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Radiological Risk due to Naturally Occurring Radioactive Materials in the Soil of Al-Samawah Desert, Al-Muthanna Governorate, Iraq

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ABSTRACT

Introduction: The risk of radioactivity addresses human life directly. The natural rock radioactivity is mainly due to ^{232}Th, ^{238}U), and ^{40}K series. Activities involving blasting, crushing, and processing of rocks into numerous pieces lead to release of radionuclides into the atmosphere in the form of dust particles.

Material and Methods: Sixteen soil samples were collected from various locations of the Al-Samawah desert, Al-Muthanna Governorate, Iraq. The specific activities of ^{238}U, ^{232}Th, and ^{40} K were measured using NaI(Tl) 3"x3" gamma-ray spectroscopy.

Results: It is demonstrated that ^{238}U, ^{232}Th, and ^{40}K were 11.53±0.76, 8.70±0.43, and 319.27±4.4 Bq/kg, respectively. The specific activity values were lower than the recommended United Nations Scientific Committee on the Effects of Atomic Radiation values. The H_{ex} with the mean of 0.131 ranged from 0.094 to 0.171. The range for D, R_{aeq}, and total *AEDE* were obtained as 17.468-30.967 nGy/h, 34.956-63.173 Bq/kg, and 0.02-0.038 mSv/y, respectively. Moreover, the means of dose rate, radium equivalent activity, and *AEDE* were 23.893 nGy/h, 48.549 Bq/kg, and 0.029 mSv/y, respectively. The low mean of H_{ex}, is found to be < 370 Bq/kg.

Conclusion: Results showed that the mean specific activity of ^{238}U, ^{232}Th, and ^{40}K nuclides were lower than the worldwide recommended values. Furthermore, the H_{ex} values for all the soil samples were lower than unity and R_{aeq} as another good indicator was below the value considered as hazard (370 Bq/kg).

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Introduction

In addition to the Naturally Occurring Radioactive Materials (NORM), the radiation made by human enters the environment daily from the consumer products [1], as well as the activities, such as medical procedures and nuclear power plants. The NORM could be divided into two main groups, the first of which being the radioactive materials that occur naturally and have too long half-lives (i.e., hundreds of millions of years) [2]. The second group of NORM originated cosmogenically from the interactions between the cosmic ray and outer atmosphere [3]. The latter group, known as primordial or terrestrial nuclides, was already present when the earth was created about 4.5 billion years ago. These are available in sedimentary igneous rocks and can transfer into water, soil, and even air [4].

Therefore, naturally the NORM are a part of earth. Most of the radionuclides produced by uranium and thorium decay are NORM radium and radon. Exposure to radon was found to be high in homes and locked places. Technological and human activities, such as burning fossil fuel, mineral extraction, and fertilizer application often augment NORM concentrations. Industrial practices involving natural resources frequently concentrate radionuclides and pose a risk to human and the environment [5].

Terrestrial radionuclides are mainly derived from three separate decay chains, namely thorium–232 (^{232}Th), uranium–238 (^{238}U), and uranium–235 (^{235}U), in addition to the single radioactive potassium (^{40}K). In all these spontaneous changes, three types of radiation were recognized, including α- (energetic helium nuclei), β- (electrons), and γ- (energetic photons) radiations [6]. Radioactive decay of ^{238}U and ^{232}Th produces several series of daughter radioisotopes of different elements with distinct physical characteristics in terms of the half-life, mode of decay, as well as type and energy of the emitted radiation [7].

Gamma spectrometry can easily measure the nuclides actinium-228 (^{228}Ac), lead-214 (^{214}Pb), bismuth-212 (^{212}Bi), and thallium-208 (^{208}Tl). The

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decay of ^{212}Bi is branched – only 35.94% of decays produce ^{208}Tl by alpha decay. The beta decay branch produces polonium-212 (^{212}Po) that cannot be measured by gamma spectrometry. To estimate the thorium activity, the measured ^{208}Tl must be divided by 0.3594 to correct the branching [8].

