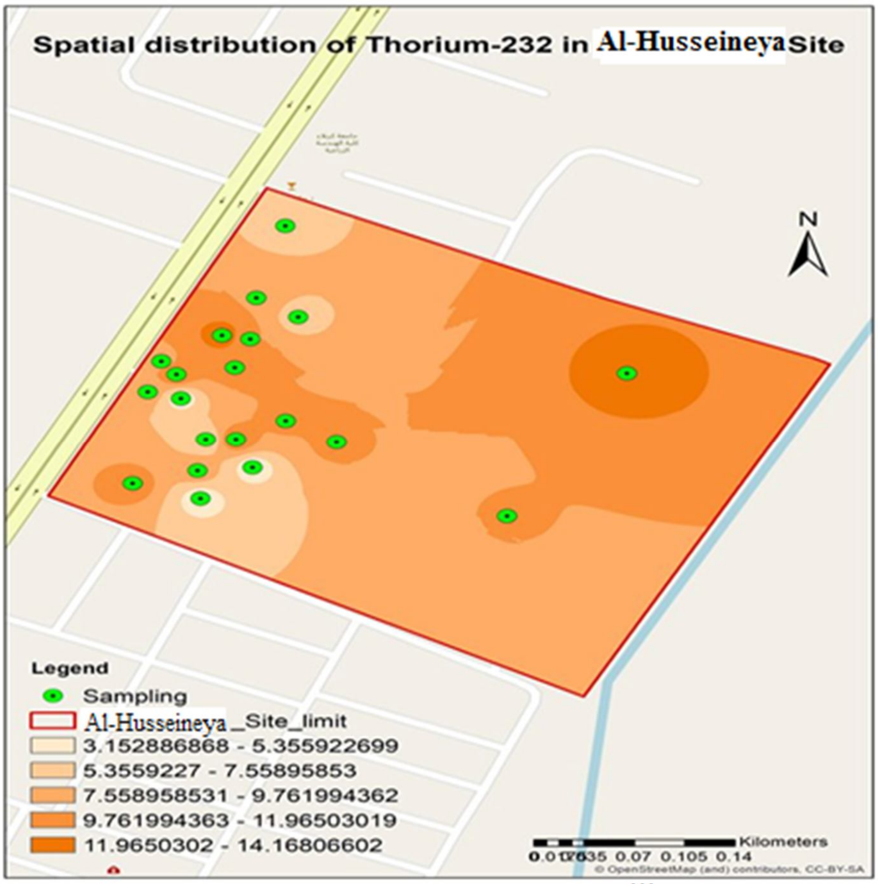

FIG. 6. Spatial distribution map of the specific activity values of ^{232}Th using GIS Technology.

