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Radiological Dose and Risk Assessment for Selected Residential Regions in Baghdad City, Iraq

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ABSTRACT

Fifty-one surface soil samples were collected from two selected residential areas in Baghdad city (Al-Adhamiya and Al-Sha'ab areas) and analyzed using gamma-ray spectroscopy system. The activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs for soil samples collected from Al-Adhamiya area ranged from 9.19 to 22.7 Bq/kg, 5.91 to 17.8 Bq/kg, 236.36 to 507.56 Bq/kg and below minimum detectable activity to 3.07 Bq/kg, respectively. For soil samples collected from Al-Sha'ab area, the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs ranged from 9.21 to 24.51 Bq/kg, 6.41 to 16.81 Bq/kg, 246.32 to 402.78 Bq/kg and below minimum detectable activity to 4.8 Bq/kg, respectively. The RESRAD-Onsite code version 7.2 has been used to evaluate radiation dose and risk for the occupants of the areas of the study. The maximum total dose rates of 0.204 and 0.245 mSv/y were estimated for Al-Adhamiya and Al-Sha'ab areas, respectively. The total peak dose rates are about 5 times lower than the public radiation dose limit of 1 mSv/y. Based on the findings of the current study, it can be concluded that occupants in the investigated areas would not get any unacceptable radiological hazards due to radionuclides in soil.

***Keywords*:** Natural radioactivity, RESRAD code, radionuclides, radiological hazards, Baghdad, ^{238}U, ^{232}Th, ^{40}K, ^{137}Cs

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1. INTRODUCTION

Humans are continuously exposed to ionizing radiation from naturally occurring radioactive materials (NORM). Although the origin of these materials is the Earth's crust, they find their way into building materials, air, water, food, and the human body itself. Studies of natural radiation considered relevant because it is the primary source of exposure to human kind. About 90% of radiation exposures come from natural sources such as terrestrial radiation, cosmic radiation, and radon gas. The exposure of the public to natural radiation sources has been estimated to result in an annual effective dose equivalent of 2.4 mSv. Studying the possible impacts resulting from exposure to ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K often requires the modelling of the contaminant transport in the environment.

The aim of this study is to analyze the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in soil over two residential areas at Baghdad city. It further evaluates the human exposure pathway contributions to the peak dose, when it occurs over a span of 1000 years and calculates the excess lifetime cancer risk [1-18].

2. MATERIALS AND METHODS

2. 1. Areas of the study

Baghdad is the capital of Iraq. The population of Baghdad, as of 2016, is approximately 8,765,000, making it the largest city in Iraq, the second largest city in the Arab world, and the second largest city in Western Asia. Two residential areas in Baghdad city were selected to be the areas of the current study (Figures 1a & 1b):

- Al-Adhamiya region: This residential area is located near the center of Baghdad city, within Al-Rusafa sector. It has a population of 350,000 and an area of 36 km^2. Al-Adhamiya region has five districts (Al-Kahira district, Al-Maghrib district, Al-Waziriyah district, Tunis district and Al-Rabee district).
- Al-Sha'ab region: this residential area is located to the north-east of Baghdad city, within Al-Rusafa sector. It has a population of 800,000 and an area of 120 km^2. Al-Sha'ab region has five districts (Orchards district, Al-Baydaa district, Al-Sha'ab district, Or district and Al-Mahdi district).

2. 2. Soil sampling and analysis

51 surface soil samples were collected according to the internationally accepted soil sampling procedure (19 soil samples were collected from Al-Adhamiya region, 32 soil samples were collected from Al-Sha'ab area). For each soil sample collected, an area of about 0.5 m × 0.5 m was marked and carefully cleared of debris before collection of the soil samples. At the center of each marked area, 2 kg of soil was collected using shovel at a depth of about 0.1 m from the ground. Each soil sample was labeled according to the geographical coordinates of the sampling area.

The 2 kg soil samples were transported to the Al-Tuwaitha nuclear site laboratory for analysis. In the analytical laboratory, the soil samples were crushed into fine powder using a mortar and pestle.

Figure 1a. Areas of the study

Figure 1b. Areas of the study

The fine form of each soil sample was obtained using a sieve of 0.2-mm mesh, dried in an oven at about 80 ºC for 5 hours, hermetically sealed in standard 500 mL plastic Marinelli beakers, dry-weighed and stored for about four weeks prior to counting to allow radioactive equilibrium among radon (^{222}Rn), thoron (^{220}Rn), and their short lived progenies [4, 5]. On average, 0.6 – 0.7 kg of soil was taken from each sample and put into 500 mL Marinelli beakers for measurements using the gamma-ray spectrometry system (high purity germanium (HPGe) detector).

