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Analysis of Natural Radionuclides in Soil in the Northern and central Iraq

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ABSTRACT

Naturally occurring radionuclides of terrestrial origin (also called primordial radionuclides) are present in various degrees in all media in the environment, which includes the human body itself. Their concentrations in the environment decrease continually by decaying. In this study, the specific activities of different natural radionuclides were determined by using gamma-ray spectrometry. The analysis of two radionuclides (^{214}Bi, ^{234m} Pa) that belong to the ^{238}U series and one radionuclide ^{228}Ac belonging to the ^{232}Th series, ^{40}K, ^{226}Ra, and ^{137}Cs, was done for soil samples obtained from different locations in Iraq, which include factories, hospitals, and other facilities. The analysis of radionuclides measurement was done by using the high purity Germanium (HPGe) detector coupled with a computer-based high-resolution multichannel analyzer. The results showed that the average specific activities of ^{228}Ac in sample 6, ^{214}Bi, ^{234m} Pa, and ^{226}Ra in sample 2, ^{40}K in sample 10, and ^{137}Cs in sample 21 were higher than other samples. However, the activity concentrations of the analyzed radionuclides were very low in most samples.

Introduction

Humans are exposed to radiation from natural sources, such as ^{238}U and ^{232}Th series, and natural ^{40}K or anthropogenic sources, such as ^{137}Cs [1]. Assessing the effects of radiation exposure based on the knowledge of radionuclide distribution and radiation levels in the environment [2] is important for public health protection [3]. Such studies are important in analyzing the absorbed doses and health risks. Furthermore, documenting any future possible changes in the environmental radioactivity induced by humans [4], especially in Iraq, is important because Iraq has undergone series of wars since 1980. The main objective of this study is to evaluate the radioactivity levels and health risks due to terrestrial radionuclide in soil. In this study, the specific activities of the radionuclides and the γ-radiation dose were measured by using the high purity Germanium (HPGe) detector.

Experimental details:

Soil samples were obtained from different locations in the middle and northern parts of Iraq. These locations have different geographies, soil types, and nature of work. The locations are shown in Table 1.

The samples were dried at 60 ^{o}C [5] and crushed into fine powder. The crushed powder was weighed and sealed in Marinelli beakers. The sealed beakers were stored in the laboratory (under natural conditions) for four weeks prior to measurement to achieve a radiological equilibrating [6]. The HPGe detector used had a relative efficiency of 40% and energy resolution of 1.745 keV at 1332 keV ^{60}Co peak. Before measurement, HPGe was calibrated by using ^{137}Cs with gamma ray energy of 662 keV and ^{60}Co with energy of 1173 and 1332 keV. Converting the channel number to the energy scale is possible by using these sources.

Prior to the activity measurement of the selected samples, the environmental gamma background in the laboratory was determined by using an empty Marinelli beaker under identical measurement conditions, while measuring time was adjusted to 7200 sec. The ^{226}Ra concentration was determined from gamma lines of 295, 352, 609, and 1765 keV, which originated from ^{214}Pb and ^{214}Bi as the mean values of the results of these gamma lines. The concentration of ^{232}Th was determined from gamma lines of 583, 911, and 2614 keV from ^{208}Tl and ^{228}Ac. The ^{40}K concentration was calculated from its 1460.8 keV gamma line. The specific activity concentration of the investigated samples was calculated using Equation (1) [7].

$$A = \frac{CPS \times 1000}{\varepsilon(abs) \times I_{\gamma}(abs) \times W} \quad \ldots\ldots \quad 1$$

Where:

$A_{.}$ is the activity concentration (Bq/kg).

CPS: is the net peak count per second.

$\mathcal{E}(abs)$: is the absolute gamma peak detection efficiency.

I_{γ}: is the absolute gamma intensity of the corresponding gamma ray energy considered.

And *W*: is the weight of sample (g).

The distribution of ^{226}Ra, ^{232}Th, and ^{40}K in soil was not uniform. Uniformity with respect to exposure to radiation was defined in terms of radium equivalent activity (Ra_{eq}) in Bq/kg to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th, and ^{40}K. Ra_{eq} was calculated by using Equation (2)

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_{K} \quad \ldots\ldots\ldots \quad 2$$

Where:

C_{Ra}, C_{Th} and C_{K} are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively.

The 370 Bq/kg ^{226}Ra, 259 Bq/kg ^{232}Th, and 4810 Bq/kg ^{40}K were assumed to produce the same gamma dose rate [8].