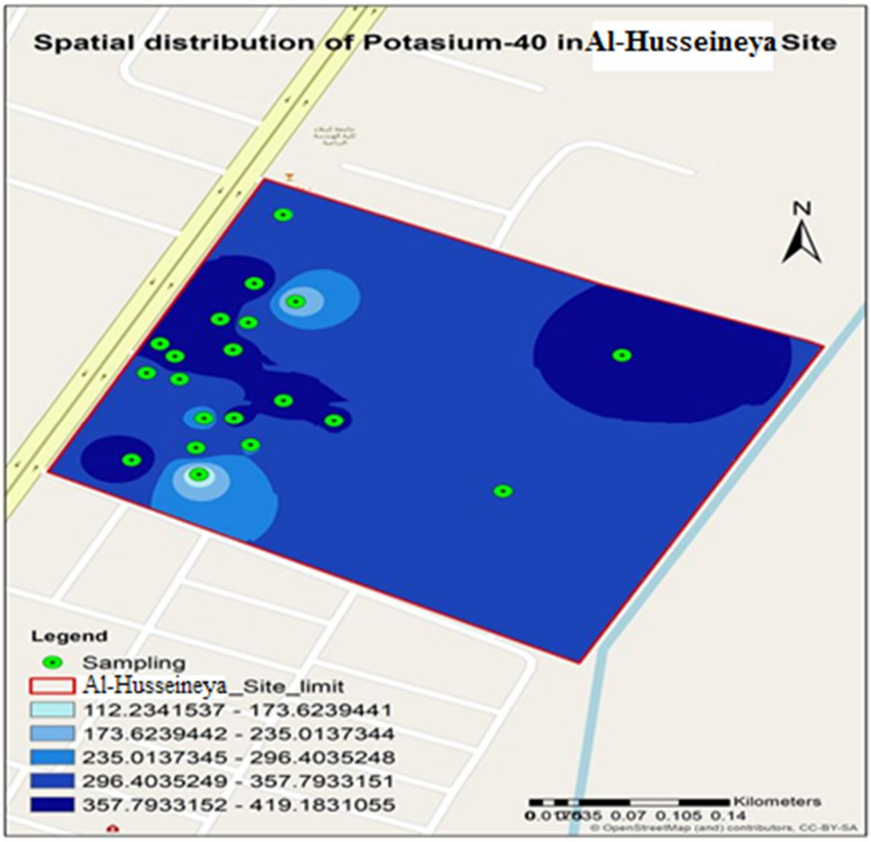

FIG. 7. Spatial distribution map of the specific activity values of ^{40}K using GIS technology.

TABLE 2. Specific activity results in Al-Mothafeen site.

No.	Sample code	Specific activity (Bq/kg)					
		Uranium-238		Thorium-323		Potasium-40	
		Average	±S.D.	Average	±S.D.	Average	±S.D.
21	U21	16.3	0.9	11.0	0.5	403.6	4.8
22	U22	14.5	0.9	6.7	0.4	249.5	3.8
23	U23	16.3	1.0	6.1	0.4	360.9	4.8
24	U24	17.6	1.0	11.9	0.5	397.5	5.1
25	U25	37.2	1.5	12.1	0.5	373.7	4.9
26	U26	17.5	1.0	13.0	0.5	313.9	4.6
27	U27	25.1	1.4	17.2	0.7	448.4	6.0
28	U28	17.7	1.0	6.1	0.3	374.4	4.7
29	U29	27.3	1.5	10.5	0.6	314.1	5.3
30	U30	31.4	1.5	10.5	0.5	424.7	5.6
31	U31	32.2	1.2	10.1	0.4	240.4	3.3
32	U32	30.1	1.4	16.8	0.6	340.5	5.0
33	U33	31.1	1.4	14.7	0.6	216.1	3.9
34	U34	41.5	1.4	10.8	0.4	290.5	3.9
35	U35	13.1	0.8	17.3	0.5	207.1	3.2
36	U36	12.4	0.8	10.9	0.4	313.0	4.1
37	U37	12.9	0.8	6.6	0.3	244.6	3.6
38	U38	11.0	0.7	11.2	0.5	348.7	4.4
39	U39	24.4	1.3	10.4	0.5	396.9	5.2
40	U40	18.4	0.9	9.9	0.4	403.7	4.4
	Max.	41.5	1.4	17.3	0.5	448.4	6.0
	Min.	11.0	0.7	6.1	0.3	207.1	3.2
Average± S.D.		22.4±8.8		11.2±3.3		333.1±70.7	
Worldwide average [20]		35		45		420	

