ASSESSMENT OF NATURAL RADIO ACTIVITY LEVEL AND RADIATION HAZARD INDICES OF SOIL SAMPLES FROM BANI WALEED, LIBYA

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Abstract

The activity concentrations of some radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) were measured at three sites in Bani Waleed City, which had been bombed during Libyan 2012 chaos. Nine Soil samples were collected from three sites (Tagrafeet Camp, City Centre Camp, and Sakia Camp) at depth of 10 cm.

Hyper-pure germanium (HPGe) gamma-ray detection technology was used to measure these activity concentrations, and the results were compared to the international permissible values. The results of ^{226}Ra, ^{232}Th, and ^{40}Kin the samples were found to exceed the world permissible values of 35, 30, and 400 Bq/kg respectively. However, in the City Centre Camp, the ^{40}K was found to be below the world average, and the mean average of Radium Equivalent Activity (R_{aeq}) of the three locations was found within the recommended safety level.

In Tagrafeet and Sakia Camps, the absorbed dose rate mean value was found to be higher than the world mean value of (60 nGyh^{-1}) whereas the City Centre Camp mean value was within the permissible world value. Moreover, in Tagrafeet and Sakia Camps, the Annual Effective Dose Equivalent (AEDE) outdoor mean value was found higher than the world permissible value but the mean value in the City Centre Camp was lower than the world value. The AEDE indoor and Hazard indices (H_{ex} and H_{in}) were found to be lower than the permissible world values.

Keywords: Tagrafeet Camp; Sikia Camp; City Centre Camp; Natural Radionuclides; HPGe detector.

Introduction

The soil is a major source of natural radioactivity and of radiation hazard for the population and a pathway for radionuclide migration and transfer into the environment. Hence, the natural radioactivity of soil is used as a basic indicator of radiological contamination (Rahman and Faheem, 2008).

The main radioisotopes of natural uranium on surface of the earth are ^{238}U and ^{235}U, which have abundances of 99.28 % and 0.72 %, respectively. The only primordial

isotope of thorium is ^{232}Th, which has a 100% abundance on Earth. Non-series radionuclides like ^{40}K can be found in variable concentrations almost everywhere, including animal and human tissues, soils, and oceans. On Earth, the natural isotopic abundance of ^{40}K is around 0.012 % Environmental Science Division (EVS, 2010).

Studying the levels of radionuclide distribution in the environment provides the essential radiological information (Alaamer, 2008). The amount of radioactivity in the soil varies widely so it is important to monitor the terrestrial background radiation mainly due to natural radionuclides in soil (Faweya and Babalola, 2010). Many studies worldwide have measured the activity concentration of natural radionuclides in the soil to ascertain the levels of contamination (Alaamer 2008; Kabi et *al.*, 2009; ICRP, 1990).

This study is to determine the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected from three locations in Bani Waleed City, (Tagrafeet Camp, City Centre Camp, and Sakia Camp). The results of this study constitute baseline data for the Libyan radiation protection board due to the lack of similar investigations in Libya.

Supplementary Materials and Methods

Research Area

Bani Waleed is located about 170 kilometres south of Tripoli, at 14 00 50" E and 31 45 43" N, and is 837 feet above sea level. The city, which has about 100,000 residents, is known for its grazing and olive farming. It also connects cities in the east, west, and south-central regions. Bani Waleed experienced some kind of Libyans' conflict of which 2012 is the most recent. In this recent conflict, three sites were bombed namely Tagrafeet camp, city centre camp, and the Sakia Camp. The tree sites were targeted in this study.

Sample Collection and Preparation

Nine samples were collected from Tagrafeet Comp, City Centre Camp, and Sakia Camp. The positions of soil samples were determined using a handheld Global Positioning System (GPS) device. The samples were taken 10 cm below the soil surface, as shown in Figure (1) and placed into coded polythene bags and then sent to the Environmental Studies radiation laboratory at Alexandria University's Institute of Graduate Studies and Research (IGSR) to be checked using a high gamma spectrometry (HPGe) detector. The samples were air-dried in a 110°C oven until all moisture was removed then they were weighed using an electronic scale. With a pestle and mortar, the samples were ground into a fine powder and sieved through a 2 mm pore size mesh. The sample was sealed and stored for four weeks to allow the ^{226}Ra and ^{232}Th short-lived daughter radionuclides to achieve secular equilibrium with their long-lived parent radionuclides.

