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Natural radioactivity Measurements of Dur-Kurigalzu's Ziggurat, Baghdad Governorate-Iraq using HPGe detector

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Abstract

Measurement of ^{238}U, ^{233}Th and ^{40}K concentrations in soil samples collected from Ziggurat of Dur-Kurigalzu west region of Baghdad, have been evaluated, using high purity germanium detector. The activity concentrations of ^{238}U, ^{233}Th and ^{40}K varied from 16.040 Bq/kg to 26.620 Bq/kg, 14.510 Bq/kg to 31.480 Bq/kg, and 153.820 Bq/kg to 266.320 Bq/kg with average values of 20.604±2.9 Bq/kg, 24.534±3.3 Bq/kg, 212.22±25.1 Bq/kg, respectively. The importance of these measurements lies in the estimation of radiation risk, radium equivalent, absorbed dose, annual effective dose, risk indices, gamma index, and cancer risk. The average value of the absorbed dose ranged from 33.187 nGy/h outdoors to 63.111 nGy/h indoors. The mean annual effective dose value was estimated to be 0.043 mSv/y outdoors and 0.310 mSv/y indoors from the study area. The total calculated lifetime risk of cancer ranged from 0.991×10^{-3} to 1.485×10^{-3}, while the indoor lifetime cancer risk exceeded the recommended limit in samples 6, 8, 9, and 10. The areas examined in this study showed radioactive contamination less than the internationally permissible limits for the sites inhabited by the population.

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Keywords: Natural radioactivity; HPGe detector; soil, Ziggurat; cancer risk; Iraq

قياسات النشاط الإشعاعي الطبيعي لزقورة دور كوريغالزو، محافظة بغداد ، العراق باستخدام كاشف الجرمانيوم عالي النقاوة

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الخلاصة

تم تقييم تراكيز U238 و Th233 و K40 في عينات التربة التي تم جمعها من زقورة دور كوريغالزو غرب بغداد ، باستخدام كاشف الجرمانيوم عالي النقاوة. تراوحت تراكيز النشاط الاشعاعي لل U238 و Th233 و K40 من 16.040 Bq/kg .620 , Bq/kg، 14.510 Bq/kg إلى 31.480 Bq/kg و 153.820 Bq/kg إلى 266.320 Bq/kg بمتوسط قيم 20.604±2.9 Bq/kg 24.534±3.3، Bq/kg 212.22±25.1 , Bq/kg على التوالي لتقدير المخاطر الإشعاعية ، معادل

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الراديوم ، ومعدل الجرعة الممتصة ، والجرعة الفعالة السنوية ، ومؤشرات المخاطر ، ومؤشر جاما ، وخطر الإصابة بالسرطان. تراوحت متوسط قيمة الجرعة الممتصة من 33.187 nGy/h في الهواء الطلق إلى 63.111 nGy/h في الداخل. تم تقدير متوسط قيمة الجرعة الفعالة السنوية بـ 0.043 mSv/y في الهواء الطلق إلى 0.310 mSv/y في الداخل في منطقة الدراسة. تراوح إجمالي مخاطر الإصابة بالسرطان المحسوبة على مدى العمر من 0.991×10^{-3} إلى 1.485×10^{-3} ، بينما تجاوز خطر الإصابة بالسرطان في الأماكن المغلقة الحد الموصى به في العينات 6 و 8 و 9 و 10. أظهرت المناطق التي تم فحصها في هذه الدراسة أنها مشعة. وان التلوث أقل من الحدود المسموح بها دوليا للمواقع التي يسكنها السكان.

