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Determination of Radioactivity Concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Soil Samples in the City of Zliten, Libya, and the Associated Radiation Hazards

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A B S T R A C T

The concentrations of natural radioactive elements, namely radium, thorium, and potassium, were measured and analysed in 51 soil samples taken from 16 different sites within Zliten, Libya. These activity measurements were conducted using a high-purity germanium radiation detector (HPGe), with a measurement duration set at 13.9 h. The average activity concentration values recorded were approximately 22.16 Bq/kg for radium (^{226}Ra), 12.18 Bq/kg for thorium (^{232}Th), and 294.30 Bq/kg for potassium (^{40}K). These values are below the globally recognized average activity concentration levels. The radiation risk associated with these natural nuclides in the soil was assessed through various indicators. The radium equivalent activity (Ra_{eq}) had an average value of 61.53 Bq/kg, while the absorbed dose rate in air (D) averaged at 30.05 nGy/h. The annual effective dose equivalents, calculated for outdoor (AD_{out}) and indoor (AD_{in}) exposure, were found to be 0.037 mSv/year and 0.154 mSv/year, respectively. Additionally, the mean values of the hazard indices were determined as follows: the external hazard index (H_{ex}) at 0.165, the internal hazard index (H_{in}) at 0.228, and the gamma radiation hazard index ($I\gamma i$) at 0.465. Upon comparing these findings with the global standards outlined in the Radiation Protection Report (UNSCEAR 2000), it was concluded that the soil in the studied region does not present radiation hazards and poses no significant health risks to the local population.

Keywords: *sample, activity concentrations, radium equivalent activity, absorbed dose rate, annual effective dose equivalent, hazard indices, Libya*

تحديد تراكيز النشاط الاشعاعي ^{226}Ra و ^{232}Th و ^{40}K في عينات التربة في مدينة زليتن، ليبيا، والمخاطر الإشعاعية المرتبطة بها

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الملخص

تم قياس وحساب تراكيز النشاط الإشعاعي الطبيعي للنويدات الراديوم (^{226}Ra) والثوريوم (^{232}Th) والبوتاسيوم (^{40}K) في 51 عينة تربة جُمعت من 16 موقعا مختلفا داخل مدينة زليتن (ليبيا). وقد تم الحصول على قياسات النشاط الاشعاعي لهذه العينات باستخدام كاشف إشعاع عالي النقاوة من نوع الجرمانيوم (HPGe)، وحدد زمن القياس بـ 13.9 ساعة. أظهرت النتائج أ متوسط تراكيز النشاط الاشعاعي في جميع مناطق الدراسة بأكملها كالتالي: 22.16 Bq/kg للراديوم (^{226}Ra) و12.18 Bq/kg للثوريوم (^{232}Th) و294.30 Bq/kg للبوتاسيوم (^{40}K)، وتشير هذه القيم إلى إنها أقل من معدلات العالمية المعتمدة لتراكيز النشاط الاشعاعي.

ولتقييم المخاطر الاشعاعية الناتجة من النويدات الاشعاعية الطبيعية في التربة تم استخدام المؤشرات الاشعاعية التالية:
النشاط المكافئ للراديوم (Ra_{eq}) بمتوسط 61.53 Bq/kg، ومتوسط معدل الجرعة الممتصة في الهواء (D_{out}) بمتوسط 30.05 nGy/h والجرعة الفعالة السنوية المكافئة الخارجية (AD_{out}) بمتوسط 0.037 mSv/y والجرعة الفعالة السنوية الداخلية (AD_{in}) بمتوسط 0.154 mSv/y، وبلغ متوسط مؤشر الخطر الخارجي (H_{ex}) ومتوسط مؤشر الخطر الداخلي (H_{in}) ومتوسط مؤشر خطر اشعاع جاما ($I\gamma_i$) بمتوسط 0.169 و0.228 و0.465 على التوالي. بعد مقارنة النتائج المتحصل عليها في هذه الدراسة بالقيم العالمية الموصى بها في تقرير الحماية من الاشعاع (Unscear 2000)، نستنتج بان التربة في المنطقة المستهدفة قيد الدراسة خالية من مخاطر الاشعاع ولا تشكل تهديدا لصحة السكان بها.

