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EVALUATION OF NATURAL RADIOACTIVITY LEVELS AND CORRESPONDING DOSE RATES IN SOIL SAMPLES COLLECTED FROM DUHOK PROVINCE, KURDISTAN REGION-IRAQ

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ABSTRACT:

One of the significant concerns in daily human life is exposure to elevated levels of natural background radiation, both outdoors and indoors. This radiation primarily originates from primordial radioisotopes such as Uranium, Thorium, and Potassium, which emit harmful gamma rays. This study examines the activity concentrations of natural radioisotopes Ra-226, Th-232, and K-40 in soil samples collected from various locations in the Duhok Governorate, northern Iraq. To the best of our knowledge, comprehensive studies on these three radioisotopes in this region are limited, highlighting the novelty of this work. Gamma-ray spectrometry using a high-purity NaI(Tl) detector was employed to measure activity concentrations. Several radiological parameters were assessed, including the radium equivalent activity (Ra_{eq}), indoor and outdoor absorbed dose rates (D_{in}, D_{out}), internal and external hazard indices (H_{in}, H_{ex}), and annual effective dose rates (AE_{in}, AE_{out}). Results showed average concentrations of 30 Bq/kg for Ra-226, 56 Bq/kg for Th-232, and 145 Bq/kg for K-40. While Ra-226 and K-40 levels were within global safety limits, Th-232 exceeded recommended values, raising potential health concerns.

KEYWORDS: Natural radioactivity, Duhok province, Gamma-ray spectroscopy, Soil Radioactivity, Activity concentration, Annual effective dose rate.

1. INTRODUCTION

Radioactivity is considered a natural process that has always been present on the Earth (Ismail *et al*., 2010). There exist three main types of natural radiation: galactic and solar radiation, radiation from natural radionuclides in the Earth's crust, and internal radiation.

Cosmic radiation originates from outer space, primarily from stars. Cosmic radiation contains high-energy charged particles, including X-rays and gamma rays. Under long exposure, it can harm living beings on Earth as well as their environment and ecosystem (Baba *et al.,* 2004; Kurnaz *et al*., 2007).

Terrestrial radiation is due to the presence of naturally radioactive materials and elements on Earth. Some of these radioactive elements include uranium, radium, thorium, and potassium, which can be present in the soil, water, atmosphere, and in radioactive remains, such as those from radioactive weapon testing, reactor accidents, and vegetation (Kurnaz *et al.,* 2007; Ahmed *et al.,* 2018).

Internal radiation can occur when radioactive elements enter the human body through ingestion or inhalation. These radioactive elements can accumulate in human blood and bone, which in turn can damage cells and cause adverse effects. Since humans primarily rely on the soil as a food source, it is crucial to determine whether the soil contains radioactive elements (background radiation). It is worth mentioning that around 99% of radioactive precipitations are stored in soils, as scientific studies have revealed that the soil acts as a barrier to the accumulation of radioactive materials from both natural and human-caused sources (Dizman *et al*., 2016; Łukaszek-Chmielewska *et al.,* 2019).

Several studies have shown that natural radiation contributes a significant proportion to total human radiation exposure (Ahmed *et al.,* 2018; Zubair & Shafiqullah, 2020). Therefore, individuals are exposed to natural background radiation daily from sources in the ground, building materials, the air they breathe, food, and even elements within their own bodies (Kurnaz *et al.,* 2007; Hussein & Ahmed, 2023). The natural background radiation is different in various geographical locations on the Earth (Hendry *et al.,* 2009). The presence of radioactive elements can harm humans and other living beings. The primary radioisotope elements that appear in the Earth's crust, which can lead to internal and external exposure, comprise Thorium-232 (Th-232), Uranium-235 (U-235), Uranium-233 (U-233), and Potassium-40 (K-40), as well as their radioactive decay products (Hassan & Al-Alaway, 2023). Radium and radon are naturally occurring radioactive elements that are closely related through radioactive decay. Radium-226, a solid alkaline earth metal found in rocks and soil, undergoes alpha decay to produce radon-222, a noble gas. In this mother-progeny relationship, radium acts as the parent isotope, while radon is its immediate

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decay product. Unlike radium, radon is a gas that can easily migrate through soil and enter buildings, posing significant health risks when inhaled. Although both elements are radioactive, radium remains fixed within materials, whereas radon disperses into the air. Understanding this relationship is crucial for assessing environmental radiation exposure (Alhamdi & Abdullah, 2021; Othman *et al.,* 2024).

