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Investigation of Radioactivity Levels and Radiation Hazards in Soil Samples Collected from Different Sites in Tafila Governorate, Jordan

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Abstract: Natural and artificial radioactivity levels in surface soil samples collected from various sites in Tafila governorate in Jordan, have been determined using gamma-ray spectrometry. The average concentrations of ^{238}U, ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs were 23.6 ± 3.1, 23.3 ± 0.7, 16.7 ± 1.0, 234.1 ± 9.85 and 5.4 ± 0.3 Bq kg^{-1}, respectively. The activity ratio between ^{238}U and ^{226}Ra for all samples was close to unity. The average values of radium equivalent activity, gamma-absorbed dose rate in air, annual effective dose equivalent, external hazard index, internal hazard index and excess lifetime cancer risk were 65.2 Bq kg^{-1}, 30.6 nGy h^{-1}, 37.6 μSv y^{-1}, 0.18, 0.24 and 1.39×10^{-4}, respectively. These values for the collected samples do not exceed the permissible limits. Therefore, the studied area does not pose any significant radiation hazard to the public. Furthermore, it has been found that the activity concentration of ^{137}Cs radionuclide is within the values of recommended safe levels.

Keywords: Soil samples, Natural radioactivity, Artificial radioactivity, Gamma-ray spectrometry, Radiation hazard assessment.

1. Introduction

Due to Jordan's growing need for electrical power, Jordan government has commissioned the Jordan Atomic Energy Commission JAEC to construct a nuclear power plant capable of generating electricity. Therefore, a need has emerged for a radiological mapping of Jordan, which is intended to enhance our knowledge of the varying radioactivity in our environment. As one of the primary research fields in the Department of Physics in Tafila Technical University (TTU), Jordan, the present study is a corner stone in enhancing and enriching the radiological mapping for different sites in Tafila governorate. Therefore, the main aim of this work is to measure the specific activities of ^{238}U, ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs and to estimate the radiological hazard associated with these radionuclides in soil samples obtained from different areas in Tafila governorate in Jordan.

^{238}U, ^{226}Ra, ^{232}Th and ^{40}K radionuclides mainly constitute the natural radioactivity which is nearly found everywhere in soil, water and rock [1-5]. ^{137}Cs is the most important anthropogenic radionuclide with a relatively long half-life of 30.17 years [6]. It is widely distributed globally due to nuclear weapon testing and nuclear power plant accidents. Humans can get exposed to radiation from these radionuclides in two ways, either by direct exposure or by the accumulation of these

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radionuclides in the body through inhaling or food consumption. Soil is considered to be the medium of transferring these radionuclides to human beings and constitutes a serious radiation hazard. Moreover, determining the activity concentrations of natural and anthropogenic radionuclides is important for the purposes of establishing baseline data for ascertaining their radiological levels.

There have been several studies in the past decades conducted for the determination the natural and/or anthropogenic radioactivity levels in Jordan [7-13]. However, these studies were specific to certain geographical areas and did not include all areas of Jordan. In a recent study [14], the natural radioactivity levels and radiation hazard in the south of Jordan were assessed. It focused on determining the natural radioactivity levels and the associated hazards, but did not study the levels of anthropogenic radiation in this region. All the previous reasons and the lack of measurements motivated the authors to determine the activity concentrations of both natural and anthropogenic radionuclides as well as the radiation hazards in Tafila region.

In this paper, the natural and anthropogenic radioactivity levels in surface soil samples in Tafila governorate in Jordan are investigated using gamma-ray spectrometry. This type of work in the study area is distinctive that no prior work has investigated the activity concentrations of anthropogenic radionuclides as well as the natural radionuclides and the radiation hazards in the sites located nearby the Royal highway and other touristic sites; namely, Dana Wildlife Reserve and the old Sela' town in Tafila. Thus, there is a great interest to provide information regarding the radioactivity levels in these areas to the inhabitants and visitors of these areas and to provide them with awareness advices about the radiological effects on their health.

The rest of the paper is organised as follows: In Section 2, details of the soil sample collection and preparation, detector calibration and sample analysis utilized during this study are described. The calculation of radium equivalent activity, gamma-absorbed dose rate in air, annual effective dose equivalent, external and internal hazard indices and excess lifetime cancer risk are presented in Section 3. The activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs as well as the results of radiation hazards are presented in Section 4. The last section summarizes the work and conclusions are discussed.

