Soil radioactivity levels, radiation hazard assessment and cancer risk in Al-Sadr City, Baghdad Governorate, Iraq

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ABSTRACT

Background: Natural radioactivity concentrations of ^{238}U, ^{232}Th, and ^{40}K in surface soil specimens from various sectors in Sadr City were collected and measured by HPGe detector. ***Materials and Methods***: Twenty specimens were collected from selected sites in the study district. The total average activity concentrations of radionuclides ^{238}U, ^{232}Th and ^{40}K were 15.35±0.82 Bq/kg, 13.31±0.79 Bq/Kg, and 315.39±18.05 Bq/kg, respectively. Correlations between these radionuclides demonstrate a secular equilibrium in the examined soil. ***Results***: It was found that the average rate of absorbed dose is 87.510±21.555 nGy/h which is below the maximum limit except for specimens S13 and S14, where their values are close to the permissible limit. The indoor gamma-ray absorbed dose rate exceeds the permissible limit in the soil specimens S13 and S14. Radium equivalent activities, external and internal hazard indices, representative, with respect to the examined soil, do not override the global limits. ***Conclusions***: Average concentrations of the radioactive elements were lower than the worldwide mean values. ^{40}K concentration and lifetime cancer risk $ELCR_{in}$ and $ELCR_{tatal}$ in soil specimens S13, S14, and S20 were above the recommended limit, while total annual effective dose equivalent $AEDE_{tatal}$ is very close to the permissible limits provided by UNSCEAR and ICRP.

INTRODUCTION

Soil is naturally radioactive, which is a main origin for popular exposure to radiation, while it is a good medium for the transfer of radionuclides within the environment and to the human body [1]. The main and natural radionuclides are potassium-40, radionuclides of the decay series uranium-238 and thorium-232. The natural radioactivity may vary widely from soil to soil, depending on the mineral composition of each soil [2, 3]. Naturally radiation from soil increases the probability of adverse health issues [4]. The study of soil radioactivity can provide reference data that can be used to know the potential future effects of radioactive hazards and their impact on human health, agriculture, and other human resources [5]. It was important to establish basic information about the level of radioactivity in the soil that could be used as constructing materials or as growing food [6].

Humans and all living organs are constantly exposed to natural radiation. Its sources are either from cosmic rays or from radionuclides found in soil, building materials, water, and foods [7]. Exposures vary according to human activities and practices. For example, high concentricity of uranium-238 and thorium-232 in the soil in particular spaces, particularly in building materials, the design of homes and ventilation systems, as well as the potassium concentrations in the soil and the dose of its intake in foods, all of which contribute significantly to absorbed doses [8]. Exposure to natural sources of radiation results in an annual effective dose of 2.4 mSv [9]. Regarding the dose range for human being, predict that 65% will have effective annual doses between 1-3 mSv, about 25% will have less than 1 mSv and 10% will have more than 3 mSv [10]. Exposure was optimized by ICRP 103 as a source-related process to preserve exposure potential so that the magnitude of individual doses that could reasonably be achieved could be estimated by (ALARA) [11]. Estimating cancer risks and paving the way for reducing this problem is important [12]. The annual effective dose equivalent is used to estimate cancer risks and effects to provide effective protection for the population [13]. Sadr City is located in the Al-Rusafa side, east of Baghdad governorate, Iraq. It is an important area with a high population density, in which about 45% of the total population of the capital lives, which makes an assessment of environmental radioactivity and radiation risk assessment very important. The Google map of studied area is illustrated in figure 1 (14).

Figure 1. Study region (Google Map, 2021) (14). Specimen location

Sadr City is one of the most popular and densely populated areas in Baghdad province and contains many industrial and commercial areas. Radiological assessment in these areas is an urgent necessity because of its role in the health of the population. Therefore, this study aimed to evaluate radiation hazards by measuring the concentricity of ^{238}U, ^{232}Th, and ^{40}K in soil specimens selected from various sectors in the city.

