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DETERMINATION OF THE NATURAL RADIOACTIVITY LEVELS IN SELECTED AREAS OF ZARQA, JORDAN

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ABSTRACT

In the current study, the concentration levels of naturally occurring radioactive materials (NORMs) of ^{238}U, ^{232}Th, and ^{40}K in the surface soil samples of selected areas in Zarqa/Jordan were studied. The collected soil samples were analyzed by means of gamma-ray spectrometry. Radioactivity concentration of the naturally occurring radionuclide of ^{238}U, ^{232}Th, and ^{40}K in the soil samples varies from 30.72± 2.48 Bq kg^{-1} to 1428.57 Bq kg^{-1}, below detection limit (BDL) to 22.98 ±2.95 Bq kg^{-1}, and < 8.21 Bq kg^{-1} to 584.59 ±26.3 Bq kg^{-1} respectively. Radium equivalent activity, absorbed dose rate, annual effective dose equivalent were also calculated for assessment of radiological risk. External hazard value (H_{ex}) is between 0.71 and 3.863. In this study ^{238}U concentration is higher than the acceptable reported by UNSCEAR-2000.

KEYWORDS: Gamma-Ray Spectrometry, HPer-Pure Germanium (HPGe) Detector, Radium Equivalent Activity, Annual Effective Dose Equivalent, Radiation Hazard Indices.

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Original Article

INTRODUCTION

Radioactivity is a natural phenomenon occurring in the environment. The most common terrestrial radio elements that produce gamma-rays are uranium ^{238}U, thorium ^{232}Th, and potassium ^{40}K (United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)). Natural environmental radioactivity depends on geological conditions, and appears at different levels in the soils of each different geological region (Rohit Menra, Manmahan Singh). Primordial radionuclides, such as ^{40}K, and radioisotopes from ^{238}U, and ^{232}Th series and their products in the surface soil is the main source of pollution of natural radioactivity, the largest source of radiation dose to humans.

Concentration levels of naturally occurring radioactive materials in soil samples collected from nine locations across the old phosphate mine at Russifa of Jordan were studied by Al-Bedri et al (2014)using HPGe detector. They found that the measurement values of specific activity concentrations and radium equivalent activities of ^{238}U, ^{232}Th series and ^{40}K were found to be higher than the worldwide median values recommended by UNSCEAR-1988 and UNSCEAR-2000. Activity concentrations of naturally occurring and technological enhanced levels of radiation in 34 representative soil samples in north of Dukhan Qatar were determined by Al-Sulaiti et al (2012) using HPGe detector. They observed highest value of ^{226}Ra concentration among 129 soil samples. Bala et al (2014) measured the concentration of ^{238}U, ^{232}Th, and ^{40}K in building material and soil samples collected from different location of Una, Himachal Pradesh, India. They found that the concentration of ^{238}U in soil sample is lower than the world figures. However, the concentration for ^{226}Ra is very much comparable and

concentration of ^{40}K is higher than the world figures.

Similar studies have been determined the natural radionuclides concentrations in the surface soil (O. Abu-Haija (2012), Ademola et al (2014), Malkaw et al (2013), Apriantoro et al (2013), Saleh (2014), Harab et al (2014), and Yousef et al (2007.

The aim of the current study is to measure natural radioactivity of ^{238}U, ^{232}Th, and ^{40}K in the soil samples from different areas of Zarqa/Jordan, and estimated of the radiation hazard.

MATERIAL AND METODS

- **Soil Sampling and Preparation**

Soil samples were collected randomly from different areas of Zarqa/Jordan during September 2015, samples locations are marked in Figure 1, and their identifications details are listed in Table 1.

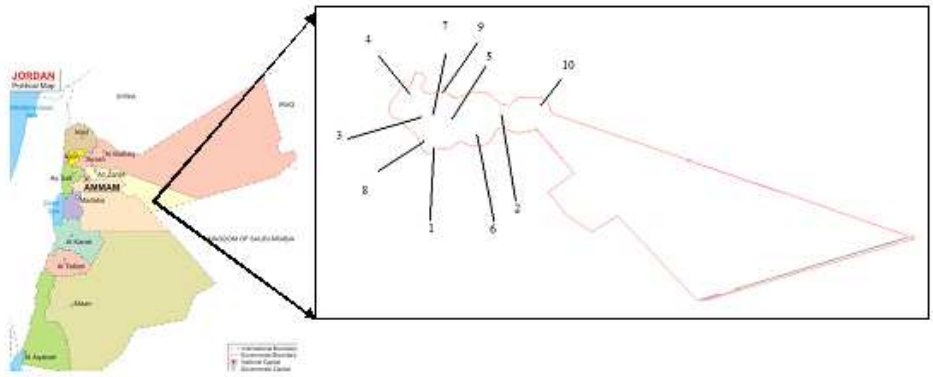

Figure 1

Table 1: Sample Identification and Global Positioning System (GPS)