2. Experimental Methods and Materials

2.1 Study Area

Tafila governorate is located in the south of Jordan about 180 km from Amman the capital of Jordan. Its population is nearly 100,000. Its area is approximately 2100 km^2. It is considered to be one of the oldest areas in the country which was the most populated as result of the succession of different nations. Tafila is mostly a mountainous area as it has mountain chains of a height ranging from 1200 m in the eastern part to1600 m in the west (Al-Qadisyya). These mountain chains are crossed with deep valleys. Dana Wildlife Reserve which is one of the biggest wildlife reserves in Jordan is part of Tafila governorate. Its area is about 300 km^2 with curved terrain facing the Afro-Asian Rift-Valley.

2.2 Soil Sample Collection and Preparation

In this study, sixteen soil samples were collected from different sites in Tafila governorate. Soil samples were taken to a depth of 5 cm and Global Positioning System GPS was used for tracking the data recording as seen in Table 1 and Fig. 1.

For homogeneous soils, the samples were sieved in order to separate stones and grasses from the samples. Then, the samples were crushed and placed in an oven at 95 ^{o}C for 15 h. Finally, the samples were sealed in plastic containers and left for one month before counting in order to ensure equilibrium between ^{226}Ra and ^{222}Ra and their daughter products.

TABLE 1. Sample identifications and GPS position locations.

Site	Site Name	Altitude (m)	GPS position	
			LAT.	LONG.
Site 1	Sa'wa	1240	30°46' 19"	35°36' 34"
Site 2	Eima	900	30°52' 36"	35°35' 45"
Site3	Rawath	1450	30°42' 16"	35°38' 09"
Site4	Al-Qadisyya	1590	30°39' 53"	35°37' 16"
Site5	Umm Sarab	1270	30°44' 53"	35°38' 01"
Site6	Garandal	1340	30°43' 15"	35°38' 44"
Site7	Zoabar	1370	30°46' 49"	35°36' 46"
Site8	Busira	1170	30°43' 36"	35°37' 15"
Site9	Dana	1290	30°40' 31"	35°36' 47"
Site10	Izhaiqa	1260	30°49' 12"	35°38' 29"
Site11	Lahda	1460	30°41' 52"	35°35' 56"
Site12	Al Ayes	1240	30°50' 44"	35°38' 06"
Site13	Dra'	1365	30°46' 02"	35°37' 47"
Site14	Alhala	1420	30°46' 15"	35°38' 27"
Site15	Sela	1090	30°46' 18"	35°35' 04"
Site16	Rashadiyah	1560	30°40' 59"	35°37' 21"

