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Assessment of the cumulative effects of radioactive elements in selected areas of the soil of Ramadi city in Anbar, western Iraq

Ahmed M. Ahmed[1,*], Abd Alsatar K. Maroof[2], Sabah S. Farhan[1]

[1]*Department of Physics, College of Science, University of Anbar, Ramadi, Iraq.*
[2]*Ministry of Education, Direction of Education in Al-Anbar, Ramadi, Iraq.*

[*]**Corresponding author:** sc.ahmedmud76@uoanbar.edu.iq

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Abstract:

The study site suffers from a dearth of prior radiological and environmental investigations, especially after the city of Ramadi's neighborhoods were subjected to significant military activities. In the current investigation, 15 specimens that were collected from 5 various sites of Ramadi soil in Anbar, western Iraq, were evaluated utilizing gamma (γ) beams spectrum analyses with high purity solid-state Ge (HPGe) detectors. The authorized levels of ^{238}U, ^{232}Th, and ^{40}K varied from (22.953 − 33.896), (21.983 − 32.688), and (137.251 − 387.980) Bq/kg, successively, with an overall rate of (28.880 ± 2.580, 28.205 ± 2.051 and 285.660 ± 65.133) Bq/kg, successively. Soil potential hazards to human health and the environment were assessed. Both the specific activity level/concentration and total radiological hazards indicators are below US Environmental Protection Agency (USEPA) limits that have been permitted for the worldwide rate. No obvious indications of radiation hazards to soil exist in the study area. To protect the soil and environment, the study suggests that new Iraqi guidelines be proposed that outline the authorized rates of specific activity level/concentration and total radiological hazard indicators in soil.

Keywords: Ramadi Soil; Specific activity; (HPGe) detector; Hazards assessment

1. Introduction

Radioactivity is a phenomenon caused by unsteady atomic nuclei with extra energy or mass that spontaneously split apart and release ionizing radiation in the shape of gamma beams, alpha, beta, or neutrons [1, 2]. According to parameters including charge, mass, and other features, there are two categories of radiation exposure. However, the quantity of energy is the most crucial categorization. Non-ionizing radiation exposure (NIRE) is referred to as such when it has a low state of photon energy. This energy is enough to propel atoms about substance molecules or maybe cause them to vibrate, but not enough for ejection of electrons like visible light waves [3], whereas ionizing radiation exposure (IRE) is referred to as such when it has an elevated state of photon energy. This energy is enough for ionization or to excite the substance's interacting atoms, so it can remove electrons from the majority of atoms like X-rays and gamma beams [4].

The existence of naturally happening radionuclide substances in both soil and rock is well documented. These radionuclides, including ^{238}U and ^{232}Th, or their daughters, in addition to ^{40}K, can have their origins in the primeval epoch. They can be thought of as always present in soils and rocks due to their extremely long half-lives (up to 10^{10} years) [5–7]. Scientific sources indicate that exposure to radiation in two routes, direct and indirect that the direct method of radiation exposure for humans and animals is exterior exposure to radioactive material deposited on earth or inhalation of radioactive material stuck in the atmosphere, the indirect method of exposure is through the intake of food and water containing radioactive substances. Radioactive substances deposited on the soil are transmitted to plant tissues via roots or absorption through leaves. Thus, humans receive an interior dose as a result of inhaling radioactive substances or consuming contaminated plants, as well as an exterior dose as a result of direct exposure to radioactive substances in the soil [8–10]. The quantity of radionuclides in the soil is influenced by the substance's organic content, soil-to-water proportion, geological characteristics of the site, the quantity of rainfall, and soil drainage. Additionally, various biochemical processes have an impact upon radionuclide conduct within soil [11].

In view of the fact that elements of natural soil are influenced by radiation since the study area was susceptible to human activities and disorders, including significant military activities in the years 2014 – 2016, environmental radiological investigations of the study area declined following these events. Consequently, it's important to appreciate the potential cumulative influences of the radionuclides ^{238}U, ^{232}Th, ^{40}K in the soil specimen collected from various Ramadi areas as a radioactive indication of soil contamination and to know the extent to which they influence environmental equilibrium and somewhat minimize the side effects of soil contamination, it is also necessary to estimate radiation due to the high population density in these areas, which may have an impact on both people and the surroundings while comparing the results studied with the values reported worldwide.

