Environmental Radioactivity Assessment in Selected Areas of Maysan Governorate

Rasoul Jasim Khlaif and Hadi D. Alattabi
Department of Physics, College of Science,Wasit University, 52001 Al-Kut, Wasit, Iraq
std2023204.ranbar@uowasit.edu.iq, alattabih@uowasit.edu.iq

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Abstract: Increasing levels of environmental radioactivity arising from both natural and anthropogenic sources have become a global concern due to their potential adverse effects on human health. This study assesses the activity concentrations (Bq/kg), radium equivalent activity (Raeq), external hazard index (Hex), internal hazard index (Hin), and gamma index (Iγ) of natural radionuclides in soil samples collected from the center of Maysan Governorate, Al-Majar city, and Kmet district, southern Iraq. Measurements were carried out using a high-purity germanium (HPGe) gamma-ray spectrometer (BE503P, Canberra), and the activities of ^{40}K, ^{226}Ra, and ^{228}Ac were determined. The average activity concentrations were 294 ± 18.81 Bq/kg for ^{40}K, 16.43 ± 1.14 Bq/kg for ^{226}Ra, and 16.14 ± 1.17 Bq/kg for ^{228}Ac. The mean values of Raeq (61.93 Bq/kg), Hex (0.17), Hin (0.21), and Iγ (0.47) were all below the recommended limits set by UNSCEAR (2008). These results indicate that the investigated areas are free from radiological hazards and pose no significant risk to human health.

1 INTRODUCTION

Assessing radioactivity levels to which humans are exposed is critically important, as it provides accurate data on radioactive sites, contributing to human health protection, particularly in areas with high radiation levels. Humans are exposed to varying amounts of ionizing radiation from natural and industrial sources. Radiation is transmitted in two ways: as particles or electromagnetic waves [1]. The global increase in radiation levels results from human activities, which redistribute radioactive concentrations. Radioactivity is defined as the spontaneous disintegration of an unstable radioactive element into a more stable one, accompanied by the emission of one or more types of radiation (alpha particles, beta particles, and gamma rays) [2]. Nuclear radiation from radionuclides poses significant health risks to populations living near contaminated sites. This occurs through bioaccumulation: plants absorb radionuclides from soil or contaminated water, transferring them through the food chain to humans via plant consumption, animal products, or dairy. The radiation dose depends on radiation intensity, energy, type, exposure duration, and the affected body part [1]. Ionizing radiation produces numerous biological effects by ionizing molecules as it passes through the human body, causing health issues such as cancer, hair loss, sterility, and bone necrosis [3]. Recent studies have measured environmental radioactivity in Iraq (Wasit [4], Qadisiyah [5], and Thi Qar [6] Governorates) and other countries (Saudi Arabia [7], Bangladesh [8]). Results from Wasit and Qadisiyah showed radiation concentrations, radium equivalent activity (Raeq), external/internal hazard indices (Hex, Hin), and gamma index (Iγ) within UNSCEAR 2008 permissible limits [9], [10]. However, Thi Qar exhibited uranium contamination from wartime bombing. While elevated levels were observed globally, they remained within safe limits. This study evaluates radioactivity levels in Maysan Governorate to identify and document high-radiation sites.

2 MATERIALS AND METHODS

2.1 Study Area

Maysan Governorate is located in southern Iraq. Its administrative center (Amarah) is situated in the southeast of Iraq, 350 kilometers away from

Baghdad, at latitude 47°17'23" N and longitude 31°39'54.6" E. See table 1 for Latitude and longitude of the soil samples of study area. When the Tigris River enters Maysan Governorate, it branches into three arms: the Musharah River, the Kahlaa River, and the main channel toward Qalat Salih District, which continues as the primary Tigris branch toward Basra Governorate. From this main channel, a tributary flows toward Al-Majar District. The Musharah and Kahlaa Rivers flow into the Al-Hawizeh Marshes, forming a natural border between Iraq and Iran. See Figure 1 location of soil sample

Figure 1: The location of soil samples in Maysan Governorate, Iraq.

Table 1: Latitude and longitude of the soil samples study area.

