Environmental and Anthropogenic Radioactivity in Soils of the Kurdistan Region, Iraq: A Review

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***Abstract*—The aim of this review is to establish baseline data of anthropogenic and environmental radioactivity levels in soils of the Kurdistan region before potential radiological releases from regional nuclear incidents in 2025. This review collects and analyses previous research and measurements of man-made radionuclides, such as ^{137}Cs and naturally occurring radionuclides, such as ^{226}Ra, ^{232}Th, and ^{40}K from a variety of locations in the study area. The data analysis indicates that the average activity concentrations of the detected radionuclides are typically lower than the global average levels as reported by the United Nations Scientific Committee on the Effects of Atomic Radiation. The findings provide an accurate framework for assessing the safety of the environment and identifying possible future changes in soil radioactivity.**

***Index Terms*—Activity concentration, Fallout radionuclide, Gamma ray spectrometry, Radiation hazard, Soil radioactivity.**

I. Introduction

In recent decades, there has been increasing concern over the public's exposure to natural radiation. Radionuclides are widely dispersed throughout the environment, including in various media, such as soil, air, and water (Wais, et al., 2025; Ahmed, 2021; Samad, Ahmed and Ahmad, 2023). Investigation of the distribution of natural radionuclides is significant for the study of radiological effects, as well as exposure to gamma rays and the irradiation of lung tissue due to inhalation of radon and its short-lived decay products (Singh, et al., 2005). Natural gamma radiation is a major source of radiation exposure to the world population; hence, estimating it is important (Unscear, 1988). Radionuclides found in the environment can be categorized into several types based on their source. Radionuclides can be classified into three groups: Terrestrial, man-made, and cosmogonic radionuclides (Dinh Chau, et al., 2011). A class of radioactive isotopes called terrestrial radionuclides has been present on Earth since its own creation. These elements have not yet decayed behind the limit of detection because of their extremely long half-lives, which are comparable in duration to the age of the solar system. Radioactive potassium isotope (^{40}K) is the most abundant component in this category; it is responsible for almost 16% of the effective dose that people worldwide receive annually from naturally occurring radionuclides (Unscear, 2008). The Earth's atmosphere and the topmost layer of the crust are the sources of cosmogonic radionuclides, which are formed when cosmic radiation interacts with elements in these areas. More than twenty elemental isotopes, from hydrogen to krypton, make up this category. Spallation, neutron capture, and muon capture are the three primary nuclear processes that involve cosmic particles and produce the majority of cosmogonic radionuclides. A little under one percent of the total mean effective dose from natural radionuclides comes from cosmogenic radionuclides. Radiocarbon-^{14}C is the most important component, making up nearly all of this dosage (Unscear, 2008). Approximately 83% of the mean effective dose that the world's population receives from naturally occurring radionuclides comes from decay series radionuclides, making them the principal source of ionizing radiation on Earth. They are formed by the decay of the radionuclides ^{235}U, ^{238}U, and ^{232}Th. The decay series of ^{232}Th, ^{235}U, and ^{238}U produce stable lead isotopes ^{208}Pb, ^{207}Pb, and ^{206}Pb, respectively, through nuclear transformations and the emission of alpha and beta particles. Gaseous radon isotopes (^{219}Rn, ^{220}Rn, ^{222}Rn) and the products of their decay in natural decay series constitute almost half of the total effective dose that the world's population receives from ionizing radiation sources (Unscear, 2000). Anthropogenic radionuclides which are produced by human technological activities are also found in the environment and added to the total effective dose that people around the world receive. These radioactive materials can be categorized into two main groups: Some of them have entered the environment as a result of the atmospheric nuclear weapon experiments that took place in the 1950s and 1960s, while others come from the normal operation of nuclear facilities, such as nuclear power stations or from

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uncontrolled releases. Radioisotopes, including ^{134}Cs, ^{137}Cs, ^{90}Sr, and plutonium isotopes ^{239}Pu, ^{240}Pu, and ^{241}Pu were not normally present in the surroundings in measurable amounts before the nuclear century (Dinh Chau, et al., 2011).