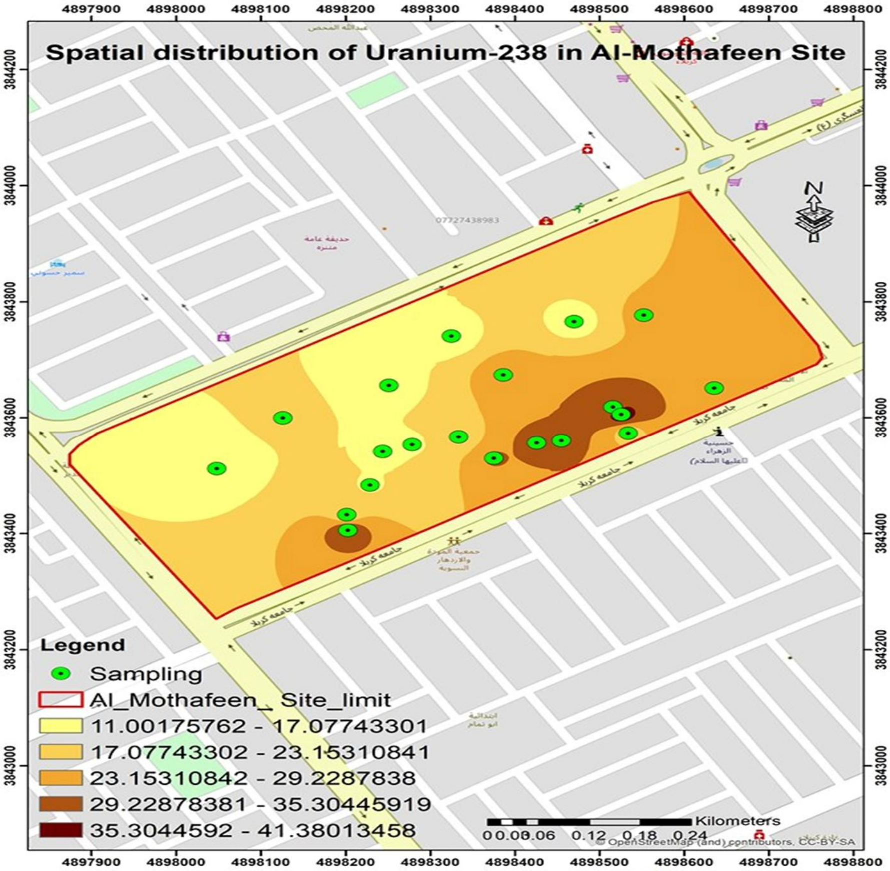

FIG. 8. Spatial distribution map of the specific activity values of ^{238}U using GIS technology.

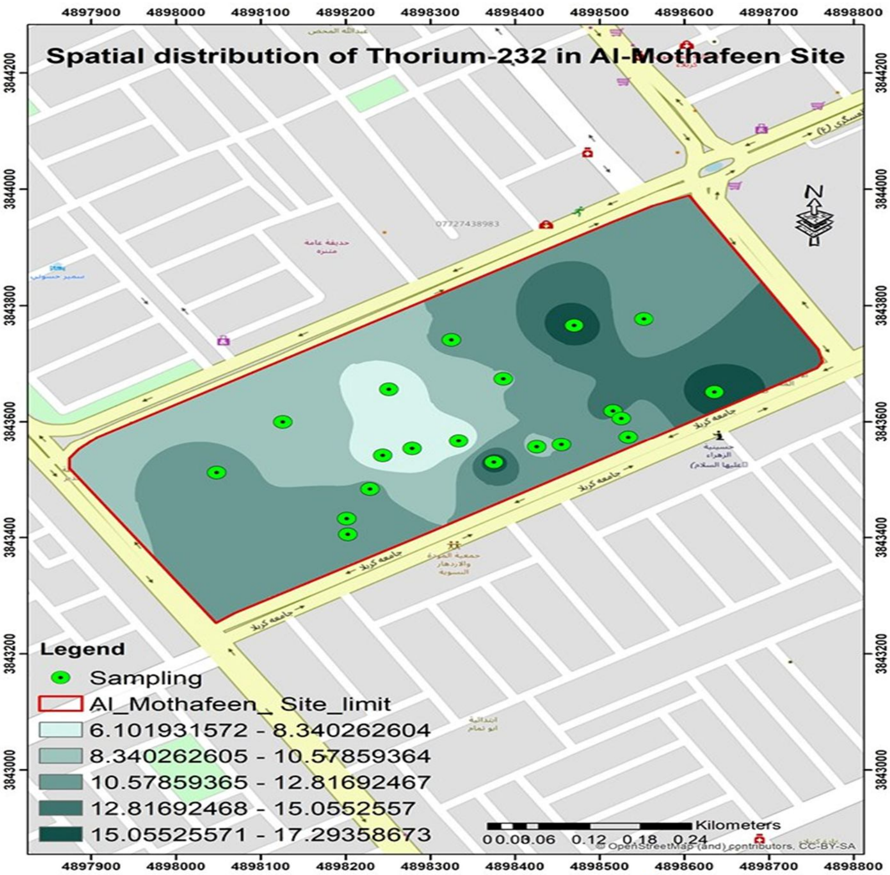

FIG. 9. Spatial distribution map of the specific activity values of ^{232}Th using GIS technology.

