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ASSESSMENT OF THE LEVELS OF NATURAL RADIOACTIVITY AND THE POSSIBILITY OF RADIATION RISKS IN SOIL SAMPLES TAKEN FROM DIFFERENT LOCATIONS IN SOUTHERN ALMAZAR-ALKARAK, JORDAN

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Abstract. A wide study of environmental radioactivity levels in soil samples from Southern Almazar-Alkarak in Jordan was performed to develop a radiological map of the area. 15 soil samples were collected from different locations across the region and subjected to analysis using a high-purity germanium detector (HPGe). The study showed that the average levels of natural radionuclides ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K were 34.5±0.98, 25.6±1.3, 32.2±3.7 and 278.5±15.7 $Bq.kg^{-1}$, respectively. Also, to evaluate the radiological danger, the radium equivalent activity (*Raeq*) is calculated, absorbed gamma dose rate (*D*), annual effective dose equivalent (*AEDE*) and external hazard index (*Hex*), internal hazard index (*Hin*). The average values for these parameters were determined to be 92.5 $Bq.kg^{-1}$, 43.0 $nGy\ h^{-1}$, 52.7 $\mu Sv\ y^{-1}$ and 0.25$Bq.kg^{-1}$, 0.34$Bq.kg^{-1}$ respectively. The values of the gathered samples stay below the allowable limits. Consequently, the examined region does not present any radiation risk to the general population. Moreover, it has been discovered that there is no concentration of ^{137}Cs radionuclide activity in the studied area.

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

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1. Introduction

High-energy cosmic rays and Radionuclides from the Earth's crust are the primary sources of radiation exposure for humans. These compounds, in addition to artificial radiation, contribute to the elevation of the natural background radiation level (UNSCEAR, 2000; Tabar *et al*., 2013; Tabar *et al*., 2017). As a result, people are frequently exposed to this background radiation. Concerning radiological dose, the primary radionuclides to be concerned about are ^{40}K, ^{232}Th, ^{238}U and ^{12}Ra, along with the decay products of these elements. The naturally occurring radioactivity found in rock,

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water and soil is mainly composed of these radionuclides. Soil is recognized as the medium through which these radionuclides are transferred to humans, forming a significant radiation hazard. Moreover, it is crucial to investigate the activity of both naturally occurring and human-made radionuclides to establish baseline data and assess their radiological levels ((UNSCEAR, 2000; Tabar *et al*., 2013).

Natural radionuclides are not evenly distributed throughout the world; instead, they vary from one place to another. The main factors influencing their concentrations in soil are geological formations and the surrounding terrain. It is well known that the level of radioactivity and rock composition are strongly correlated. Igneous rocks, such as granite, exhibit higher natural radiation levels, whereas sedimentary rocks, like limestone, have lower radiation levels. Additionally, regions with soil composed of shales and phosphate rocks tend to have comparatively higher natural radiation (Tabar *et al*., 2013; Gabdo *et al*., 2016; Sahin *et al*., 2017; Adewoyin *et al*., 2022; Kareemah *et al*., 2024; Zhang *et al*., 2024; Sead *et al*., 2024). Conversely, due to human activity, the amounts and chemical compositions of radionuclides vary over time, especially in areas that are cultivated using phosphate fertilizers (Chinnaesakki *et al*., 2011; Janković *et al*., 2023).

The levels of natural radioactivity in Jordan have been determined by several studies carried out over the previous few decades (Al-Hamarneh & Awadallah, 2009; Hamideen & Sharaf, 2012; Al-Jundi *et al*., 2003; Partignani *et al*., 2016; Saleh & Shayeb, 2014; Al-Kharouf *et al*., 2008; Abusini *et al*., 2008; Abumurad & Al-Tamimi, 2005; Al-Qararah *et al*., 2019; Hadi *et al*., 2024). These studies, however, only looked at particular regions of Jordan; they did not cover the entire country. A recent study (Abu_kharma *et al*., 2023; Al-Hamarneh, 2018) investigated the levels of radioactivity and radiation risk in some regions in southern Jordan. It did not investigate the levels of Human-made radiation in these regions, instead concentrating on estimating the levels of natural radioactivity and the risks that go along with it. The author was driven to ascertain the activity concentrations of human-made and natural radionuclides, along with the radiation hazards in the Alkarak region, due to the aforementioned factors and the dearth of measurements.