The primordial radionuclides that are commonly detected include ^{232}Th, ^{238}U, their decay progenies, and ^{40}K. The geological and geographical characteristics of the regions under study greatly impact the concentration of naturally occurring radioactive materials in the soil and surrounding environments (Unscear, 2000). Radionuclides present in soil can participate in natural radioactivity through two mechanisms. First, individuals may acquire external dosages by being directly exposed to gamma or beta radiation. Furthermore, internal exposure can occur through the inhalation or ingestion of radionuclides and their decay products, which are present in the soil and released into the air similarly to radon. These radionuclides can also be transported to plants and animals, ultimately entering the human body indirectly. Areas with significant amounts of uranium or thorium exhibit increased levels of radon, which accounts for more than half of the environmental radiation (El-Arabi, 2007). ^{222}Rn is produced via the alpha-decay of ^{226}Ra in the decay sequence of ^{238}U, while ^{220}Rn, also known as thoron, is produced in the decay sequence of ^{232}Th. Among several radon isotopes, ^{222}Rn is regarded as the most significant due to its half-life of 3.8 days, which is much greater than the half-lives of ^{219}Rn and ^{220}Rn. During the decay of ^{222}Rn, the radioactive isotopes ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po, which have short half-lives, are produced (Rahman and Faheem, 2008). Radium, thorium, and uranium can cause leukemia if inhaled or ingested over a long period of time (Taskin, et al., 2009). During the decay process, these radionuclides emit alpha particles that penetrate soft tissues at a distance of 40 μm. These particles collide with the molecules and atoms of the tissues, which make up the organs, causing harmful consequences that can be considered a reason for various cancer types in humans (Alam, et al., 2020; Sedeeq, Smail and Ahmad, 2026). The objective of this study is to describe the research state of natural and anthropogenic radioactivity in soils of the Kurdistan region through a systematic review limited to articles published in the past two decades. In addition, this review provides baseline data on radioactivity levels in soils of the study area, which is essential for evaluating any upcoming changes brought on by potential radiological releases from regional nuclear incidents in 2025.

II. Search Strategy

This study included a systematic review confined to literature published internationally during 2010–2025. The literature search was conducted using the PubMed, Science Direct, Medlib, and Google Scholar databases. Research articles which assessed radioactivity in soils of the Kurdistan region were searched for and collected. The search approach was based on the combination of the suggested descriptors. The keywords used to conduct the search comprised three terms. The first one was “Kurdistan”, the second was “Soil” and the third was “radioactivity”.

III. Experimental Methods

Gamma-ray spectroscopy systems based on HPGe detectors are mainly used by research groups to measure the levels of radioactivity in various samples collected from the Kurdistan region. The use of high-purity germanium HPGe detectors is recommended over NaI(Tl) detectors for gamma-ray measurements in environmental samples due to their higher resolution, which allows close peaks to be distinguished in a spectrum, although the NaI(Tl) detectors are attractive due to their high efficiency for gamma-ray detection and no need for liquid nitrogen for cooling. Energy and efficiency calibrations are necessary for both high-purity germanium detectors and scintillation detector systems. Calibration relies on keeping all parameters constant, including sample spot, counting time, volume, photo peaks, and geometry. The counting time is a significant factor during measurements and depends on the detector crystal size, the counting rate from the sample, and the distance between the source and detector. Providing a reasonable measuring time is important for obtaining more precise counting statistics, minimizing uncertainty in statistics, and obtaining a precise measurement. Furthermore, to reduce the impact of background radiation, it is preferable to encircle the detector with a lead shield (Salih, Hussein and Sedeeq, 2019). It is difficult to measure the activity concentration of ^{238}U because of its low probability of emission and low energy of its photo peaks. However, in the ^{238}U series, approximately ninety-eight percent of the radiation impacts come from ^{226}Ra. Therefore, the activity concentration of ^{238}U is occasionally considered to be similar to that of ^{226}Ra under specific condition, which has a photo peak at 186.1 keV. This 186.1 keV is so close to the 185.7 keV photo peak of ^{235}U that the detection systems cannot distinguish these two energies by producing two peaks at their own energies on a spectrum. Therefore, this energy is not a suitable choice to measure the activity of ^{226}Ra. The activity concentration of ^{226}Ra can be measured using the photo peaks of its decay products after secular equilibrium. As well, the low energy of gamma rays and low emission probability of ^{232}Th make gamma-ray spectrometry inefficient for measuring its activity concentration in samples. The samples are usually placed in Marinelli beakers and then weighed and stored for approximately four weeks to allow for the attainment of radioactive secular equilibrium between ^{226}Ra and ^{232}Th with their decay products, especially ^{214}Bi and ^{214}Pb for ^{226}Ra and ^{228}Ac and ^{208}Tl for ^{232}Th.