الكلمات المفتاحية: *عينات التربة، تراكيز النشاط الاشعاعي، النشاط المكافئ للراديوم، معدل الجرعة الممتصة في الهواء، الجرعة الفعالة السنوية المكافئة، مؤشرات مخاطر الاشعاع، ليبيا.*

1. Introduction

Over the past three decades, researchers have been interested in conducting measurements of natural radiation in soil and rocks to assess the risks of radiation to living organisms. Permissible radiation doses were calculated to minimize radiation risks. For example, humans are constantly exposed to radiation hazards due to the presence of radioactivity in the ocean. High concentrations of natural and industrial radioactive elements are an indicator of the risk of radioactivity [1,2]. Natural radioactivity in the soil originates from the ^{238}U and ^{232}Th radiation series, with their concentrations varying greatly based on the source. The cesium radionuclide is one of the most important industrial radionuclides resulting from radioactive dust due to nuclear weapons tests [3,4].

The naturally occurring radioactive nuclides ^{238}U and ^{232}Th, along with their decay products and the ^{40}K nuclide, are present in the environment in significant amounts. These contribute substantially to the overall radiation dose experienced by humans and are regarded as the primary sources of both internal and external exposure to natural radiation. As such, it is crucial to examine the distribution of these radionuclides in environmental samples and understand their potential pathways of human exposure to evaluate the associated radiation hazards [5].

This study aims to measure the natural radiation present in soil samples collected from the city of Zliten, Libya. The analysis involves measuring the concentrations of radioactive elements ^{226}Ra, ^{232}Th, and ^{40}K. Additionally, the absorbed dose, radium equivalent activity, annual effective dose, internal and external hazard indices, and gamma index are measured. A total of 51 soil samples, collected from 16 randomly distributed sites across various directions, will be analyzed. The results will be compared with similar studies conducted in other Arab countries to offer a comprehensive assessment of radiological parameters across the region.

2. Sample collection and preparation

After the field visit to the target area under study, it was divided into 16 sites with similar areas. Three to four samples were collected from each site in a random manner so that a total of 51 samples were collected, as shown in Figure 1 [6]. The sampled locations are flat areas, free from natural or artificial barriers that could limit processes associated with radioactive precipitation in the area. In addition, these sites are not irrigated agricultural areas where various fertilizers could result in increased radioactive background levels.

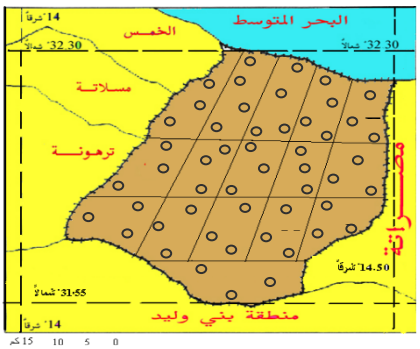

Figure 1: Map showing the sites of the collected samples in the city of Zliten.

The samples were collected after studying the target area and dividing it into sixteen sites. Each site was given an alphabetic letter denoting it. After identifying the target location of the sample, an area in the form of a circle with a diameter of approximately 1 m was determined. The upper layer was then removed, and a sample was collected from a depth of 10 to 15 cm. The collected samples were placed in specialized plastic bags with a capacity of approximately 3 kg. Each bag was properly labeled with the collection date and a unique sample number. Afterwards, the samples underwent a drying process at a temperature of 80°C for two hours; the samples were ground and sifted to eliminate gravel and impurities. After that, each sample was transferred into a measuring container known as the Marinelli vessel [7]. The vessels were securely sealed and kept at room temperature for a period of three to four weeks before the measurement process. This was done to allow the radioactive radium (^{226}Ra), the radioactive radon gas (^{222}Rn), and its decay products to reach radioactive equilibrium.