Study district

Ramadi city is situated in central Iraq and about 100 km west of the capital Baghdad with coordinates north at a point (33° 26′ 12″) and east at a point (43° 19′ 46″) as demonstrated by Fig. 1, Its area is (8,543) km^2 and comprises several neighborhoods. The current study covered neighborhoods that have been subjected to major military activities (Al-Malab, Al-Bakr, Al-Dhubbat, Al-Hawz, Al-Andalus).

2. Materials and strategies

2.1 Specimen collection and preparation

15 specimens were collected from multiple sites of Ramadi soil (within Anbar governorate) during October and November 2022 for the purpose of assessing the specific activity level/concentration and radiological hazards indicators of ^{238}U, ^{232}Th, and ^{40}K. All the studied soil specimens were grinded for the purpose of reducing the spaces between the soil atoms. Subsequently, these specimens were dried in an oven at a temperature of 150 °C for 30 minutes to verify the removal of any remaining moisture. A sieve with 500 μm diameter holes was utilized to take soil specimens in a homogenous manner. Then, weigh 1 kg for each specimen. The specimens were packaged in 1 L Marinelli plastic container of fixed dimensions for optimal geometric homogenization around the detector. The containers were tape-sealed and kept for approximately a 1 month prior to they were analyzed to allow a secular balance between radionuclides.

2.2 High purity Ge (HPGe) system

This system comprises a gamma spectrometry type (DSA-2000) developed via (CANBERRA) company with a high-purity Ge detector with an analyzing ability to measure 2.0 keV at the energy level of the quantum line 1332 keV emitted from the (^{60}Co) isotope, and a count efficiency almost roughly equivalent to (40%). This system includes a primary amplifier (Pre amp), head amplifier (Amp), voltage-equipped, and multi-channel analysis (MCA), as depicted in Fig. 2; the 8,192-channel is connected to a computer for utilize in operation, analysis of the resulting spectrum, and