IV. Summary of Results

Studies conducted by research groups in the Kurdistan region were summarized. This review provides an overview of the studies that various groups have carried out in the Kurdistan region to determine the radiation levels in soils. Table I presents the locations and coordinates of the research

areas. In addition, Fig. 1 displays a map of the Kurdistan region, which is the study area.

V. Activity Concentration of Natural and Anthropogenic Radionuclides in Soils of the Kurdistan Region from 2011 to 2025

The activity of a radionuclide is defined as the number of disintegrations (decays) occurring in a radioactive sample per unit time. It reflects the rate at which unstable atomic nuclei spontaneously decay, and is expressed in the SI unit of Becquerel (Bq), where 1 Bq = 1 disintegration per second. The activity concentration of a radionuclide can be calculated from the net photo-peak counts obtained by a gamma-ray spectrometry system using the equation below (Sedeeq, Smail and Ahmad, 2025).

$$A = \frac{N_{net}}{\varepsilon . I_{\gamma} . t . m} \quad (1)$$

Where: A is the activity concentration of the radionuclide (Bq/kg), N_{net} is the net photo-peak counts obtained from the gamma-ray spectrum, ε is the detection efficiency of the detector at the specific gamma-ray energy, I_{γ} is the gamma-ray emission probability of the radionuclide at the specific energy, t is the counting time of the measurement (s), and m is the mass of the measured sample (kg).

TABLE I
The Geographical Coordinates of the Various Studied Areas

Study area	Latitude	Longitude
Erbil	36.1901° N	43.9930° E
Koya	36.0751° N	44.6199° E
Shaqlawa	36.4063° N	44.3162° E
Duhok	36.8632° N	42.9885° E
Bekhma	36.7008° N	44.2711° E
Sulaimani	35.5558° N	45.4351° E
Raparin	36.2482° N	45.0190° E
Halabja	35.1654° N	45.9896° E
Garmian	34.1715° N	44.3130° E



Fig. 1. Map of the study area-the Kurdistan region (Mohammed, Jaff and Schrock, 2019).