Location	Sample Code	N	E
Kmet	C1	46° 53' 18.31"	32° 1' 41.52"
	C2	46° 53' 20.796"	32° 1' 42.88"
Al-Majar city	D1	47° 6' 33.22"	31° 44' 58.27"
	D2	47° 6' 30.92"	31° 44' 44.98"
	D3	47° 6' 54.97"	31° 44' 54.99"
	D4	47° 6' 54.972"	31° 44' 47.97"
Al Jomhoureya Bridge	F1	47° 8' 53.7"	31° 50' 17.26"
	F2	47° 8' 50.20"	31° 50' 16.47"
Yugoslav Bridge	G1	47° 8' 40.09"	31° 51' 25.45"
	G2	47° 8' 39.15"	31° 51' 21.85"

Figure 2: Location of the Kmet district samples C1 and C2.

Figure 3: Location of Fourth Corps of the former Iraqi Army samples D1, D2, D3, and D4.

Figure 4: Location the Al-Jomhoureya Bridge Samples F1 and F2.

2.2 Samples Collection Preparation and Measurements

The soil samples were collected from the center of Maysan Governorate, Al-Majar city, and the Kmet district.These sites include areas near the Tigris River, such as the Al Jomhoureya Bridge (F), the Yugoslav Bridge (G) see Figures 4 and 5, agricultural areas on the outskirts of Al-Majar city at the site of the warehouses of the Fourth Corps of the former Iraqi army (D) see Figure 3 that were bombed during the war, and the Kmet district (C) see Figure 2. A total of 10 soil samples were collected from the same depth (0-10 cm). The samples were dried, crushed,

homogenized, and placed in special plastic containers. The radioactive concentrations were measured using a high-purity germanium (HPGe) detector-a gamma-ray spectrometer model BE503P with associated electronics supplied by Canberra. The detector has a resolution of 0.45 keV at 5.9 keV, 0.72 keV at 122 keV, and 1.8 keV at 1332.5 keV. The resolution and efficiency are shown in Table 2 and Figure 7.

Figure 5: Location the Yugoslav Bridge Samples G1 and G2.

Table 2: The resolution and Efficiency of high purity Germanium detector.

Isotope	^{55}Fe	^{57}Co	^{60}Co
Energy (KeV)	5.9	122	1332.5
FWHM (eV)	367	673	1772
FWTM (eV)		1235	3270

Where: FWHM - Full width at Half Maximum.

The high-purity germanium (HPGe) detector - a gamma-ray spectrometer - requires cooling to -196°C using liquid nitrogen. The sample is placed inside the measurement system, and the Gamma analysis program is operated on the computer to apply a high voltage of 4500 V. See Figure 6.

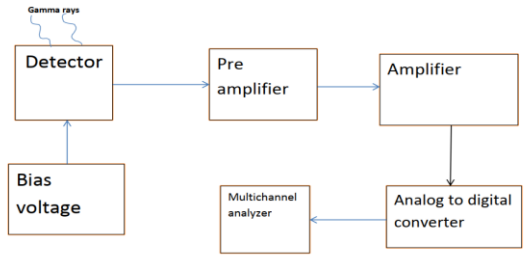

Figure 6: Experimental setup High purity Germanium detector [11].

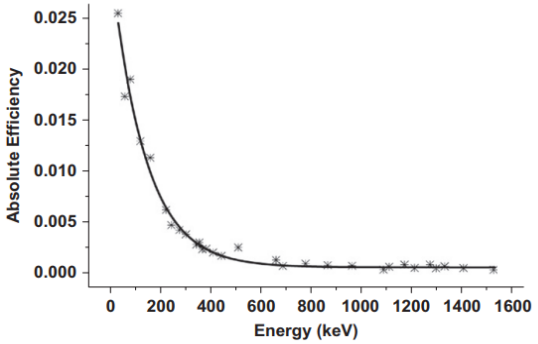

Figure 7: The Efficiency calibration curve for HPGe detector [12].