This study uses gamma-ray spectrometry to examine the levels of anthropogenic and natural radioactivity in surface soil samples in the Alkarak governorate in Jordan, with a focus on Almazar-Alkarak, a town located south of Alkarak. Assessing the activity concentrations of both human-made radionuclides and natural radionuclides, along with measuring radiation hazards, makes this study distinctive within the study area. The targeted area is bordered by the lowest region in the world (Al Ghor and the Dead Sea) to the west. The altitude decreases to zero from sea level after 7 km from site 11. Additionally, it is bordered by large phosphate fields to the east, which might contain terrestrial radionuclides with significant doses. This inspired me to look at the radiation map of the area and determine whether any terrestrial radionuclides are carried by the industry in the west and the dust in the east, which could affect the average doses. Given that approximately 100,000 people are living in the area, it stands to reason that they will be affected by the radiation doses.

This paper is organized as the following: Section 1 contains the introduction. Section 2 provides specifics on the preparation and collection of soil samples, detector calibration and sample analysis used in this investigation. In Section 3, the value of the (Ra_{eq}) Radium equivalent activity, (D) Gamma-absorbed dose rate, ($ELCR$) Excess lifetime cancer risk, ($AEDE$) Annual effective dose equivalent and (H_{in}, H_{ex}) External

and Internal hazard indices are calculated. Section 4 presents the activity concentrations of ^{40}K, ^{232}Th, ^{238}U and ^{226}Ra along with the outcomes of radiation hazards. The work is summarized and conclusions are discussed in the final section.

2. Materials and method

A. Study area

The sampling points are determined using GPS (Global Positioning System) and their locations are recorded. These points were chosen randomly from 15 locations in the Almazar-Alkarak region on October 12–13, 2023. The arrangement of sampling locations is depicted in Figure 1. Almazar-Alkarak is located in the eastern part of the Alkarak governorate, approximately 150 kilometers from the capital city of Jordan, Amman. The population is approximately 110 thousands and its approximate area is 1200 km^2. The study area spans an approximate area of 1000 km^2. Most residents in this region work in livestock, investing in the less popular area by cultivating wheat and barley fields to feed their animals. Additionally, there are a few archaeological sites, primarily sites 1 and 3. Moreover, the targeted area is bordered by the lowest region in the world (Al Ghor and the Dead Sea) to the west. The elevation drops to zero from sea level after 7 *km* from site 11. Furthermore, it is bordered by extensive phosphate fields to the east, which may contain terrestrial radionuclides with significant doses. All of these factors motivated me to examine the radiation map in this location and provide acceptable suggestions for the community there.