This study aims to assess the natural radioactivity level in Duhok province by measuring the activity concentrations and radiation hazard indices of radioisotope elements (K-40, Ra-226, Th-232) in soil samples collected from different parts of the study area.

2. MATERIALS AND METHODS:

Study Area:

The field of study is located in Duhok city, in the northwest of Iraq. The geological structure of Duhok city mainly consists of three red beds, including silt, hard clay, and limestone (Alhamdi & Abdullah, 2022). The soil of the study field is mainly characterized by very low permeability, broad synclines, well-defined folds of asymmetrical anticlines, and thick sedimentary cover.

Table 1: Geographical coordinates of the study area

Sample No	Place	Geographical coordinates	
		North (Latitude) (DMS)	East (Longitude) (DMS)
1	Duhok University	36° 50' 51.036"	43° 4' 46.092"
2	Duhok University	36° 50' 59.172"	43° 3' 56.808"
3	Duhok University	36° 50' 58.164"	43° 4' 0.84"
4	Amedi-1	37° 5' 43.26.88"	43° 29' 4.344"
5	Amedi-2	37° 5' 28.032"	43° 29' 15.936"
6	Tenahi-1	36° 53' 13.524"	42° 52' 46.164"
7	Tenahi-2	36° 52' 6.348"	42° 54' 3.312"
8	Summel	36° 52' 7.32"	42° 53' 59.784"
9	Hetit-1	36° 50' 44.52"	42° 53' 59.784"
10	Hetit-2	36° 51' 38.232"	42° 40' 36.66"
11	Zawita-1	36° 51' 8.604"	42° 55' 4.98"
12	Zawita-2	36° 52' 2.28"	42° 55' 3.72"
13	Zawita-3	36° 34' 55.632"	43° 0' 24.912"

Sample Collection:

Thirteen soil samples (150 g) were taken from 6 locations within the Duhok governorate. Ten samples were taken in the Duhok district, two from Amedi, and one from Summel. The geographical coordinates of the locations where samples have been collected from are presented in Table 1. In the present work, samples measuring 50 cm x 50 cm were collected from the Duhok land. The collected soil samples were taken to the laboratory after separating them from debris and sediments. The samples were air-dried at ambient temperature for nearly four days. Afterward, the samples were subjected to oven drying at 110 °C for one hour, pulverized, homogenized, and then processed through a 250 mm mesh.

Radiation Measurements:

In this research work, activity concentration and radiation hazard indices of the radioisotope elements were measured.

In the nuclear laboratory, a sodium iodide 3” × 3” NaI(Tl) detector was used for data acquisition. To minimize background radiation, the detector was surrounded by a 4π shield made of lead 6 cm thick, and an extra 2 mm layer of electrolytic copper. The upper of the shielding is open allowing for easy sample placement. In the lower part of the shield house, there is a 5 cm diameter hole to hold the detector. To decrease electrical noise and avoid direct contact with the shielding, the photomultiplier tube was enfolded in a thin plastic sheet (see Figure 1). In this study, gamma-ray spectra were acquired and analyzed using the MAESTRO software, a widely utilized tool in nuclear spectroscopy. Developed by ORTEC, MAESTRO provides a user-friendly interface for real-time data acquisition and detailed spectral analysis. The software enables precise peak identification, energy and efficiency calibration, and quantification of radionuclides through its advanced peak fitting algorithms. Its compatibility with a range of multichannel analyzers makes it suitable for high-resolution gamma spectrometry applications, contributing significantly to the accuracy and reliability of radioactive measurements in this research.

Figure 1: a) the detector inside the lead house, b) the sample tube used for measuring the activity concentration c) placing the sample inside the shield house

Initially, resolution and efficiency calibrations were performed using standard calibration sources. For each radioactive source, spectra were collected over a counting period of approximately 14,400 seconds to ensure adequate statistical accuracy. Energy calibration and resolution were verified using standard gamma sources, with particular attention to the energy resolution at 662 keV, characteristic of Cs-137, typically determined by the full width at half maximum (FWHM) for the NaI(Tl) detector. To ensure accurate peak identification and net area calculation, background subtraction was carefully performed. This involved measuring a control sample using an empty beaker without soil to assess and eliminate background contributions from the container and surroundings, thereby validating the net activity derived from each measured sample.