The soil samples' activity concentration was determined utilizing a high-purity Germanium detector with the following specifications:

- High Pure Germanium Detector (HPGe) with 30% Efficiency
- Measured resolution in 1332 KeV: 1.96.
- Geometrical characteristics of the germanium crystal: -
  (External diameter = 58 mm, Length = 53.1 mm, Sensitive volume = 135.8 cm^3, Distance from cap = 5 mm).
- Operation high voltage: + 3000 V, polarity positive.
- (FWTM/ FWHM) ratio = 1.85

The measurement duration for each sample was 50,000 seconds for ^{226}Ra, ^{232}Th, and ^{40}K.

Table 1 presents the gamma-ray data lines utilized to determine the concentration of radioactivity [8].

Table 1: Gamma energy data from each radioactive source are used to determine the concentrations of ^{226}Ra, ^{232}Th, and ^{40}K

Nuclide	*Isotopes*	*Energy (KeV)*
^{226}Ra	^{214}Bi	609.3
	^{214}Bi	1763.4
	^{214}Pb	295.4
	^{214}Pb	352.0
^{232}Th	^{208}Tl	538.0
	^{228}Ac	338.0
	^{228}Ac	911.1
^{40}K	40K	1460.7

3. Results and Discussion

3.1 Average radioactivity concentration A (Bq/kg)

The average radioactivity concentration (A) of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples was determined using the following equation [9]:

$$A = \frac{N_{net}}{\varepsilon \cdot m \cdot I_{\gamma} \cdot t}, \qquad (1)$$

here, N_{net} is the net count rate under the corresponding peak, ε represents the efficiency of the detector, I_{γ} denotes the emission probability of the energy photopeak, m represents the mass of the sample in kilograms, while t denotes the counting time in seconds.

The average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the soil were assessed across 51 samples collected from various sites in Zliten, Libya. The measurements were conducted using an HPGe radiation detector. Figure 2 illustrates a graphical representation of the results in Table 2. These results indicate the presence of natural radioactivity across all sites, likely attributable to the area's geological composition, which includes various rock types and diverse soil characteristics. The average radioactivity concentrations of ^{226}Ra ranged between 15.56 Bq/kg (at site B) and 34.13 Bq/kg (at site K). For ^{232}Th, the averages varied from 8.08 Bq/kg (at site B) to 15.33 Bq/kg (at sites M and P). Meanwhile, the average activity concentrations of ^{40}K spanned from 131.19 Bq/kg (at site G) to 427.40 Bq/kg (at site F). It is noted that there is no significant variation in activity concentration level for ^{226}Ra and ^{232}Th across most sites.

Table 2: Average radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K detected in soil samples from Zliten city

Site code	*Number of samples per site*	*Average radioactivity concentration (Bq/kg)*		
		^{226}Ra	*^{232}Th*	*^{40}K*
A	3	17.53	09.53	300.14
B	4	15.56	08.28	245.49
C	4	17.37	09.54	241.83
D	4	18.54	10.29	298.33
E	3	20.30	12.07	266.95
F	3	22.20	13.56	427.40
G	3	29.00	12.32	131.19
H	3	20.01	12.70	335.20
I	3	18.35	11.77	297.57
J	3	22.17	09.40	214.37
K	3	34.13	14.07	281.83
L	3	22.03	14.30	297.93
M	3	25.17	15.33	366.37
N	3	25.67	14.78	313.80
O	3	19.05	11.57	315.68
P	3	26.77	15.33	375.03
average		22.16	12.18	294.30
min		15.56	08.28	131.19
max		34.13	15.33	427.40
global average		35	30	400