B. Samples and sample Analysics

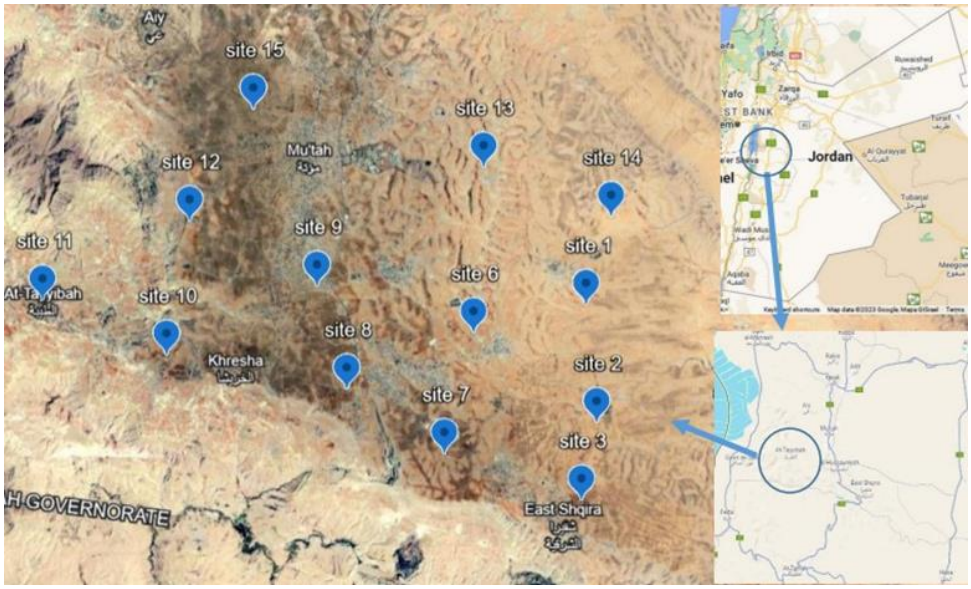

Figure 1. Map of the study area with sample sites

Table 1. Coordinates of the selected sites

Location	*Location Name*	Altitude (m)	Position	
			LONG.	LAT.
1	*Alfag 1*	1137	35°47’30”E	31°02’55”N
2	*Alfag 2*	1055	35°47’43”E	31°00’49”N
3	*Shqira*	1066	35°47’24”E	30°59’27”N
4	*Mhaei*	975	35°50’36”E	31°00’19”N
5	*Alfag 3*	956	35°51’46”E	31°03’38”N
6	*Omhammat*	1156	35°45’11”E	31°02’25”N
7	*That Rass*	1157	35°44’35”E	31°00’17”N
8	*Alhussayniya*	1244	35°42’34”E	31°01’26”N
9	*Alamaqa*	1254	35°41’57”E	31°03’15”N
10	*Majra*	1251	35°38’51”E	31°02’01”N
11	*Altaybaa*	1011	35°36’16”E	31°03’00”N
12	*Aleraq*	1118	35°39’19”E	31°04’24”N
13	*Nshanish*	1081	35°45’23”E	31°05’21”N
14	*Nakeal*	1052	35°48’01”E	31°04’29”N
15	*Ayi*	1190	35°40’38”E	31°06’23”N

At each sampling site, a designated area of 0.5 x 0.5 m^2 was demarcated and its coordinates were documented using a Global Positioning System (GPS). The illustration, which features sample location points, can be found in Figure 1 and the corresponding information is presented in Table 1. A brick trowel and hands were employed to eliminate organic materials and stones from the surface of the specified area. A composite soil sample weighing 1000 to 900 g was created by excavating soil at a depth of 5 cm. Each soil sample was perfectly blended to ensure uniformity, resulting in a homogeneous mixture. The composite sample, drawn from this blend, was chosen to be ready to be measured. Each sample was placed individually into a plastic container with labels. The sample containers were then dried and left for 30 days to ensure stability between ^{226}Ra and ^{222}Ra and their radioactive products.

C. Detector Calibration

To identify gamma-ray emitting radionuclides and measure their levels of activity, The gamma-emitting spectrometry system equipped with a High Purity Germanium (HPGe) detector produced by Canberra company is utilized, exhibiting a relative efficiency of 40%. To reduce the potential influence of ambient gamma radiation on the accuracy of gamma spectrometry and consequently, the measurement results, the detector was enclosed in a lead shield. Before conducting observations, the background spectrum is obtained and peak area correction was applied to eliminate the peaks in the background spectrum.

Energy calibration was performed using radioactive sources, namely ^{137}Cs, ^{57}Co, ^{65}Zn, ^{109}Cd, ^{113}Sn, ^{54}Mn, ^{155}Eu, ^{22}Na and ^{241}Am. Canberra produced these point sources on January 18, 2010, except for ^{155}Eu and ^{22}Na, which were produced on June 23, 2009. Each point source had an initial emission rate of 37 kBq. Before the actual tests, an efficiency calibration was conducted using a standardized mixed source calibration Petri plate. The efficiency calibration curve went through adjustments to account for the cascade summing effect, employing geometry correction software. The soil samples

were positioned towards the detector. Each sample was counted for 24 hours. Leaving the sample in the detector overnight allows for a longer integration time, leading to a higher count rate and improved statistical accuracy in the measurements.