MATERIALS AND METHODS

Collection and preparation of specimens

Twenty soil specimens were collected from different locations in Sadr City, Baghdad province, through October and November of the year 2020. Soil specimens were gathered of 10-15 cm depth, so the Global Positioning System (GPS) was used to recognize the specimens. Table 1 shows the codes, locations, and coordinates of the specimens. The collected specimens have transported to the Ministry of Science and Technology (Department of Central Laboratory) by sealed and labeled polyethylene bags for evaluation. Soil specimens were prepared by placing each specimen in a small German industry HUMBOLDT oven for six hours of drying at 100 °C to get rid of all moisture. The residual specimens were crushed and sieved with a standard 300 µm sieve. Homogenous specimens were packed into a 500 ml Marinelli beaker, hermetically sealed, and labeled each. Marinelli beakers were stored for four weeks to achieve radioactive equilibrium (15, 16).

Table 1. Soil specimen codes, name of sectors, and their geographical coordinates.

Soil Sample Code	Name of Sectors	Geographical Coordinates	Soil Sample Code	Name of Sectors	Geographical Coordinates
S1	Kasra and Atash District	N= 33° 24′ 37″ E= 44° 27 ′ 18″	S11	Sector-55 Al-Shaheed Al-Sader General Hospital	N= 33° 22′ 41 ″ E= 44° 27 ′ 47″
S2	Kasra and Atash District	N= 33° 24′ 53 ″ E= 44° 27 ′ 37″	S12	Army Cannel Street Wahran Square	N= 33° 21′ 01 ″ E= 44° 26 ′ 40″
S3	Sector-73	N= 33° 24′ 43 ″ E= 44° 27 ′ 37″	S13	Army Cannel Street Near Muzaffar Square	N= 33° 21′ 46″ E= 44° 25 ′ 43″
S4	Sector-37	N= 33° 23′ 53 ″ E= 44° 28 ′ 13″	S14	Army Cannel Street Near Al-Talbieh	N= 33° 22′ 35″ E= 44° 24 ′ 40″
S5	Sector-46	N= 33° 23′ 33 ″ E= 44° 28 ′ 14″	S15	Sector-67	N= 33° 23′ 26 ″ E= 44° 25 ′ 43″
S6	Sector-50	N= 33° 23′ 28″ E= 44° 28′ 48″	S16	Sector-57	N= 33° 22′ 50″ E= 44° 26 ′ 29″
S7	Sector-79	N= 33° 24′ 23″ E= 44° 26 ′ 52″	S17	Sector-12	N= 33° 22′ 26 ″ E= 44° 27 ′ 09″
S8	Sector-20	N= 33° 23′ 48″ E= 44° 26 ′ 19″	S18	Al-Habibiah Apartments Near Rainbow Nursery	N= 33° 21′ 45″ E= 44° 27 ′ 23″
S9	Sector-34 Al-Imam Ali Hospital	N= 33° 23′ 40 ″ E= 44° 27 ′ 44″	S19	Atar Al-Ward Govern-mental Kindergarten	N= 33° 21′ 55″ E= 44° 26 ′ 34″
S10	Sector-30	N= 33° 23′ 08″ E= 44° 27 ′ 29″	S20	Jamila Industrial District	N= 33° 22′ 52″ E= 44° 25′ 19″

Gamma ray spectrometer

The gamma-ray spectrum was measured for each soil specimen with a high purity germanium detector (model GC4018 from Canberra). Genie 2000 software was used. For efficiency and energy calibrations a standard mixed source, 550 ml Marinelli beaker, containing ^{241}Am, ^{109}Cd, ^{57}Co, ^{60}Co, ^{113}Sn, ^{203}Hg, ^{88}Y, and ^{137}Cs, was used (The standard mixing source from the Czech Republic). The energy and efficiency calibration curves of the spectrometer were verified using a standard calibration source, as shown in figures 2 and 3. The background radiation measurement was repeated for two hours every two days before the specimen was placed in the system.