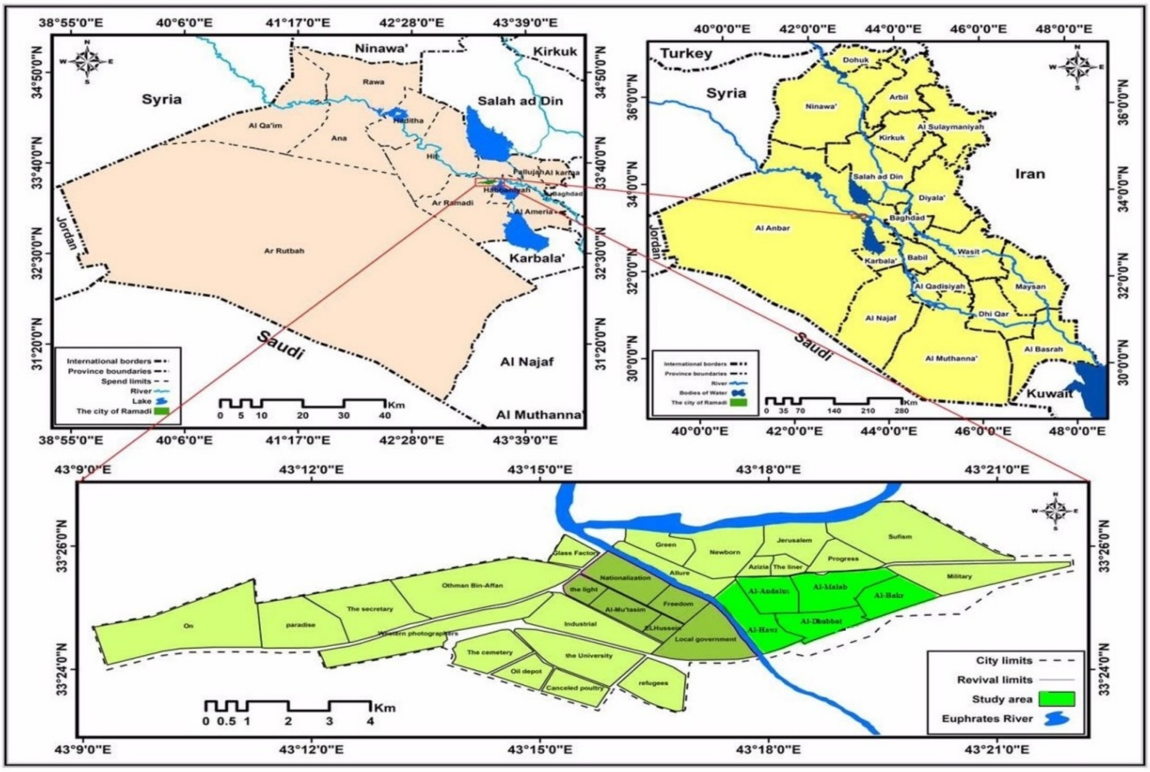

Figure 1. Specimens distribution in the research area.

reading of measurements. Nitrogen liquid is utilized to cool this germanium (Ge) system. The detector shield has a gap that can contain large specimens; the main sidewalls of the detector shield are 10 cm in thickness, and its inner high absorption ability materials that are both Cadmium Cd and Copper Cu with 1.6 mm and 0.4 mm thickness successively. The Genie 2000 Programme for Measurement and Analysis of Recorded Information was utilized to detect radionuclide radioactivity.

2.3 Assessment of specific activity level

It is computed via placing the soil in the Marinelli container, which is fixed around the (HPGe) detector and registers the spectrum of Gamma radiation for (3600 sec). The program draws spectrum and provides a report that contains channel numbers, related energies, and the net peak area of the spectrum curve. the specific activity level of ^{238}U, ^{232}Th, and ^{40}K is estimated utilizing the following formula [12, 13]:

$$A = \frac{N_{net}}{\varepsilon I_\gamma m t} \pm \frac{\sqrt{N_{net}}}{\varepsilon I_\gamma m t} \tag{1}$$

which N_{net} is the net number of counts under photo peak for the specimen, ε is the efficiency at a certain photo peak energy, I_γ is the percentage of gamma emission probability, m is the mass of the investigated specimen (kg), and t is time for the detector to be registered (sec).

2.4 Assessment of some radiological hazard indicators

Radiological hazard indicators are extremely important since they are often utilized to assess the level of a given area's radiological hazard to humans and its suitability for habitation.

1. Radium matching activity ($Ra_{Mat.}$)

It is referred to as the aggregate radioactivity focus of the three radioactive substances ^{238}U, ^{232}Th, and ^{40}K, relying upon the hypothesis that 370 of ^{238}U, 259 of ^{232}Th, and 4810 of ^{40}K in Bq.kg^{-1} unit successively provide a similar dosage rate of gamma [14], substances in which the radium matching exceeds 370 Bq.kg^{-1} are hazardous substances. Radium matching ($Ra_{Mat.}$) is estimated from the following formula [10]:

$$Ra_{Mat.}\ (\text{Bq.kg}^{-1}) = A_{^{238}\text{U}} + [143A_{^{232}\text{Th}} + 7.7A_{^{40}\text{K}}] \times 10^{-2} \tag{2}$$

$A_{^{238}\text{U}}, A_{^{232}\text{Th}}, A_{^{40}\text{K}}$ are the specific activity level/concentration value of ^{238}U, ^{232}Th and ^{40}K successively.