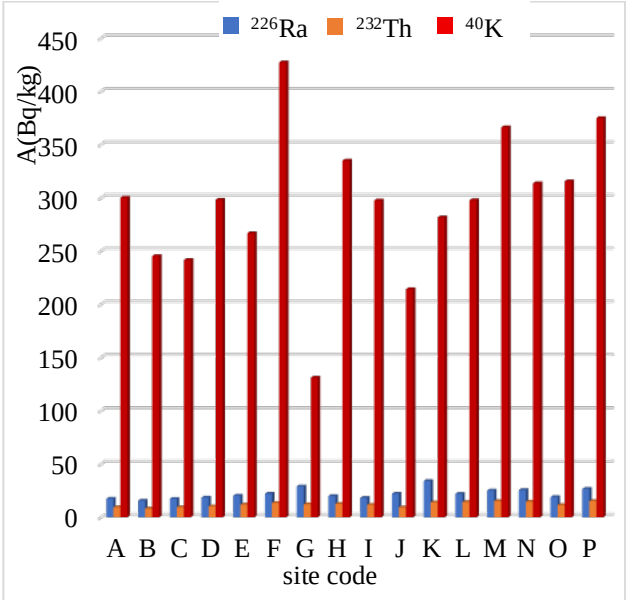

Figure 2: Average radioactivity concentrations A of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples from Zliten city

The land quality at site K is categorized as agricultural, benefiting from irrigation using groundwater extracted from considerable depths below the Earth's surface. This has resulted in the highest recorded average radioactivity concentration of ^{226}Ra in that area. The reason for recording the highest value of the average radioactivity concentration of ^{232}Th at sites M and P is the

abundance of granite rocks in them. Site F contains a large percentage of sedimentary rocks compared to other sites, which resulted in recording the highest average radioactivity concentration of ^{40}K.

Table 2 displays the average radioactivity concentrations for ^{226}Ra, ^{232}Th, and ^{40}K, measured at 22.16 Bq/kg, 12.18 Bq/kg, and 294.30 Bq/kg, respectively. These levels remain within the recommended safety limits of 35 Bq/kg for ^{226}Ra, 30 Bq/kg for ^{232}Th, and 400 Bq/kg for ^{40}K [1].

Figure 3 illustrates a comparison of the average radioactivity concentrations of ^{226}Ra, ^{234}Th, and ^{40}K obtained in this study with the average values reported in soil samples from other Arab countries.

The analysis indicates that the average radioactivity concentrations of ^{226}Ra determined in this study are lower compared to those reported in Qatar [10], Syria [11], Jordan [12], Algeria [1], and Yemen [13]. On the other hand, they exceed the average radioactivity concentrations recorded in Saudi Arabia [14], Iraq [15], and Egypt [1].

The study revealed that the average radioactivity concentrations of ^{226}Ra observed during this research, along with those reported in Qatar, Jordan, Syria, Iraq, Egypt, and Saudi Arabia, fall within the globally acceptable limits. Conversely, the average radioactivity concentrations documented in Yemen and Algeria were identified as exceeding this allowable range [1].

The study found that the average radioactivity concentrations of ^{232}Th were lower than those recorded in Saudi Arabia, Egypt, Syria, Yemen, Algeria, and Iraq. On the other hand, the values observed were higher than those reported in Qatar and Jordan. Despite these variations, the averages from this study, alongside data from Saudi Arabia, Egypt, Qatar, Jordan, Syria, and Algeria, fell within globally acceptable limits. Conversely, the average radioactivity concentrations in Iraq and Yemen surpassed the internationally permissible levels.

The average radioactivity levels of ^{40}K detected in this study were found to be lower than those recorded in Saudi Arabia, Egypt, Yemen, and Algeria, yet higher than the levels reported in Qatar, Syria, Iraq, and Jordan. It is important to note that the average ^{40}K concentrations observed in Yemen and Saudi Arabia surpassed the internationally recognized safety limit. In comparison, the ^{40}K activity levels identified in this study, along with those documented in Qatar, Jordan, Syria, Iraq, Egypt, and Algeria, stayed within the globally acceptable range.