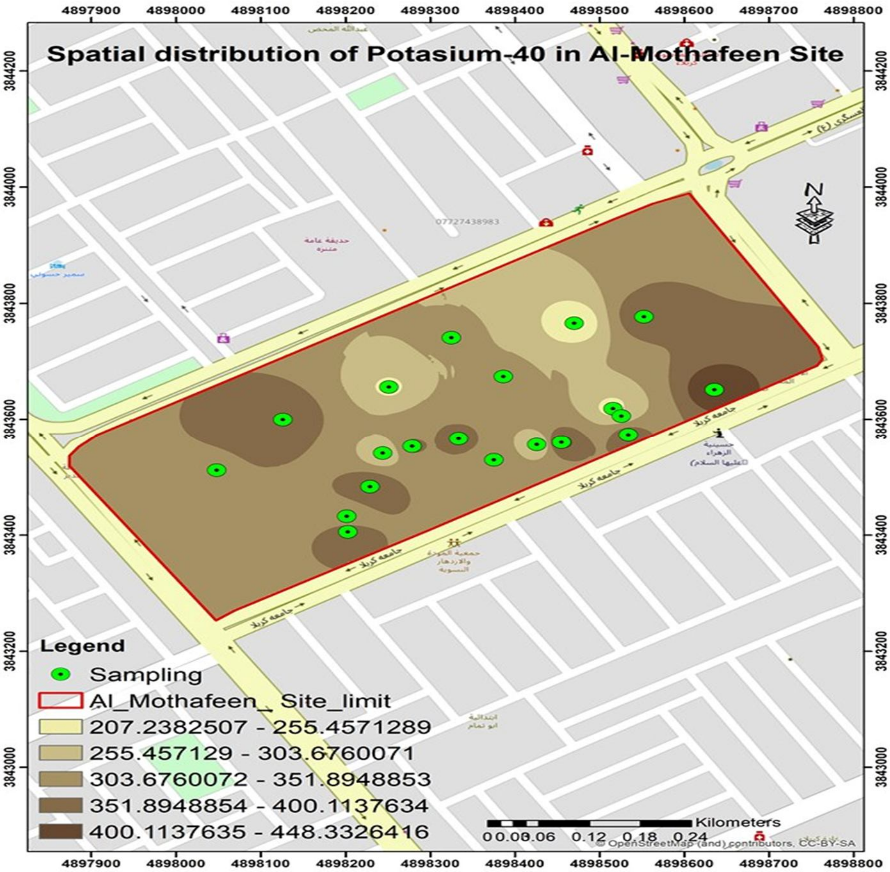

FIG. 10. Spatial distribution map of the specific activity values of ^{40}K using GIS technology.

From the readings of the natural radioactivity concentrations presented in Tables (1) and (2), one can notice that these values are different for ^{238}U, ^{232}Th and ^{40}K due to the differences in the types of soil (different sites) (sandy and clayey) for the locations where the samples are tested. Furthermore, the uranium specific activity is higher than that corresponding to thorium for most of the tested samples. In addition, the specific activity that was measured for ^{40}K is found to exceed noticeably the specific activity values for thorium and uranium, as it is the richest radioactive element. The highest allowable concentration was found in some samples because of the increase in the concentration of potassium nuclide in some areas due to the existence of agricultural land and areas containing phosphate fertilizers, in which potassium (^{40}K) is concentrated. Based on the recommended standard levels, the mean specific activity values of ^{238}U, ^{40}K and ^{232}Th are 35 Bq/kg, 420 Bq/kg and 45 Bq/kg, respectively [11]. It is noted that all specific activity values of ^{238}U (with the exception of U19 in Al-Husseineya site, U25 and U34 in Al-Mothafeen site) are lower that the values recommended by UNSCEAR 2008 for the world. All specific activity values of ^{232}Th in Al- Husseineya and Al-Mothafeen sites were within the limits recommended by UNSCEAR 2008. For ^{40}K, those values were lower than the mean activity world's values recommended by UNSCEAR 2008 [11]. Exceptions are samples U27 and U30 in Al-Mothafeen site, which might be due to the unnecessary usage of potassium-containing fertilizers in the area near to the sampling sites, which may contribute to the higher values of ^{40}K activity.