1. Introduction

Radioactive materials have been ubiquitous on earth since their inception. The most common is the synthetic, natural, or degraded cores of the naturally occurring radioactive main chains. The presence of natural radioactivity in the soil leads to internal and external exposure to humans. Humans inhale and ingest radionuclides every day of their lives. The most common radionuclides to which the human body is exposed through external exposure mainly caused by gamma radiation are ^{238}U, ^{235}U, ^{233}Th, and ^{40}K and their radioactive decay products [1]. Nuclei can also decay through alpha and beta particles emission [2]. This radioactive decay may also involve a change in the physical and chemical nature of the element. Often the new element produced in the radioactive process is also radioactive [3]. The main radionuclides ^{238}U, ^{233}Th, and ^{40}K are always present in the soil, rocks, water, plants, food, and in many building materials. Studies on the soil radioactivity concentration are very important for the assessment of radioactive risks to human health, and for the possible alteration of environmental radioactivity due to human activities.

Several studies on soil radioactivity have been reported in different reviewed articles. Al-Alawy et al. measured the natural radioactivity of ^{238}U, 232Th, and ^{40}K in sediments from Al-Husseiniya River with High-Purity Germanium HPGe detector. The average of total annual effective dose equivalent for sediment was 288.815 µ*Sv/y* [4]. Al-Alawy and Salim evaluated the specific activity of natural radionuclides in soil from the antiquities area of Girsu city in Dhi-Qar Governorate in southern Iraq using NaI detector. The annual effective dose and external and internal hazard indices were acceptable values according to the worldwide average [5]. Mouandza et al. determined the natural activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected in Mounana in the Southeastern region of Gabon using HPGe detector. The mean value of the absorbed dose was 1352.76 nGy h^{-1}. The mean value of the annual effective dose was 10.96 mSv y^{-1}. The results showed strong radioactive contamination of sites inhabited by populations [6]. Al-Alawy and Salim evaluated the natural radioactivity in soil samples from antiquities area of Ur city in Dhi-Qar province, Iraq using NaI(Tl) detector. All results were acceptable as compared with the worldwide average [7]. Aladeniyi et al. determining the activity concentrations of radionuclides ^{40}K, ^{226}Ra, and ^{232}Th in the soils of Ondo state, Nigeria using gamma spectrometric technique using NaI(Tl) scintillation detector. The results showed that the soil might not pose significant hazards to members of the public [8]. Hassan et al. investigated the radiation activity of soil samples from different schools sites in Mosul Province, Iraq using NaI (TI) detector. All results were found to be lower than the allowed world average limits [9]. Ebraheem et al. measured the activity concentrations of natural radionuclides and cesium from soil to plant in common different plants species grown at Abu-Ghraib city in the capital Baghdad using NaI(Tl) gamma spectroscopy. The excess lifetime cancer risk in roots was higher than the worldwide recommended limit. Also K-40 had very high soil-to-plant transfer factor. Therefore, there is a risk of their administration [10]. Al-Alawy et al. measured the activity concentrations of natural radionuclides, in soil as well as the soil-to-plant transfer factor in common different plants species grown at Al-Tuwaitha City in the capital Baghdad using NaI(Tl) gamma spectroscopy. The results showed that the uranium and thorium concentration exceeded the permissible limits in the mint roots. The potassium concentrations had very high soil-to-plant transfer factor compared to other radionuclides in the samples and the excess lifetime cancer risk was higher than the worldwide average [11]. Al-Alawy et al. examined the concentrations of natural radionuclides in various common plant species grown in the city of Al-Taji in the capital Baghdad using NaI (Tl) gamma spectroscopy. The results showed that the lifetime cancer risk was above the global average limit. The concentration of uranium, thorium and potassium did not exceed the permissible limit in all parts of plants. The radium equivalent activity and maximum absorbed dose rate in soil samples were less than the recommended limit in soil samples [12]. Therefore, the importance of research has become for the possibility of controlling the health effects from natural and artificial radioactive sources [13] .