Figure (1): Location of Collecting Samples in Bani Waleed City.

Measurements of Gamma-Ray Spectra

At the ^{60}Co source's 1332 keV g-ray line, the detector's energy resolution full-width high material (FWHM) was 1.9 keV. It was measured with a high purity germanium vertical (HPGe) detector, which is a p-type coaxial with a relative efficiency of 24.5 percent and a peak to Campton ratio of 54:1. The detector was linked to a Camberra data acquisition system, which was managed using Genie-2000 software.

A 10 cm thick cylindrical lead castle with a 2 mm thick copper cylinder inside to absorb lead X-rays shielded the HPGe detector. For a while, the sample containers were placed on top of the detector for counting (14400s). The laboratory regularly participates in proficiency testing for radiation measurements through the Mixed Analytic Performance Evaluation Program (MAPEP).

The radionuclide concentration of ^{238}U series radionuclides was determined using the photo peaks of the ^{214}Pb (295 keV) line, ^{214}Bi (609 keV), and (185.6 keV) of ^{226}R. The radionuclide concentrations of the ^{232}Th series were calculated using photo peaks of the ^{212}Pb (238KeV) line, ^{208}TI (583KeV) line, and ^{228}Ac (911KeV) line of ^{232}Th. The radionuclide concentration of ^{40}K was calculated using gamma-ray transitions at (1460.8KeV) line. 661.8KeV was used to determine the radioactivity of ^{137}Cs. The result was calculated using the 477.6KeV line. These peaks were chosen to cover the full range of radiation ratio error, as well as the relevant statistical data at various energies. The activity concentrations of the samples were calculated using the net area under the photo peaks.

$$Ac = \frac{Cn}{P\gamma M\varepsilon}$$

where *Ac* is the radionuclide's activity concentration in Bqkg^{-1}, *Cn* is the net count rate under the corresponding peak, $P\gamma$ is the absolute transition probability of the specific γ, *M* is the sample mass (kg), and ε is the detector efficiency at the specific γ -ray energy.

Result and Discussion

The Activity Concentration

The following relationship was used to calculate the activity concentrations of radionuclides within the measured samples: (Rohit *et al*., 2010)**.**

$$A(BqKg)^{-1} = \frac{cps \times 1000}{\varepsilon(abc) \times I\gamma(abc) \times W} \qquad (1)$$

Where A is the activity concentration (Bq kg^{-1}), CPS is the netpeak count per second, ε(abs) is the absolute gamma peak detection efficiency, Iγ is the absolute gamma intensity of the corresponding gamma-ray energy considered and W is the weight of the sample (k).

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides were measured in the soil samples as shown in Table (1).

Table (1): The Radioactivity Concentrations A (Bq Kg^{-1}) in the Soil Samples.

Sites	Sample No.	^{226}Ra	^{232}Th	^{40}K
Tagrafeet Camp	A1	34.32 ± 0.097	29.23 ± 0.090	570.3 ± 0.398
	A2	40.39 ± 0.105	21.63 ± 0.077	511.4 ± 0.376
	A3	62.49 ± 0.131	37.90 ± 0.102	408.2 ± 0.336
City Center Camp	B1	30.46 ± 0.091	11.46 ± 0.056	51.99 ± 0.120
	B2	59.16 ± 0.128	61.84 ± 0.131	707.4 ± 0.443
	B3	45.51 ± 0.112	19.95 ± 0.074	381.2 ± 0.325
Sakia Camp	C1	69.3 ± 0.138	29.54 ± 0.090	480.9 ± 0.365
	C2	26.01 ± 0.085	40.84 ± 0.106	640.7 ± 0.421
	C3	86.53	33.11	549.2

	± 0.155	± 0.095	± 0.390
Min	**26.01** ± 0.085	**11.46** ± 0.056	**381.2** ± 0.325
Max	**86.53** ± 0.155	**61.84** ± 0.131	**707.4** ± 0.443
Mean Value	**50.46** ± 0.118	**31.72** ± 0.093	**477.92** ± 0.364
World average value	**35**	**30**	**400**

The measured activity concentration of ^{226}Ra in Tagrafeet Camp ranged from 34.32 ±0.097Bq/kg to 62.49 ±0.131Bq/kg, with a mean value of (45.73 ±0.112) Bq/kg. City Centre values ranged from 30.46 ±0.091 to 59.16 ±0.128 Bq/kg, with a mean of 45.04 ±0.111 Bq/kg. Finally, Sakia Camp values ranged from 26.01 ±0.085 to 86.53 ±0.155 Bq/kg, with a mean of 60.61 ±0.129 Bq/kg (as illustrated in Figure (2).