The activity concentration of the terrestrial radioisotopes of three elements, K-40 using a gamma spectrum of (1460 keV), Th-232 using a gamma spectrum (338 keV) (Hassan & Al-Alaway, 2023), and Ra-226 with two gamma spectra (352 keV and 609 keV) was calculated, which were collected from six different places in the Duhok governorate. The activity concentration of the sample was calculated using the following equation (Shanthi *et al*., 2010).

$$Ac = \frac{C}{m p_{\gamma} \varepsilon} \qquad (1)$$

With Ac (Bq/kg) denoting the activity concentration of radioisotope, C is the count rate of net counts per unit time (sec^{-1}), p_{γ} is the gamma intensity, m is the mass of the sample, ε is the energy efficiency at a specific energy. Detailed specifications and characteristics of energy efficiency are available in previously published literature (Alhamdi & Abdullah, 2021) using the same detector model and identical experimental setup. The efficiency values relevant to the gamma energies used were 0.04 for 40K (1460 KeV), 0.24 for 232Th (338 KeV), 0.22 for 226Ra (352 KeV), 0.14 for 226Ra (609 KeV) (Alhamdi & Abdullah, 2021).

Radium Equivalent Activity (Ra_{eq}): The radium equivalent activity can be determined by the following formula (Turhan *et al*., 2008).

$$Ra_{eq} = \left(\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{48170}\right) * 370 \qquad (2)$$

Where A_{Ra}, A_{Th}, and A_k are the activity concentrations of radium, thorium, and potassium, respectively.

Absorbed Dose Rate (D): This is the quantity of the absorbed gamma rate that is exposed from the ionizing radiation to a specific body.

Outdoor and Indoor Absorbed Dose (nGy h^{-1}): The outdoor and indoor radiation dose is determined by substituting the specific activity of A_{Ra}, A_{Th}, and A_K into equations (3) and (4) as follows (Hassan & Al-Alaway, 2023):

$$D_{out} = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \qquad (3)$$

$$D_{in} = 0.92A_{Ra} + 1.1A_{Th} + 0.08A_K \qquad (4)$$

External and Internal Hazard Index (H_{ex}, H_{in}):

Radioactive isotopes, primarily Ra-226, Th-232, and K-40, present in sand can expose human beings to external radiation resulting from the isotopes' radioactive decay in the soil. External radiation due to gamma rays is called the external hazard index, symbolized as H_{ex}, and by using equation (5), it is possible to determine H_{ex} (Qureshi *et al*., 2013).

$$H_{ex} = \frac{A_{Ra}}{\frac{370Bq}{Kg}} + \frac{A_{Th}}{\frac{259Bq}{Kg}} + \frac{A_K}{\frac{4810Bq}{Kg}} \qquad (5)$$

Another hazard index, which is called the internal hazard index, is given by the following formula:

$$H_{in} = \frac{A_{Ra}}{185Bq/Kg} + \frac{A_{Th}}{259Bq/Kg} + \frac{A_K}{4810Bq/Kg} \qquad (6)$$

A_{Ra}, A_{Th}, and A_K are activity concentrations of radium, thorium, and potassium, respectively.

Annual Effective Dose (AE): The outdoor and indoor annual effective dose rates can be determined by the formulas shown below (Qureshi *et al.,* 2013).

Annual Effective Dose-Outdoor:

$$AE_{out} = 1.4 * 10^{-3} D_{out} \text{ (mSv/Y)} \qquad (7)$$

Annual Effective Dose- Indoor (mSv/Y):

$$AE_{in} = 3.068 * 10^{-3} D_{in} \text{ (mSv/Y)} \qquad (8)$$

Which D_{out} and D_{in} are the outdoor and indoor absorbed dose rates.

Statistical Analyses:

The data analysis was based on several key factors that may affect the activity concentration of radioactive materials, including geology and depth of the study area, the choice of an appropriate soil storage tube, and proper experimentation techniques. Statistical analyses were used to arrange and summarize the findings. In this study, the measurements were repeated three times under the same conditions. The statistical parameters (average, minimum, maximum, and standard deviation) were calculated using the Microsoft Excel software program.