The aim of this study is to measure the concentration of uranium, thorium and potassium activity in soil samples collected from the Dur-Kurigalzu (its common name is Aqar-Qūf) known nowadays as area in western Baghdad. For many years, this area has been a center for archaeological tourism. This area has never been directly bombed. The natural radioactivity concentrations of this area have not been studied. It is important to assess the radiological hazards to the population in this area. For this purpose, Gamma spectroscopy was used with a high-purity germanium detector of high resolution [14]. In this work, the radium equivalent, absorbed radioactive parameters, including dose rate, annual effective dose, indicator of internal and external hazards, and cancer risk were estimated from radioactivity concentrations of ^{238}U, ^{233}Th and ^{40}K. This is in order to evaluate the natural contribution of radioactivity and the radiological risks received by the population living in the Dur-Kurigalzu area. The results were compared with the internationally permissible limits, and with the results of other similar studies.

2. Description of Study Area

Dur-Kurigalzu was a city located west of Baghdad, the capital, near the Tigris River. It was founded during the reign of King Korigalzu I of king Babylon in the fourteenth century BC. This city contained the ziggurat and temples of the Sumerian deities, as well as the royal palace. Its height is 52 meters [15], [16], as shown in Figure 1 [17]

Figure 1: The Ziggurat of Dur-Kurigalzu in 2010 [17].

The Aqar-Quf area is currently suffering from environmental damage as a result of changes in the natural weathering factors that led to the erosion and damage of some parts of the ziggurat, in addition to the damages as a result of the American invasion of Iraq [18], [19]. A program has been prepared for the revival of this historical edifice in 2008 [20], [21].

3. Materials and Method

3.1. Collection and Preparation of Samples

Ten consecutive sites were selected (five soil samples were collected from each site) from the current study area, Ziggurat of Dur-Kurigalzu in Baghdad Governorate. Figure 2 shows the locations from which the samples were collected [22]. The soil samples were collected from 50 cm depth between April and July 2020. The samples were placed in plastic bags with the code affixed to them. They were then dried at 50 °C for 2 hours to eliminate all moisture contents. The samples then were ground and sieved with a 250 µm sieve. Each soil grain sample weighted about 850 grams. Each sample was placed in a Marinelli beaker, tightly closed and labelled. The sealed Marinelli beakers were kept for one month before the measurements to equilibrate the secular ^{232}Th and ^{238}U with their own progenies.

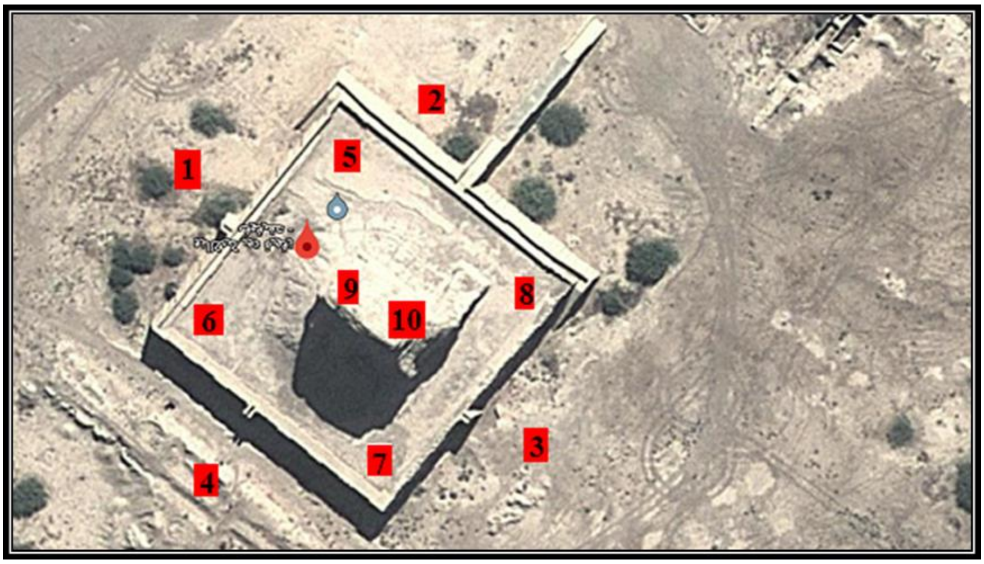

Figure 2: Satellite view of Ziggurat of Dur-Kurigalzu showing locations of the studied area [22].