The calibration of the counting system was done using standard reference materials (MBSS2) from the Czech Metrology Institute. The detector is a co-axial n-type and has a resolution of 2 keV at 1332 keV of ^{60}Co with a relative efficiency of 40%. The output of the detector was analyzed using Genie™ 2000 software. The detector is lead shielded to reduce the background level of the system. The radioactivity of each sample was measured using the calibrated HPGe-detector for counting period of 3600 second. ^{238}U activity concentrations were determined from the average activity concentrations of the ^{214}Pb and ^{214}Bi decay products. Activity concentrations of ^{232}Th were determined from the mean of the activities of ^{228}Ac, ^{212}Pb and ^{208}Tl. ^{40}K and ^{137}Cs activity concentrations were determined using the gamma ray energies of 1461 and 661 keV, respectively.

2. 3. Radiation dose and risk assessment

The RESRAD onsite code version 7.2 (2016) was used in current study to calculate both radiological dose and risk arising from ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs activity concentrations in the soils for on-site exposures for the following human exposure pathways: external gamma, plant ingestion, meat ingestion, milk ingestion, drinking water and inadvertent soil ingestion. The RESRAD onsite code version 7.2 (2016) is developed by the U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) to evaluate environmental radioactivity. The code is also used to derive clean-up criteria or Derived Concentration Guideline Levels (DCGLs) and estimate radiation dose or risk from radioactive material under various human exposure scenarios. The average radionuclides activity concentrations in each investigated area were used as input parameters to evaluate the individual dose rates.

3. RESULTS AND DISCUSSION

The results of radiometric analysis of ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs in the collected soil samples are listed in tables 1 and 2. The activity concentrations of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K in soil samples collected from Al-Adhamiya region were found to be in the range of 9.19 - 22.7 Bq/kg, 5.91 – 17.8 Bq/kg, <MDA - 3.07 Bq/kg and 236.36 – 507.56 Bq/kg, respectively. For soil samples collected from Al-Sha'ab area, the activity concentrations of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K were found to be in the range of 9.21 - 24.51 Bq/kg, 6.41 – 16.81 Bq/kg, <MDA - 4.8 Bq/kg and 246.32 – 402.78 Bq/kg, respectively. In the two investigated areas, the average activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were found to be less than the average world values as reported in UNSCEAR 2000 report (35, 30 and 400 Bq/kg, respectively), indicating that the investigated areas are located in a region of normal background radioactivity.

RESRAD-Onsite computer code was used to evaluate the potential radiological dose and risk incurred by an individual living in studied areas. The total peak dose rate at time t = 120 year due to ^{238}U, ^{137}Cs, ^{232}Th and ^{40}K were estimated to be 0.204 and 0.245 mSv/y for Al-

Adhamiya and Al-Sha'ab areas, respectively (Figures 2 and 3). 95% of the total estimated dose arising from ^{40}K. The percentage contributions to the total dose from each pathway were estimated to be 34% from external exposure, 0.07% from inhalation, 28.3% from plants ingestion, 26.3% from meat ingestion, 11% from milk ingestion and 0.12% from soil ingestion. As seen in figures 2 and 3, the total peak dose at time t = 120 year for all pathways is about 5 times lower compare to the basic radiation dose limit for the public of 1 mSv/y. The projection of annual effective dose received by residents using RESRAD-Onsite computer code shows that the total dose rates decrease from the initial year to 30 years, increase for the period between 30 to 120 years but still below the recommended limit of 1 mSv/y, and significantly reduced after 120 years.

The evaluated excess cancer risks are shown in figures 4 and 5. For Al-Adhamiya region, the peak excess cancer risk due to ^{238}U, ^{137}Cs, ^{232}Th and ^{40}K exposure was estimated to be about 6.5×10^{-4} or 1 extra cancer case per 1540 exposed individuals. For Al-Sha'ab region, the peak excess cancer risk due to ^{238}U, ^{137}Cs, ^{232}Th and ^{40}K exposure was estimated to be about 8.2×10^{-4} or 1 extra cancer case per 1206 exposed individuals.

Table 1. Results of radiometric analysis for soil samples collected from Al-Adhamiya region.