Many studies investigated the concentrations of radioactive elements in the soil samples using different techniques. Some authors evaluated the radioactivity-related problems and measured the NORM in soil [9-12]. Pourimani et al. used gamma-ray spectrometry and high-purity germanium (HPGe) detector to assess the specific activities of radium-226 (^{226}Ra), ^{232}Th, ^{40}K, and caesium-137 (^{137}Cs) in 34 soil samples collected from over 20 km of the distance between Arak city and Shazand Power Plant [13]. In the mentioned study, 12 ores were collected from the iron ore mining areas of Arak region, Iran with each mass weighing about 2 Kg [14].

In another study, Casanovas et al. determined the natural activity of 19 soil samples collected from the selected regions in Nineveh province, Iraq for radionuclides ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K [15]. These authors compared their findings with the world mean activity and concluded that the mean activity concentrations of ^{238}U and ^{226}Ra are higher than the world mean value. On the other hand, the activities of ^{232}Th and ^{40}K were found to be lower, compared to the worldwide mean.

Natural radioactivity and the resulting health effects are of remarkable importance in human life. To the best of our knowledge, no survey has evaluated natural radioactivity in the area of the present study. Therefore, we examined the specific activity of the radionuclides and radiological risk in the soil of Al-Samawah desert, Al-Muthanna Governorate, Iraq using NaI(Tl) detector. Furthermore, the radiological hazard index values and the related influence were assessed.

Materials and Methods

Study Area

The study samples were taken from the western Samawah desert, west of Samawah city, Al-Muthanna province, Iraq. The studied desert region is located in 45 degrees east and 30.25 degrees north. As shown in Figure 1, the area has limited human activity and is used as an open area to set up solar-powered stations that are not currently exploited.

Preparation and Collection

The 16 soil samples were collected from some sites of Al-Samawah desert in Al-Muthanna Governorate, Iraq during January 2018. We aimed to check the specific activity and hazard index of ^{238}U and ^{232}Th families, in addition to ^{40}K. The samples were collected from a 15 cm depth of the random places depicted in Figure 1. The study was carried out in the nuclear laboratory at the Department of Physics, Faculty of Pure Sciences, and University of Kufa, Iraq.

The samples were crushed and some of them were dried in an oven at 100 ˚C for 60 min in order to remove the moisture completely. Next, the researchers used a sieve with 500-µm holes to get 1 kg homogeneous powder from each sample. Afterwards, the powder was packed into 1-liter polyethylene plastic Marinelli beakers of constant volume in order to ensure the geometric homogeneity around the detector.

To allow secular equilibrium between radon-222 (^{222}Rn) and its parent radon-226 (^{226}Ra), in uranium chain, we sealed the plastic Marinelli with a tape and stored it in the uranium chain for approximately 30 days prior to measurements [12]. All the steps of measuring the radioactivity of the soil samples were completed using the detection system of low background gamma-ray.