3 RESULTS AND DISCUSSION

3.1 The Radioactive Concentrations

Radioactive concentrations were measured at the Radiological and Nuclear Applications Laboratories, Directorate of the Iraqi Atomic Energy Commission, using a HPGe detector (gamma-ray spectrometer). The measurement time was 3600 s per sample (total 36,000 s for all samples), identifying three radionuclides: ^{40}K, ^{226}Ra, and ^{228}Ac. Concentrations were calculated using the following (1):

$$C = \frac{(N - N_b)}{t \,.\, P_\gamma . \varepsilon \,.\, Q} \,.\, e^{\frac{0.693 \,.\Delta t}{T_{1/2}}} \qquad (1)$$

Where:

- C: Radionuclide concentration (Bq/Kg);
- N: Counts in the peak at energy E;
- Nb: Background counts in the peak at energy E;
- t: measurement live time (sec);
- Q:sample quantity (Kg);
- Δt: time interval from sampling to measurement (h);
- T1/2: radionuclide half-life (h).

3.2 Radium Equivalent Activity

Radium equivalent activity (Raeq) is used to assess radiation hazards associated with materials containing ^{226}Ra, ^{232}Th, and ^{40}K (expressed in Bq/kg) [3], [13]. It is calculated as follows (2):

$$Ra_{eq}\left(\frac{Bq}{Kg}\right) = C_{Ra} + 1.43C_{Ac} + 0.077C_K \qquad (2)$$

Where: C(Ra), C(Ac) and C(k) are activities in Bq/kg of ^{226}Ra,^{228}Ac and ^{40}K respectively.

3.3 The External Hazard Index (Hex)

The external hazard index (Hex) evaluates the hazard from natural gamma radiation. Its primary objective is to ensure the annual radiation dose remains below the permissible limit of 1 mSv y^{-1} [13], [14]. This index, proposed by Beretka and Mathew (1985), is calculated using the following (3):

$$H_{ex} = {}^{C_{Ra}}/_{370} + {}^{C_{Ac}}/_{259} + {}^{C_K}/_{4810} \leq 1 \quad (3)$$

3.4 The Internal Hazard Index (Hin)

Alpha particles emitted by short-lived radionuclides such as radon pose a risk to the human respiratory system. Therefore, the internal hazard index (Hin) should be less than unity to ensure radiation levels are not dangerous to humans [15], [16]. It is calculated using the following (4):

$$H_{in} = {}^{C_{Ra}}/_{185} + {}^{C_{Ac}}/_{259} + {}^{C_K}/_{4810} < 1 \quad (4)$$

3.5 Gamma Level Index (Iγr)

It is used to measure the gamma radiation hazard associated with natural radionuclides in the investigated sample and is given by the following (5), [4], [17]:

$$I_\gamma = \frac{C_{Ra}}{150} + \frac{C_{Ac}}{100} + \frac{C_K}{1500} \quad (5)$$

The results of soil radioactivity concentrations are presented in Table 3. The highest ^{40}K concentration was 342 ± 21.2 Bq/kg in sample F1 (Al Jomhoureya Bridge, Maysan Governorate center), and the lowest was 217.8 ± 15.7 Bq/kg in sample C1 (Kmet district), with an average of 294 ± 18.81 Bq/kg across all samples. Potassium concentrations are generally similar due to consistent geological composition, although variations in some agricultural samples may result from fertilizer use. For ^{226}Ra, the highest value was 25.3 ± 1.3 Bq/kg in sample G1 (Yugoslav Bridge, Maysan Governorate center), the lowest was 10.8 ± 1 Bq/kg in sample C1 (Kmet district), and the average was 16.43 ± 1.14 Bq/kg. For ^{228}Ac, the highest concentration was 19.7 ± 1.2 Bq/kg in sample D1 (Fourth Corps warehouses, Al-Majar city), the lowest was 10.7 ± 1.3 Bq/kg in sample C1 (Kmet district), and the average was 16.14 ± 1.17 Bq/kg. All values are within permissible limits [9], [18]. See Figures 8, 9, and 10.