No.	Sampling area	Activity concentration (Bq/kg)			
		^{238}U series	^{232}Th series	^{137}Cs	^{40}K
1	Al-Kahira district	14.13±0.65	15.97± 0.78	<MDA	319.33±13.46
2	Al-Kahira district	11.89±0.62	13.07±0.18	0.63 ± 0.19	271.13±12.24
3	Al-Kahira district	14.55±0.64	10.09±0.58	<MDA	307.28±12.32
4	Al-Kahira district	15.79±0.74	13.32±0.70	3.07±0.37	433.49±17.05
5	Al-Maghrib district	12.20±0.56	9.58 ± 0.51	<MDA	292.93±11.79
6	Al-Maghrib district	11.19±0.54	8.26 ± 0.48	0.72 ± 0.15	297 ± 11.86
7	Al-Maghrib district	15.16±0.79	13.4± 90.76	<MDA	371.42±15.51
8	Al-Waziriyah district	11.46± 0.60	11.64±0.73	<MDA	254.17±11.48
9	Al-Waziriyah district	20.95±0.92	17.80±0.89	<MDA	507.56±19.53
10	Al-Waziriyah district	11.52±0.61	10.55±0.59	1.83±0.29	289.77±13.13
11	Tunis district	14.61±0.66	10.55±0.59	1.43±0.23	337.21 ± 13.4

12	Tunis district	14.55±0.78	15.67±0.85	0.84±0.21	297.79±13.87
13	Tunis district	16.59±0.78	17.72±0.95	<MDA	354.38±15.34
14	Al-Rabee district	11.22±0.54	10.31±0.56	0.55 ± 0.15	296.82±12.08
15	Al-Rabee district	15.44±0.67	17.41±0.83	<MDA	361.48± 13
16	Al-Rabee district	12.01±0.44	9.26± 0.38	<MDA	296±11.86
17	Al-Rabee district	9.19 ± 0.46	5.91 ± 1.13	<MDA	236.36 ± 9.97
18	Al-Rabee district	14.76±0.66	12.75±0.61	<MDA	341.57±13.62
19	Al-Rabee district	22.7±0.92	16.75± 0.9	1.07 ± 0.22	402.82±16.03
Minimum		9.19	5.91	<MDA	236.36
Maximum		22.7	17.8	3.07	507.56
Average		14.2	12.63	0.53	329.92
Standard deviation		3.34	3.5	0.83	65.41

Table 2. Results of radiometric analysis for soil samples collected from Al-Sha'ab area.

No.	Sampling area	Activity concentration (Bq/kg)			
		^{238}U series	^{232}Th series	^{137}Cs	^{40}K
1	Orchards district	14.84±0.6	12.02±0.55	<MDA	333.4±12.12
2	Orchards district	14.77±0.56	14.76±0.53	<MDA	337.34±12.96
3	Orchards district	17.04 ± 0.7	16.37±0.73	0.66±0.18	374.3±14.66
4	Al-Baydaa district	13.8 ± 0.75	11.05 ±1.84	4.8 ± 0.40	283 ± 12.6
5	Al-Baydaa district	15.44±0.98	9.08±1.7	1.15±0.26	339.7±15.12
6	Al-Baydaa district	10.19±0.45	6.41 ± 1.17	<MDA	246.32 ± 9.32

7	Al-Baydaa district	13.72±0.76	11.95± 0.68	<MDA	342.56±14.62
8	Al-Sha'ab district	24.51±0.94	15.57±0.75	0.41±0.13	367.72±14.78
9	Al-Sha'ab district	17.71±0.73	16.81±0.83	<MDA	387.29±14.75
10	Al-Sha'ab district	16.7±0.71	14.05±0.68	<MDA	391 ± 14.2
11	Al-Sha'ab district	14.15±0.47	13.33±0.41	0.53±0.16	320.6±11.34
12	Al-Sha'ab district	14.97±0.72	13 ± 0.71	0.54±0.26	346.17±14.72
13	Al-Sha'ab district	17.38±0.81	13.8±0.77	<MDA	402.78±16.35
14	Or district	9.21±0.74	8.05±0.5	2.3±0.26	259.6±11.64
15	Or district	11.55±0.91	8.21 ± 0.56	1.58 ±0.24	338.06±14.15
16	Or district	14.18±0.61	14.13±0.59	<MDA	341.15±13.96
17	Or district	14.36± 0.5	12.98±0.48	<MDA	315.75±11.8
18	Or district	14.29±0.57	11.89±0.5	<MDA	338.43±13.39
19	Al-Mahdi district	14.01±0.65	9.94±0.58	2.04±0.32	349.17±14.26
20	Al-Mahdi district	13.84±0.71	16.06±0.83	1.04±0.22	332.63±13.91
21	Al-Mahdi district	14.71±0.76	12.32±0.81	<MDA	343.39±16.11
22	Al-Mahdi district	15.87±0.66	14.37±0.59	<MDA	364.36±15.5
23	Al-Mahdi district	18.04±0.82	12.4± 0.7	<MDA	398.85±17.62
24	Al-Mahdi district	17.97±0.61	16.76±0.66	<MDA	394.95±15.06
25	Al-Mahdi district	17.04±0.72	13.5±0.67	<MDA	371.74±16.72
26	Al-Mahdi district	16.16±0.6	15.88±0.63	<MDA	395.69±14.09
27	Al-Mahdi district	16.66±0.78	14.47±0.74	1.41±0.29	398.62±16.5
28	Al-Mahdi district	14.19±0.85	14.13±0.73	2.36±0.33	369.39±16.22