Activity concentrations of natural radionuclides (^{226}Ra, ^{232}Th, ^{238}U, and ^{40}K) and the anthropogenic ^{137}Cs were measured across multiple locations of the Kurdistan Region using HPGe and NaI(Tl) gamma-ray spectrometry systems (Table II). Across the majority of studied areas, mean ^{226}Ra values ranged from 9.4 to 34.5 Bq/kg, ^{232}Th from 7.6 to 42.5 Bq/kg, and ^{40}K from 174.9 to 460 Bq/kg, most of which remain below the UNSCEAR global reference averages of 35, 30, and 400 Bq/kg, respectively. This broad uniformity indicates that natural background radiation in the region is generally within internationally acceptable levels. However, notable spatial anomalies were identified. Garmian District recorded the highest ^{226}Ra and ^{232}Th values in the dataset (34.5 and 42.5 Bq/kg, respectively), exceeding the UNSCEAR world averages for both radionuclides and suggesting locally elevated geological contributions. Similarly, Duhok exhibited the highest ^{40}K concentration (460 Bq/kg), marginally surpassing the global average of 400 Bq/kg. In contrast, Raparin recorded among the lowest ^{40}K values (174.9 Bq/kg), approximately half the worldwide reference value, suggesting to high geochemical heterogeneity across the region. For ^{238}U, measurements were only available for Sulaimani and Halabja. Sulaimani showed notably elevated concentrations, ranging from 67.9 to 83.6 Bq/kg across soil depths of (0–50 cm), far exceeding the typical global average. Halabja also returned elevated ^{238}U values (74.4-76.4 Bq/kg across 0–20 cm depth), indicating that the southeastern part of the Kurdistan Region may be underlain by uranium-enriched geological formations. A consistent depth-dependent trend was evident in Sulaimani, where all radionuclide concentrations ^{238}U, ^{232}Th, and ^{40}K decreased progressively from the surface layer (0–10 cm) to the deepest sampled layer (40–50 cm). The anthropogenic radionuclide ^{137}Cs was detected across several districts, reflecting the long-range atmospheric deposition following the 1986 Chernobyl accident. The highest ^{137}Cs concentrations were recorded in Koya agricultural soils (9.5 Bq/kg) and Duhok undisturbed soils (9.17 Bq/kg), while Raparin agricultural soil also showed a notable value of 8.3 Bq/kg. Marapasta (Ranya district) showed markedly lower ^{137}Cs in agricultural fields (1.3 Bq/kg) compared to undisturbed soils (7.5 Bq/kg), suggesting that tillage and land-use practices have redistributed the fallout radionuclide in cultivated areas. Importantly, several sites, including Erbil (virgin and agricultural soil), Shaqlawa, and the deeper layers of Koya undisturbed soil recorded zero or non-detectable ^{137}Cs, indicating that fallout deposition was not uniform across the region.

A comparison between soil types reveals that undisturbed soils generally showed higher ^{226}Ra and ^{232}Th concentrations than agricultural soils at comparable locations, which may reflect the dilution effect of plowing and fertilizer inputs in cultivated fields. Elevated ^{40}K in some agricultural soils, particularly in Koya district, is consistent with the application of potassium-based fertilizers.

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TABLE II
RADIOACTIVITY MEASUREMENTS USING DIFFERENT TECHNIQUES IN THE KURDISTAN REGION

Studied area	Soil type	Soil sample depth (cm)	Measurement technique	Mean value of activity concentration (Bq/kg)					Reference code	References
				^{238}U	^{226}Ra	^{232}Th	^{40}K	^{137}Cs		
Koya	Agricultural soil	0.0–10	HPGe-detector	NC	14.7	19.9	329	9.5	R1	Salih, Hussein and Sedeeq, 2019
Koya	Agricultural soil	0.0–30	HPGe-detector	NC	12.3	7.55	263	2.66	R2	Salh, et al., 2024
Koya	Undistributed soil	5–10	HPGe-detector	NC	11.42	20.54	336.48	0.0	R3	Babakr, et al., 2022
		15–25			9.42	17.79	296.45	0.0		
Erbil	Virgin soil	20.0	HPGe-detector	NC	14.3	10.0	290.2	0.0	R4	Azeez, Mansour and Ahmad, 2020
	Agricultural soil				16.0	10.3	294.6	0.0		
Erbil	Agricultural soil	0.0–20.0	HPGe-detector	NC	16.04	10.32	293.08	NC	R5	Azeez, Mansour and Ahmad, 2019
Erbil	Undistributed soil	0.0–15.0	HPGe-detector	NC	25.61	20.15	326.54	NC	R6	Hussein, 2019
Shaqlawa	Agricultural soil	20.0	HPGe-detector	NC	16.24	20.85	306.25	0.0	R7	Wais, et al., 2025
Duhok	Undistributed soil	0.0–10.0	NaI (Tl) detector	NC	18.11	25.44	460	9.17	R8	Abdullah and Ramadhan, 2011
Bekhma	Agricultural soil	0.0–15.0	NaI (Tl) detector	NC	14.67	NC	NC	NC	R9	Akray and Ahmed, 2013
Sulaimani	Undistributed soil	0.0–10.0	NaI (Tl) detector	83.6	NC	19.1	284.7	NC	R10	Yousuf and Abullah, 2013
		10.0–20.0		81.1	NC	16.8	260.6	NC		
		20.0–30.0		77.7	NC	15.3	258.3	NC		
		30.0–40.0		71.5	NC	13.3	247.7	NC		
		40.0–50.0		67.9	NC	12.8	225.3	NC		
Halabja	Undistributed soil	0.0−10.0	HPGe-detector	76.4	NC	16.6	244.7	NC	R11	Abdullah, et al., 2021
		10.0–20.0		74.43	NC	16.2	229.2	NC		
Raparin	Agricultural soil	0.0–15.0	HPGe-detector	NC	NC	NC	NC	1.3±0.6	R12	Mustafa, 2019
	Undistributed soil			NC	NC	NC	NC	7.5±1.6		
Raparin	Agricultural soil	0.0–20.0	HPGe-detector	NC	15.5	9.1	174.9	8.3	R13	Abdulla and Mohammed, 2025
Garmian	Undistributed soil	0.0–15.0	HPGe-detector	NC	34.5	42.5	272.9	NC	R14	Mamand, Abda and Abdullah, 2025