3.2. Determination of Radiation Parameters

1- Activity Concentration

It is possible to calculate the concentration of one element in terms of another element in a series when the elements are in equilibrium, with ^{238}U (^{226}Ra) by focusing effectively on calculating the ^{214}Bi nuclide (1764 keV), and also in the ^{232}Th series was the focus of the radionuclide activity ^{208}Tl (2614 keV), which represents the concentration of ^{232}Th account, and then the concentration of ^{40}K (1460 keV).
The activity concentration of the sample can be given by [23]:

$$A = \frac{NET}{\varepsilon \, I_\gamma \, m \, t} \tag{1}$$

Where: NET represents the net area under the energy spectrum curve, ε is the energy efficiency, I_γ is the gamma intensity, m is the mass of the sample in kg, t is the time of measurement, 3600 sec.

2- Radium Equivalent (Ra_{eq})

Radium equivalent can be defined by [24]:

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \tag{2}$$

Where A_U, A_{Th}, A_K are the activity concentration of Uranium, Thorium and Potassium, respectively.

3- Absorbed Dose Rate (D_γ)

The activity concentration of ^{238}U, ^{232}Th, and ^{40}K radionuclides can be converted into dose. The indoor and outdoor absorbed dose rates are calculated as follows [25]:

$$D_{in}(nGyh^{-1}) = 0.92A_U + 1.1A_{Th} + 0.081A_K \tag{3}$$

$$D_{out}(nGyh^{-1}) = 0.427A_U + 0.662A_{Th} + 0.043A_K \tag{4}$$

4- Annual Effective Dose (AED)

The indoor and outdoor annual effective doses can be calculated from the following equations [24]:

$$AED_{in}(\mu Sv/y) = D_{in}(nG/h) \times 8760(h/y) \times 0.80 \times 0.7(Sv/Gy) \times 10^{-3} \tag{5}$$

$$AED_{out}(\mu Sv/y) = D_{out}(nG/h) \times 8760(h/y) \times 0.20 \times 0.7(Sv/Gy) \times 10^{-3} \tag{6}$$

5- Hazard Index (H)

The internal and external hazard indices due to exposure to gamma ray are given by UNSCEAR, 2000 as follows equations [24]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \le 1 \tag{7}$$

$$H_{ext} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \le 1 \tag{8}$$

6. Gamma Index (I_γ)

The gamma index I_γ for soil samples was calculated by the flowing Equation [26]:

$$I_\gamma = \frac{A_U}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \tag{9}$$

7. Excess Life-Time Cancer Risk ($ELCR$)

The excess life-time cancer risk ($ELCR$) can be calculated using the following equation [27]:

$$ELCR_{in} = AED_{in} \times DU \times LF \tag{10}$$

$$ELCR_{out} = AED_{out} \times DL \times RF \tag{11}$$

Where DU and LF are the duration of life 70 years, and risk factor 0.05/Sv, respectively as defined by ICRP (2012) [28]:

Results and Discussion

The results of the present work are summarized in Table 1. The following can be noted; the highest value of A_U was 26.620 Bq/kg in sample 10, while the lowest value was 16,040 Bq/kg in sample 2, with an average 20.604±3.613 Bq/kg, see Figure 3. The present results showed that the A_U values in the Ziggurat of Dur-Kurigalzu were lower than the recommended value of 35 Bq/kg [24]. The highest value of A_{Th} was 31.480 Bq/kg in sample 10, while the lowest value for A_{Th} was found in sample 7, with a value 14.510 Bq/kg, see Figure 3, with an average 24.534±4.704 Bq/kg. The present results showed that the A_{Th} values in the Ziggurat of Dur-Kurigalzu were lower than the recommended value of 30 Bq/kg [24]. The highest value of A_K was found in sample 9 which was equal to 266.320 Bq/kg, while the lowest value of A_K was found in sample 2 which was equal to 153.820 Bq/kg, see Figure 3, with an average value of 212.22±33.195 Bq/kg. The present results showed that the A_K values in the Ziggurat of Dur-Kurigalzu were lower than the recommended value of 400 Bq/kg [24].