29	Al-Mahdi district	14.66±1.86	9.62±0.63	<MDA	366.12±12.8
30	Al-Mahdi district	17.42±0.76	15.62±0.73	1.21±0.22	400.09±15.45
31	Al-Mahdi district	15.04±0.74	10.76±0.6	<MDA	367.58±15.32
32	Al-Mahdi district	11.2±0.51	10.58± 0.41	<MDA	303.74±10.45
Minimum		9.21	6.41	<MDA	246.32
Maximum		24.51	16.81	4.8	402.78
Average		15.17	12.8	0.62	350.67
Standard deviation		2.74	2.7	1.06	39.61

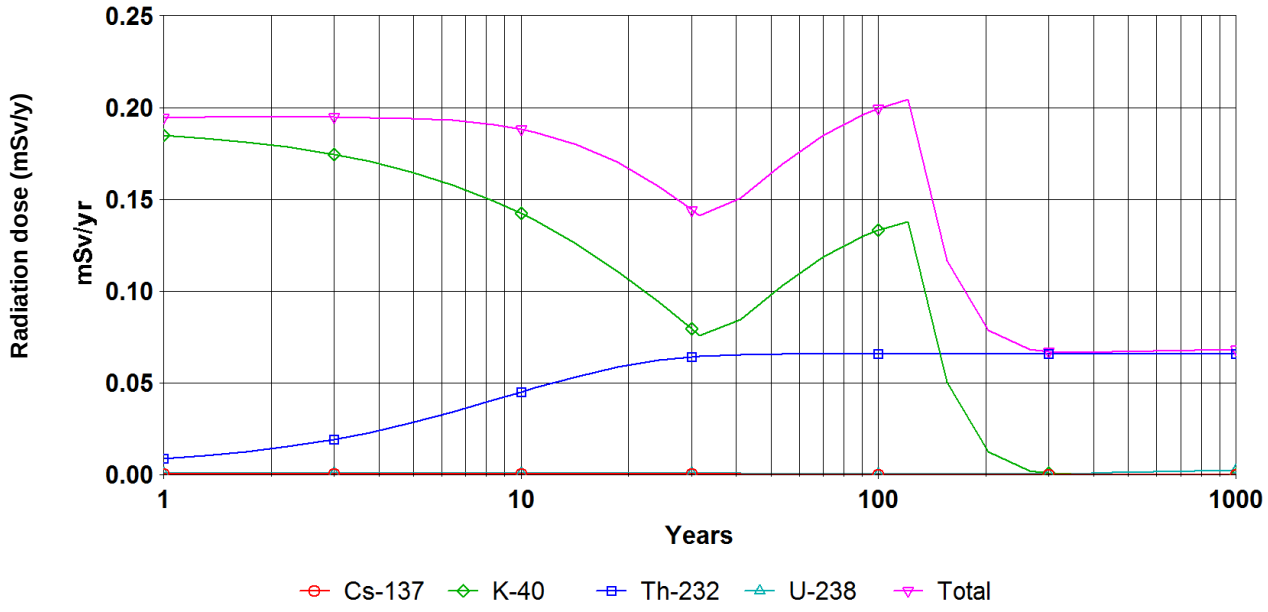

Figure 2. Summed total dose due to all nuclides and all pathways for Al-Adhamiya region