Radiological Effects

The values of external and internal hazard indices (H_{ex} and H_{in}, respectively), radium equivalent activity (Ra_{eq}), alpha index (I_α), representative level index (I_γ), annual gonadal equivalent dose (AGED), exposure rate ($\dot{x}$), absorbed dose rate in air (Dr), annual effective indoor and outdoor dose equivalent and excess lifetime cancer risk (ELCR) in Al- Husseineya and Al-Mothafeen sites are presented in Tables (3) and (4), respectively. From Table (3), the results of Ra_{eq} (measured in Bq/kg) ranged from 37.5 to 77.1 with a mean value of 61.11±2.589.

As for H_{ex}, the measured values ranged from 0.101 to 0.208 with a mean value of 0.165±0.0070. For H_{in}, the measured values ranged from 0.157 to 0.302 with a mean value of 0.224±0.009. The measured values for Iγ ranged from 0.269 to 0.58 with a mean value of 0.463±0.019. And for $I_α$, the measured values ranged from 0.0325 to 0.1755 with a mean value of 0.108±0.0080. In addition, it was found that the maximum value of ẋ in sample U8 was 167.7 μR/h and the minimum value in sample U14 was 77.3 μR/h, with a mean value of 134.1± 5.735 μR/h. The results of D_r ranged from 17.8 nGy/h to 37.3 nGy/h with a mean value of 29.745±1.259 nGy/h. The results of AGED ranged from 123.7 mSv/y to 264.9 mSv/y with a mean value of 212.115±9.031 mSv/y. The values of $AEDE_{outdoor}$ started from 0.022 mSv/y to 0.046 mSv/y, with a mean value of 0.0365±0.0015 mSv/y. At last, the results of ELCR started from $0.077×10^{-3}$ to $0.160×10^{-3}$ with a mean value of $0.12775±0.0053×10^{-3}$. The results of radiological hazard indices (Ra_{eq}, H_{ex}, H_{in}, $I_γ$ and $I_α$) for Al-Mothafeen site that can be seen from Table 4 are as follows: Ra_{eq} ranged from 41.2 to 84.2 Bq/kg with a mean value of 64.055±2.7 Bq/kg, while H_{ex} ranged from 0.111 to 0.227 with a mean value of 0.173±0.0075. H_{in} ranged from 0.146 to 0.326 with a mean value of 0.2335±0.0122. Iγ ranged from 0.315 to 0.638 with a mean value of 0.4832±0.0199 and $I_α$ ranged from 0.055to 0.2075 with a mean value of 0.112±0.0098. The results for $\dot{X}$ ranged from 91.3 μR/h to 184.5 μR/h with a mean value of 139.73±5.734 μR/h, while the results for D_r ranged from 20.1 nGy/h to 40.7 nGy/h with a mean value of 31.005±1.313 nGy/h and the results for AGED ranged from 144.3 mSv/y to 290.3 mSv/y with a mean value of 220.60±9.119 mSv/y. The results for $AEDE_{outdoor}$ ranged from 0.025 mSv/y to 0.05 mSv/y with a mean value of 0.038±0.0015 mSv/y and the results for ELCR ranged from $0.086×10^{-3}$ to $0.175×10^{-3}$ with a mean value of $0.133±0.005×10^{-3}$. All values of Ra_{eq} were lower than the acceptable value of 370 [23] (equivalent to 1 ms); therefore, the maximum value in this study lies within the acceptable level. Also, it was found that the results of H_{ex}, H_{in}, $I_γ$ and $I_α$ were less than unity [24]. The values of D_r were lower than the corresponding world mean (55 nGy/h) recommended by UNSCEAR 2000 [22]. AGED values were lower than the corresponding values recommended for the world mean, ≤ 300 mSv/y [12]. All values of $AEDE_{outdoor}$ are lower than the worldwide value, 0.08 mSv/y [25]. ELCR values are small; therefore, the risk of cancer can be ignored.

TABLE 3. Radiological hazard indices for Al-Husseineya site in the present work.