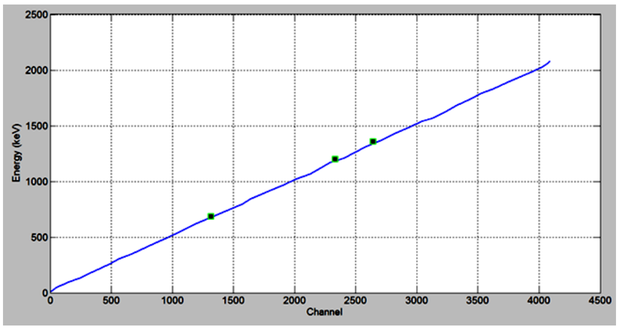

Figure 2. Energy calibration curve.

The specific activity A in a unit (Bq/kg) can be specified with the aid of equation (1) (17):

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$$A(Bq/kg) = \frac{N}{I_\gamma \, \varepsilon \, M \, T} \quad (1)$$

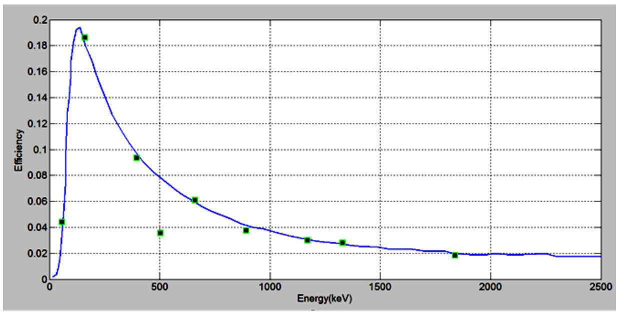

Figure 3. Efficiency calibration curve.

Where N is the net area below the peak (count per sec), I_γ is the absolute gamma intensity of the corresponding gamma-ray energy considered, ε is the absolute gamma peak detection efficiency, *T* is the live time in seconds for gathering the spectrum, and *M* is the specimen's weight in (kg).

Radium equivalent R_{eq}

The radium equivalent activity Ra_{eq}(Bq/kg), can be calculated by using equation (2) [10]:

$$Ra_{eq}(Bq/kg) = A_U + 1.43A_{Th} + 0.077A_K \quad (2)$$

Where A_U, A_{Th}, and A_K are the specific activity of uranium, thorium, and potassium, respectively.

External hazard index H_{ex}

For specimens under the conditions, the external hazard index can be determined by equation (3) [18]:

$$H_{ex} = A_u/370 + A_{Th}/259 + A_K/4810 \quad (3)$$

Internal hazard index H_{in}

The internal hazard index can be guessed as in equation (4) [19]:

$$H_{in} = A_u/185 + A_{Th}/259 + A_K/4810 \quad (4)$$

The values of H_{ex} and H_{in} must be less than unity for the radiation hazard to be negligible.

Absorbed dose rate D_γ

The outdoor absorbed dose rate can be calculated by equation (5) [20]:

$$D_\gamma \text{ out (nGy/h)} = 0.462A_U + 0.604A_{Th} + 0.041A_K \quad (5)$$

The indoor absorbed dose rate can be calculated from equation (6), European Commission (EC), 1999 [21].

$$D_\gamma \text{ in (nGy/h)} = 0.92A_U + 1.1A_{Th} + 0.081A_K \quad (6)$$

Annual effective dose equivalent (AEDE)

The (AEDE) estimated from equations (7) and (8) as recommended by UNSCEAR, 2016 [22]:

$$AEDE_{out}\ (\mu Sv/y) = D_\gamma out(nGy/h) \times 8760(h/y) \times 0.20 \times 0.7\ (Sv/Gy) \times 10^{-3} \quad (7)$$

$$AEDE_{in}\ (\mu Sv/y) = D_\gamma\ in(nGy/h) \times 8760(h/y) \times 0.80 \times 0.7\ (Sv/Gy) \times 10^{-3} \quad (8)$$

Excess life time cancer risk ELCR

If we consider the average human lifespan DL is seventy, with a risk factor RF $0.05 \times 10^{-3}\ Sv^{-1}$ as given by ICRP, 2012 [23]. Then equation (9) and (10) respectively can be used to evaluate the outdoor and indoor cancer risk [17]:

$$ELCR_{out} = AEDE_{out} \times DL \times RF \quad (9)$$

$$ELCR_{in} = AEDE_{in} \times DL \times RF \quad (10)$$

Statistical analysis

The data were presented as activity concentration values obtained from gamma spectra analysis as well as mean and standard deviation. In addition to estimate the calculated radiation hazards. All analyzes were performed in SPSS 23.0 and differences were considered significant if $p<0.05$.