3. RESULTS AND DISCUSSION

Activity concentration of three natural radioisotopes (K-40, Th-232, and Ra-226) from 13 different places within and around the Duhok governorate is calculated, and the results are summarized in Table 2.

Table 2: Activity concentrations (Bq/ kg) of natural radioisotopes in terrestrial samples.

Sample No.	Place	K-40	Th-232	Ra-226
1	Duhok University	147.5±30	45 ± 12	25 ± 5
2	Duhok University	140 ± 10	51 ± 5.5	26 ± 2.2
3	Duhok University	169 ± 14	56 ± 3.1	32 ± 1.9
4	Amedi-1	150 ± 1.4	50 ± 1.6	30 ± 0
5	Amedi-2	120 ± 33	66 ± 18	31 ± 8.6
6	Tenahi-1	137 ± 38	46 ± 13	32 ± 8.9
7	Tenahi-2	177 ± 49	64 ± 18	34 ± 9
8	Summel	170 ± 47	71 ± 20	29 ± 8
9	Hetit-1	145 ± 40	54 ± 15	33 ± 9
10	Hetit-2	134 ± 37	61 ± 17	29 ± 8
11	Zawita-1	135 ± 37	59 ± 16	27 ± 7
12	Zawita-2	146 ± 40	45 ± 12	29 ± 8
13	Zawita-3	115 ± 32	66 ± 18	27 ± 7
	Max	177	71	34
	Min	115	45	25
	Average	145 ±18.47	56 ± 8.79	30 ± 2.79
	World wide limit	400	30	35

Table 2 shows that potassium activity A_K ranged between 177 to 115 Bq/kg and had a mean value of 145 Bq/kg. The thorium activity A_{th} ranged between 45 to 71 Bq/kg, having a mean value of 56 Bq/kg. While the radium activity A_{Ra} range was between 25 to 34 Bq/kg, showing a typical value of 30 Bq/kg. The highest value for A_K, A_{Th}, and A_3 was found in samples 7, 8, and 7, respectively (see Table 2 and Figure 2).

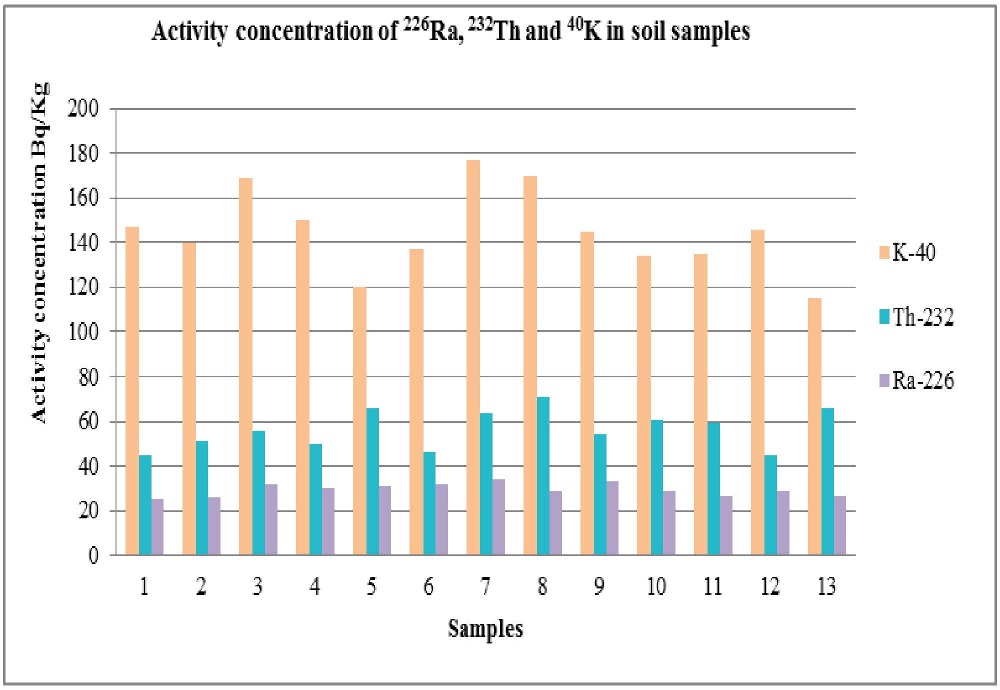

Figure 2: The activity concentration of Thorium, Radium, and Potassium.