NC: Not calculated by the research group

VI. Comparative Analysis of Radiological Hazard Indices in Kurdistan Region Soils

The calculated radiation hazard metrics across all studied sites consistently fell within internationally recommended safety thresholds, though meaningful variability between locations and soil types was observed. Radium equivalent activity (Ra_{eq}) ranged from 41.9 Bq/kg in Raparin agricultural soil to 116.2 Bq/kg in Garmian undisturbed soil, all remaining well below the globally accepted limit of 370 Bq/kg. Similarly, the outdoor absorbed dose rate (D) varied between 19.9 and 52.9 nGy/h across all sites, compared to the world average of 59 nGy/h. This shows that no studied site exceeded this standard. The corresponding outdoor annual effective dose equivalent ($AEDE_{outdoor}$) ranged from 24.4 to 64.9 μSv/y, all below the UNSCEAR reference value of 70 μSv/y. External and internal hazard indices (H_{ex} and H_{in}) were below their respective safety limits of 1.0 across all sites, ranging from 0.11 to 0.31 for H_{ex} and 0.15 to 0.40 for H_{in}. Similarly, the representative level index (RLI) ranged from 0.15 to 0.41, remaining under the permissible ceiling of 1.0. Garmian undisturbed soil (R14) stood out as the highest-risk site across all indices, recording the largest Ra_{eq} (116.2 Bq/kg), absorbed dose rate (52.9 nGy/h), annual effective dose equivalent (64.9 μSv/y), and the highest H_{ex} (0.31), H_{in} (0.40), and RLI (0.41) in the dataset. This is consistent with the elevated ^{226}Ra and ^{232}Th concentrations reported for this area as shown in Table II, and likely reflect its underlying geology. Duhok undisturbed soil (R8) ranked second, with a Ra_{eq} of 89.9 Bq/kg and the second-highest absorbed dose rate (42.9 nGy/h), also attributable to its comparatively high natural radionuclide concentrations. At the lower end of the hazard spectrum, Raparin agricultural soil (R13) and the Koya (0–30 cm) agricultural layer (R2) recorded the lowest values across nearly all indices (Ra_{eq} of 41.9 and 43.3 Bq/kg, respectively), suggesting minimal radiological concern in these cultivated areas. When comparing soil types within the same location, the data do not reveal a consistent pattern. In Erbil (R4), undisturbed soil actually yielded slightly lower hazard indices (Ra_{eq} = 50.9 Bq/kg, D = 24.7 nGy/h) than the agricultural soil from the same site (Ra_{eq} = 53.4 Bq/kg, D = 25.8 nGy/h), suggesting that cultivation slightly elevated radionuclide concentration in soils, possibly through the addition of fertilizers or the redistribution of deeper soil material during plowing. In contrast, in Koya, agricultural soil sampled over the 0–30 cm depth interval (R2: Ra_{eq} = 43.3 Bq/kg) showed notably lower indices than the undisturbed soil sampled over the shallower 5–10 cm layer (R3: Ra_{eq} = 66.7 Bq/kg), though this comparison is complicated by the difference in sampling depths between the two studies, making a direct soil-type attribution difficult.