The differences in study outcomes are likely due to factors like geological composition, climate variations, or irregular fertilizer use on farmland.

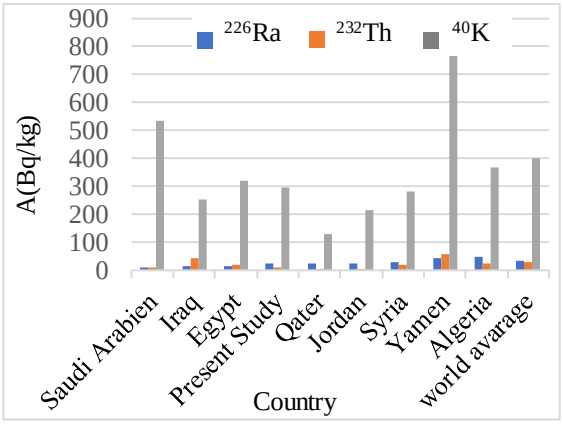

Figure 3: A comparison of average radioactivity concentration in the present study with several other Arab countries.

3.2 Radium equivalent activity Ra_{eq} (Bq/kg)

Radium, thorium, and potassium isotopes exhibit a heterogeneous distribution within terrestrial soil compositions. To evaluate their collective radiological consequences, a standardized radiometric metric referred to as radium equivalent activity is employed. This metric quantifies the aggregate radioactivity of ^{226}Ra, ^{232}Th, and ^{40}K, predicated on the premise that 370 Bq/kg of ^{226}Ra, 481 Bq/kg of ^{232}Th, and 4810 Bq/kg of ^{40}K yield consistent gamma dose rates. A determination of radium equivalent activity at 370 Bq/kg is regarded as tantamount to an annual effective dose equivalent of 1 mSv/y [1].

Eq. (2) is employed to evaluate the potential health risks linked to the presence of radium, thorium, and potassium radionuclides in soil samples [16]:

$$Ra_{eq} = A(^{226}Ra) + 1.43A(^{232}Th) + 0.077A(^{40}k), \quad (2)$$

where A(^{226}Ra), A(^{232}Th) and A(^{40}K) are the average radioactivity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in (Bq/kg), respectively.

The Radium equivalent activity (Ra_{eq}) was determined using Eq. (2) for each soil sample. The results of Ra_{eq} are illustrated in Figure 4 and summarized in Table 3. The data indicate that Ra_{eq} values range from 46.30 Bq/kg at site B (the lowest) to 77.57 Bq/kg at site P (the highest), with an average value equal to 61.53 Bq/kg for all sites. According to these results, the Radium values in the entire study area are significantly lower than the global average for the radioactivity of a radium equivalent level of 370 Bq/kg [1].

3.3 Absorbed Dose Rate D (nGy/h)

The human health implications of exposure to gamma

radiation are evaluated based on the dose rate of energy absorbed (D), which is estimated in the open air at a height of 1 meter above the Earth's surface. Therefore, certain conversion factors are used to calculate the dose absorbed into the air: 0.462 (nGy.kg)/(h.Bq) for ^{226}Ra, 0.621 (nGy.kg)/(h.Bq) for ^{232}Th, and 0.0417 (nGy.kg)/(h.Bq) for ^{40}K. Eq. (3) is then applied as follows [17,18].