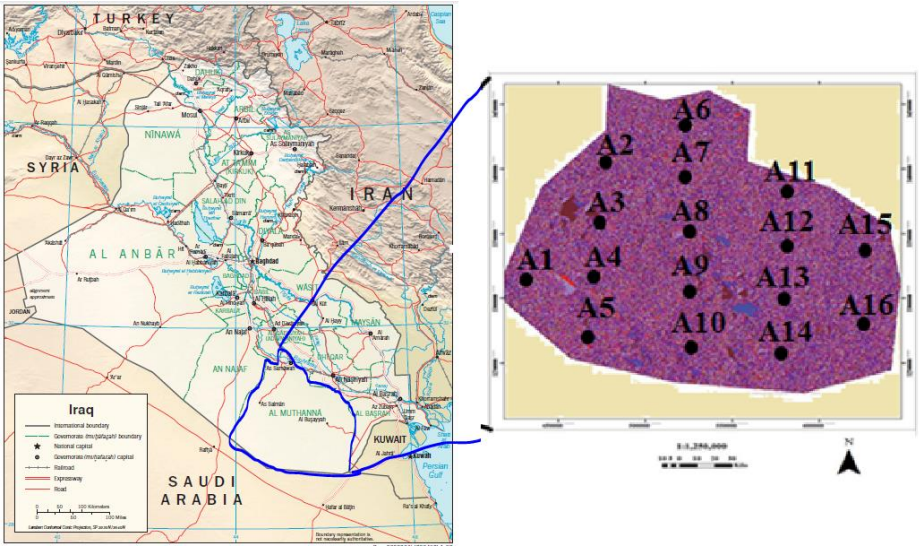

Figure 1. Study area with the marked sampling locations

Detection and Measurement System

Gamma-ray spectrometer system contains a scintillation detector of NaI(Tl) crystal with the dimensions of 3"×3" (Alpha Spectra Inc., model: -12I12/3) connected to a multichannel analyzer (ORTEC–DigiBase, USA) reaching about 4096 channels. The system was coupled with an analog to digital converter unit through an interface. All the spectroscopic measurements and data analysis were performed by the MAESTRO-32 software. A collection of standard gamma-ray sources was applied to execute energy calibration for this detector. The sources entailed sodium-22 (^{22}Na), manganese (^{54}Mn), ^{137}Cs, and cobalt-60 (^{60}Co) from the United States Nuclear Regulatory Commission and State License Expert Quantities, Gamma Source Set, Model RSS–8. The calculated resolution was 7.9% for the standard source energy of 661.66 keV.

Calculations

Specific Activity

The specific activity (a) of the gamma-emitting radionuclides in the study samples were calculated using the following equation [15-17]:

$$a = \frac{N}{I_\gamma \varepsilon M T} \quad (1)$$

Where N refers to the area under the peak of efficiency of the g-factor, I_γ denotes the identifies the probability of gamma decay, M represents the weight of the measured sample in kg, and T is the time for collecting the spectrum in sec.

External Hazard Index (H_{ex})

The calculated H_{ex} is intended to estimate the radiological natural gamma radiation hazard [18]. Beretka and Mathew in 1985 made a model to calculate this index as follow [19]:

$$H_{ex} = \frac{A_{238_U}}{370} + \frac{A_{232_{Th}}}{259} + \frac{A_{40_K}}{4810} \leq 1 \quad (2)$$

Where A_{238_U}, $A_{232_{Th}}$, and A_{40_K} are the specific activities for ^{238}U, ^{232}Th, and ^{40}K, respectively.

Radium Equivalent Activity

The activity of radium equivalent could be explained by mathematics as [19]:

$$Ra_{eq} = A_{238_U} + 1.43A_{232_{Th}} + 0.077A_{40_K} \quad (3)$$

Annual Effective Dose Equivalent (AEDE)

The outdoor annual effective dose equivalent could be estimated by the following formula [20]:

$$AEDE_{Outdoor} = D\left(\frac{nGy}{h}\right) \times 8760(h) \times 0.2 \times 0.7\left(\frac{Sv}{Gy}\right) \times 10^{-3} \quad (4)$$

Absorbed Dose Rate in Air

According to the literature, the absorbed dose rate in air at one meter above the ground surface could be assessed by [21,22]:

$$D = 0.462A_{238_U} + 0.604A_{232_{Th}} + 0.0417A_{40_K} \quad (5)$$

As reported [20], the conversion coefficient value was 0.7 (Sv/Gy) for both males and females, as well as both indoor and outdoor. The outdoor occupancy fraction was considered as 0.2.