There is no specific rule regarding the time it takes to get data, as it depends on reaching the desired level of statistical accuracy for the principal line emitted by the nuclide being measured.

3. Radiological Hazard Indices

The concentration of activity, denoted as A, for the nuclide sources found in the collected sample was determined using the following formula (Shinji *et al*., 2019; Bineng *et al*., 2020; Bobbo *et al*., 2019):

$$A = \frac{C}{\varepsilon \times I_{\gamma} \times \omega}, \tag{1}$$

here A represents the activity concentration in $Bq.kg^{-1}$, C stands for the net count rate in counts per unit of time and ϵ represents the detector efficiency, I_{γ} signifies the absolute transition probability of gamma decay and w denotes the sample weight in kilograms.

A. Radium equivalent activity

Radium equivalent activity refers to the measurement of the total radioactivity of a sample, taking into account the combined effects of several radionuclides present. Ra_{eq} is a widely used index for evaluating the potential danger of radioactivity in terms of radiological hazard. The index is derived from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, representing a single substance. The gamma ray exposure rate was determined using Eq.2, considering that 370 $Bq.kg^{-1}$ of ^{226}Ra, 259 $Bq.kg^{-1}$ of ^{232}Th and 4810 $Bq.kg^{-1}$ of ^{40}K yield an equivalent dose rate (Singh *et al*., 2017).

$$Ra_{eq} = A_{R_a} + 1.43A_{T_h} + 0.077A_k\,. \tag{2}$$

B. Gamma Absorbed Dose Rate (D)

The gamma absorbed value serves as a metric for quantifying the external absorbed gamma dose rate in the air, arising from radionuclides in the soil, at 1 meter above ground level. Equation 3 provided by UNSCEAR (2020) is used to estimate it using the activity concentration values of ^{238}U, ^{232}Th and ^{40}K

$$D(nGy\ h^{-1}) = 0.462A_{R_a} + 0.604A_{T_h} + 0.0417A. \tag{3}$$

C. Annual Effective Dose Equivalent (AEDE)

The yearly outdoor effective dose is calculated by estimating the absorbed gamma radiation rate in the air using Equation 4 (UNSCEAR, 2000). In this equation, the value 8766 represents the projected number of hours per year. The value 0.7 is considered as a conversion factor from *Gy* to *Sv*. An occupancy factor of 0.2 is considered for outdoor cases. Equation 4 is condensed as follows (UNSCEAR, 2000):

$$AEDE(\mu Gy\ h^{-1}) = D(nGyh^{-1}) \times 8760\ h \times 0.2 \times 0.7Sv\ Gy^{-1} \times 10^{-3} \tag{4}$$

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

Equation 4 can be reduced to:

$$AEDE(\mu Gyh^{-1}) = D(nGyh^{-1}) \times 1.23 \times 10^{-3} \quad (5)$$

D. External and internal hazard (H_{ex}, H_{in})

H_{ex} and H_{in} are represented in Equation 6 and Equation 7 (UNSCEAR, 2000). For both indices, the condition for the radiation hazard to be considered negligible is that the values of H_{ex} and H_{in} must not exceed unity, as indicated in Equation 6 and Equation 7. H_{ex} is utilized to assess the external radiation impacts, focusing on radiation exposure from the surroundings. On the other hand, H_{in} is employed to evaluate internal exposure arising from ^{222}Ra and its short-lived radon progeny within building materials.

$$H_{ex} = \frac{A_{Ra-226}}{370} + \frac{A_{Th-232}}{259} + \frac{A_{K-40}}{4810} < 1, \quad (6)$$

and

$$H_{in} = \frac{A_{Ra-226}}{185} + \frac{A_{Th-232}}{259} + \frac{A_{K-40}}{4810} < 1. \quad (7)$$

E. Excess Lifetime Cancer Risk

The following relation is employed to calculate excess lifetime cancer risk (ELCR), which represents the probability of acquiring cancer as a result of radiation exposure effects throughout a specific duration of life of an individual:

$$ELCR = AEDE \times LE \times RE \quad (8)$$

1. AEDE : is in the unit of ($\mu Sv\, y^{-1}$).
2. LE: represents the life expectancy, which is approximately 74 years in Jordan.
3. RF: represents the lethal cancer hazard per Sievert, which is set at 0.05 Sv^{-1}.