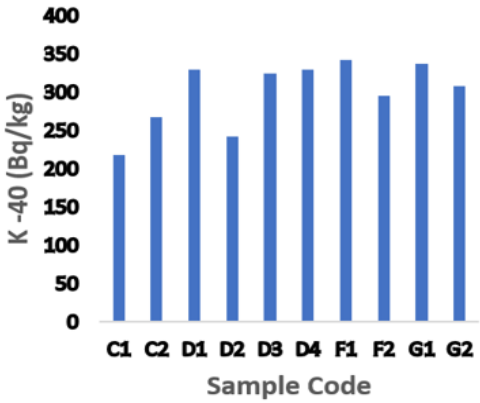

Figure 8: ^{40}K concentration in all soil samples.

Table 3: Concentrations (Bq/kg), radium equivalent activity (Raeq, Bq/kg), external hazard index (Hex), internal hazard index (Hin), and gamma index (Iγ) of radionuclides in soil samples from the study area.

Sample Code	Radionuclide concentration (Bq/kg)			Raeq Bq/Kg	Hex	H_{in}	I_γ
	^{40}K	^{226}Ra	^{228}Ac				
C1	217.8±15.7	10.8±1	10.7±1.3	42.87	0.116	0.145	0.324
C2	267±16.9	11.2±1	12.5±1.1	49.63	0.134	0.164	0.378
D1	330±20.2	14.2±1.1	19.7±1.2	67.78	0.183	0.221	0.512
D2	241.9±15.3	11.1±0.8	12.4±0.9	47.46	0.128	0.158	0.359
D3	324.6±20.1	14.25±1.1	17.8±1.2	64.70	0.175	0.213	0.489
D4	329.1±20.8	14.75±1	18±1.2	65.83	0.178	0.218	0.498
F1	342±21.2	23.2±1.5	18.1±1.4	75.42	0.204	0.266	0.564
F2	295.3±19.2	23.8±1.5	16.2±1.3	69.70	0.188	0.253	0.518
G1	337.3±20	25.3±1.3	16.6	75.01	0.203	0.271	0.560
G2	308.1±18.7	15.7±1.1	15±1.2	60.87	0.164	0.207	0.460
Average	294 ±18.81	16.43± 1.14	16.14 ±1.17	61.93	0.17	0.21	0.47

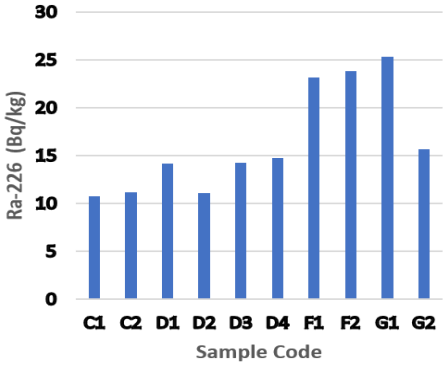

Figure 9: ^{228}Ra concentration in all soil samples.

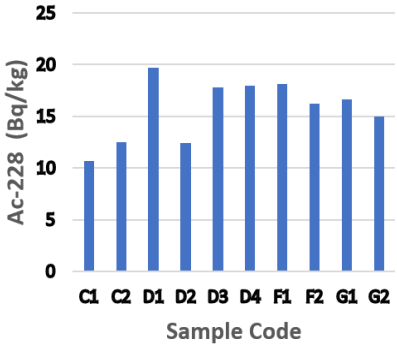

Figure 10: ^{228}Ac concentration in all soil samples.

The highest radium equivalent activity (Raeq) was 75.42 Bq/kg in sample F1 (Al Jomhoureya Bridge, Maysan Governorate center), the lowest was 42.87 Bq/kg in sample C1 (Kmet district), and the average across all samples was 61.93 Bq/kg (see Fig. 11). All values are safe for human health.

Figure 11: Radium Equivalent Activity for all samples.

The highest external hazard index (Hex) was 0.204 in sample F1 (Al Jomhoureya Bridge, Maysan Governorate center), the lowest was 0.116 in sample C1 (Kmet district), and the average was 0.17 across all samples. The highest internal hazard index (Hin) was 0.271 in sample G1 (Yugoslav Bridge, Maysan Governorate center), the lowest was 0.145 in sample C1 (Kmet district), and the average was 0.21. Hin values are consistently higher than Hex due to greater risk from internal radon inhalation compared to external exposure. All Hex and Hin values are normal and within permissible limits (see Fig. 12).