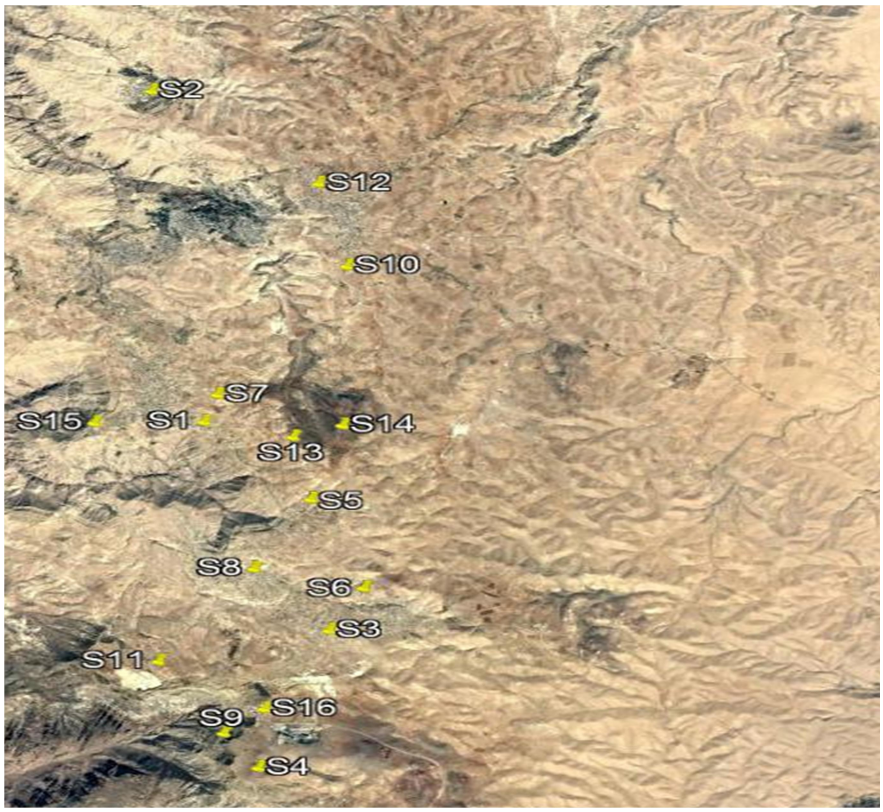

FIG. 1. Location map of the study area (using Google Maps).

2.3 Detector Calibration

For identifying gamma-emitting radionuclides and determining their activity concentrations, a gamma-ray spectrometry with High Purity Germanium (HPGe) detector measuring system of 50 % relative efficiency manufactured by Canberra [22] was used. The gamma radiation of the environment may influence the gamma spectrometry which in turn might affect the measurement. Therefore, the detector was surrounded by a lead shield. The background spectrum was collected before the measurements and the peaks of the background

spectrum were subtracted using peak area correction.

The energy calibration was performed using radioactive sources (^{137}Cs, ^{57}Co, ^{65}Zn, ^{109}Cd, ^{113}Sn, ^{54}Mn, ^{155}Eu, ^{22}Na and ^{241}Am). These point sources were manufactured by Canberra on 18 January 2010 (except for ^{155}Eu and ^{22}Na, which were produced on 23 June 2009). The initial activity for each point source is 37 kBq. Efficiency calibration has also been done before the measurements using a standard -Petri dish-calibration mixed source. The performed efficiency calibration curve has been corrected for cascade summing effect using a geometry correction software.

2.4 Sample Analysis

Soil samples were placed facing the detector. The counting time for each sample was 24 h. Any thumb rule concerning the acquisition time does not exist, because it depends on achieving the desired counting statics on the primary line emitted by the nuclide subject of measurement.

The average activity concentrations of the three photopeaks of ^{214}Pb at 295.2 *keV* and 352.0 *keV* and ^{214}Bi at 609.3 *keV* were used to determine the activity concentration of ^{226}Ra. The activity concentration corresponding to the photopeaks of ^{228}Ac at 911.1 *keV*, ^{212}Pb at 238.6 *keV* and ^{208}Ti at 583.1 *keV* was used in order to determine the activity concentration of ^{232}Th. The activity concentration corresponding to the photopeak of ^{234}Th at 63.3 *keV* was used in determining the activity concentration of ^{238}U. The activity concentrations of ^{40}K and ^{137}Cs were determined directly using the photopeaks at 1460.8 *keV* and 661.6 *keV*, respectively.

3. Calculations

3.1 Activity Concentration

The activity concentration, A, of the radionuclides present in the sample was calculated based on the following expression:

$$A = \frac{C}{\varepsilon \times I_\gamma \times w} \quad (1)$$

where A is the activity concentration in Bq kg^{-1}, C is the net count rate in counts per second, ε is the detector efficiency, I_γ is the fractional number of decays that yield the radiation to be detected and w is the sample weight in kg.

3.2 Radium Equivalent Activity

Radium equivalent activity Ra_{eq} is a common index used for the assessment of radiological hazard of radioactivity. It uses the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K to create an index of a single quantity. It was calculated, as shown in Eq. 2, based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma ray dose rate [15].

$$Ra_{eq}(Bq\,kg^{-1}) = A_{Ra-22} + 1.43\,A_{Th-232} + 0.077\,A_{K-40} \quad (2)$$

where A_{Ra-22} , A_{Th-232} and A_{K-40} are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively.