Generally, the present study results listed in Table 2 showed that the average activity concentration values of Ra-226 and K-40 in the Duhok governorate were lower than the worldwide approved average values of 35 Bq/kg for A_{Ra}, and 400 Bq/kg for A_K. However, the average activity of Th-232 was above the standard average value of 30 (Bq/kg) (UNSCEAR 2008) (see Figure 3). The elevated average activity of Th-232 (56 Bq/kg) in the soil samples from Duhok City may be attributed to the region's underlying geological formations, which are rich in naturally occurring thorium-bearing minerals. Additionally, past or ongoing anthropogenic activities, such as construction or use of phosphate-based fertilizers, may have contributed to increased levels (Alhamdi & Abdullah, 2021).

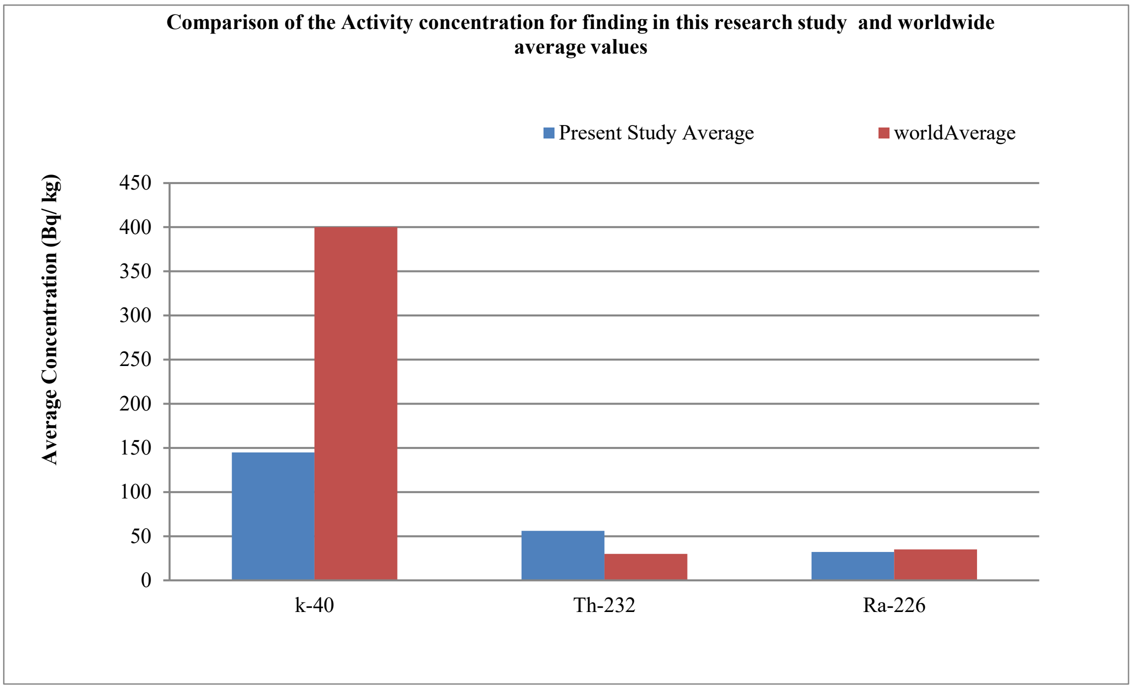

Figure 3: Comparison of the Activity concentration found in this research study and worldwide average values (UNSCEAR 2008).

The radium equivalent activities' results for the soil samples are listed in Table 3. From the results, one can note that sample 8 and sample 1 showed the maximum and minimum values of Ra_{eq}, with the values of 143.5 and 100.6 Bq/kg, respectively. The calculated Ra_{eq} average value was 121.4 Bq/kg. Compared to the worldwide average value, the Ra_{eq} of all samples was lower than the recommended value of 370 Bq/kg (UNSCEAR 2008).

Table 3: Estimated values of radiation hazard indices (radium equivalent activity (Bq/kg), indoor and outdoor absorbed dose rate (nGy h^{-1}), External and internal hazard index, indoor and outdoor Annual effective dose for soil samples (mSv/y).