VII. Discussion

Table II summarizes the measurement techniques and mean activity concentration levels of both anthropogenic and naturally occurring radionuclides reported by research groups in soils across the Kurdistan Region. It is evident that high-resolution HPGe detectors have been the predominant choice for radioactivity measurements across the region. While some research groups used NaI(Tl) scintillation detectors between 2011 and 2014; however, their use declined after that period. This is mainly because NaI(Tl) detectors have

TABLE III
RADIATION HAZARD INDICES CALCULATED FROM NATURAL RADIONUCLIDE CONCENTRATIONS ACROSS THE KURDISTAN REGION

Reference code	Soil type	Sampling depth (cm)	Radiation hazard metrics					
			Ra_{eq} (Bq/kg)	D (nGy/h)	$AED_{Eoutdoor}$ (μSv/y)	H_{ex}	H_{in}	RLI
R1	Agricultural soil	0.0–10.0	68.4	32.5	39.8	0.18	0.22	0.25
R2	Agricultural soil	0.0–30.0	43.3	21.2	26.0	0.11	0.15	0.16
R3	Undistributed soil	5.0–10.0	66.7	31.7	38.8	0.18	0.21	0.25
		15.0–25.0	57.6	27.4	33.6	0.15	0.18	0.21
R4	Undistributed soil	0.0–20.0	50.9	24.7	30.3	0.13	0.17	0.19
	Agricultural soil		53.4	25.9	31.8	0.15	0.19	0.21
R5	Agricultural soil	0.0–20.0	53.3	25.8	31.7	0.14	0.18	0.20
R6	Undistributed soil	0.0–15.0	79.5	37.6	46.1	0.21	0.28	0.29
R7	Agricultural soil	0.0–20.0	69.6	32.8	40.3	0.18	0.23	0.26
R8	Undistributed soil	0.0–10.0	89.9	42.9	52.6	0.24	0.29	0.34
R13	Agricultural soil	0.0–20.0	41.9	19.9	24.4	0.11	0.15	0.15
R14	Undistributed soil	0.0–15.0	116.2	52.9	64.9	0.31	0.40	0.41

RLI: Representative level index

a lower energy resolution compared to HPGe detectors, and HPGe systems became more widely available in research centers across the Kurdistan Region. It is also worth noting that neutron activation analysis (NAA), despite its high sensitivity and multi-element capability, has not been adopted by any of the research groups reviewed in this study. The presence of the anthropogenic radionuclide ^{137}Cs in regional soils is primarily attributed to the Chernobyl nuclear accident of 1986. The extent of soil contamination varied across the region depending on several factors, including distance from the accident site, precipitation patterns at the time of fallout, and the physicochemical properties of the local soils. Notably, the findings of Smail, Ahmad and Mansour, (2021) and Salih, Hussein and Sedeeq (2019) confirmed that ^{137}Cs concentrations were positively correlated with elevation above sea level, with higher-altitude areas exhibiting greater deposition. The concentrations of naturally occurring radionuclides in soil are governed primarily by the geological and geographical characteristics of each area. Across the reviewed studies, the highest activity concentrations of ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K were generally reported in Sulaimani, Halabja, Duhok and Erbil, respectively. The considerable variability in radionuclide concentrations observed among different research groups is likely attributable to differences in soil type, geological formation, climatic conditions, and land use practices (Rafique, et al., 2013). The radiological hazard indices presented in Table III provide a quantitative basis for evaluating the public health implications of the reported radionuclide concentrations. All calculated indices across the studied sites were within internationally recommended limits. However, it should be noted that these assessments carry inherent uncertainties. Since the indices are based on mean activity concentration values, spatial variability within each study area may not be fully represented, especially in studies with limited sample sizes. Furthermore, variations in sampling depth, soil preparation methods, and detector calibration among different research groups may affect the comparability of results across studies. Overall, the findings confirm that soils across the Kurdistan Region do not contain anthropogenic and naturally occurring radioactive elements at levels that pose a significant health risk to the population.