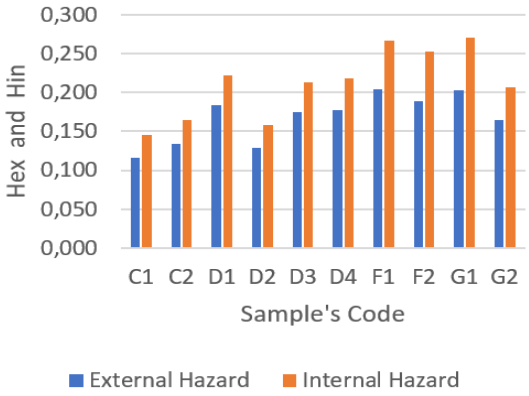

Figure 12: External and internal hazard for all samples.

The highest gamma index (Iγ) was 0.564 in sample F1 (Al Jomhoureya Bridge, Maysan Governorate center), the lowest was 0.324 in sample C1 (Kmet district), and the average was 0.47 across all samples. All values are within UNSCEAR permissible limits (see Fig. 13).

Figure 13: Gamma Level Index for all sample.

3.6 Comparison Between Present Study and Previous Study Reported from Different Governorate in Iraq and Different Countries of the World

Table 4 compares radioactivity concentrations (Bq/kg) in soil samples from the present study with previous studies from other Iraqi governorates and countries worldwide. Average concentrations were

294 ± 18.81 Bq/kg for ^{40}K, 16.43 ± 1.14 Bq/kg for ^{226}Ra, and 16.14 ± 1.17 Bq/kg for ^{228}Ac. In Iraqi governorates, Maysan showed the highest ^{40}K values, while Thi-Qar had the highest ^{226}Ra (279.47 Bq/kg) due to military equipment bombed during wars. Wasit recorded the highest ^{228}Ac (33.05 Bq/kg). Internationally, ^{40}K values in Iraqi governorates were lower than in other countries, with Bangladesh showing the highest (874.89 ± 119.96 Bq/kg), followed by Malaysia for ^{226}Ra and Bangladesh for ^{228}Ac (90.56 ± 17.94 Bq/kg). All values are within UNSCEAR (2008) permissible limits [9], [10], except ^{226}Ra in Thi-Qar Governorate (279.47 Bq/kg), which exceeds limits. Differences from previous studies result from geological variations, war contamination, sampling depth, and measurement methods (see Fig. 14, 15, and 16).

Table 4: Comparison of radioactivity concentrations (Bq/kg) in soil samples from the present study with previous studies from other Iraqi governorates and countries worldwide.

Governorate In Iraq and different countries of the world.	Mean Radionuclide concentration (Bq/kg)			Reference
	^{40}K	^{226}Ra	^{228}Ac	
Maysan Governorate, Al-Majar and Kmet	294 ±18.81	16.43± 1.14	16.14±1.17	Present study
Thi-Qar Governorate	174.1	279.47	-	[6]
Wasit Governorate	268.64	31.2	33.05	[4]
Qadisiyah Governorate	262.43 ±26	-	20.55±1.28	[5]
Saudi	791	28.6	27.1	[7]
Palestine	120.0	34.5	23.8	[19]
Yemen	566.05	14.28	25.78	[20]
Malaysian	427 ±17	57±72	68±73	[12]
Mali	244.99 ±35.33	45.31 4.63	58.39 ± 6.66	[21]
Kenya	354.81± 67.06	7.23 ± 1.67	8.03 ± 1.91	[22]
Bangladesh	874.89 ±119.96	29.1±4.88	90.56 ± 17.94	[8]