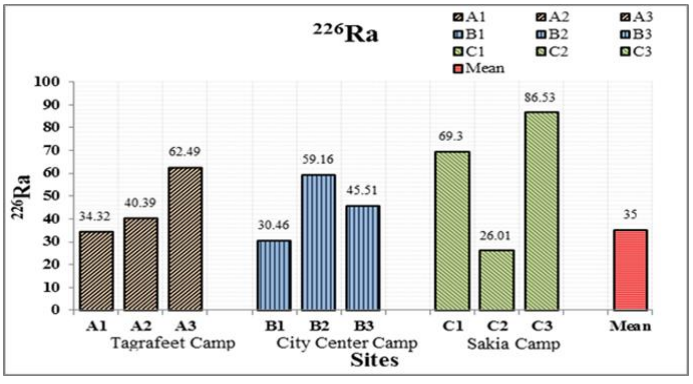

Figure (2): The Activity Concentration of ^{226}Ra in the Study Area.

The activity concentration of ^{232}Th values in Tagrafeet Camp ranged from 21.63 ± 0.077 to 37.90 ± 0.102 Bq/kg with an average of (29.59 ± 0.090) Bq /kg. In the City Centre Camp, measured values of the ^{232}Th ranged from 11.46 ±0.056 to 61.84 ±0.131 Bq/kg, with an average of 31.10 ±0.092 Bq/kg. The values in Sakia Camp ranged from 29.54 ±0.090 to 40.84 ±0.106 Bq/kg, with a mean of 31.10 ±0.092 Bq/kg Figure (3).

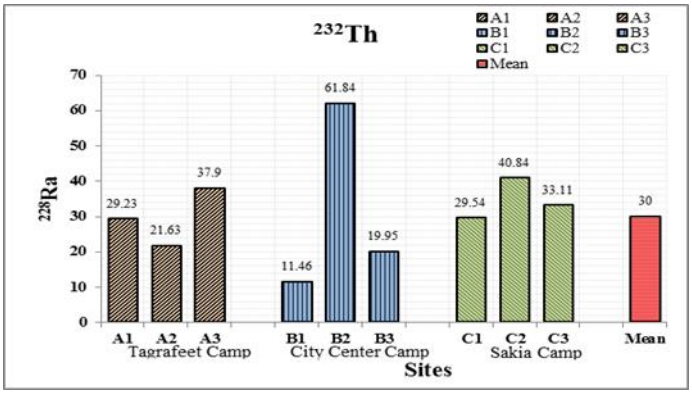

Figure (3): The Activity Concentration of ^{232}Th in the Study Area.

In the Tagrafeet Camp, the activity concentration values for ^{40}K ranged from 408.2 ±0.336 to 570.3 ±0.398 Bq/kg, with a mean value of 495.2 ±0.370 Bq/kg. The City Centre values ranged from 51.99 ±0.129 to 707.4 ±0.443 Bq/kg, with an average of 380.20 ±0.324 Bq/kg. Finally, the ^{40}K values in Sakia Camp ranged from 480.90.365 to 640.7 ±0.421 Bq/kg, with a mean of 556.93 ±0.393 Bq/kg. as shown in Figure (4).

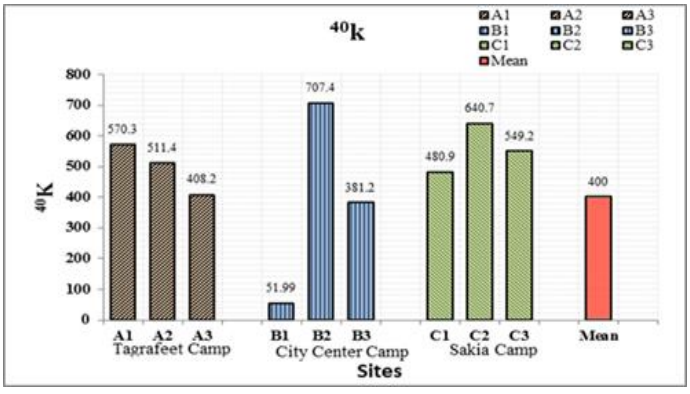

Figure (4): The Activity Concentration of ^{40}K in the Study Area.