Excess Lifetime Cancer Risk (ELCR)

The ELCR for the public due to natural radioactivity was estimated using equation 6 [23]:

$$ELCR = annual\ effective\ dose\ (mSvy^{-1}) \times Life\ expectancy(y) \times ICRP\ risk\ factor\ (10^{-2}\ Sv^{-1}) \quad (6)$$

It should be mentioned that the life expectancy for Iraq is 74.85 years. The risk factors for the public is 0.041 Sv^{-1} from the International Commission on Radiological Protection publication 103 [24].

Results

The specific activity of the sixteen soil samples collected from the different sites of Al-Samawah desert, Al-Muthanna Governorate, Iraq was measured for ^{238}U and ^{232}Th families, in addition to ^{40}K using equation (1). Table 1 shows that the specific activities for the samples ranged from 3.6±0.49 Bq/kg to 21.35±1.04 Bq/kg with the mean value of 11.53±0.76 Bq/kg. The minimum value was found in sample A5, while the maximum was observed in sample A9.

The mean value reported in the current work is less than the worldwide mean (35 Bq/kg) [20]. The specific activity of ^{232}Th in the soil samples was estimated as 1.69±0.23 to 12.54±0.54 Bq/kg with the mean of 8.7±0.43 Bq/kg. The minimum and maximum values were found in samples A6 and A15, respectively. According to our findings, the mean value was lower than what was mentioned in the United Nations Scientific Committee on the Effects of Atomic Radiation 2008 (i.e., 45 Bq/kg) [20].

The specific activity of ^{40}K was obtained for the samples as listed in Table 1. As shown, the minimum and maximum values of 216.82±3.45 and 407.42±5.11 Bq/kg were reported in samples A16 and A7, respectively. The mean was found to be 319.27±4.4 Bq/kg, which is less than the worldwide mean concentration of 412 Bq/kg [20]. The relatively higher specific activity, H_{ex}, and other indices in some samples may be attributed to the geological structure and chemical fertilizers.

The H_{ex} is mainly used to evaluate the radiological risk of natural radionuclides emitted by the gamma radiation. In order to prevent the radiological risks, value of the Hex must be less than unity. Table 2 demonstrates that this index had the range of 0.094-0.171 with the mean of 0.131. Therefore, we can conclude that there are no significant radiological hazards the soil samples from the study area.

Equation 5 was used to calculate the absorbed dose rate in air and the obtained values are summarized in Table 2. The range and mean were reported as 17.468-30.967 and 23.893 nGy/h, respectively. In addition, sample A2 was observed to have the minimum value, while sample A10 had the maximum value.

Table 1. Radioactivity in Al-Samawah desert

No.	Sample code	Specific activity Bq/kg					
		^{238}U		^{232}Th		^{40}K	
		Mean	SD	Mean	SD	Mean	SD
1	A1	13.34	0.81	9.62	0.44	254.96	3.78
2	A2	4.59	0.46	6.44	0.35	274.76	3.77
3	A3	14.26	0.89	2.56	0.24	241.15	3.87
4	A4	15.52	0.94	12.09	0.53	381.68	4.97
5	A5	3.6	0.49	8.58	0.49	317.39	4.93
6	A6	7.2	0.73	1.69	0.23	396.7	5.73
7	A7	11.3	0.8	12.29	0.54	407.42	5.11
8	A8	18.71	1.02	8.69	0.45	377.38	4.86
9	A9	21.35	1.04	7.12	0.39	265.28	3.9
10	A10	14.55	0.86	12.25	0.51	403.97	4.84
11	A11	10.73	0.75	10.94	0.49	350.23	4.57
12	A12	18.56	0.92	11.56	0.46	294.43	3.88
13	A13	6.33	0.53	8.11	0.38	295.08	3.84
14	A14	4.23	0.47	9.82	0.46	262.06	3.93
15	A15	5.21	0.55	12.54	0.54	369	4.89
16	A16	14.99	0.85	4.84	0.31	216.82	3.45
Mean±SD		11.53±0.76		8.70±0.43		319.27±4.4	