3.3 Absorbed Dose Rate

Gamma-absorbed dose rate D in air outdoors at a height of 1 m above the ground surface can be calculated using the activity concentrations of ^{238}U, ^{232}Th and ^{40}K. Gamma-absorbed dose rate D can be calculated based on the guidelines provided by UNSCEAR [16]:

$$D(nGy\,h^{-1}) = 0.462\,A_{Ra-2} + 0.604\,A_{Th-23} + 0.0417\,A_{K-40} \quad (3)$$

where A_{Ra-226}, A_{Th-2} and A_{K-40} are the activity concentrations of ^{222}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} and D is in nGy h^{-1}, respectively.

3.4. Annual Effective Dose Equivalent (AEDE)

To estimate the annual effective dose received by the public due to soil radioactivity, the following formula provided by UNSCEAR [16] was used:

$$AEDE(\mu Sv\,y^{-1}) = D(nGy\,h^{-1}) \times 8760\,h \times 0.2 \times 0.7\,Sv\,Gy^{-1} \times 10^{-3} \quad (4)$$

where 0.7 Sv Gy^{-1} is the conversion coefficient from absorbed dose in air to effective dose received by adults and 0.2 for the outdoor occupancy factor.

3.5 External and Internal Hazard Indices

The external hazard index H_{ex} deals with the external radiation effects and can be calculated using the following expression:

$$H_{ex} = \frac{A_{Ra-226}}{370} + \frac{A_{Th-232}}{259} + \frac{A_{K-40}}{4810} < 1. \quad (5)$$

The value of H_{ex} must not exceed the limit of unity for the radiation hazard to be negligible, which corresponds to the upper limit of Ra_{eq} (370 Bq kg^{-1}).

The internal hazard index H_{in} is used for internal exposure from radon ^{222}Rn and its short-lived progeny in building material. Internal hazard index H_{in} can be calculated using the following formula [17]:

$$H_{in} = \frac{A_{Ra-226}}{185} + \frac{A_{Th-23}}{259} + \frac{A_{K-40}}{4810} < 1. \quad (6)$$

3.6 Excess Lifetime Cancer Risk

To estimate the probability of developing cancer due to the radiation exposure effects for a specific lifetime of a person, the excess lifetime cancer risk, ELCR, is calculated using the following relation:

$$ELCR = AEDE \times LE \times RF \quad (7)$$

where AEDE is in $\mu Sv\, y^{-1}$, LE is the life expectancy in Jordan that is 74 years and RF is the fatal cancer risk per Sievert which is 0.05 Sv^{-1}.

4. Results and Discussion

4.1 Activity Concentration of ^{235}U, ^{226}Ra, ^{232}Th and ^{40}K

Table 2 summarizes the activity concentrations of ^{235}U, ^{226}Ra, ^{232}Th and ^{40}K collected from sixteen different locations in Tafila governorate soil. The table illustrates the activity concentration of radionuclides for each sample followed by the minimum, maximum and average values of all samples. Activity concentrations of ^{238}U for all the soil samples were found to be ranging from 11.6 to 44.3 Bq kg^{-1} with an average value of 23.6 Bq kg^{-1}. The activity concentration of ^{226}Ra ranged from 21.1 to 41.4 Bq kg^{-1} with an average value of 23.3 Bq kg^{-1}. The activity concentration of ^{232}Th varied from 7.3 to 28.8 Bq kg^{-1} with an average value of 16.7 Bq kg^{-1}. The activity concentration of ^{40}K ranged from 115.6 to 435.5 Bq kg^{-1} with an average value of 234.1 Bq kg^{-1}. Site 15 had the highest values of ^{238}U, ^{226}Ra and ^{40}K, while site 13 had the highest value of ^{232}Th. The differences in the activity concentrations among the samples depend primarily on the geological conditions [18]. However, the average activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in the studied area were lower than the worldwide average concentrations in soils of various countries which are 33 Bq kg^{-1} for ^{238}U, 32 Bq kg^{-1} for ^{226}Ra,45 Bq kg^{-1} for ^{232}Th and 412 Bq kg^{-1} for ^{40}K [4].

Table 3 compares the results of this work with results for other regions in Jordan. It is clear that the natural activity concentrations of ^{238}U, ^{226}Ra and ^{232}Th in other regions are higher. The average activity concentration of ^{40}K in Tafila is not the least, but the value is close to the values of the other regions.