No.	Sample code	Ra_{eq} (Bq/kg)	H_{ex}	H_{in}	$I_γ$	$I_α$	Exposure (μR/h)	D_r (nGy/h)	AGED (mSv/y)	$AEDE_{outdoor}$ (mSv/y)	ELCR×10^{-3}
1	U1	58.2	0.157	0.175	0.457	0.0325	132.7	28.6	207.5	0.035	0.123
2	U2	73.2	0.198	0.266	0.553	0.1255	159.9	35.4	252.3	0.043	0.152
3	U3	44.6	0.120	0.157	0.345	0.068	100.3	22.1	158.8	0.027	0.095
4	U4	39.4	0.106	0.160	0.288	0.0995	83.1	18.8	131.9	0.023	0.081
5	U5	66.7	0.180	0.255	0.499	0.138	144.3	32.3	228.7	0.040	0.139
6	U6	61.3	0.166	0.207	0.478	0.0765	138.8	30.4	219.2	0.037	0.130
7	U7	72.3	0.195	0.269	0.545	0.1355	157.5	35.0	249.1	0.043	0.150
8	U8	77.1	0.208	0.285	0.580	0.1415	167.7	37.3	264.9	0.046	0.160
9	U9	47.3	0.128	0.186	0.355	0.108	102.8	23.1	163.6	0.028	0.099
10	U10	52.9	0.143	0.189	0.404	0.0855	116.9	25.8	184.8	0.032	0.111
11	U11	72.3	0.195	0.260	0.551	0.1195	159.7	35.3	252.5	0.043	0.152
12	U12	69.1	0.187	0.262	0.521	0.1385	150.8	33.6	239.2	0.041	0.144
13	U13	69.7	0.188	0.270	0.520	0.1505	150.1	33.6	238.0	0.041	0.144
14	U14	37.5	0.101	0.167	0.269	0.1205	77.3	17.8	123.7	0.022	0.077
15	U15	60.4	0.163	0.214	0.453	0.094	130.8	28.9	205.4	0.035	0.124
16	U16	55.7	0.150	0.183	0.432	0.0605	125.3	27.3	197.1	0.034	0.117
17	U17	65.8	0.178	0.234	0.504	0.1035	146.0	32.2	230.7	0.040	0.138
18	U18	61.8	0.167	0.198	0.482	0.057	140.0	30.4	219.8	0.037	0.131
19	U19	76.6	0.207	0.302	0.572	0.1755	165.5	37.2	263.2	0.046	0.160
20	U20	60.3	0.163	0.241	0.457	0.145	132.5	29.8	211.9	0.037	0.128
Max.		77.1	0.208	0.302	0.269	0.1755	167.7	37.3	264.9	0.046	0.160
Min.		37.5	0.101	0.157	0.58	0.0325	77.3	17.8	123.7	0.022	0.077
Average ±S.D.		61.11 ±2.5	0.165 ±0.007	0.224 ±0.009	0.463 ±0.01	0.108 ±0.008	134 ±5.7	29.7 ±1.2	212.1 ±9.0	0.03 ±0.001	0.12 ±0.005
Worldwide mean		<370[23]	<1[24]	<1[24]	<1[24]	<1[24]	------	55 [22]	≤ 300[12]	0.08 [25]	------

TABLE 4. Radiological hazard indices for Al-Mothafeen site in the present work.