2. Absorbed dosage rate (AD)

To estimate the quantity of radiation hazard in every soil specimen in absorbed dosage formula (i.e. energy formula absorbed by the mass unit of radiation-prone substance), in order to do, it is necessary to estimate the percentage of dosage that is absorbed into air at (1) meter up the earth's surface as a consequence of the existence of natural radionuclides particles like ^{238}U, ^{232}Th and ^{40}K in soil specimens, which may be computed utilizing the formula below [16, 17]:

$$AD\ (\text{nGy/h}) = [46.2A_{^{238}\text{U}} + 60.4A_{^{232}\text{Th}} + 4.17A_{^{40}\text{K}}] \times 10^{-2} \tag{3}$$

3. Yearly effective dosage matching ($YEDM$)

It is estimated, relying on the absorbed dosage rate in the air, to converting it to a matching dosage via pummeling it a factor of 0.7; moreover, the matching dosage is also pummeled by a further coefficient of (0.80) or (0.20). (which is the proportion of a person's life spent inner or outer of their dwellings successively), to eventually turn into a yearly effective dosage in (mSv/y) unit as indicated in the following

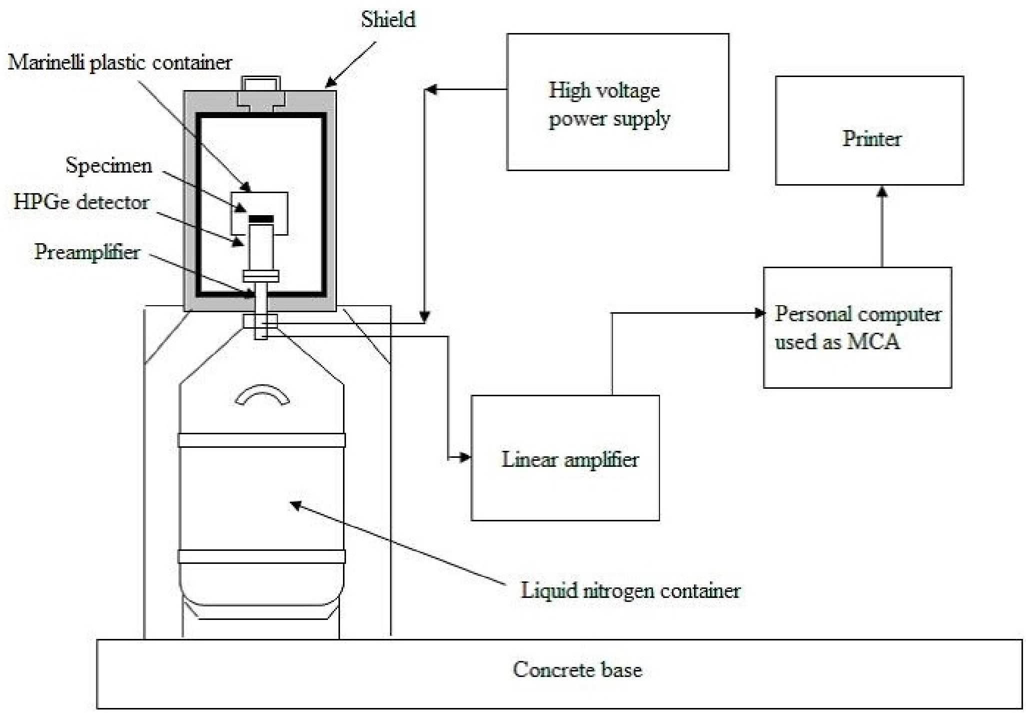

Figure 2. Scheme of germanium (Ge) detector system.

formula [17, 18]:

$$YEDM_{\text{in}} = [AD \times 8.760\text{h/y} \times 0.80 \times 0.7] \times 10^{-3} \quad (4)$$

$$YEDM_{\text{Out}} = [AD \times 8.760\text{h/y} \times 0.20 \times 0.7] \times 10^{-3} \quad (5)$$

4. Gamma concentration indicator (I_γ)
It is utilized to estimate the harmful due to gamma radiation, which is linked with the natural radionuclides particles (^{238}U, ^{232}Th and ^{40}K) in the soil specimen; the gamma concentration indicator (I_γ) is expressed via the following formula [10, 19]:

$$I_\gamma = \frac{A_{^{238}\text{U}}}{300} + \frac{A_{^{232}\text{Th}}}{200} + \frac{A_{^{40}\text{K}}}{3000} \quad (6)$$