Sample Number	Wet Mass (g)	Dry Mass(g)	Geometry Mass(g)	GPS Position	
				LAT.	LONG
1	1630	1615	91.8	32^0 0`12.33"	36̊`57.20"
2	1470	1460	86.6	32^0 3`33.19"	36̊`2.88"
3	1185	1175	81.8	32^0 2`25.04"	36̊`32.29"
4	1335	1285	70.7	32^0 9`21.88"	35^0 58`3.43"
5	1170	1155	73.8	32^0 5`20.79"	5 36̊`42.07"
6	1290	1285	95.7	32^0 3`27.57"	36̊`57.20"
7	1190	1175	74.2	32^0 4`29.19"	36̊`47.77"
8	1340	1335	89	31^0 59`55.82"	36̊`45.95"
9	1345	1335	82.7	32^0 9`10.15"	36̊`55.01"
10	1015	970	79.8	32^0 8`52.39"	36̊`21.28.76"

The collected samples were sent to the radiation measurement laboratory of Jordan Atomic Energy Commission (JAEC). The 10 samples were cleaned and crushed, then homogenized using mixer. Each homogenized sample was dried in oven at 105^0 C about 16 hours.

- **Detection Technique**

Spectral analysis of the collected samples was carried out using γ-ray spectrometry equipped with high purity germanium (HPGe) detector of 50% relative efficiency. The spectral analysis is performed with the aid of computer

software ORTEC Gamma Vission-32. Energy calibration was done by using the reference nuclides (^{241}Am, ^{109}Cd, ^{139}Ce, ^{60}Co, ^{137}Cs, ^{113}Sn, ^{85}Sr, ^{88}Y, ^{54}Mn, and ^{65}Zn). The activity concentration of each sample is calculated, taking into account, the counting time, the geometry of the samples, and the mass of each sample.

RESULTS AND DISCUSIONS

Direct determination of ^{238}U (^{226}Ra) using γ-ray spectrometer is very hard because it does not have γ-lines of its own. But have been determined from the average concentrations of its daughter products ^{214}Pb and ^{214}Bi. The activities of its daughter equal those of their parents in the state of secular equilibrium. ^{232}Th activity concentration was determined from the average concentration of ^{208}Tl, ^{212}Pb, ^{228}Ac in the collected samples, ^{40}K activity concentration was measured for its own γ-ray energy of 1461.8 keV (Harb, S., 2008).

Table 2 shows the activity concentration of the studied nuclei ^{238}U, ^{232}Th, and ^{40}K.

Table 2: Activity Concentration of the Studied Nuclei ^{238}U, ^{232}Th, and ^{40}K

Soil Sample No.	Activity Concentration Bq/Kg		
	^{226}Ra(^{238}U)	^{232}Th	^{40}K
1	75.23 ±12.6	6.89±1.98	82.23±11.7
2	43.92 ± 2.92	10.54±1.31	187.67±14.4
3	103.19±19.37	13.47±2.50	153.54±11.4
4	69.11±15.57	22.98±2.95	584.59±26.30
5	130.12±5.08	14.71±2.06	210.8±13.40
6	74.30±14.34	10.94±2.25	208.24±14.60
7	111.99±4.33	7.66±1.50	110.62±13.70
8	1428.567±141.8	BDL*	< 8.21
9	47.21±3.43	13.73±0.45	291.49±16.60
10	30.72±2.48	7.18±0.89	291.31±16.90
This study rang	30.72-1428.57	BDL-22.98	< 8.21-584.59
This study mean	211.44	11.10	212.87
Worldwide rang**	17-60	11-64	140-850
Mean**	35	30	400

***BDL:** below detection limit

**M. Bashir et al (2013)

In this study the measured activity concentration of ^{238}U in soil was higher than that of ^{232}Th and ranged between 30.72 Bqkg^{-1} to 1428.57 Bqkg^{-1} with mean of 211.44 Bqkg^{-1}, and for ^{232}Th ranged between BDL to 22.98 Bqkg^{-1} with mean of 11.10 Bqkg^{-1}, whereas ^{40}K activity concentration ranged between < 8.21 Bqkg^{-1} to 584.59 Bqkg^{-1} with average 212.87 Bqkg^{-1}. The wide variation of ^{238}U activity concentrations especially in the sample number 8 is due to existing of old phosphate mine at Russifa which is in Zarq area. One among the samples has activity concentration higher than the others. This may be due to use of more fertilizers in the soil Bala et al (2014). The measured levels of ^{238}U is higher than the world average, whereas for ^{232}Th, and ^{40}K are lower than the world averages.