In another study, Ahmad et al. [19] reported that the specific activities in soil samples collected in Amman, the capital of Jordan, were 56.4, 28.8 and 501.3 Bq Kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively. Moreover, they reported that the specific activities in Jerash soils were 27.9, 12.4 and 120 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively. The activity concentrations in soil samples taken along the Amman-Aqaba highway have been investigated by Al-Jundi et al. [9]. They found that the activity concentrations varied from 22 to 104 Bq kg^{-1} for ^{238}U, from 21 to 103 Bq kg^{-1} for ^{232}Th and from 138 to 601 Bq kg^{-1} for ^{40}K. Also, a recent study [14] reported that the average activity concentrations in areas in the southern governorates of Jordan were 45, 39, 23 and 233 Bq kg^{-1} for ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K, respectively. Table 3 shows that the average values of the activity concentrations in this study are in agreement with the previous cited results.

Fig. 2 shows the relationship between uranium and radium concentrations in soil samples collected in Tafila. A strong correlation between ^{238}U and ^{226}Ra can be seen. The ratio of ^{238}U / ^{226}Ra is very close to unity. This result is expected, since they belong to the same series and should be in equilibrium. The strong correlation between ^{238}U and ^{226}Ra indicate that the results for anyone of them represent a good predictor for the other.

TABLE 2. Activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K, in Tafila governorate soil.

Site	^{238}U (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})
Site 1	11.6 ± 1.6	12.1± 0.5	8.5 ± 0.6	115.6 ± 5.9
Site 2	28.1 ± 2.4	30.7± 0.6	17.9 ± 0.8	225.2 ± 8.2
Site 3	21.4 ± 2.0	20.8± 0.6	19.9 ± 0.9	264.4 ± 8.6
Site 4	27.6 ± 3.6	29.9± 0.7	20.9 ± 1.2	163.6 ± 11.9
Site 5	17.6 ± 2.0	17.7± 0.6	12.9 ± 0.7	203.7 ± 7.8
Site 6	19.9 ± 1.1	20.7± 0.4	17.4 ± 0.5	208.4 ± 5.7
Site 7	28.4 ± 5.9	24.7± 0.9	20.5 ± 1.2	225.1 ± 9.4
Site 8	23.2 ± 2.2	24.2± 0.7	18.9 ± 0.8	267.6 ± 9.1
Site 9	18.3 ± 3.2	17.8± 0.6	15.7 ± 0.8	419.9 ± 9.8
Site 10	19.6 ± 5.6	19.0± 1.0	14.2 ± 1.8	149.2 ± 18.0
Site 11	22.9 ± 2.2	23.8± 0.6	19.4 ± 1.1	202.5 ± 8.2
Site 12	23.4 ± 2.3	24.2± 0.6	19.7 ± 0.8	272.1 ± 8.8
Site 13	27.2 ± 4.7	27.2± 0.9	28.8 ± 1.7	289.8 ± 15.5
Site 14	22.7 ± 5.4	23.5± 0.9	7.3 ± 1.0	173.4 ± 8.5
Site 15	44.3 ± 2.4	41.4± 0.9	13.5 ± 0.8	435.5 ± 11.4
Site 16	21.4 ± 3.7	16.0± 0.8	11.4± 1.2	130.0 ± 10.9
Min.	11.6 ± 1.6	12.1 ± 0.5	7.3 ± 1.0	115.6 ± 5.9
Max.	44.3 ± 2.4	41.4 ± 0.9	28.8 ± 1.7	435.5 ± 11.4
Average	23.6 ± 3.1	23.3 ± 0.7	16.7 ± 1.0	234.1 ± 9.9

TABLE 3. Comparison of the average activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K with other parts of Jordan's soil.