3. Result and Discussion

Various components, including sand type, sand texture, weathering grades of source rocks, sand transport systems, geochemical attributes and ambient environment, could influence the concentration of radioactivity in geological structures (Zaim & Atlas, 2016). In the current study, the activity concentrations of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K that were measured in soil from fifteen distinct locations in Southern Almazar-Alkarak, Jordan are summarized in Table 2. The table displays the minimum, maximum and average values for all samples after the activity concentration of radionuclides for each sample. All of the soil samples showed activity concentrations of ^{238}U ranging from 25.5 to 44.7$Bq.kg^{-1}$, with an average of 32.2 $Bq.kg^{-1}$, the activity concentration of ^{226}Ra ranged from 27.3 to 50.4 $Bq.kg^{-1}$. Meanwhile, with an average value of 34.5 $Bq.kg^{-1}$, the activity concentration of ^{226}Ra exhibited variations from 27.3 to 50.4 $Bq.kg^{-1}$. Additionally, with an average of 25.6 $Bq.kg^{-1}$, the activity concentration of ^{232}Th ranged from 10.0 to 39.6 $Bq.kg^{-1}$. With an average of 278.5 $Bq.kg^{-1}$, the activity concentration of ^{40}K varied from 118.5 to 362.7 $Bq.kg^{-1}$. Site 8 had the highest value of ^{232}Th, whereas Site 7 had the highest levels of ^{238}U, ^{226}Ra and Site 13 had the highest value of ^{40}K. It must be noticed that the usage phosphate fertilizers some of soil samples especially sites 2, 3 and 7 lead to enrich the soil with regard to ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K in these sites, that is obvious in Table 2. Nonetheless, the mean concentrations of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K in the examined region were less than the global average values found in soils across multiple nations, which stand at 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 (UNSCEAR, 2020). As indicated above, sites 1, 2, 3 and 14 are positioned on the border with huge phosphate fields to the east. It is obvious from Table 2 that the dust from these fields does not alter the usual activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K in these sites. All the activities in these sites were lower than the global averages.

Table 3 provides a comparison between the results of this study and those from various regions in Jordan. Evidently, the natural concentrations of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K in my study are approximately at the average activity concentration in the surrounding regions and these values closely align with the concentrations observed in other regions. In Figure 2, the connection between ^{238}U and ^{226}Ra concentrations in soil samples from Southern Almazar-Alkarak is depicted. A notable correlation between ^{238}U and ^{226}Ra is evident, with the ^{238}U / ^{226}Ra ratio closely approximating unity. This alignment is anticipated, given that they are part of the same family and are expected to be in equilibrium. The powerful correlation between ^{238}U and ^{226}Ra suggests that the findings for either can reliably predict the other.