Calculation of the Radiological Effects

Radium equivalent (Ra_{eq}), absorbed dose rate (D), annual effective dose equivalent (AEDE), external radiation hazard index (H_{ex}), and internal radiation hazard index (H_{in}) have been used for assessment for naturally occurring radioactive materials (NORM) ^{238}U, ^{232}Th, and ^{40}K.

- **Radium Equivalent (Ra_{eq})**

The exposure to the γ-rays of materials that contain ^{238}U, ^{232}Th, and ^{40}K is defined in terms of radium equivalent given by (UNSCEAR-2000-17,19)

$$Ra_{eq}(Bq\ kg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_K \leq 370$$

Where: A_{Ra}, A_{Th}, and A_K are specific activity concentrations of Radium, Thorium and Potassium respectively.

- **Absorbed Dose Rate (D)**

Absorbed dose rate is defined by (UNSCEAR-1988,24)

$$D(nGy\ h^{-1}) = 0.427A_{Ra} + A_{Th} + 0.043A_K$$

The absorbed dose rate in air outdoors at 1m above the ground surface due to specific activity concentrations of ^{238}U, ^{232}Th, and ^{40}K.

- **Annual Effective Dose Equivalent** (AEDE)

Annual effective dose equivalent due to the activity in soil is calculated by the equation:

$$AEDE(mSv\ y^{-1}) = D(nGy\ h^{-1}) \times 8760(hy^{-1}) \times 0.2 \times 0.7(Sv\ Gy^{-1}) \times 10^{-6}$$

Where the values 0.7 $SvGy^{-1}$ is the conversion coefficient from absorbed dose in the air to effective dose received by adults, 8760 is the time in hours in one years, 0.2 represents the outdoor occupancy factor (UNSCEAR-2000), and is the observed dose rate.

The maximum permissible limit of Ra_{eq} activity is 370 $Bq\ kg^{-1}$ corresponds to annual effective dose equivalent to 1 $mSvy^{-1}$ for general public. For radiation workers, the five years average is 100 mSv (ICRR-60. 1990)

- **External (H_{ex}) And Internal (H_{in}) Radiation Hazard Indices**

The external hazard index (H_{ex}) was calculated from the equation (Al-Badri et al, 2014)

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4180} \leq 1$$

Whereas the internal hazard index (H_{in}) was calculated from the equation

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4180} \leq 1$$

Table 3 shows the different radiological effects of ^{238}U, ^{232}Th, and ^{40}K in the surface soil of Zarqa area.

Table 3: Different Radiological Effects of ^{238}U, ^{232}Th, and ^{40}K

Soil Sample No.	Ra_{eq} (Bq/Kg)	D (nGy/h)	AEDE (mSv/y)	H_{ex}	H_{in}
1	91.41	40.22	0.049	0.247	0.450
2	77.63	35.74	0.044	0.210	0.328
3	134.27	59.58	0.073	0.363	0.642
4	146.98	69.86	0.086	0.397	0.584
5	167.39	74.36	0.091	0.452	0.804
6	105.98	47.92	0.059	0.286	0.487
7	131.46	57.65	0.071	0.355	0.658
8	1429.20	610.35	0.749	3.863	7.724

9	89.29	41.78	0.051	0.241	0.369
10	63.42	30.40	0.037	0.171	0.254
This study Average	243.704	106.787	0.131	0.659	1.230
±S.D	396.4	168.4	0.207	1.07	2.17
Table 3: Contd.,					
This study Range	63.42-1429.20	30.4-610.35	0.037-0.749	0.171-3.863	0.254-7.724
World Median Value*	< 370	57	0.48	≤1	≤1
World Range*		18-93	0.3-0.6		
*UNSCERA-2000					

The estimated radium equivalent activity of the surface soils vary from 63.42 $Bq\ kg^{-1}$ to 1429.20 $Bq\ kg^{-1}$, one of the samples exceeds the permissible level (370 $BqKg^{-1}$) recommended by UNSCEAR-2000.

The absorbed dose rate lies between 30.4 $nGyh^{-1}$ and 610.35 $nGyh^{-1}$, with average of 106.787 $nGyh^{-1}$ was higher than the permissible limit which is expected because the presence of phosphate mines.

Annual effective dose equivalent were found to be vary from 0.037 $mSvy^{-1}$ to 0.749 $mSvy^{-1}$ with average of 0.131 $mSvy^{-1}$, the values are less than worldwide median except for one sample as shown in table 3, the same sample have higher value of external and internal hazard indices.

CONCLUSIONS

The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil samples from selected area of Zarqa have been studied using HPGe detector. The results of the current study show difference of the activity concentration between different areas. The concentration of ^{238}U in one of the soil samples is higher than the world figures; the same sample has higher radium equivalent activity, absorbed dose rate, annual effective dose equivalent, and external and internal hazard indices. All other samples were within the permissible limit.

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