RESULTS

The specific activities were measured for twenty soil specimens selected from different sectors in Sadr City, near Al-Rusafa from Baghdad governorate. The data for each specimen was cumulatively calculated for two hours using gamma spectroscopy to determine the activity concentricity, as shown in table 2.

Table 2. Specific activities in soil specimens at Sadr City.

Soil Sample Code	Activity Concentrations (Bq/kg)				
	**U-238			**Th-232	**K-40
	Ra-226	Pb-214	Bi-214	Ac-228	
S1	13.7±2.4	12.6±0.5	13.8±0.8	11.3±0.7	307.0±16.5
S2	17.7±2.8	13.4±0.5	14.0±0.8	11.7±0.7	313.0±17.5
S3	21.8±3.1	13.4±0.9	16,0±0.9	12.1±0.7	327.0±16.8
S4	11.9±0.6	11.9±0.5	12,0±0.7	12.4±0.6	303.3±15.6
S5	11.5±2.1	7.7±0.5	9.9±0.7	7.9±0.6	226.9±13.2
S6	14.1±2.7	12.2±0.6	15.2±0.8	13.0±0.7	370.9±18.3
S7	17.7±2.8	12.6±0.5	15.7±0.8	14.0±0.8	371.7±19.0
S8	16.2±2.2	10.5±0.4	11.2±0.6	9.2±0.1	289.7±15.3
S9	20.1±2.7	14.4±0.5	16.5±0.8	11.3±0.7	317.5±16.4
S10	11.7±0.7	10.2±0.6	13.2±0.8	11.0±0.6	262.5±14.6
S11	24.7±3.0	15.4±0.6	17.4±0.9	16.7±0.8	374.8±19.3
S12	25.5±2.8	14.5±0.5	18.3±0.9	15.1±0.7	386.0±18.7
S13	24.7±3.5	20.0±0.7	21.8±1.1	19.2±0.9	532.6±25.5
S14	20.2±0.8	19.6±0.7	20.8±1.0	24.8±0.9	525.9±25.3
S15	15.6±4.9	13.9±0.6	16.8±0.9	10.6±0.9	312.4±17.5
S16	12.0±1.4	11.0±0.4	13.2±0.6	10.9±0.5	293.7±15.1
S17	12.5±4.2	14.6±0.7	17.3±1.0	11.3±0.7	379.9±20.0
S18	13.9±2.0	9.9±0.4	12.1±0.6	8.8±0.6	219.8±12.2
S19	13.6±2.6	12.1±0.5	13.5±0.8	14.5±2.6	413.0±20.0
S20	22.9±3.2	16.3±0.6	18.3±0.9	20.3±0.9	500.3±24.1
Average	17.09	13.31	15.35	13.31	351.39
Standard Deviation	±2.50	±0.56	±0.82	±0.79	±18.05
Worldwide mean [24]	33			45	420

* $p<0.05$, ** $p<0.01$, *** $p<0.001$. A p-value of <0.05 was considered statistically significant.

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Activity concentration

Table 2 shows the results of measuring the activity concentration of natural isotopes in the samples, as the activity concentrations of U-238 daughters (Ra-226, Pb-214, and Bi-214) were with an average value of 17.09±2.50, 13.31±0.56, and 15.35±0. 82 Bq/kg, respectively. As well as the mean activity concentrations of Th-234 (Ac-228) and K-40 is 13.31±0.79 and 351.39±18.04 Bq/kg, respectively.

Radiological effects

The radium equivalent Ra_{eq} values were estimated in selected soil specimens. The results summarized in table 3 show that the values are in the range of 38.668 Bq/kg in specimen S5 to 96.758 Bq/kg in specimen S14 with an average value of 61.434±15.326 Bq/kg.

The results of H_{ex} and H_{in} are explained in table 3. The values of H_{ex} varied from 0.105 in specimen S5 to 0.261 in specimen S14 with an average value 0.166±0.041; and the values of H_{in} range between 0.131 in specimen S5 and 0.318 in specimen S14 with an average values 0.208±0.049.