$$D = 0.462A(^{226}Ra) + 0.621A(^{232}Th) + 0.042A(^{40}k), \quad (3)$$

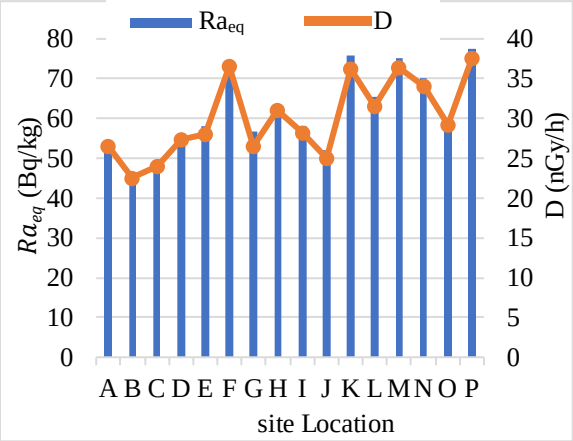

Figure 4: Radium Equivalent Activity and absorbed dose rate (D) in soil samples from Zliten city

Table 3: Radium equivalent activity (Ra_{eq}) and absorbed dose rate (D) in soil samples from Zliten city.

Site code	*Number of Samples per Site*	Ra_{eq} (Bq/kg)	D (nGy/h)
A	3	54.27	26.53
B	4	46.30	22.57
C	4	49.50	24.03
D	4	56.14	27,40
E	3	58.12	28.01
F	3	74.50	36.50
G	3	56.72	26.52
H	3	63.40	31.11
I	3	58.09	28.20
J	3	52.12	25.02
K	3	75.95	36.26
L	3	65.54	31.48
M	3	75.30	36.43
N	3	70.00	34.12
O	3	59.90	29.15
P	3	77.57	37.53
Average		61.53	30.05
Min		46.30	22.57
Max		77.57	37.53
global average		370	59

The absorbed dose rate values for soil samples taken from the study area are presented in Figure 4. These values were calculated using Eq. (3) and are listed in Table 3. The absorbed dose rate, D, exhibited values ranging between 22.57 nGy/h (at site B) and 37.53 nGy/h (at site P), with an overall average value of 30.05 nGy/h, which is lower than the global average of 59 [1].

3.4 Annual Effective Dose Equivalent AD {mSv/y)

When determining the annual effective dose equivalent, consideration of the study area is essential. This is achieved through external exposure from the study area or nearby and internal exposure resulting from the type of buildings that people live in. Thus, the external annual effective dose equivalent (AD_{out}) and internal annual effective dose equivalent (AD_{in}) must be calculated in the unit mSv/y, where the conversion factor of 0.7 Sv/Gy is applied to convert the absorbed dose in air to the effective dose, which corresponds to an external occupancy factor of 0.2, internal occupancy of 0.8, and a time factor of 8760 h. Through the following equation, we obtain the annual effective dose [17]:

$$AD_{out} = Dx10^{-6} * 8760\frac{h}{y} * 0.7\frac{Sv}{Gy} * 0.2 \quad (4)$$

$$AD_{in} = Dx10^{-6} * 8760\frac{h}{y} * 0.7\frac{Sv}{Gy} * 0.8 \quad (5)$$

Table 4: Annual effective equivalent dose (AD) for soil samples from Zliten city.

Site code	*Number of Samples per Location*	AD_{out} *(mSv/y)*	AD_{in} *(mSv/y)*	$AD_{tot.}$ *(mSv/y)*
A	3	0.033	0.130	0.163
B	4	0.028	0.111	0.139
C	4	0.029	0.118	0.147
D	4	0.033	0.134	0.167
E	3	0.031	0.137	0.168
F	3	0.045	0.179	0.224
G	3	0.033	0.130	0.163
H	3	0.038	0.153	0.191
I	3	0.035	0.138	0.173
J	3	0.031	0.123	0.154
K	3	0.044	0.178	0.209
L	3	0.039	0.154	0.193
M	3	0.045	0.179	0.224
N	3	0.042	0.167	0.209
O	3	0.036	0.143	0.179
P	3	0.046	0.184	0.230
Average		0.037	0.154	0.183
Min		0.028	0.111	0.139
Max		0.046	0.184	0.230
global average		0.07	0.41	0.48