If the I_γ value exceeds one, then the soil is radiologically hazardous.
5. Radiological exposure indicators (H)
The interior exposure indicators (H_{in}) is a term utilized to refer to the inhaling of alpha particles from short-term isotopes like ^{222}Rn and ^{232}Th that are associated with gamma (γ) radiation. The formula utilized to assess it is as follows [18]:

$$H_{\text{in}} = \frac{A_{^{238}\text{U}}}{185} + \frac{A_{^{232}\text{Th}}}{259} + \frac{A_{^{40}\text{K}}}{4810} \quad (7)$$

Unlike the interior exposure indicators, utilize the term "exterior hazard indicators" ($H_{\text{ex.}}$) to estimate the radiation hazards posed by naturalist gamma (γ) radiation. It can be provided as follows [18]:

$$H_{\text{ex.}} = \frac{A_{^{238}\text{U}}}{370} + \frac{A_{^{259}\text{Th}}}{259} + \frac{A_{^{40}\text{K}}}{4810} \quad (8)$$

In the ideal soil specimens, it is preferred that the levels of (H_{in}), ($H_{\text{ex.}}$) be below one.

3. Results and discussion

The 15 specimens of Ramadi soil were collected from 5 various sites in western Iraq's Anbar province. Gamma (γ) beam spectrum analyses with high-purity solid-state Ge (HPGe) detectors were utilized to analyze radionuclides, and assess specific activity levels/concentration (^{238}U, ^{232}Th and ^{40}K) and radiological hazards indicators. Utilizing the data given in the Tables 1 and 2, we can infer that:
It emerged that the levels in (Bq/kg) varied from 22.953 at specimen (S.7) to 33.896 at specimen (S.4), from 21.983 at specimen (S.7) to 32.688 at specimen (S.3), 137.251 at specimen (S.9) to 387.980 at specimen (S.4), 65.105 at specimen

Table 1. The specific activity level and radiological hazards indicators ($Ra_{Mat.}$, AD) of soil specimen checks.

Study area	Site	Specimen name	$A_{^{238}\text{U}}$ (Bq/Kg)	$A_{^{232}\text{Th}}$ (Bq/Kg)	$A_{^{40}\text{K}}$ (Bq/Kg)	$Ra_{Mat.}$ (Bq/Kg)	AD (nGy/h)
Ramadi City/ Anbar Governorate	Al-Malab	S.1	32.358	28.963	307.132	97.424	45.250
		S.2	27.606	31.739	286.951	95.088	43.890
		S.3	30.510	32.688	302.426	100.541	46.450
	Al-Bakr	S.4	33.896	27.150	387.980	102.595	48.237
		S.5	29.922	28.210	344.389	96.780	45.224
		S.6	31.658	30.390	361.722	102.968	48.065
	Al-Dhubbat	S.7	22.953	21.983	139.175	65.105	29.686
		S.8	28.392	26.753	142.456	77.618	35.216
		S.9	25.710	24.295	137.251	71.020	32.276
	Al-Hawz	S.10	24.923	27.192	355.252	91.162	42.752
		S.11	31.274	26.743	321.253	94.253	43.998
		S.12	26.275	30.720	294.330	92.868	42.967
	Al-Andalus	S.13	26.955	28.550	235.256	85.896	39.508
		S.14	29.834	29.760	310.943	96.333	44.725
		S.15	30.937	27.935	358.376	98.479	46.110
		Ave.	28.880 ±2.580	28.205 ±2.051	285.660 ±65.133	91.209 ±8.699	42.290 ±4.330
		Min.	22.953	21.983	137.251	65.105	29.686
		Max.	33.896	32.688	387.980	102.968	48.237
		worldwide rate [15]	35	30	400	370	55

Table 2. Radiological hazards indicators ($YEDM_{\text{in, out.}}$, I_γ and $H_{\text{in, ex.}}$) of soil specimen checks.