The highest value of $Ra_{eq}$was found in sample 10, which was equal to 88.110 Bq/kg, while the lowest value was found in sample 7, which was equal to 56.314 Bq/kg with an average value of 72,029±11.012 Bq/kg. The present results showed that the values in Ziggurat Dur-Kurigalzu were lower than the recommended value of 370 Bq/kg [24].

The maximum values for D_{in} and D_{out} were found in sample 10 which were equal to 76.448 nGy/h and 40.234 nGy/h, respectively, while the lowest values were found in sample 7 which were equal to 50.989 nGy/h and 26.587 nGy/h, with average values of 63.111±9.42 nGy/h and 33.187±7.512 nGy/h, respectively The present results show that maximum values of the absorbed dose rate in Ziggurat of Dur-Kurigalzu tend towards the recommended value of 55 nGy/h [24].

Table 2 presents comparison between the average values of the activity concentrations for U-238, Th-232, and K-40, radium equivalent Ra_{eq}, and the absorbed dose rates D_γ in the soil samples of Dur-Kurigalzu's Ziggurat with corresponding average values from results of different studies.

The highest value of AED_{in} in sample 10 was 0.375 mSv/y, while the lowest value of AED_{in} in sample 10 was 0.250 mSv/y, with an average value 0.310±0.046 mSv/y. Whereas the highest value of AED_{out} was of sample 10 of 0.049 mSv/y, and the lowest value of sample 7 which was 0.033 mSv/y, with an average value of 0.043±0.009 mSv/y. The present results showed that the values of AED_{in} and AED_{out} of Ziggurat of Dur-Kurigalzu were lower than the recommended value of 1 mSv/y given by UNSCEAR, 2000 [24].

The highest value of H_{in} was found in sample 10 which was equal to 0.310, while the lowest value of H_{in} was found in sample 7 which was equal to 0.201 ,with an average value of 0.250±0.039. Besides that The highest value of H_{ext} was found in sample 10 which was equal to 0.238, while the lowest value was found in sample 7 which was equal to 0.152, with an average value of 0.195±0.030. The present results have shown that values of H_{in} and H_{ext} in Ziggurat of Dur-Kurigalzu were less than the recommended value ≤1 recorded by UNSCEAR, 2000 [24].

The highest value of I_γ was found in sample 10 which was equal to 0.317, while the lowest value of 0.209 was found in sample 7 with an average value of 0.262±0.039. The present results showed that the I_γ values in the Ziggurat of Dur-Kurigalzu were lower than the recommended value of 1 given by UNSCEAR, 2000 [24].

The excess lifetime cancer risk in samples 9 and 10 exceeds the recommended limit value of 1.45×10^{-3} given by UNSCEAR, 2000 [24]. The increase in the $ELCR_{in}$ is due to increase in D_{in} due to the increase in potassium concentration, which is attributed to the fact that it was agricultural soil as well as the increase in uranium and thorium; this is attributed to the presence of elements in the soil that contain an increase in the concentration of these two elements.

Table 1: Specific activity of radionuclides with some other parameters in soil samples in the Ziggurat of Dur-Kurigalzu.