Sample No.	Radiation Hazard Indices						
	Raeq (Bq/kg)	Dout (nGy h^{-1})	Din (nGy h^{-1})	Hex	Hin	AEout (mSv/y)	AEin mSv/y
1	100.6	44.88	84.30	0.27	0.34	0.06	0.26
2	109.6	48.65	91.22	0.30	0.37	0.07	0.28
3	125.0	55.66	104.56	0.34	0.42	0.08	0.32
4	113.0	50.32	94.60	0.31	0.39	0.07	0.29
5	134.5	59.19	110.72	0.36	0.45	0.08	0.34
6	108.3	48.28	91.00	0.29	0.38	0.07	0.28
7	139.0	61.74	115.84	0.38	0.47	0.09	0.36
8	143.5	63.37	118.38	0.39	0.47	0.09	0.36
9	121.3	53.91	101.36	0.33	0.42	0.08	0.31
10	126.5	55.83	104.50	0.34	0.42	0.08	0.32
11	121.7	53.74	100.54	0.33	0.40	0.08	0.31
12	104.5	46.67	87.86	0.28	0.36	0.07	0.27
13	130.1	57.13	106.64	0.35	0.42	0.08	0.33
Max	143.5	63.37	118.38	0.39	0.47	0.09	0.36
Min	100.6	44.88	84.30	0.27	0.34	0.06	0.26
Average	121.4	53.80	100.89	0.33	0.41	0.08	0.31
Worldwide limit	370.0	55.00	84.00	<=1	<=1	1	1

The outdoor and indoor absorbed dose rates for all tasters are listed in Table 3 as well. The highest values for D_{out} and D_{in} were also observed for sample 8 which was 63.37 nGy h^{-1} and 118.38 nGy h^{-1} respectively, while the lowest absorbed dose rate again was observed for sample 1 with a value of 44.88 nGy h^{-1} and 84.30. The calculated average value of D_{out} was 55.80 nGy h^{-1} and D_{in} was 100.89 nGy h^{-1}. All values of outdoor absorbed dose lie in the safe zone based on the globally approved limit value of 55 nGy h^{-1} while D_{in} values are over the worldwide limit zone of 84 nGy h^{-1} (UNSCEAR 2008). In addition, external (H_{ex}) and internal (H_{in}) hazard indices were calculated and were listed in Table 3. From the table, it can be seen that the values of H_{ex} and H_{in} ranged from 0.27 to 0.39 and 0.34 to 0.47, respectively. The calculated average values of H_{ex} and H_{in} were in the range of 0.33 and 0.41, respectively. One can observe from Figure 4 that all the results were below Unity (UNSCEAR 2008).

Also, annual effective doses for indoor and outdoor showed values in the range between 0.26 to 0.36 mSv/y and 0.06 to 0.09 mSv/y, respectively. The calculated average values for AE_{out} and AEin were in the range of 0.31 mSv/y and 0.08 mSv/y, respectively. It can be noted from Figure 4 that all values of AE_{out} and AEin were less than <1 which means they lie in the safe zone according to the worldwide limit value of 1 (UNSCEAR 2008).

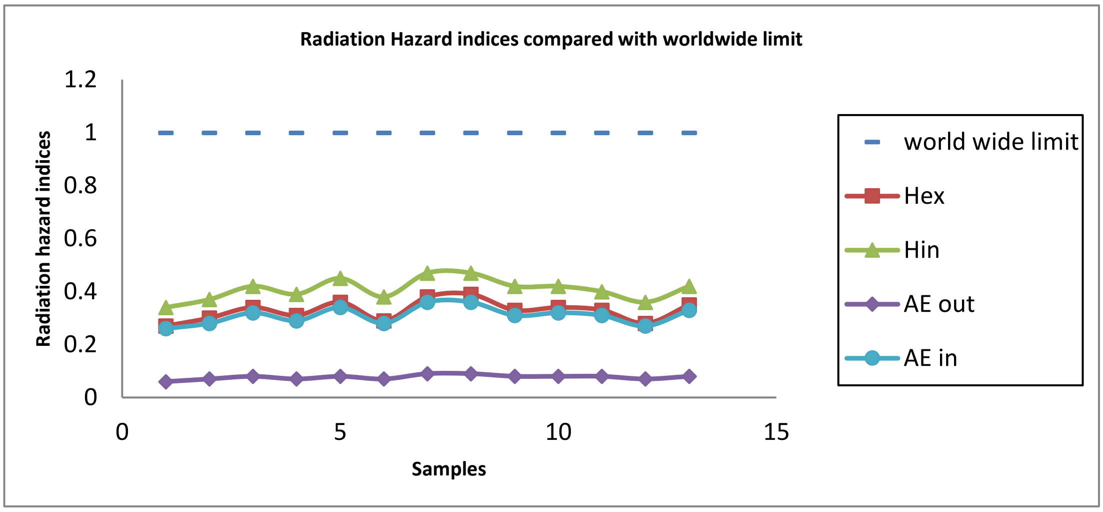

Figure 4: Radiation hazard indices for Soil Samples compared with the global limit (UNSCEAR 2008).