The mean values of ^{226}Ra, ^{232}Th, and ^{40}K in all study areas exceed the world permissible values of 35, 30, and 400 Bq/kg, but not ^{40}K in the City Centre Camp, which is below the world average (UNCEAR, 2000; ICRP,1991). These differences in activity concentration could be due to the presence of radioactive materials in the ruins of buildings that contained bricks and ceramics.

Radium Equivalent Activity (Ra_{eq})

To determine the risk of gamma radiation exposure on humans, the radium equivalent activity was calculated using the equation 2 (Berekts and Metheu 1985; UNCEAR, 2000).

$$R_{aeq}\left(\frac{Bq}{Kg}\right) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively; the values of radium equivalent activity are presented in Table (2).

Table (2)1: The Radium Equivalent Activity (R_{aeq}), the Absorbed Dose Rate (D), the Outdoor ($Aede_{out}$) and Indoor ($Aede_{in}$) Annual Effective Dose Equivalent, the External (H_{ex}) and Internal (H_{in}) Hazard Index for the Soil Samples Collected from Three Locations in Bani Waleed City –Libya.

Sites	Sample ID	Ra_{eq} (Bq Kg^{-1})	D ($nGYh^{-1}$)	$AEDE_{out}$ ($mSvy^{-1}$)	$AEDE_{in}$ ($mSvy^{-1}$)	H_{ex}	H_{en}
Tagrafeet Camp	A1	120.03	58.53	0.072	0.287	0.324	0.417
	A2	110.7	53.56	0.066	0.263	0.299	0.408
	A3	148.12	69.33	0.085	0.340	0.400	0.569
City Center Camp	B2	50.85	22.83	0.028	0.112	0.137	0.220
	B2	202.06	96.62	0.118	0.474	0.546	0.706
	B3	103.03	49.03	0.060	0.241	0.279	0.402
Sakia Camp	C1	148.57	69.83	0.086	0.343	0.401	0.589
	C2	133.75	65.69	0.081	0.322	0.361	0.431
	C3	276.17	82.48	0.101	0.405	0.476	0.710
Min		**50.85**	**22.83**	**0.028**	**0.112**	**0.137**	**0.220**
Max		**276.17**	**96.62**	**0.118**	**0.474**	**0.546**	**0.706**
Mean value		**143.697**	**63.09**	**0.077**	**0.307**	**0.387**	**0.494**
World average value		**370**	**60**	**0.07**	**0.50**	**1.0**	**1.0**

The Tagrafeet Camp values ranged from 34.32 to 62.49 Bq/kg with mean values of 45.73 Bq/kg. The City Centre Camp values ranged from 30.46 to 59.16 Bq/kg with an average value of 45.04 Bq/kg. Finally, the values of Sakia Camp ranged from 26.01 to 86.53 Bq/kg with an average value of 60.61 Bq/kg. These values of the three sites are less than the global standard value limit of 370 Bq/kg. as seen in Figure (5).

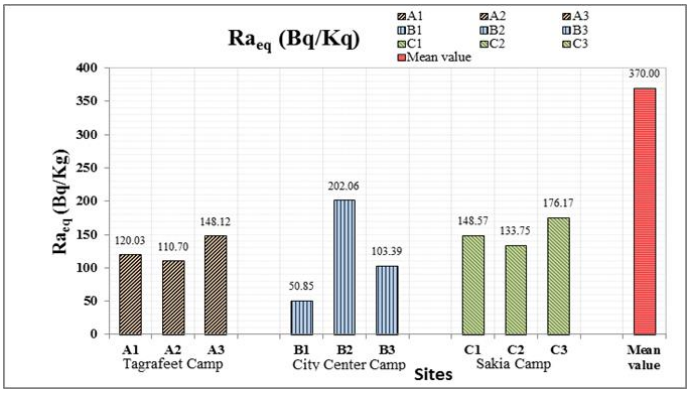

Figure (5): Radium Equivalent Activity in the Study Area.