Study area	Site	Specimen name	$YEDM$ (mSv/y)		I_γ	H_{in}	$H_{\text{ex.}}$
			$YEDM_{\text{in}}$	$YEDM_{\text{out}}$			
Ramadi City/ Anbar Governorate	Al-Malab	S.1	0.222	0.055	0.355	0.351	0.263
		S.2	0.215	0.054	0.346	0.331	0.257
		S.3	0.228	0.057	0.366	0.354	0.272
	Al-Bakr	S.4	0.237	0.060	0.378	0.369	0.277
		S.5	0.222	0.055	0.356	0.342	0.261
		S.6	0.236	0.059	0.379	0.364	0.278
	Al-Dhubbat	S.7	0.146	0.036	0.233	0.238	0.176
		S.8	0.173	0.043	0.276	0.286	0.210
		S.9	0.158	0.040	0.253	0.261	0.192
	Al-Hawz	S.10	0.210	0.052	0.337	0.314	0.246
		S.11	0.216	0.054	0.345	0.339	0.255
		S.12	0.211	0.053	0.339	0.322	0.251
	Al-Andalus	S.13	0.194	0.048	0.311	0.305	0.232
		S.14	0.219	0.055	0.352	0.341	0.260
		S.15	0.226	0.057	0.362	0.350	0.266
		Ave.	0.208 ±0.021	0.052 ±0.005	0.332 ±0.034	0.324 ±0.029	0.246 ±0.023
		Min.	0.146	0.036	0.233	0.238	0.176
		Max.	0.237	0.060	0.379	0.369	0.278
		worldwide rate [15]	1	1	1	1	1

(S.7) to 102.968 at specimen (S.6) and the levels in (nGy/h) varied from 29.686 at specimen (S.7) to 48.237 at specimen (S.4) for ^{238}U, ^{232}Th, ^{40}K, $Ra_{Mat.}$ and AD successively, as in (Fig. 3). The soil in the research area has a heterogeneous distribution of (^{238}U, ^{232}Th, ^{40}K, $Ra_{Mat.}$ and AD). The proportional variation of the values measured serves as an illustration of this. This is due to the fact that the distribution of radioactive contaminants in soil depends upon

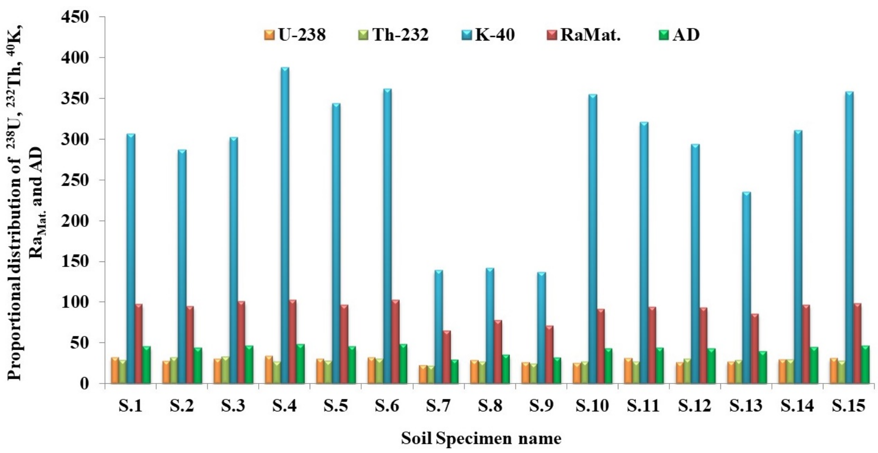

Figure 3. Proportional distribution of (^{238}U, ^{232}Th, ^{40}K, $Ra_{Mat.}$ and AD) for soil specimen checks in Ramadi's district.