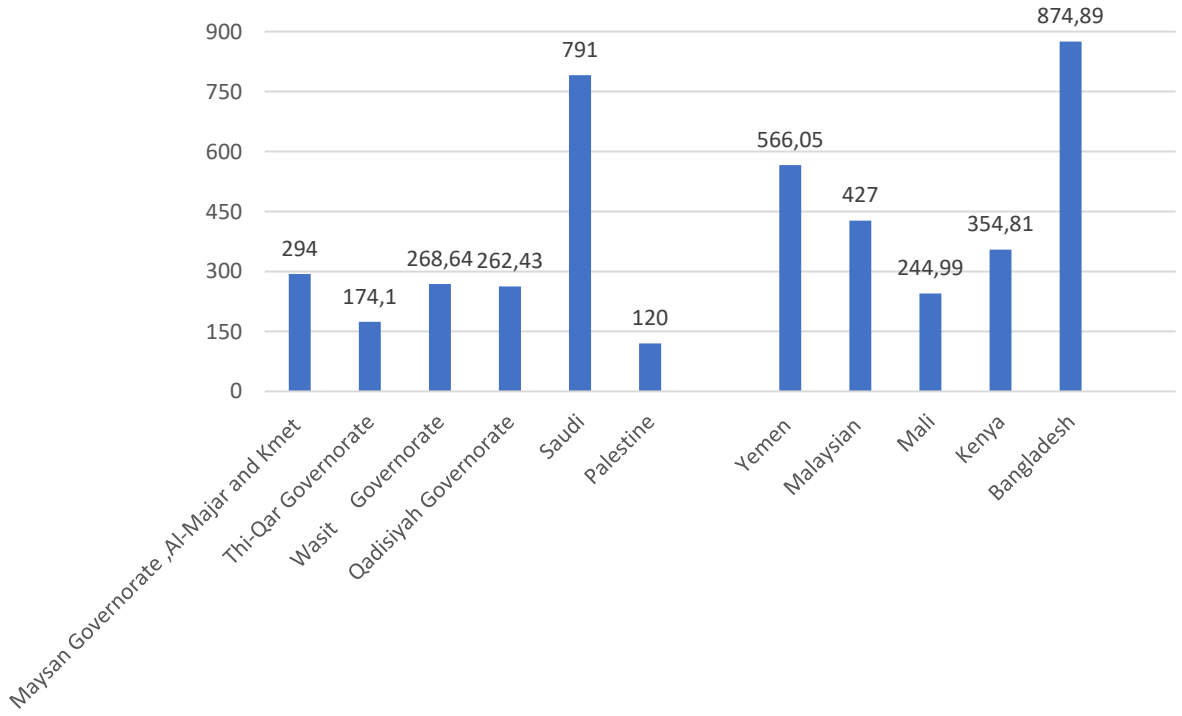

Figure 14: Concentration of K-40.

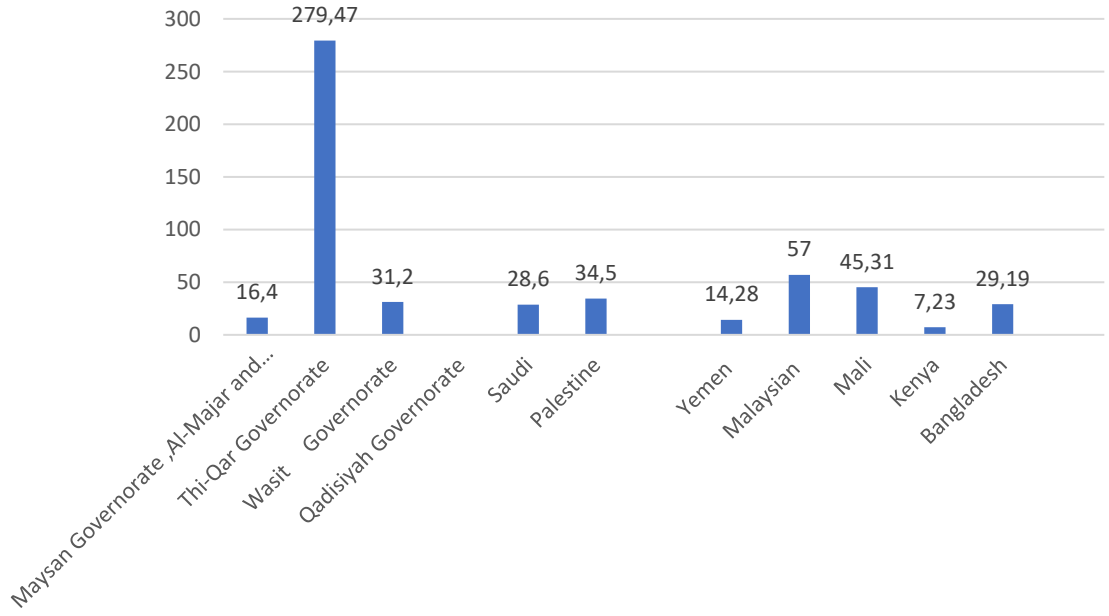

Figure 15: Concentration of Ra-226.