This indicates that the radionuclides in soil samples from the study area do not pose a direct radiological hazard to the public, but that excess for an extended period may cause disease, such as stochastic effects.

Absorbed Dose Rate (D nGyh^{-1})

The awareness of natural radionuclides on the rate of dose absorbed in the air relies upon the concentration of radionuclides in the soil. The dose may be calculated by using the absorbed dose-rate conversion elements depending on the radionuclides within the soil. The conversion factor specified by equation 3 was used, (UNCEAR, 1993; Abu jassim *et al*., 2016).

$$\boldsymbol{D(nGyh^{-1}) = 0.427A_{Ra} + 0.662A_{Th} + 0.043A_K} \qquad (\mathbf{3})$$

Where D is the absorbed dose rate in nGyh^{-1} at one meter above the ground, and the A_{Ra}, A_{Th} and A_k are the activity concentration of the ^{226}Ra, ^{232Th}, and ^{40}K in the soil sample respectively (Saito and Jacob, 1995). The absorbed dose rate was calculated for the three study sites as shown in Table (2). The values of Tagrafeet Camp ranged from 53.56 nGyh^{-1} to 69.33 nGyh^{-1} with a mean average of 60.47 nGyh^{-1}. The City Centre Camp values ranged from 22.83 to 96.62 nGyh^{-1} with a mean value of 56.16 nGyh^{-1}. The values of Sakia Camp ranged from 65.69 to 82.48 nGyh^{-1} with an average value of 72.66 nGyh^{-1}. It can be observed that the Tagrafeet and Sakia Camps are higher than the world permissible value of (60 nGy h^{-1}) while the absorbed dose rate in City Centre Camp is lower than the world mean value as shown in Figure (6).

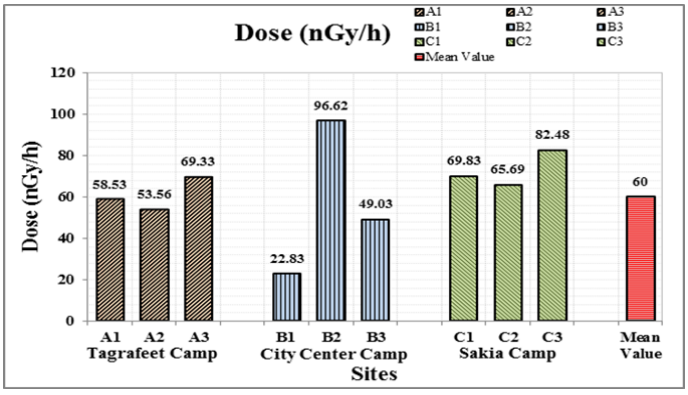

Figure (6): Absorbed Dose Rate (D nGyh^{-1}) in the Study Area.

Annual Effective Dose Equivalent (AEDE mSvy^{-1})

The annual effective dose was calculated from the absorbed rate by using equations 4 and 5. The conversion factor 0.7 Sv/Gy, outdoor occupancy factor 0.2, which drifted from 5/24, and indoor occupancy factor 0.8, which drifted from 19/24, were taken into consideration (UNSCEAR, 2000; Veiga *et al*., 2006).

$$\boldsymbol{AEDE_{OUT} = D \times 0.7(SvGy^{-1}) \times 0.2 \times 8760(hy^{-1}) \times 10^{-6}} \quad (\mathbf{4})$$

$$\boldsymbol{AEDE_{in} = D \times 0.7(SvGy^{-1}) \times 0.8 \times 8760(hy^{-1}) \times 10^{-6}} \quad (\mathbf{5})$$

D is the absorbed rate and 8760 are hours in a year. The corresponding worldwide values of $AEDE_{out}$ and $AEDE_{in}$ are 0.07 mSv, and 0.42 mSv respectively (UNSCEAR, 2000).

The values of the outdoor annual effective dose within the study area were calculated by using Equation 4. It was found that Tagrafeet Camp values ranged from 0.072 to 0.085 mSvy^{-1} with a mean value of 0.074 mSvy$^{-1,}$ the City Centre Camp values ranged from 0.028 to 0.118 mSvy^{-1} with an average of 0.068 mSvy^{-1}, and the Sakia Camp values ranged from 0.081 to 0.101 mSvy^{-1} with a mean value of 0.089 mSvy^{-1}. Figure (7) illustrates that.