Governorate	^{238}U (Bq kg^{-1})	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Reference
Irbid	43.9 ± 34.9	36.0 ± 42.9	25.3 ± 10.9	226.3 ± 84.2	[7]
Mafraq	33.3 ± 14.3	25.6 ± 7.4	27.6 ± 6.0	350.2 ± 78.1	[7]
Ajloun	31.2 ± 14.3	31.0 ± 12.9	28.0 ± 10.5	298.4 ± 113.1	[7]
Jerash	33.2 ± 15.5	30.1± 10.8	29.5 ± 7.2	315.3 ± 71.4	[7]
Balqa	37.4 ± 27.5	26.6 ± 26.7	26.0 ± 9.1	277.3 ± 101.5	[7]
Zarqa	257.8 ± 355.5	213.9 ± 315.4	21.5 ± 9.1	248.5 ± 121.5	[7]
Amman	47.0 ± 71.5	44.0 ± 69.8	20.9 ± 10.6	241.6 ± 120.8	[7]
Madaba	28.0 ± 14.4	28.0 ± 10.4	27.4 ± 5.1	303.6 ± 47.3	[7]
Ma'an	44.9 ± 6.3	57.7 ± 5.4	18.1 ± 1.4	138.1 ± 40.8	[10]
Tafila	23.6 ± 3.1	23.3 ± 0.7	16.7 ± 1.0	234.1 ± 9.9	

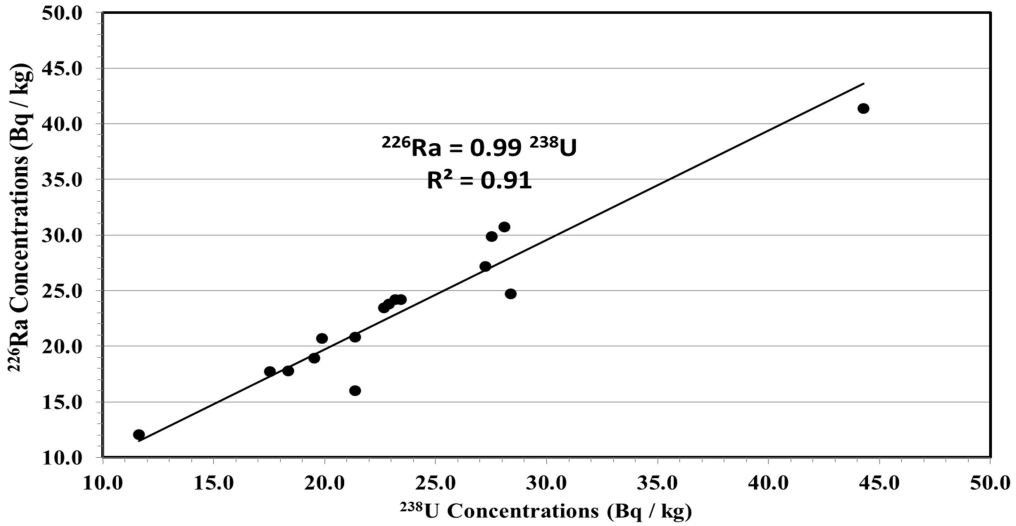

FIG. 2. Uranium *vs*. radium concentrations.

4.2 Activity Concentration of ^{137}Cs

Fig. 3 displays the activity concentrations of anthropogenic ^{137}Cs in soil samples collected from Tafila governorate. Activity concentrations of ^{137}Cs were determined for 13 soil samples, since there is no ^{137}Cs in the collected soil samples from sites 14-16. Those concentrations ranged from 0.58 to 10.57 Bq kg^{-1} with an average value of 5.41 Bq kg^{-1}. The highest activity value of ^{137}Cs is for Garandal sample (site 6). The lowest activity is for Sa'wa sample (site 1). Hamarneh and coworkers [20] found that the activity concentrations of ^{137}Cs in Irbid region varied from 12.11 to 24.83 Bq kg^{-1}. However, most of the activity concentrations of ^{137}Cs in Tafila region were less than those in Irbid region. It is worth mentioning that the reported data by IAEA expert missions mentioned that the activity concentration of ^{137}Cs should be ranging between 5 and 100 Bq kg^{-1} [16]. Globally, all soil samples in this work showed that the values of activity concentration of ^{137}Cs were much below this range.