Table 3. Radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}).

Soil Sample Code	**Ra_{eq} (Bq/kg)	**H_{ex}	**H_{in}
S1	53.598	0.145	0.182
S2	54.832	0.148	0.186
S3	58.482	0.158	0.201
S4	53.086	0.144	0.176
S5	38.668	0.105	0.131
S6	62.349	0.168	0.210
S7	64.341	0.174	0.216
S8	46.663	0.126	0.156
S9	57.107	0.154	0.199
S10	49.143	0.133	0.168
S11	70.141	0.190	0.237
S12	69.615	0.188	0.238
S13	90.266	0.244	0.303
S14	96.758	0.261	0.318
S15	56.013	0.151	0.197
S16	51.402	0.139	0.175
S17	62.711	0.170	0.216
S18	41.609	0.113	0.145
S19	66.036	0.178	0.215
S20	85.852	0.232	0.282
Average	61.434	0.166	0.208
Standard Deviation	±15.326	±0.041	±0.049
Worldwide mean	370 [25]	≤1 [21]	

* p< 0.05, **p< 0.01, ***p< 0.001. A p-value of <0.05 was considered statistically significant.

The results of the studied radiological characteristics D_γ, AEDE, and ELCR of the soil specimens are tabulated in table 4.

The average values D_γ, D_γ in, and D_γ total are 29.53 nGy/h, 57.97 nGy/h and 87.51 nGy/h, respectively. $AEDE_{out}$ values ranged from 0.023 mSv/y to 0.057 mSv/y with an average value 0.037mSv/y while $AEDE_{in}$ values ranged from 0.180 mSv/y to 0.442 mSv/y with an average value 0.285 mSv/y. The result showed the total AEDE and ELCR with average values 0.323 mSv/y and 1.125×10^{-3}, respectivly.

DISCUSSION

Environmental pollution and increased concentration of activity of natural isotopes in soils and buildings are important causes affecting human health. Increased radiation exposure, therefore, increases the risk of cancer. Sadr City, east of Baghdad, is one of Iraq's most densely populated cities. There is an increase in environmental pollution rates in this city as a result of the increased industrial environment surrounding the city and the lack of green areas, which threatens the health and safety of the population.

The results showed that the radioactivity of ^{238}U, ^{232}Th, and ^{40}K were lower than the global rates, so the radiological effect values (Ra_{eq}, H_{ex}, and H_{in}) are also lower than the global rates [21, 24, 25]. With the exception of specimens S13, S14, and S20, the permissible limits were exceeded.

The observed higher values of $ELCR_{in}$ and $ELCR_{total}$ in soil specimens S13, S14, and S20 are due to the high concentrations of ^{40}K in soil specimens, which is directly depends on the quality of soil, whether it is virgin or agricultural, and on the geological structure of the area and the soil. Since plants and animals are the pathways to human beings from which radionuclides can be ingested, excessively high ELCR values deserve further study and research to verify ingestion levels.

When comparing the results of the activity concentrations of the natural isotopes present in the samples with the previous studies as in table 5, relatively increased concentrations were observed, especially with those studies in central and southern Iraq.

The calculated radiological hazard values may not be high in most samples, but they do indicate risks. Therefore, requires more studies about the types of pollution in this city and its impact on the general health of its residents.

CONCLUSIONS

The different uses of soil for different human needs do not pose effective risks, so there is no gamma radiation hazard in the studied sites. However, this study indicates that there is an urgent need to examine and study the great depths to take samples from the soil and study the amount of ingestion as well as study the level of water and air pollution.

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Table 4. Absorbed dose rate (D_γ), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR) in Sadr city.