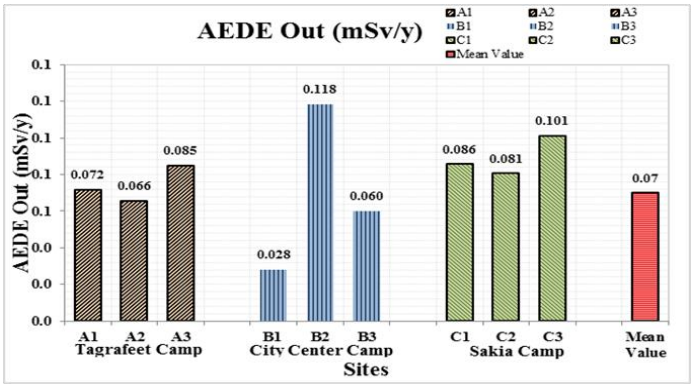

Figure (7): Outdoor Annual Effective Dose of the Study Area.

The values of Tagrafeet and Sakia Camps exceeded the global average value of 0.07 $mSvy^{-1}$(UNSCEAR, 2000) while the mean value of the City Centre Camp is below the worldwide permissible value. The indoor annual effective dose values of Tagrafeet Camp ranged from 0.263$mSvy^{-1}$ to 0.340 $mSvy^{-1}$ with a mean of 0.296 $mSvy^{-1}$, the City Center Camp values ranged from 0.112 to 0.474 $mSvy^{-1}$ with a mean of 0.273, and the Sakia Camp values ranged from 0.322 to 0.405 $mSvy^{-1}$ with mean of 0.353 $mSvy^{-1}$. Figure (8) illustrates that. It lies below the permissible world value of 0.48 ($mSvy^{-1}$) (UNSCEAR, 2000).

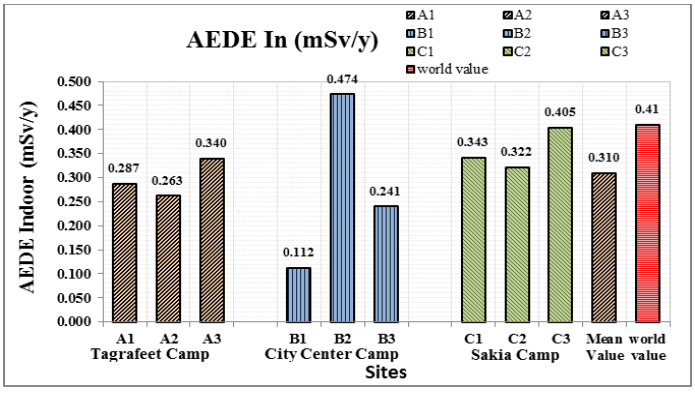

Figure (8): Indoor Annual Effective Dose of the Study Area.

Hazard indices (H_{ex} and H_{in})

Both indices represent the external and internal radiation risks. These indices are calculated by Equations 6 and 7 (Orgun *et al*., 2007).

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \qquad (6)$$

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (7)$$

C_{Ra}, C_{Th}, and C_K represent the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K.It is worth mentioning that the external hazard index, radon, and its short-lived progeny are harmful to the respiratory organs so the external hazard index must be below the minimum amount, which is equivalent to a maximum value of Radium equivalent to 370 Bq/kg (Beretka and Matthew, 1985). The internal exposure due to radon and its daughter progenies is measured by the internal hazard index H_{in} (Orgun *et al*., 2007). For the radiation hazard to be negligible, the values of the H_{in} should be less than one (Diab *et al*., 2008).

The values of the external hazard index are calculated by using Equation 6. It was found that the values of Tagrafeet Camp ranged from 0.299 to 0.400 with a mean value of 0.341. City Center Camp values ranged from 0.137 at B1 to 0.546 at B2 with a mean value 0.962, and the Sakia camp values ranged from 0.361 at C2 to 0.476 at C3 with a mean value of 0.412. The mean values of the external hazard index in the three locations are below the permissible world value of 1.0. See Figure (9).