Soil Samples	Specific Activity (Bq/kg)			Ra_{eq} (Bq/kg)	D_{γ} (nGy/h)		Annual Effective Dose (mSv/y)		Hazard Index		I_{γ}	Life-Time Cancer Risk × 10^{-3}		
	U-238	Th-232	K-40		D_{in}	D_{out}	AED_{in}	AED_{out}	H_{in}	H_{ext}		$ELCR$	$ELCR$	$ELCR_{t}$
1	17.730	23.480	173.570	64.671	56.198	29.611	0.276	0.036	0.223	0.175	0.234	0.966	0.126	1.092
2	16.040	22.620	153.820	60.231	52.098	27.487	0.256	0.034	0.206	0.163	0.218	0.896	0.119	1.015
3	17.590	21.020	231.550	65.478	58.060	30.478	0.285	0.037	0.224	0.177	0.241	0.998	0.130	1.128
4	20.460	24.290	213.250	71.615	62.602	33.016	0.307	0.040	0.249	0.193	0.261	1.075	0.140	1.215
5	18.810	24.530	183.760	68.037	59.173	31.169	0.290	0.038	0.235	0.184	0.247	1.015	0.133	1.148
6	21.630	27.620	222.910	78.291	68.337	35.971	0.335	0.044	0.270	0.211	0.285	1.173	0.154	1.327
7	18.070	14.510	227.210	56.314	50.989	26.587	0.250	0.033	0.201	0.152	0.209	0.875	0.116	0.991
8	23.730	27.160	235.870	80.731	70.812	37.204	0.348	0.046	0.282	0.218	0.294	1.218	0.161	1.379
9	25.360	28.630	266.320	86.808	76.396	40.114	0.375	0.049	0.303	0.234	0.316	1.313	0.172	1.485
10	26.620	31.480	213.940	88.110	76.448	40.234	0.375	0.049	0.310	0.238	0.317	1.313	0.172	1.485
Average	20.604	24.534	212.22	72.029	63.111	33.187	0.310	0.043	0.250	0.195	0.262	1.084	0.142	1.227
SD	±3.613	±4.704	±33.195	±11.012	± 9.42	±7.512	±0.046	±0.009	±0.039	±0.030	±0.039	± 0.162	± 0.021	±0.183
Min.	16.040	14.510	153.820	56.314	50.989	26.587	0.250	0.033	0.201	0.152	0.209	0.875	0.116	0.991
Max.	26.620	31.480	266.320	88.110	76.448	40.234	0.375	0.049	0.310	0.238	0.317	1.313	0.172	1.485
World wide Average [24]	33	45	420	370	84	55	1	1	≤1	≤1	1	1.16	0.29	1.45

Note: Each sample code is an average of five samples collected from different locations at the same site.

Table 2: Comparison of the average values of current study results in soil with different locations.

City/Region/ Country	U-238	Th-232	K-40	Ra_{eq} (Bq/kg)	D_{γ} (nGy/h)	References
Iraq/Northeastern of Kurdistan	5.65	21.40	203.34	44.80	24.81	Ahmed and Hussein, 2011 [29]
Malaysia	3.70	6.40	25.80	239.00	112.00	Alnour et al., 2012 [30]
Yemen/North Sana'a	21.79	19.15	399.30	147.80	72.80	Harb et al., 2012 [31]
Iran/North West	17.40	28.77	416.43	_____	_____	Raiesi and Beheshti, 2014 [32]
Turkey/Bursa	36.23	25.05	253.80	159.95	73.65	Akkurt and Günoğlu, 2014 [33]
Iraq/ Dhi –Qar	17.9	13.66	314.00	61.67	29.66	Al-Alawy and Salim, 2015 [5]
Nigeria SouthWest	39.00	249.00	332.00	310.00	260.00	Panel et al., 2016 [34]
Iraq/Al-Tuwaitha	21.83	25.29	363.74	85.97	40.51	Saied et al., 2016 [35]
India/Karnataka state	35.00	30.00	400.00	34.36	136.57	Prakash et al., 2017 [36]
Bangladesh	14.00	16.00	237.04	57.00	27.20	Azmary et al., 2018 [37]
Iraq/ Karbala	15.80	11.2	311.0	55.959	27.511	Al-Alawy et al., 2018 [4]
Egypt/Abu Khuruq	1.55	112.01	153.89	251.89	112.01	El-Gamal and El-Haddad, 2019 [38]
Iraq/Baghdad/Al-Doura/City	38.03	42.48	16.34	100.00	44.60	Kaddoori et al., 2021 [39]
Iraq/middle and south regions	6.21	4.11	23	13.86	0.087	Jasim et al., 2021 [40]
Iraq/Baghdad/Aqar-Qūf	20.604	24.534	212.22	72.029	33.187	Present work
Worldwide mean [24]	33	45	420	370	55	