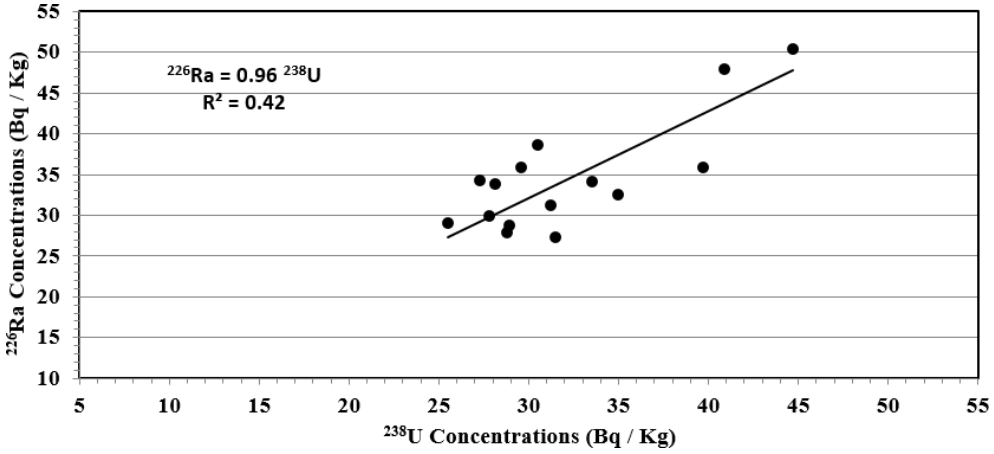

Figure 2. ^{238}U vs ^{226}Ra concentrations

The primary goal of investigating soil radioactivity levels is to assess the radiation exposure to the public. In Figure 3-1, the Ra_{eq} is presented for all samples gathered from the Southern Almazar region. It is evident that the Ra_{eq} across all 15 soil samples in current study varies between 52.5 and 130.9 $Bq.kg^{-1}$, with an average of 92.5 $Bq.kg^{-1}$. The maximum activity is observed in the Alhussayniya sample (site 8), while the minimum is in the Aleraq sample (site 12). Notably, the average Ra_{eq} in this investigation falls below the allowable upper limit of 370 $Bq.kg^{-1}$ (UNSCEAR, 2020). Figure 3-2 displays the rate at which gamma radiation is absorbed in the air for the all samples collected from the Southern Almazar region. Regarding *D*, which represents the gamma-absorbed dose rate, fluctuates between 24.4 $nGy\ h^{-1}$ for the Aleraq sample at site 12 to 60.3 $nGy\ h^{-1}$ for the Alhussayniya sample at site 8. The average value is 43 $nGy\ h^{-1}$, which is below the global average of 60 $nGy\ h^{-1}$ (UNSCEAR, 2020). The outcomes for the *AEDE* outdoors are depicted in Figure 3-3. The outdoor annual effective dose ranged between 30 and 62.9 $\mu Sv\ y^{-1}$, averaging 52.7 $\mu Sv\ y^{-1}$. Notably, this figure is under the global average of 70 $\mu Sv\ y^{-1}$ (UNSCEAR, 2020). The findings for both the (H_{ex}, H_{in}) indices are illustrated in Figure 3-4 and Figure 3-5. The values of H_{ex}

index fluctuated between 0.14 and 0.35, averaging 0.25, while the (H_{in}) index varied from 0.22 to 0.48, with a mean of 0.34. Importantly, these values are considerably below the unity (ICRP, 1990). The *ELCR* values varied from 110 × 10^{-6} to 232 × 10^{-6}, with a mean value of 195 × 10^{-6} as show in Figure 3-6. The current mean is below the global average threshold of 2.9 × 10^{-4} (Kritsananuwat *et al*., 2015).

Table 2. Activity concentrations of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K, in Southern Almazar-Alkarak, Jordan soil