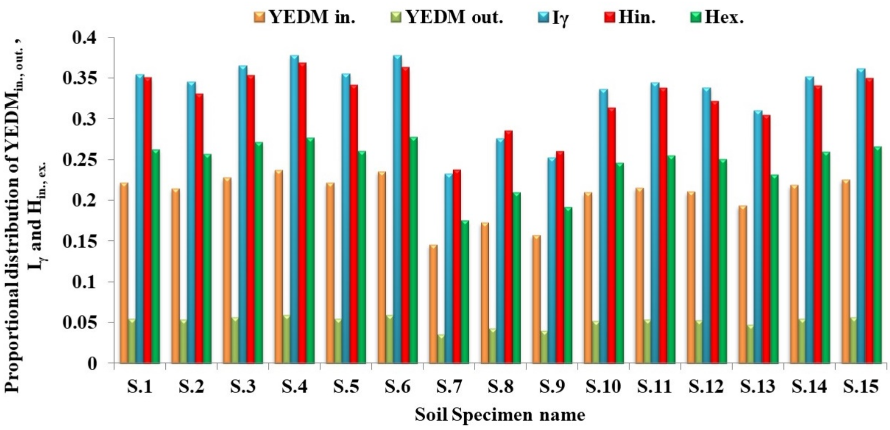

Figure 4. Proportional distribution of ($YEDM_{in,\, out}$, I_γ and $H_{in,\, ex.}$) for soil specimen checks in Ramadi's district.

the nature of the soil, the radioactive component's half-life, and also geological conditions affecting soil quality, soil erosion following contaminants deposition, and pollutant transport as a result of rainwater mitigation. The overall rate in (Bq/kg) for ^{238}U, ^{232}Th, ^{40}K, $Ra_{Mat.}$ and the overall rate in (nGy/h) for AD are 28.880 ± 2.580, 28.205 ± 2.051, 285.660 ± 65.133, 91.209 ± 8.699 and 42.290 ± 4.330 successively and as demonstrated in Table 1. The study demonstrates the overall rate of (^{238}U, ^{232}Th, ^{40}K, $Ra_{Mat.}$ and AD) are found within the authorized values of the worldwide rate, which are 35, 30, 400, 370 Bq/kg, and 55 nGy/h successively [15].

It emerged that the levels in (mSv/y) varied from 0.146 at specimen (S.7) to 0.237 at specimen (S.4), from 0.036 at specimen (S.7) to 0.060 at specimen (S.4). The levels varied from 0.233 at specimen (S.7) to 0.379 at specimen (S.6), 0.238 at specimen (S.7) to 0.369 at specimen (S.4), 0.176 at specimen (S.7) to 0.278 at specimen (S.6) for ($YEDM_{\text{in, out}}$, I_γ and $H_{\text{in, ex.}}$) successively, as in (Fig. 4). The overall rate in (mSv/y) for ($YEDM_{\text{in, out}}$) and the overall rate for (I_γ and $H_{\text{in, ex.}}$) are 0.208 ± 0.021, 0.052 ± 0.005, 0.332 ± 0.034, 0.324 ± 0.029 and 0.246 ± 0.023 successively and as demonstrated in Table 2. The newest study demonstrates that overall rate of ($YEDM_{\text{in, out}}$, I_γ and $H_{\text{in, ex.}}$) are found within the authorized values of the worldwide rate, which are 1 mSv/y and 1 successively [15].

4. Conclusion

This study demonstrates the situation of Ramadi soil specimens (Within Anbar governorate) in terms of specific activity level/concentration (^{238}U, ^{232}Th, ^{40}K) and radiological hazard indicators, as well as the repercussions upon the general public's health and environment. In several specimens, It was found that there was a proportional variation within the suggested dosage of US Environmental Protection Agency (USEPA) regulations [15]. Consequently, there are no radiation levels that are environmentally worrying, and it can be said that the area is radiologically safe. This research recommends that new Iraqi guidelines be proposed that outline the authorized rates of specific activity level/concentration and total radiological hazard indicators in soil. The research also recommends comprehensive studies regarding radioactive exposure in all soil of Ramadi areas to monitor radiation pollutants, assess the radiation background of the more thoroughly studied area, and also utilization of the current study's findings as a database of recorded radiation levels.

Authors Contributions
Authors have contributed equally in preparing and writing the manuscript.

Availability of data and materials
Data presented in the manuscript are available via request.

Conflict of Interests
The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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