Different research groups have reported the activity concentration of soil from different parts of the world and within Iraq itself (See Table 4). The comparison shows the lowest activity concentration of K-40 for the Duhok governorate. However, the activity concentration for Ra-226 and Th-232 was almost higher than all of those places shown in Table 4, except for Basrah city in Iraq and Africa in general which should be considered the main issue in Duhok Governorate.

Table 4: Comparison of activity concentrations of Ra-226, Th-232, and K-40 in the current study with similar studies in the world.

Location	K-40	Th-232	Ra-226	Reference
India	295	22	8	(Shanthi *et al*., 2010)
Iraq- Basrah	511	20	34	(Albidhani *et al*., 2019)
Nigeria	710	77	25	(Oyeyemi *et al*., 2017)
Saudi Arabia	641	19	11	(Al-Trabulsy *et al*., 2011)
Thailand	523	26	22	(Malain *et al*., 2012)
Iraq-Irbil	326	20	25	(Hussein, 2019)
Iraq-Basra	360	10	26	(Jebur *et al*., 2019)
Iran	555	37	29	(Changizi *et al*., 2012)
(Iraq- Bekhma)	452	7	14	(Hassan Ahmed *et al*., 2015)
Africa	671	157	124	(Mekongtso Nguelem *et al*., 2016)
(Iraq- Duhok)	145	56	30	Present work

CONCLUSIONS

The present study evaluates the activity concentration and radiation hazard indices of K-40, Th-232, and Ra-226 in soil samples collected from 13 locations in the Duhok governorate in the North of Iraq.

The current study shows that the activity concentrations for K-40 and Ra-226 were lower than the globally approved values, while Th-232 showed a higher activity concentration value than the acceptable worldwide limit value, considering it as the main concern in Duhok Governorate. All the radiological hazard factors studied in collected soil samples were within the recommended safety limit values, except for some indoor and outdoor absorbed dose values which exceeded the globally approved safe values for some locations in Duhok governorate. These results highlight the importance of monitoring the environment especially agricultural areas, where radioactive elements can enter the plants through the roots. The high levels of Th-232 and some samples in Ra-226 highlight to future research about determining the activity concentration of radionuclide elements in vegetables and fruits that grow in these places.

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Ethical Statement:

The research presented in this paper was conducted in full compliance with ethical standards. All experimental work, data collection, analysis, and interpretation were carried out solely by the author at the Department of Physics, College of Science, University of Duhok. No human or animal subjects were involved in this study, and therefore, ethical approval was not required.

The author affirms that the work is original, has not been published elsewhere, and does not include any form of plagiarism. All sources of data, materials, and software tools used in the research have been properly acknowledged. The author declares that there are no conflicts of interest related to the publication of this paper.

Author Contributions:

All authors reviewed and approved the final manuscript and agree to be accountable for all aspects of the work.

Concept and design: W. A. H. A., and A. H. J.

Acquisition, analysis, or interpretation of data: A. H. J., S. M. A., and W. A. H. A.

Drafting of the manuscript: A. H. J. (lead); critical revision, all authors

Competing Interests:

The authors declare that they have no known financial or personal relationships that could have appeared to influence the work reported in this paper.

Availability of Data and Measurements:

The data presented in this study were obtained through direct measurements of naturally occurring radioactive elements—uranium (U), thorium (Th), and potassium (K)—in soil samples collected from various locations across Duhok city, Iraq. Standard laboratory techniques were used for the preparation and analysis of the samples, and the radioactivity concentrations were quantified using high-resolution gamma-ray spectrometry. The dose assessments were then calculated based on these measurements. All raw data and detailed measurement protocols are available from the corresponding author upon reasonable request.

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