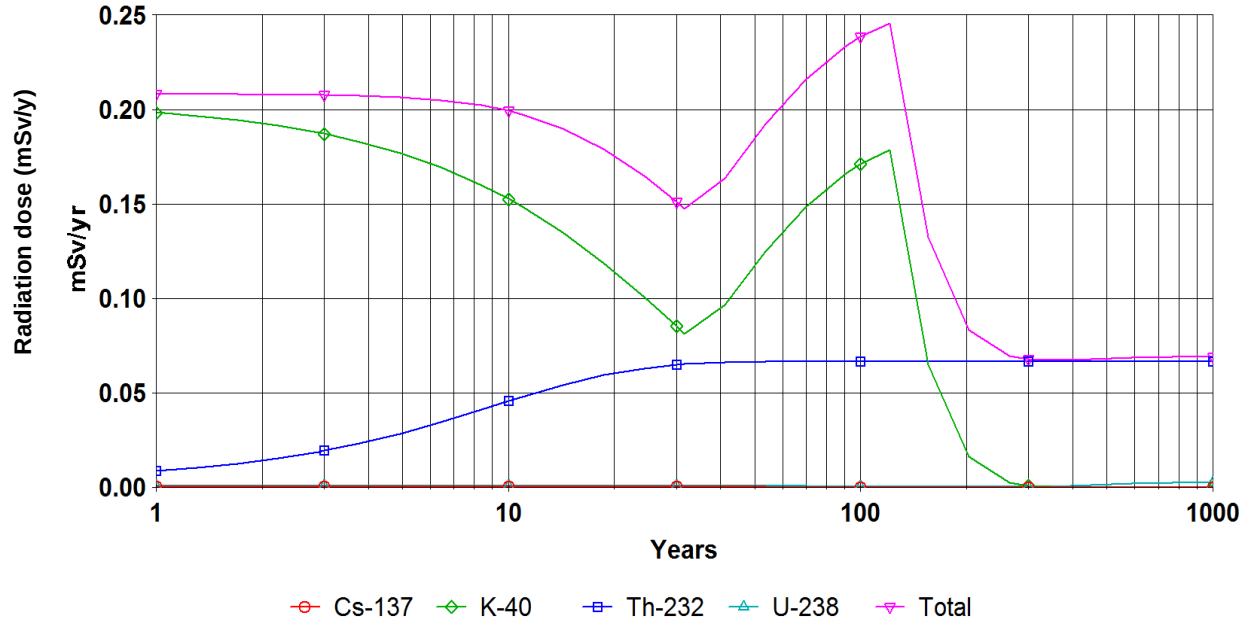

Figure 3. Summed total dose due to all nuclides and all pathways for Al-Sha'ab region