Site number	Site Name	$^{226}Ra(Bq.Kg^{-1})$	$^{232}Th(Bq.Kg^{-1})$	$^{238}U\ (Bq.Kg^{-1})$	$^{40}K(Bq.Kg^{-1})$
Site 1	**Alfag 1**	34.2 ± 1.0	26.5 ± 1.3	33.5 ± 4.2	345.8 ± 15.7
Site 2	**Alfag 2**	27.3 ± 0.9	24.8 ± 1.3	31.5 ± 4	340.6 ± 15.4
Site 3	**Shqira**	31.2 ± 1.0	23.5 ± 1.3	31.2 ± 3.6	300.9 ± 15.1
Site 4	**Mhaei**	27.9 ± 0.9	24.7 ± 1.2	28.8 ± 3.7	320.9 ± 14.4
Site 5	**Alfag 3**	29.9 ± 0.9	23.8 ± 1.2	27.8 ± 3.5	299.9 ± 14.5
Site 6	**Omhammat**	38.6 ± 1.0	20.8 ± 1.2	30.5 ± 3.6	220.0 ± 13.1
Site 7	**That Rass**	50.4 ± 1.2	26.2 ± 1.3	44.7 ± 3.8	250.9 ± 13.3
Site 8	**Alhussayniya**	48.0 ± 1.3	39.6 ± 1.7	40.9 ± 4.5	340.6 ± 17.5
Site 9	**Alamaqa**	34.3 ± 0.9	28.2 ± 1.3	27.3 ± 3.4	268.7 ± 13.3
Site 10	**Majra**	33.8 ± 0.9	25.6 ± 1.2	28.1 ± 3.4	223.4 ± 12.5
Site 11	**Altaybaa**	32.6 ± 0.9	22.8 ± 1.3	35.0 ± 3.8	206.9 ± 12.9
Site 12	**Aleraq**	29.1 ± 0.9	10.0 ± 0.9	25.5 ± 3.4	118.5 ± 11.2
Site 13	**Nshanish**	35.8 ± 1.0	32.5 ± 1.5	39.7 ± 3.9	362.7 ± 15.9
Site 14	**Nakeal**	28.7 ± 0.9	25.5 ± 1.3	28.9 ± 3.7	316.1 ± 15.5
Site 15	**Ayi**	35.8 ± 0.9	29.2 ± 1.3	29.6 ± 3.4	261.7 ± 13.3
Average		34.5 ± 0.97	25.6 ± 1.3	32.2 ± 3.7	278.5 ± 15.7

Table 3. Comparison of the average activity concentrations with surrounding regions in Jordan

Region Name	$^{226}Ra(Bq.Kg^{-1})$	$^{232}Th(Bq.Kg^{-1})$	$^{238}U\ (Bq.Kg^{-1})$	$^{40}K(Bq.Kg^{-1})$	Reference
Mafrak	25.6	27.6	33.3	350.2	(Al-Hamarneh & Awadallah, 2009)
Balqaa	26.6	26.0	37.4	277.3	(Al-Hamarneh & Awadallah, 2009)
Amman	44.0	20.9	47.0	241.6	(Al-Hamarneh & Awadallah, 2009)
Irbid	36	25.3	43.9	226.3	(Al-Hamarneh & Awadallah, 2009)
Jarash	30.1	29.5	33.2	315.3	(Al-Hamarneh & Awadallah, 2009)
Ajloun	31.0	28.0	31.2	298.4	(Al-Hamarneh & Awadallah, 2009)
Zarqaa	213.9	21.5	257.8	248.5	(Al-Hamarneh & Awadallah, 2009)
Madabaa	28.0	27.4	28.0	303.6	(Al-Hamarneh & Awadallah, 2009)

Maan	57.7	18.1	44.9	138.1	(Al-Hamarneh & Awadallah, 2009)
Tafila	23.3	16.7	23.6	243.1	(Al-Qararah *et al*., 2019)
Alkarak	54.3	20.2	61.0	234.1	(Al-Hamarneh, 2018)