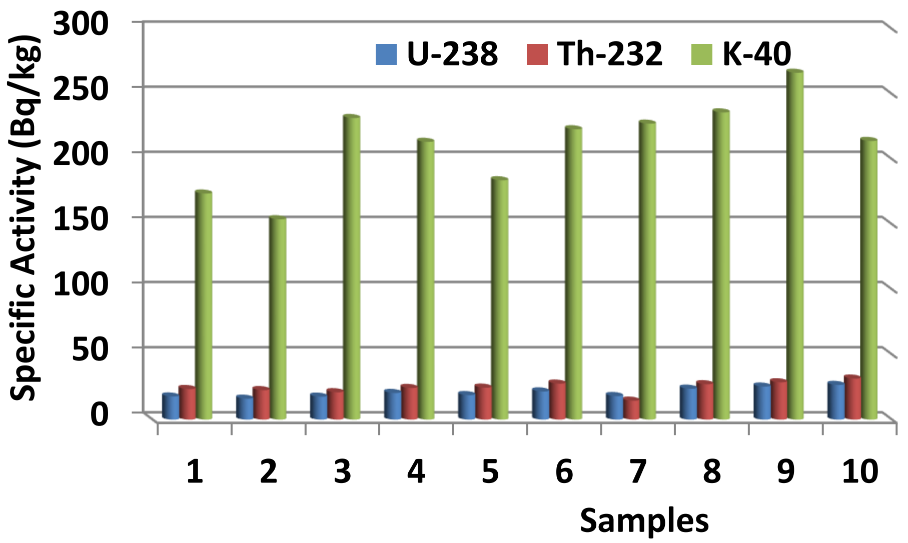

Figure 3: Specific activities of U-238, Th-232, and K-40 in soil samples.

4. Conclusions

The activity concentration of U-238, Th-232, and K-40 in soil samples in the Ziggurat of Dur-Kurigalzu region in the west of Baghdad Governorate highly varied from one sample to another. The highest levels of U-238 and Th-232 were observed in soil sample 10. The highest level of K-40 was found from soil sample 9. The main value of total absorbed dose rate and total annual effective dose were estimated at 96.298 nGy/h, 0.353 mSv/y, respectively. The results of the current research showed that the Ziggurat's soil is low in radioactive contamination and is subject to the implementation of the environmental restoration program. The soil examined in this study show radioactive contamination not exceeding the recommended levels worldwide. All results were found to be below the corresponding permissible limits and therefore would not pose any relatively sequential health risks.

The D_{in} , and D_{out} values generally did not exceeded the internationally permissible limit of 84 nGy/h, recommended by UNSCEAR, 2000. This affected the excess lifetime cancer risk scores, as they exceeded the permissible limit in both values of $ELCR_{in}$ and $ELCR_{total}$. In addition, the results showed that the excess lifetime cancer risk exceeded the permissible limit in 8, 9, and 10 samples. These results affected the limit exceeded when calculating the total value of cancer risk in samples 9 and 10, while sample 8 approached the limit. The increase in the $ELCR_{in}$ is due to increase in D_{in} due to the increase in potassium concentration, which is attributed to the fact that it was agricultural soil as well as the high concentrations uranium and thorium; this is attributed to the presence of elements in the soil that contain an increase in the concentration of these two elements. The results of this study can be used as a database for future studies and this data may be beneficial to normal radioactivity maps drawing.

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Conflicts of Interest

The authors declare no conflicts of interest.

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