External terrestrial gamma dose rate as a result of ^{238}U and ^{232}Th in soil was calculated by assuming that a secular equilibrium was established with their decay products [^{238}U

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series: ^{226}Ra (186.0 keV), ^{214}Pb (351.9 keV), and ^{214}Bi (609.2 keV); ^{232}Th series: ^{228}Ac (911 keV), ^{208}Tl (583.1 keV)]. The absorbed dose rate was calculated from the concentrations of the radionuclide based on the radioactivity levels of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs. The gamma absorbed dose rate in air (ADRA) in nGy/h at 1 m above the ground level was calculated using Equation (3) [9].

ADRA (nGy/h) = $0.461C_{Ra}$ x $0.623C_{Th}$ x $0.0417C_{K}$ x $0.1243C_{Cs}$ …… 3

Where:

C_{Cs} is activity concentration (Bq/kg) of ^{137}Cs.

The external hazard index, H_{ex}, is given as [6, 8].

$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_{K}/4810$ …... 4

From the viewpoint of radiation protection, the value of this index must be less than unity to keep the radiation hazard insignificant. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370 Bq/kg).

To estimate annual effective doses, (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the indoor occupancy factor were obtained. The annual estimated average effective dose equivalent received by a member was calculated using a conversion factor of 0.7 Sv/Gy. This factor was used to convert the absorbed dose rate to the human effective dose equivalent to an outdoor occupancy of 20% and 80% for indoors. The annual effective doses were determined as follows [6, 8, and 9]:

Indoor (Sv) = absorbed dose (Gy/h) × 24 ×365 × 0.7 × 0.8 ….. 5

Outdoor (Sv) = absorbed dose (Gy/h) × 24 ×365 × 0.7 × 0.2 ..… 6

Results and discussion:

The specific activities of radionuclides, ^{228}Ac, ^{214}Bi, ^{234m} Pa, ^{40}K, ^{226}Ra, and ^{137}Cs in the soil samples collected from the mentioned locations are given in Table 2. The range of activity concentration in the soil samples for ^{228}Ac varied from 5.8 to 34.5 Bq/kg, 10.9 to 431.3 Bq/kg for ^{214}Bi, 102.2 to 485.9 Bq/kg for ^{40}K, and 18.41 to 728.55 Bq/kg for ^{226}Ra. The minimum activity concentration for ^{234m} Pa and ^{137}Cs was below the detector detection limit, whereas the maximum activity concentration was 548 and 17.7 Bq/kg, respectively. The highest ^{137}Cs activity levels were found in sample 2, which can be referred to as the accumulation of this radionuclide in the soil. Specific activities of the radionuclides at locations 3, 4, 5, 7, 8, 11, 12, 13, 14, 17, and 20 were below the detection limit. Therefore, these locations were considered to be safe working environments for workers. The remaining locations were categorized as unsafe sites because of the presence of high activity concentration. Ra_{eq}, H_{ex}, ADRA, and annual effective dose in soil samples are shown in Table 3. Samples 1, 2, and 21 had higher values than other samples.

Conclusion:

The examined sites produced a prospective radiological map for the radionuclides that existed in the investigated workplaces. This survey is important in identifying locations with high activities that can lead to health hazards to employees. The specific activities of radionuclides in soil are:

1. The specific activities of ^{40}K are mostly below the permissible value of 420 Bq/kg [9] except for samples 9, 10, 15, 16, 18, 19, and 21. Generally, they are close to the permissible value.
2. For ^{228}Ac, ^{137}Cs, ^{214}Bi, ^{234m} Pa, and ^{226}Ra, the specific activities are within the permissible values except for samples 1 and 2.
3. Regions 1 and 2 have the maximum values of Ra_{eq}, H_{ex}, ADRA, and annual effective dose compared with other regions. The maximum values are attributed to the use of banned weapons in 2003.
4. Workers are recommended to take preventive measures and be subject to periodic radiological checks.

Table (1): Locations of the collected samples

Sample Number	Location of samples
1	The State Company of Phosphate - location 1
2	The State Company of Phosphate - location 2
3	The State Company of Glasses and Ceramic (Glasses) - location 1
4	The State Company of Glasses and Ceramic (Glasses) - location 2
5	The State Company of Glasses and Ceramic (Ceramic) - location 1
6	The State Company of Glasses and Ceramic (Ceramic) - location 2
7	Arab Company for Detergent Chemicals - location 1
8	Arab Company for Detergent Chemicals - location 2
9	The State Company of North Oil - location 1
10	The State Company of North Oil - location 2
11	Mishraq Sulphur State Company - location 1
12	Mishraq Sulphur State Company - location 2
13	The State Company of North Fertilizer Plant - location 1
14	The State Company of North Fertilizer Plant - location 2
15	Nuclear Medicine - Basra General Hospital
16	Nuclear Medicine – Department of Health Mosul
17	X-Ray - Basra General Hospital
18	X-Ray - Al-salaam hospital
19	X-Ray - Shirqat General Hospital
20	CT Scanning – Tikrit General Hospital
21	Ministry of Science and Technology - location 1
22	Ministry of Science and Technology - location 2