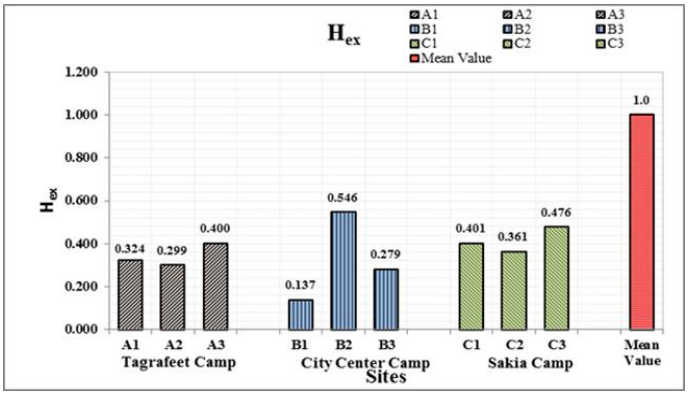

Figure (9): The External Hazard Index of the Three Locations in Study Area.

The values of the internal hazard index (H_{in}) were calculated by using equation 7. The values of Tagrafeet Camp ranged between 0.408 and 0.569 with a mean value of 0.464, the city centre camp values ranged from 0.220 at B1 to 0.706 at B2 with a mean value of 0.442, finally the Sakia camp values ranged from 0.431 at C2 to 0.710 at C3 with a mean value of 0.576. The mean values of the internal hazard index in the three locations were below the permissible world value of 1.0 as shown in Figure (10).

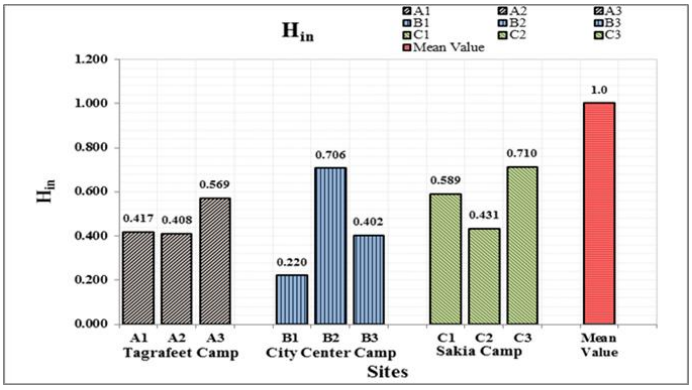

Figure (10): The Internal Hazard Index in the Three Locations of Study Area.

Conclusion

It can be concluded that the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in all study areas exceed the world permissible values of 35, 30, and 400 Bq/kg, however, the ^{40}K in the City Centre Camp found to be below the world average (UNSCER, 2000; ICRP, 1990). These differences in activity concentration could be due to the presence of radioactive materials in the ruins of buildings that contained bricks and ceramics. The mean average of Radium Equivalent Activity (R_{aeq}) was below the permissible world value in the three locations. The absorbed dose rate and the AEDE outdoor mean values were calculated and found to be higher than the world mean value in Tagrafeet and Sakia Camps but below the world permissible value in the City Centre Camp. The AEDE indoor and Hazard indices (H_{ex} and H_{in}) were calculated and found to be within the permissible world values.

It is recommended that those locations with higher activity concentrations should receive immediate treatment to reduce radioactive pollution in accordance with the environmental protection regulations and to maintain the activity levels around the accepted levels.

Abbreviations and Acronyms

^{238}U	Uranium
^{232}Th	Thorium
^{40}K	Potassium
^{226}R	Radium 226
^{228}R	Radium 228
HPGe	hyper-pure germanium gamma-ray
Bq/Kg	Becquerel per Kilogram (unit of radioactivity in the International System of Units (SI))

R_{aeq}	Radium Equivalent Activity
D ($nGyh^{-1}$)	absorbed dose rate (nano gray per hour)
$AEDE_{in}$, $AEDE_{out}$	Annual Effective Dose Equivalent inside and outside
H_{ex}, H_{in}	external Hazard index and internal Hazard index
GPS	Global Positioning System
FWHM	full-width high material
MAPEP	Mixed Analytic Performance Evaluation Program
^{214}Pb	Lead 214
^{137}Cs	Cesium 137
mSv	Millisievert
$mSvy^{-1}$	Millisievert per year
$SvGy^{-1}$	Sievert Gray per year

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