Soil Sample Code	**D_γ out (nGy/h)	**D_γ in (nGy/h)	**D_γ total (nGy/h)	**$AEDE_{out}$ (mSv/y)	**$AEDE_{in}$ (mSv/y)	**$AEDE_{total}$ (mSv/y)	**$ELCR_{out}\times10^{-3}$	**$ELCR_{in}\times10^{-3}$	**$ELCR_{total}\times10^{-3}$
S1	25.788	50.680	76.468	0.032	0.249	0.281	0.112	0.872	0.984
S2	26.368	51.798	78.166	0.033	0.254	0.287	0.116	0.889	1.005
S3	28.108	55.342	83.450	0.035	0.272	0.307	0.123	0.952	1.075
S4	25.469	49.808	75.277	0.031	0.245	0.276	0.109	0.858	0.967
S5	18.648	36.663	55.311	0.023	0.180	0.203	0.081	0.630	0.711
S6	30.081	59.051	89.132	0.037	0.290	0.327	0.130	1.015	1.145
S7	30.949	60.711	91.660	0.038	0.298	0.336	0.133	1.043	1.176
S8	22.609	44.407	67.015	0.028	0.218	0.246	0.098	0.763	0.861
S9	27.466	54.198	81.664	0.034	0.266	0.300	0.119	0.931	1.050
S10	23.505	46.195	69.699	0.029	0.227	0.256	0.102	0.795	0.897
S11	33.492	65.615	99.107	0.041	0.322	0.363	0.144	1.127	1.271
S12	33.401	65.644	99.045	0.041	0.322	0.363	0.144	1.127	1.271
S13	43.505	85.354	128.859	0.054	0.419	0.473	0.189	1.467	1.656
S14	46.151	89.986	136.136	0.057	0.442	0.499	0.200	1.547	1.747
S15	26.972	53.318	80.290	0.033	0.262	0.295	0.116	0.917	1.033
S16	24.724	48.581	73.304	0.031	0.239	0.270	0.109	0.837	0.946
S17	30.394	59.984	90.377	0.038	0.295	0.333	0.133	1.033	1.166
S18	19.917	39.267	59.185	0.025	0.193	0.218	0.088	0.676	0.764
S19	31.928	62.382	94.310	0.039	0.306	0.345	0.137	1.071	1.208
S20	41.228	80.508	121.736	0.051	0.396	0.447	0.179	1.386	1.565
Average	29.535	57.974	87.510	0.037	0.285	0.323	0.128	0.997	1.125
Standard Deviation	±7.325	±14.230	±21.555	±0.009	±0.070	± 0.079	±0.032	±0.245	±0.276
Worldwide mean	55 (10)	84 (26)	139 (26)	0.08	0.42	0.50	0.29	1.16	1.45
					(10, 27)			(10)	

* p< 0.05, **p< 0.01, ***p< 0.001. A p-value of <0.05 was considered statistically significant.

Table 5. Comparison of the average values of current study results in soil with different locations.

City/Region/Country	Activity Concentratinon (Bq/kg)			Ra_{eq} (Bq/kg)	D_γ (nGy/h)	References
	U-238	Th-232	K-40			
Tehran/Iran	24	28	635	-------	102	(28)
Saudi Arabia	14.5	11.2	225	47.8	23.3	(29)
Tehran/Iran	38.8	43.4	555.1	143.6	69.1	(30)
Dhi –Qar/Iraq	17.9	13.66	314.00	61.67	29.66	(31)
Babylon/Iraq	14.079	12.326	416.66	63.297	31.534	(32)
Bangladesh	30.85	40.88	390.10	120.65	57.73	(33)
Nineveh/Iraq	41.24	21.52	326.74	33.55	48.91	(34)
Turkey	51.45	57.96	402.60	147.51	69.79	(35)
Karbala/Iraq	15.8	11.2	311.0	55.959	27.511	(36)
Kirkuk/Iraq	40.11	15.87	302.82	81.182	38.618	(37)
Basrah/Iraq	1.35	10.16	360.55	26.11	33.216	(38)
Egypt	11.3	6.8	112	-------	-------	(39)
Baghdad/Iraq	15.292	22.560	386.053	74.383	36.320	(40)
Abu-Ghraib/Iraq	12.155	7.403	76.738	20.634	17.347	(41)
Sadr City/Iraq	15.35	13.31	351.39	61.434	29.781	Present Work
Worldwide mean (24)	33	45	420	370 (25)	55 (10)	

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