Table 2. Measured radiological risk factors in Al-Samawah desert

No.	Sample code	H_{ex}	D (nGy/y)	Ra_{eq} (Bq/kg)	$AEDE_{outdoor}$
1	A1	0.126	22.605	46.729	0.028
2	A2	0.094	17.468	34.956	0.021
3	A3	0.099	18.19	36.489	0.022
4	A4	0.168	30.389	62.198	0.037
5	A5	0.109	20.081	40.308	0.025
6	A6	0.108	20.89	40.163	0.026
7	A7	0.164	29.635	60.246	0.037
8	A8	0.163	29.63	60.195	0.036
9	A9	0.14	25.226	51.958	0.031
10	A10	0.171	30.967	63.173	0.038
11	A11	0.144	26.17	53.342	0.032
12	A12	0.156	27.835	57.762	0.034
13	A13	0.11	20.128	40.648	0.025
14	A14	0.104	18.813	38.451	0.023
15	A15	0.139	25.368	51.555	0.031
16	A16	0.104	18.89	38.606	0.023
Mean±SD		0.131	23.893	48.549	0.029

Furthermore, the radium equivalent activity was calculated using equation 3 and is indicated in Table 2 for all the samples under study. The results show that the values have the range of 34.956-63.173 Bq/kg with the mean of 48.549 Bq/kg.

The annual effective dose equivalent depends directly on the absorbed dose rate in air and was evaluated by equation 4. The minimum and maximum values were calculated as 0.021 and 0.038 mSv/y, respectively as shown in Table 2.

Discussion

The findings of this study demonstrate that the mean specific activity, H_{ex}, radium equivalent activity value, absorbed dose rate, and annual effective dose equivalent evaluated for ^{238}U, ^{232}Th, and ^{40}K in the study area were lower than the international recommended safe values.

According to the literature, the acceptable value for radium equivalent activity is 370 (equivalent to 1 mSv) [20]. Therefore, the maximum value found in this study lies in the acceptable level.

The mean dose was 0.029 mSv/y, while the worldwide mean value calculated by Hamidalddin et al. was 0.07 mSv/y [20].

The mean radiological risk of ^{238}U, ^{232}Th, and ^{40}K was obtained for all the samples from Al-Samawah desert. Afterwards, the means were compared with the corresponding values reported by the authors from other countries as summarized in Table 3.

Considering the results of this study, the radiological risk values for these nuclides were lower than the worldwide reported values [20, 21]. As a result, it could be concluded that there was no significant radiological hazard in the studied region.

Table 3. Mean absorbed dose rates, radium equivalent activity, and annual effective dose in different countries

No.	Country	D (nGy/h)	Raeq (Bq/kg)	AEDE (mSv/y)	Reference
1	Saudi Arabia	59.13	118.33	0.073	[20]
2	Jordan	37.15	94.21	0.046	[21]
3	Qatar	23.4	49.4	0.029	[22]
4	India	120.8	260.4	0.15	[23]
5	Pakistan	70.1	189.9	0.43	[24]
6	Cuba	40	82	0.049	[25]
7	Thailand	44.1	175.9	0.054	[26]
8	Iraq (Qadisiyah)	47.6	75.6	0.058	[27]
9	Iraq (Nassariya)	27.31	54.6	0.033	[12]
10	Present study	23.893	48.549	0.029	------

Conclusion

The sixteen soil samples collected from various locations of the Al-Samawah desert, Al-Muthanna Governorate, Iraq were analyzed using NaI(Tl) detector gamma-ray spectrometry. According to the results, the specific activity means for ^{238}U, ^{232}Th, and ^{40}K nuclides were lower than the international recommendations. The H_{ex} values for all the soil samples were also reported to be less than unity. Moreover, radium equivalent activity as another good indicator of radioactive status was below the acceptable cutoff of 370 Bq/kg. Furthermore, the absorbed dose rates and annual effective dose equivalents were less than the means worldwide recommendations. Therefore, we conclude that there is no significant radiological hazard in the Al-Samawah desert, Iraq.

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