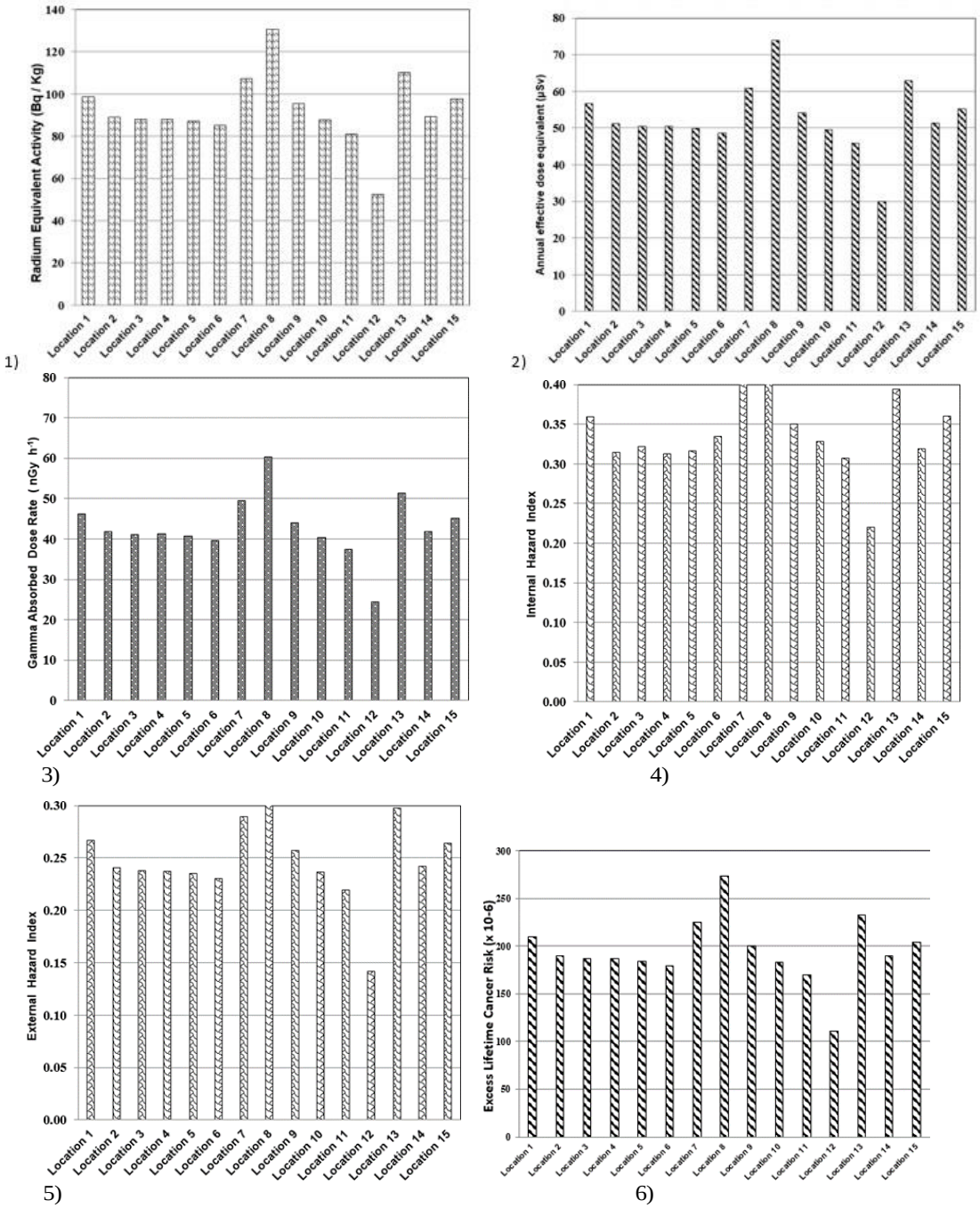

Figure 3. (1) Ra_{eq} (2) *AEDE* (3) *D* (4) H_{in} (5) H_{ex}, finally (6) *ELCR* from ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K, for soil samples collected from Southern Almazar-Alkarak region

4. Conclusion

Evaluating of natural and human-made radioactivity Levels in 15 soil samples from Southern Almazar-Alkarak, Jordan. Gamma spectrometry was employed to evaluate the concentrations of activity. The average levels of naturally occurring radionuclides ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K were found to be below global average values. The ratio of ^{238}U to ^{226}Ra in all samples was found to be near unity. Mean values for radium equivalent activity (Ra_{eq}), gamma-absorbed dose rate in air (D), annual effective dose equivalent ($AEDE$), external hazard indices (H_{ex}), internal hazard indices (H_{in}) and excess lifetime cancer risk ($ELCR$) were also below global average values. My results indicate that the investigated region poses no significant radiation risk to the general population.

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