Formulas (4) and (5) were applied to compute the

annual effective dose equivalent of AD_{out} and AD_{in} using soil samples collected from the study area. The results are summarized in Table 4, indicating that AD_{out} values range from the lowest value of 0.028 mSv/y (at site B) to a maximum of 0.046 mSv/y (at site P), with an average of 0.037 mSv/y. Similarly, AD_{in} values were found to be in the range of 0.111 mSv/y for the lowest value (at site B) and the highest value of 0.184 mSv/y (at site P), with an average value of 0.154 mSv/y. The total average annual effective dose equivalent AD_{tot} is equal to 0.183 mSv/y with a range of 0.139 mSv/y to 0.230 mSv/y. The global average annual effective equivalent dose is estimated at 0.07 mSv/y for external exposure AD_{out} and 0.41 mSv/y for internal exposure AD_{in}. Accordingly, the total global effective annual equivalent dose ($AD_{tot}=AD_{out}+ AD_{in}$) is 0.48 mSv/y [1].

As shown in Table 4, it can be observed that the values of AD_{out}, AD_{in}, and AD_{tot} are lower than the global total average annual equivalent effective dose. The total annual effective dose equivalent of AD_{out} and AD_{in} should not exceed 1 mSv/y [1].

3.5 Hazard Index

The external hazard index (H_{ex}) for soil samples is calculated using Eq. (6), expressed in the following format [19]:

$$H_{ex} = \frac{A_{226_{Ra}}}{370} + \frac{A_{232_{Th}}}{259} + \frac{A_{40_K}}{4810} \leq 1. \qquad (6)$$

To reduce radiation exposure in samples, the external hazard index should have a value of less than or equal to 1 (unity). Additionally, it should correspond to the maximum radium equivalent activity Ra_{eq} of 370 Bq/kg.

The internal hazard (H_{in}) is computed using the following formula to evaluate the population's internal exposure to natural radionuclides in the soil [19]:

$$H_{in} = \frac{A_{226_{Ra}}}{185} + \frac{A_{232_{Th}}}{259} + \frac{A_{40_K}}{4810} \leq 1, \qquad (7)$$

3.6 Gamma Radiation Hazard Index $I_{\gamma i}$

One method for determining the radiation risk that comes from naturally occurring radioactive nuclides is the gamma radiation index. Additionally, it can detect radioactive materials that pose a health risk. The index correlates with the annual dose rate of gamma radiation emitted by radioactive substances. The gamma radiation index value is always less than or equal to unity, which is equivalent to an annual dose rate of 0.3 mSv/y. If the gamma radiation index is less than or equal to 0.3, then the annual dose rate value is also less than or equal to 0.1 mSv/y. It is important for the gamma radiation index to have a safety value that is less than or equal to unity; $I_{\gamma i}$ can be calculated by the following equation [20]:

$$I_{\gamma i} = \frac{A_{226_{Ra}}}{150} + \frac{A_{232_{Th}}}{100} + \frac{A_{40_K}}{1500} \leq 1, \qquad (8)$$

Eqs. (6), (7) and (8) were used to determine the values of H_{ex}, H_{en} and $I_{\gamma i}$, respectively. The results from the analysis of soil samples in the study area are summarized in Table 5.

Table 5: Hazard indicators (H_{ex}), (H_{in}) and ($I_{\gamma i}$) for soil samples from Zliten city.

site code	*Number of Samples per site*	H_{ex}	H_{in}	$I_{\gamma i}$
A	3	0.147	0.194	0.412
B	4	0.125	0.167	0.350
C	4	0.134	0.181	0.372
D	4	0.152	0.202	0.425
E	3	0.157	0.212	0.434
F	3	0.201	0.261	0.569
G	3	0.153	0.232	0.404
H	3	0.173	0.227	0.484
I	3	0.157	0.207	0.438
J	3	0.141	0.201	0.385
K	3	0.205	0.297	0.556
L	3	0.177	0.236	0.476
M	3	0.203	0.271	0.565
N	3	0.192	0.261	0.528
O	3	0.162	0.213	0.453
P	3	0.210	0.282	0.582
Average		0.169	0.228	0.465
Min		0.125	0.167	0.350
Max		0.210	0.297	0.582
global average		≤ 1	≤ 1	≤ 1