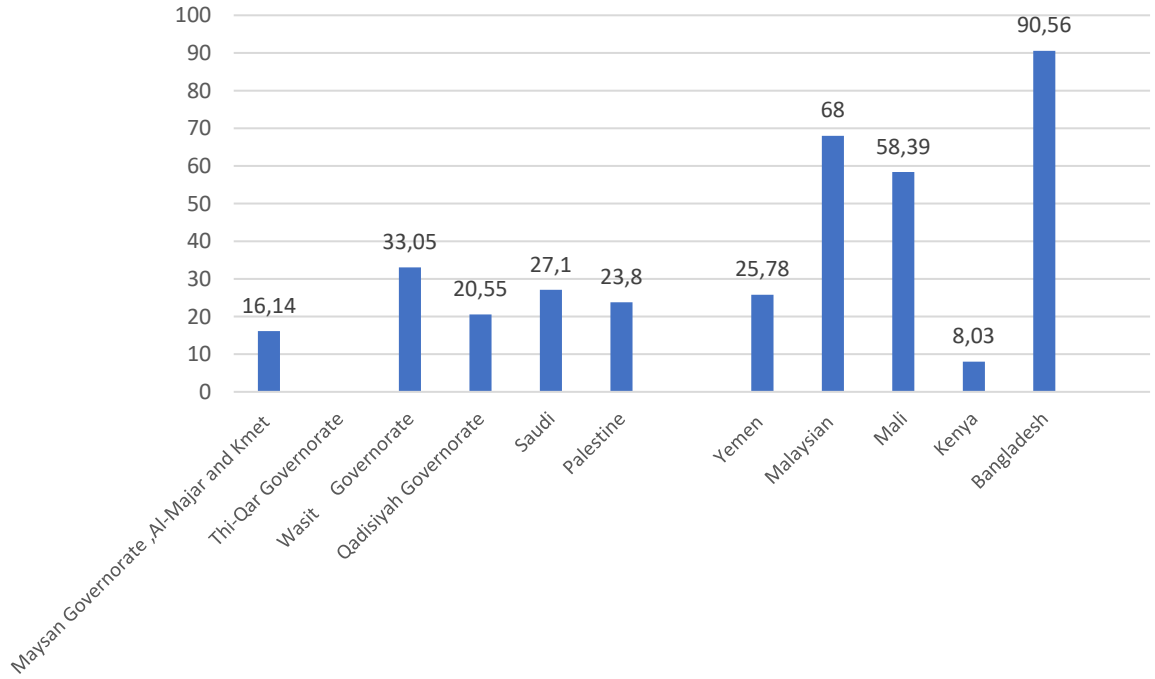

Figure 16: Concentration of Ac-228.

4 CONCLUSIONS

In this study, natural radioactivity levels in soil samples collected from the center of Maysan Governorate, Al-Majar city, and Kmet district were investigated using high-resolution gamma-ray spectrometry. The activity concentrations of ^{40}K, ^{226}Ra, and ^{228}Ac were determined, and no artificial radionuclides such as ^{137}Cs were detected in any of the analyzed samples.

The calculated radiological hazard parameters, including radium equivalent activity (Raeq), external hazard index (Hex), internal hazard index (Hin), and gamma index (Iγ), were found to be well below the recommended safety limits established by [9]. These results indicate that the investigated soils do not pose any significant radiological risk to the local population.

Overall, the findings confirm that the studied areas are free from radiological contamination and can be considered safe for human habitation and agricultural activities. The data obtained in this work provide a useful baseline for future environmental radiation monitoring in Maysan Governorate.

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