No.	Sample code	Ra_{eq} (Bq/kg)	H_{ex}	H_{in}	I_γ	I_α	Exposure (μR/h)	D_r (nGy/h)	AGED (mSv/y)	$AEDE_{outdoor}$ (mSv/y)	ELCR×10^{-3}
21	U21	63.1	0.170	0.214	0.488	0.0815	141.5	31.0	223.1	0.038	0.133
22	U22	43.3	0.117	0.156	0.330	0.0725	95.6	21.1	151.2	0.026	0.091
23	U23	52.8	0.143	0.187	0.410	0.0815	119.3	26.3	189.2	0.032	0.113
24	U24	65.2	0.176	0.224	0.501	0.088	145.3	31.9	228.9	0.039	0.137
25	U25	83.3	0.225	0.325	0.618	0.186	178.4	40.1	282.9	0.049	0.172
26	U26	60.3	0.163	0.210	0.456	0.0875	131.7	29.0	207.0	0.036	0.125
27	U27	84.2	0.227	0.295	0.638	0.1255	184.5	40.7	290.3	0.050	0.175
28	U28	55.3	0.149	0.197	0.429	0.0885	124.6	27.5	197.8	0.034	0.118
29	U29	66.5	0.180	0.253	0.496	0.1365	143.4	32.1	226.9	0.039	0.138
30	U30	79.1	0.214	0.299	0.597	0.157	172.9	38.6	274.3	0.047	0.166
31	U31	65.2	0.176	0.263	0.476	0.161	137.0	31.0	217.2	0.038	0.133
32	U32	80.3	0.217	0.298	0.596	0.1505	171.6	38.3	270.2	0.047	0.164
33	U33	68.8	0.186	0.270	0.498	0.1555	143.1	32.3	225.4	0.040	0.138
34	U34	79.3	0.214	0.326	0.578	0.2075	166.5	37.8	264.6	0.046	0.162
35	U35	53.8	0.145	0.181	0.398	0.0655	114.5	25.1	177.8	0.031	0.108
36	U36	52.1	0.141	0.174	0.400	0.062	116.0	25.4	182.2	0.031	0.109
37	U37	41.2	0.111	0.146	0.315	0.0645	91.3	20.1	144.3	0.025	0.086
38	U38	53.9	0.145	0.175	0.418	0.055	121.2	26.4	190.3	0.032	0.113
39	U39	69.8	0.189	0.255	0.531	0.122	153.9	34.1	243.5	0.042	0.146
40	U40	63.6	0.172	0.222	0.491	0.092	142.4	31.3	225.0	0.038	0.134
Max.		84.2	0.227	0.326	0.638	0. 2075	184.5	40.7	290.3	0.05	0.175
Min.		41.2	0.111	0.146	0.315	0.055	91.3	20.1	144.3	0.025	0.086
Average		64.1	0.173	0.233	0.483	0.112	139.7	31.0	220.6	0.038	0.133
± S.D.		±2.7	±0.007	±0.012	±0.019	±0.009	±5.7	±1.3	±9.1	±0.001	±0.006
Worldwide mean		<370[23]	<1[24]	<1 [24]	<1 [24]	<1 [24]	------	55 [22]	≤ 300 [12]	0.08 [25]	------

The results of this study; namely, the mean specific activities for ^{238}U, ^{232}Th and ^{40}k are compared to other results recorded in different countries and different locations in Iraq. The comparison results are listed in Table 5.

TABLE 5. Comparison between current work and other works for different countries and locations.

Country/Location	Specific Activity in Bq/kg			Reference
	^{238}U	^{232}Th	^{40}K	
Qatar	25.5	7.7	165.8	[26]
Jordan	49	70	291	[27]
Kuwait	3.82	11.27	384.47	[28]
Egypt	27	31.4	427.5	[29]
Malaysia	127	304	302	[30]
Thailand	64.48	67.04	447.7	[31]
Iran	23	31	453	[32]
Libya	7.5	4.2	27.5	[33]
Baghdad	14.09	11.53	402	[17]
Babylon	14.07	12.32	416.65	[18]
Kerbala	19.45	24.47	245.1	[15]
Kurdistan	83.33	19.147	284.86	[16]
Missan	21.19	9.72	453.91	[20]
Kerbala / Al-Husseineya site	21.7±7.2	9.4±3.2	335.8±82.2	Present study
Kerbala / Al-Mothafeen site	22.4±8.8	11.2±3.3	333.1±70.7	

The mean values of specific activity for ^{232}Th and ^{238}U in Al-Mothafeen site were the highest mean values of specific activity of natural radioactivity of Al-Husseineya site, while specific activity for ^{40}K in Al-Husseineya site was larger than in Al-Mothafeen site. These differences are attributable to the geological characteristics of the layers of the soil under study.

This result of the radiological hazard index is still compatible with the acceptable limits and lower than the action levels based on UNSCEAR, OCDE and ICRP, as well as with other studies in Iraq and in other countries. Indeed, the study area is safe and posing no significant radiological threat to the population.

Conclusion

The specific activity values for ^{232}Th, ^{238}U and ^{40}K for several samples of soil at some locations of the Faculty of Agriculture (Al-Husseineya site) and the Faculty of Medicine (Al-Mothafeen site) in Kerbala Governorate. The uranium-238 activities were within the normal values for all samples of the studied areas except for three samples that showed higher values than the worldwide average range, while the activities for potassium-40 radionuclide in all samples were higher than the worldwide average range except for some samples and the activities for thorium-232 for all samples were lower than the worldwide average range. Radiological hazard index in all soil samples of the present study was lower than the permissible limit; thus, it can be concluded that the study area is radioactively safe.

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