The external hazard index (H_{ex}) values varied between 0.125 (lowest at site B) and 0.210 (highest at site B), with an average value of 0.169. Similarly, the internal hazard index (H_{in}) averaged 0.228, ranging between 0.167 (lowest at site K) and 0.297 (highest at site B). The gamma radiation hazard index ($I_{\gamma i}$) values additionally ranged from 0.350 (lowest at site P) to 0.582 (highest at site B), with an average value of 0.465. Table 5 shows that the average values of H_{ex}, H_{in}, and $I_{\gamma i}$, as well as all values of hazard indicators in soil samples in the study area, are less than unity, which is the highest globally permissible value. Based on these results and the results of Ra_{aq} shown in Table 3, it can be concluded that the radiation risk in the study area is low and poses no threat to public health.

Conclusions

To evaluate the possible health risks due to radiation exposure, background radiation was studied. The

average radioactivity concentrations (A), radium equivalent activity (Ra_{eq}) levels for natural radionuclides, and radiological risk indicators:
Absorbed dose rate (D), annual effective dose equivalent (AD), external hazard index (H_{ex}), internal hazard index (H_{in}), and gamma radiation hazard index ($I_{\gamma i}$). A summary of the results obtained from soil samples in Zliten City is presented in Table 6 and 7, in addition to a comparison with the globally recommended levels. The following results were arrived at:

- The study's average radioactivity concentrations (A) of ^{226}Ra, ^{232}Th, and ^{40}K, as well as radium equivalent activity (Ra_{eq}), have a lower range and average values than the recommended limits. Additionally, the average values of the gamma radiation hazard index ($I_{\gamma i}$), the external hazard index (H_{ex}), the internal hazard index (H_{in}), the absorbed dose rate (D), and the external and internal annual effective dose equivalent (AD_{out} and AD_{in}) are all below the corresponding permissible limits offered by the global average.
- Based on the results obtained in this study, it can be concluded that the studied area is a safe zone from radiation hazards and does not pose any danger to human health.
- In order assess the hazards of natural radiation in Libya, the results of this study should be included in the database obtained from related investigations.

Table 6: Summary of the results obtained from average radioactivity concentrations (A), radium equivalent activity (Ra_{eq}) of soil samples from Zliten city

Average radioactivity concentration (Bq/kg)					
	This study ranges	*This Study average*	*World wide range [1]*	*Worldwide average [1]*	
				*Med**	*Pop**
^{226}Ra	15.6-34.1	22.2	17-6	35	32
^{232}Th	08.28-15.3	12.2	11-6	30	45
^{40}K	131.2-427.4	294.3	140-850	400	420
Ra_{eq}	46.3-77.6	61.4	-	370	-

Med: Median, Pop*: Population-weighted*

Table 7: Summary of the results obtained from radiological risk indicators of soil samples from Zliten city

Radiation indices					
D (nGy/h)	22.57-37.53	30.05	18-93	57	59
AD_{out} (mSv/y)	0.028-0.046	0.037	0.3-0.6	0.07	-
AD_{in} (mSv/y)	0.111-0.184	0.154	0.2-0.8	0.41	-
AD_{tot} (mSv/y)	0.139-0.230	0.183	-	0.48	-
H_{ex}	0.125-0.210	0.169	-	≤ 1	-
H_{in}	0.167-0.297	0.228	-	≤ 1	-
$I_{\gamma i}$	0.350-0.582	0.465	-	≤ 1	-

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