VIII. CONCLUSION

This work reviews the studies conducted on the radioactivity measurements in soils of the Kurdistan Region. The reported data indicate that there is a substantial difference in the concentrations of natural radionuclides found in soils across several locations in the Kurdistan region. The majority of the research groups used high-purity germanium HPGe detectors for gamma-ray measurements. Most of the studies reported approximately the same ^{137}Cs levels for topsoil. The studies indicate that the mean values of the activity levels of ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K in the soil of the Kurdistan region were below the worldwide average levels and that there is no potential risk to human health, except for several locations in the Sulaimani and Halabja provinces, which show high background radiation due to terrestrial radionuclides. Finally, based on the findings of the studies conducted before 2025, it can be confirmed that the Kurdistan Region is free from contamination with radiation originating from naturally occurring radioactive materials and fallout radionuclides. Despite the growing body of research on soil radioactivity in the Kurdistan Region, no systematic investigation has been conducted in mountainous areas, which represent a significant gap in the existing literature. Given the distinct geological characteristics of these areas and the potential for elevated atmospheric deposition of radionuclides at higher altitudes, future studies should prioritize radioactivity measurements in mountain soils to establish a more complete regional radiological baseline.

DECLARATIONS

A. Ethical Approval

All authors have read, understood, and have complied, as applicable, with the statement on "Ethical responsibilities of Authors".

B. Funding

No funding was received.

C. Data Availability

This review article does not report any new data. It synthesizes and evaluates existing research findings from previously published sources.

D. Competing Interests

The authors declare no competing interests.

E. Authors' Contributions

All of the authors contributed to the design and conception of the study. Shalaw Zrar Sedeeq, Jahfer Majeed Smail, and Saddon Taha Ahmad collected the previous works of the other researchers for interpretation and discussed their results. Shalaw Zrar Sedeeq wrote the first draft of the manuscript, and the other authors gave comments on previous drafts. The final manuscript was read and approved by all authors.

F. Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors used an AI tool to improve readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

Abdulla, N.M., and Mohammed, M.I., 2025. Assessment of radioactivity levels and radiological hazards of soil samples from vineyards in mountainous areas in the Raparin district, Iraqi Kurdistan. *Acta Geophysica,* 73(5), pp.4113-4128.

Abdullah, K., and Ramadhan, R., 2011. Determination of gamma-emitting radionuclides in Duhok city, Iraq. *The Nucleus,* 48(4), pp.295-300.

Abdullah, K.O., Hussien, A.M., Azzawi, O.K., and Sedeeq, S.Z., 2021. Determining the natural radioactivity level of soil samples from Halabja City. *Journal of University of Babylon for Pure and Applied Sciences,* 29(2), pp.177-187.

Ahmed, R.S., 2021. A review on soil radionuclide distribution in Iraq analysed using gamma ray spectroscopy. *Environmental Forensics,* 22(1), pp.91-98.

Akray, D.T., and Ahmed, A.H., 2013. Measurement of radioactivity for 226Ra radionuclide in soil samples from Bekhma region using Gamma ray spectrometry. *Concepts in Pure and Applied Science,* 1(1), pp.44-48.

Alam, I., Rehman, J.U., Ahmad, N., Nazir, A., Hameed, A., and Hussain, A., 2020. An overview on the concentration of radioactive elements and physiochemical analysis of soil and water in Iraq. *Reviews on Environmental Health,* 35(2), pp.147-155.

Azeez, H.H., Mansour, H.H., and Ahmad, S.T., 2019. Transfer of natural radioactive nuclides from soil to plant crops. *Applied Radiation and Isotopes,* 147, pp.152-158.

Azeez, H.H., Mansour, H.H., and Ahmad, S.T., 2020. Effect of using chemical fertilizers on natural radioactivity levels in agricultural soil in the Iraqi Kurdistan region. *Polish Journal of Environmental Studies,* 29(2), pp.1059-1068.

Babakr, D.A., Ahmad, S.T., and Taha, A.H., 2022. Assessment of radioactivity levels in soil of Koya district in Kurdistan Region-Iraq using high-purity germanium detector. *Jordan Journal of Physics,* 15(3), pp.259-277.

Dinh Chau, N., Dulinski, M., Jodlowski, P., Nowak, J., Rozanski, K., Sleziak, M., and Wachniew, P., 2011. Natural radioactivity in groundwater--review. *Isotopes in Environmental and Health Studies,* 47(4), pp. 415-437.