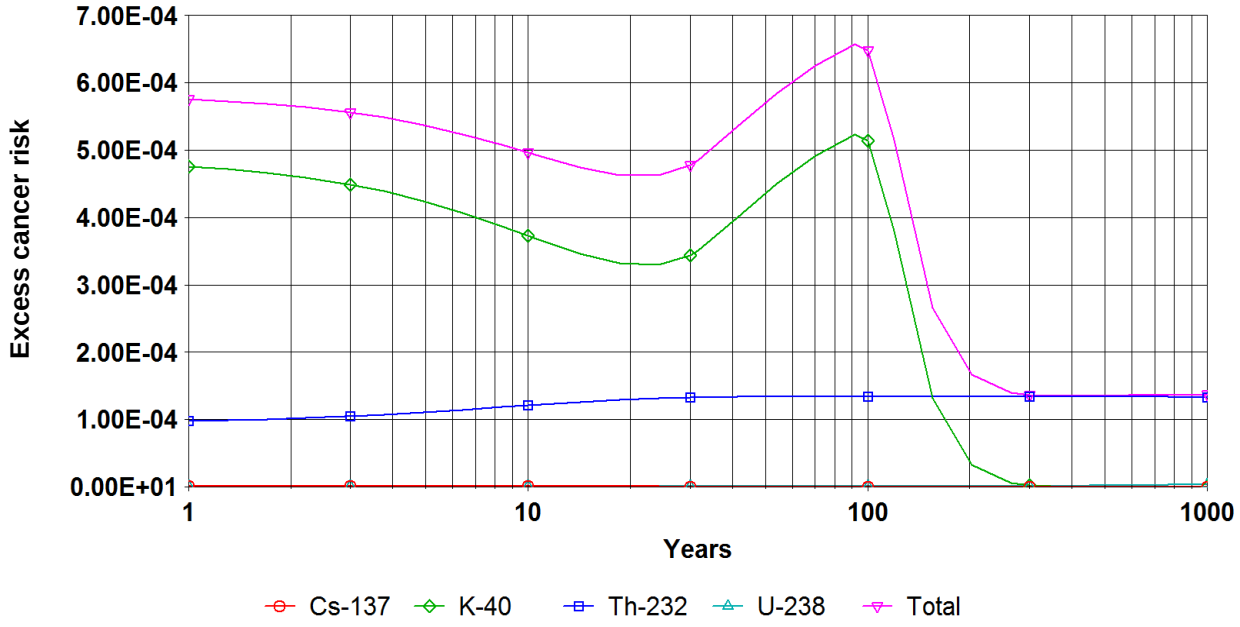

Figure 4. Summed total radiation risk due to all nuclides and all pathways for Al-Adhamiya region

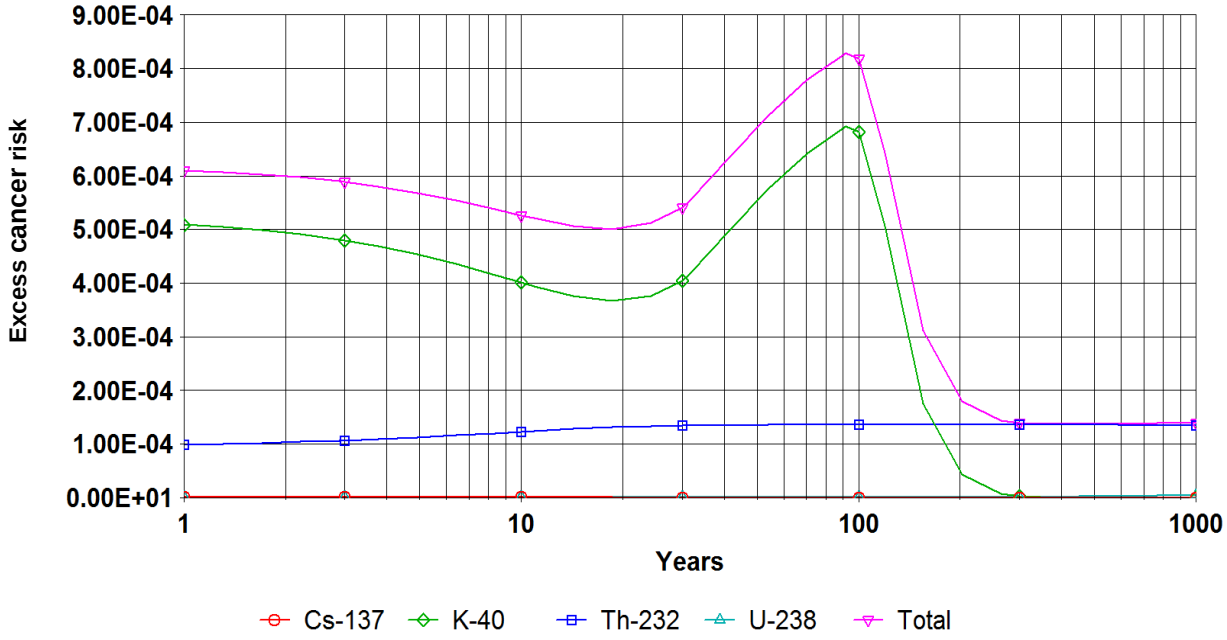

Figure 5. Summed total radiation risk due to all nuclides and all pathways for Al-Sha'ab region

4. CONCLUSIONS

A total of 51 surface soil samples have been collected and analyzed for their radioactivity content from two selected residential areas in Baghdad city. The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K were found to be lower than the average world values of 35, 30 and 400 Bq/kg, respectively.

The RESRAD-onsite code version 7.2 has been used to evaluate radiation dose and risk for the occupants of two selected residential areas in Baghdad city. The maximum total dose rates of 0.204 and 0.245 mSv/y for Al-Adhamiya and Al-Sha'ab areas, respectively were estimated at time t = 120 years with 34%, 0.07%, 28.3%, 26.3%, 11% and 0.12% contributions from external exposure, inhalation, plants ingestion, meat ingestion, milk ingestion and soil ingestion, respectively. The total peak dose rates at time t = 120 years are about 5 times lower than the basic radiation dose limit of 1 mSv/y. Based on the findings of the current study, it can be concluded that occupants in investigated areas would not get any unacceptable radiological hazards due to radionuclides in soil.

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