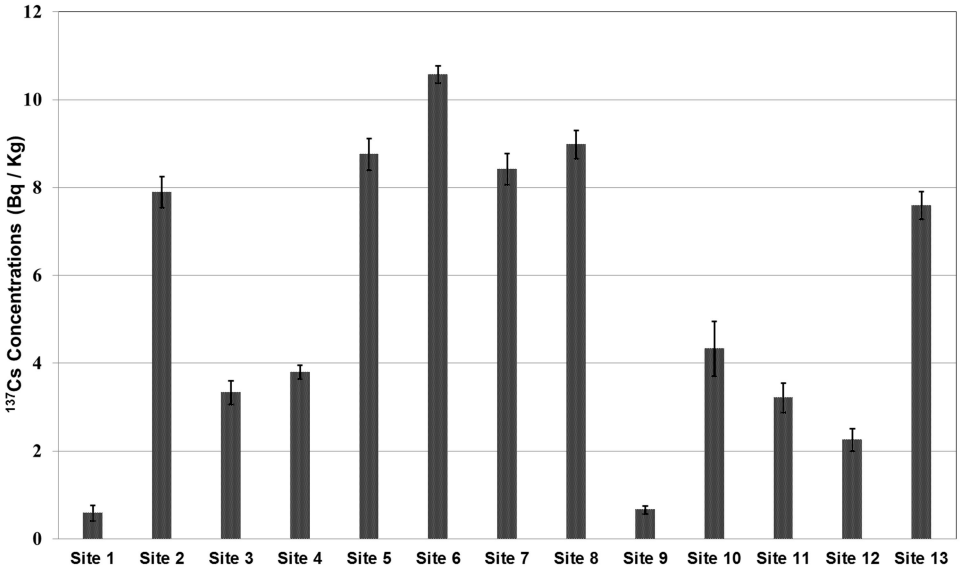

Fig. 3: ^{137}Cs activity concentrations at different locations.

4.3 Radiological Effects

The main objective of studying the radioactivity levels in soils is to calculate the radiation dose to public. Fig. 4a displays the radium equivalent activity for the soil samples collected from Tafila region. It can be clearly seen that the radium equivalent activity for all the 16 soil samples in the present work ranged from 33.1 to 90.6 Bq kg^{-1}, with an average value of 65.2 Bq kg^{-1}. The highest value is in Dra' sample (site 13) and the lowest is in Sa'wa sample (site 1). The average value of the radium equivalent activity in the present study is lower than the allowed maximum value of 370 Bq kg^{-1} [16].

Fig. 4b shows the gamma-absorbed dose rate in air for the soil samples collected from Tafila region. The gamma-absorbed dose rate varied from 15.5 nGy h^{-1} for Sa'wa sample (site 1) to 45.4 nGy h^{-1} for Sale sample (site 15), with an average value of 30.6 nGy h^{-1} which is lower than the world's average value of 60 nGy h^{-1} [16].

Results for the outdoor annual effective dose are shown in Fig. 4c. The outdoor annual effective dose varied from 19.0 to 55.7 µSv y^{-1} with an average of 37.6 µSv y^{-1}. This value is lower than the world's average value of 70 µSv y^{-1} [16].

Results for the external and internal hazard indices are shown in Fig. 4d and Fig. 4e. The external hazard index ranged from 0.09 to 0.25 with an average of 0.18, whereas the internal hazard index ranged from 0.12 to 0.37 with an average of 0.24. These values are much less than unity [17].

The values of the excess lifetime cancer risk ranged from 7.04×10^{-5} to 2.06×10^{-4} with an average value of 1.39×10^{-4}. The present average is below the world average limit of 2.9×10^{-4} [21].