Table (2): The Specific Activities of Radionuclides in Soil samples (Bq/Kg)

Sample Code	^{232}Th (^{228}Ac)	^{238}U		^{40}K	^{226}Ra	^{137}Cs
		^{214}Bi	^{234m}Pa			
1	10.8±1.7	379.6±5.09	489.6±67.7	137±10.9	641.22±8.60	5.66±0.55
2	5.8±1.4	431.3±5.36	548±63.7	102.2±9.3	728.55±9.05	17.7±0.8
3	15.09±1.04	17.4±0.8	BDL*	284.9±15.48	29.39±1.35	5.6±0.43
4	14.23±1.1	17.9±0.9	BDL	237.7±14.19	30.24±1.52	3.48±0.37
5	13.2±0.99	14.6±0.79	BDL	207.5±12.5	24.66±1.33	1.39±0.26
6	34.5±1.9	25.4±1.58	BDL	411.8±25.2	42.91±2.67	BDL
7	8.6±1.01	15.6±0.9	BDL	259.8±15.5	26.35±1.52	2.25±0.32
8	9.3±0.84	13.01±0.7	BDL	216.5±12.9	21.98±1.18	BDL
9	17.35±1.18	21.1±1.01	BDL	478.4±23.3	35.64±1.71	2.39±0.33
10	18.4±1.39	25.6±1.24	BDL	485.9±24.7	43.24±2.09	1.7±0.36
11	10.9±0.94	15.6±0.83	BDL	404.1±19.9	26.35±1.40	2.26±0.3
12	8.4± 0.89	13.78±0.79	BDL	332.2±17.7	23.28±1.33	1.68±0.28
13	10.6±1.23	12.4±1	BDL	278.8±18.29	20.95±1.69	2.28±0.4
14	11.02±1.2	16.8±1.02	BDL	325.7±19.37	28.38±1.72	5.04±0.52
15	21.5±1.4	20.67±0.77	BDL	452.4±23.15	34.92±1.30	BDL
16	16.8±0.93	19.2±0.9	BDL	435.19±21.14	32.43±1.52	2±0.28
17	13.14±0.99	13.57±0.76	BDL	376.6±18.8	22.92±1.28	2.97±0.33
18	9.17±0.89	10.9±0.72	BDL	462.1±22.16	18.41±1.22	BDL
19	9.56±1.05	14.65±0.89	BDL	453.03±23.28	24.75±1.50	BDL
20	7.57±0.77	11.64±0.66	BDL	383.77±18.4	19.66±1.11	BDL
21	24.5±1.76	21.9±1.45	BDL	429.4±19.2	36.99±2.45	10.5±0.86
22	11.7±0.85	12.4±0.81	BDL	214.3±10.7	20.95±1.37	2.19±0.3

*B.D.L below detection limit.

Table (3): The radium equivalent (Ra_{eq}), external hazard index (H_{ex}), absorbed dose rate in air (ADRD) and annual effective dose in soil samples

Sample Code	Ra_{eq} (Bq/kg)	H_{ex}	ADRD (nGy/h)	Indoor (mSv)	Outdoor (mSv)
1	667.21	1.80	7993.95	39.21	9.8
2	744.71	2.01	11379.05	55.82	13.96
3	72.91	0.20	1053.4	5.17	1.29
4	68.89	0.19	529.84	2.6	0.65
5	59.52	0.16	139.78	0.69	0.17
6	123.95	0.33	BDL	BDL	BDL
7	58.65	0.16	197.2	0.97	0.24
8	51.95	0.14	BDL	BDL	BDL
9	97.29	0.26	1052.56	5.16	1.29
10	106.97	0.29	978.43	4.8	1.2
11	73.05	0.20	390.5	1.92	0.48
12	60.87	0.16	162.45	0.8	0.2
13	57.57	0.16	210.1	1.03	0.26
14	69.22	0.19	764.21	3.75	0.94
15	100.5	0.27	BDL	BDL	BDL
16	89.97	0.24	705.98	3.46	0.87
17	70.71	0.19	501.5	2.46	0.62
18	67.11	0.18	BDL	BDL	BDL
19	73.30	0.20	BDL	BDL	BDL
20	60.04	0.16	BDL	BDL	BDL
21	105.09	0.28	6083.3	29.84	7.46
22	54.18	0.15	171.2	0.84	0.21

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All the investigated locations were mentioned in Table1.

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