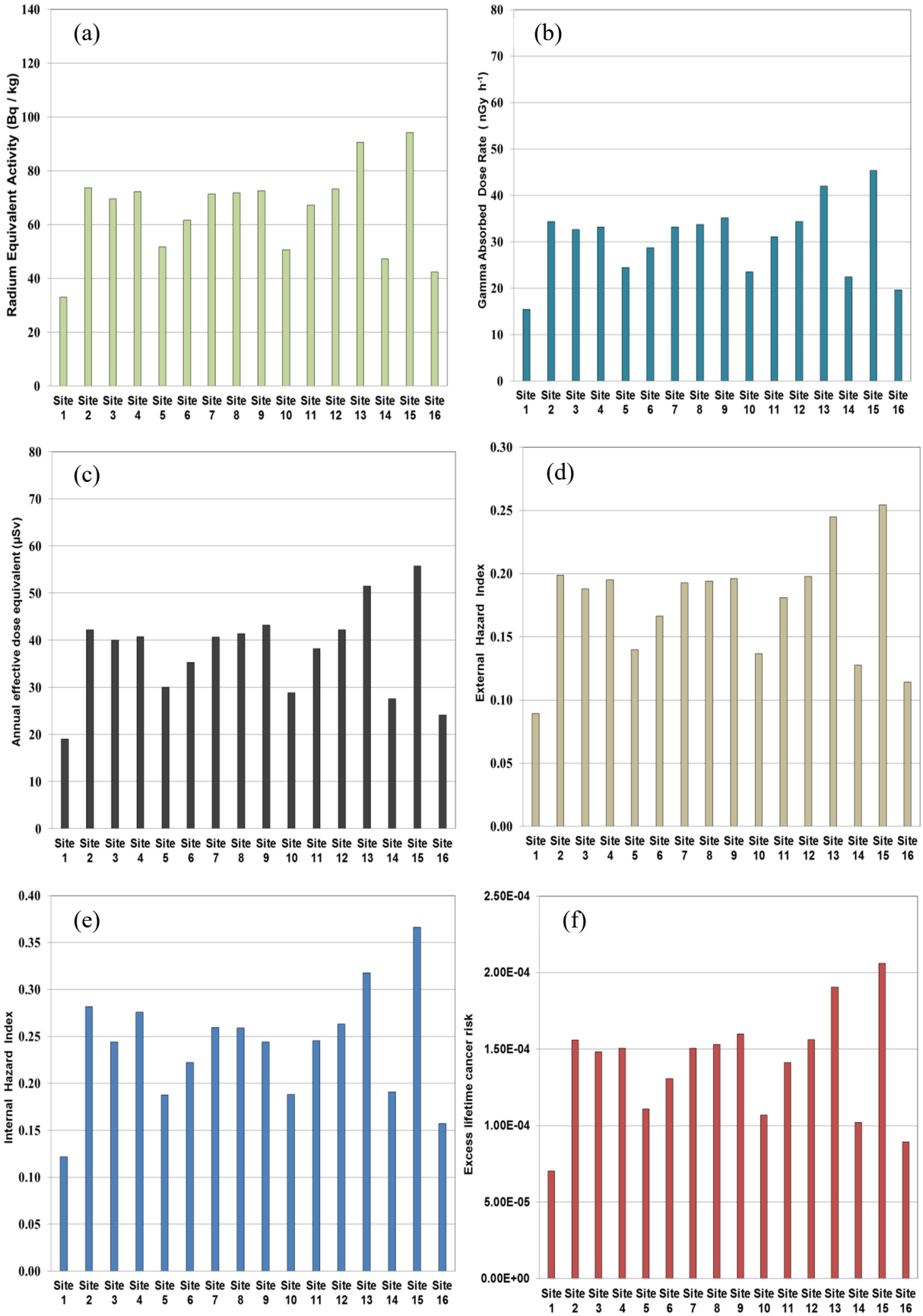

FIG. 4. Illustration of (a) Radium equivalent activity (b) Gamma-absorbed dose rate in air (c) Annual effective dose equivalent (d) External hazard index (e) internal hazard index and (f) Excess lifetime cancer risk from ^{238}U,^{226}Ra, ^{232}Th and ^{40}K, for soil samples collected from Tafila region.

Conclusion

The natural and anthropogenic radioactivity levels have been determined for 16 surface soil samples collected from various locations in Tafila governorate in Jordan. The activity concentrations were determined using gamma-ray spectrometry. The average concentrations of natural radionuclides ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K were found to be lower than the worldwide average values. The ratio between ^{238}U and ^{226}Ra for all samples was close to unity. Among the anthropogenic radionuclides, only ^{137}Cs was detected, but with very low values compared to the worldwide range. The average values of radium equivalent activity, gamma-absorbed dose rate in air, annual effective dose equivalent, external and internal hazard indices and excess lifetime cancer risk were lower than the world's average values. Our results show that the studied area does not pose any significant radiation hazard to the public.

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