El-Arabi, A.M., 2007. ^{226}Ra, ^{232}Th and ^{40}K concentrations in igneous rocks from eastern desert, Egypt and its radiological implications. *Radiation Measurements,* 42(1), pp.94-100.

Hussein, Z.A., 2019. Assessment of natural radioactivity levels and radiation hazards for soil samples used in Erbil governorate, Iraqi Kurdistan. *ARO-The Scientific Journal of Koya University,* 7(1), pp. 34-39.

Mamand, K.O., Abda, J.M.R., and Abdullah, K.O., 2025. Assessment of natural radioactivity levels and radiation hazards in soil samples from selected districts of Garmian zone, Sulaymaniyah city, Kurdistan region, Iraq (oil & gas block). *Environmental Geochemistry and Health,* 47(11), p.472.

Mohammed, H., Jaff, D., and Schrock, S., 2019. The challenges impeding traffic safety improvements in the Kurdistan region of Iraq. *Transportation Research Interdisciplinary Perspectives,* 2, p.100029.

Mustafa, M.I., 2019. Radioactivity investigation of the anthropogenic ^{137} Cs radionuclide in soil samples from the Marapasta Region in Iraqi Kurdistan. *Zanco Journal of Pure and Applied Sciences,* 31(4), pp.82-93.

Rafique, M., Jabbar, A., Khan, A.R., Rahman, S.U., Basharat, M., Mehmood, A., and Matiullah., 2013. Radiometric analysis of rock and soil samples of Leepa valley; Azad Kashmir, Pakistan. *Journal of Radioanalytical and Nuclear Chemistry,* 298, pp.2049-2056.

Rahman, S., and Faheem, M., 2008. Natural radioactivity measurements in Pakistan-an overview. *Journal of Radiological Protection,* 28(4), pp.443-449.

Salh, H., Sedeeq, S.Z., Aközcan Pehlivanoğlu, S., Albarzinji, I.M., and Külahcı, F., 2024. On transfer factors of natural radionuclides and radiological health risks assessment of some fruit samples. *Radiochimica Acta,* 112(10), pp.795-804.

Salih, N.F., Hussein, Z.A., and Sedeeq, S.Z., 2019. Environmental radioactivity levels in agricultural soil and wheat grains collected from wheat-farming lands of Koya district, Kurdistan region-Iraq. *Radiation Protection and Environment,* 42(4), pp.128-137.

Samad, A.I., Ahmed, A.H., and Ahmad, S.T., 2023. Radiological health assessment of infant milk in Erbil Governorate, Iraq. *Environmental Monitoring and Assessment,* 195(3), p.419.

Sedeeq, S.Z., Smail, J.M., and Ahmad, S.T., 2025. Natural radionuclides in sedimentary rocks: Monitoring and radiation risk assessment. *Radiochimica Acta,* 114(2), pp.151-161.

Sedeeq, S.Z., Smail, J.M., and Ahmad, S.T., 2026. Statistical analysis, spatial distribution, and radiation hazard assessment of environmental radionuclides in soils of the mountains around Koya District, Iraq. *Environmental Monitoring and Assessment,* 198(2), p.94.

Smail, J.M., Ahmad, S.T., and Mansour, H.H., 2021. Estimation of the natural radioactivity levels in the soil along the little zab river, Kurdistan Region in Iraq. *Journal of Radioanalytical and Nuclear Chemistry,* 331, pp.119-128.

Singh, S., Rani, A. and Mahajan, R.K., 2005. 226Ra, 232Th and 40K analysis in soil samples from some areas of Punjab and Himachal Pradesh, India using gamma ray spectrometry. *Radiation Measurements*, 39(4), pp.431-439.

Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hidiroglu, S., and Karahan, G., 2009. Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *Journal of Environmental Radioactivity,* 100(1), pp.49-56.

Unscear (United Nations Scientific Committee on the Effects of Atomic Radiation)., 1998. *Sources and Effects of Ionizing Radiation, Report to the General Assembly, with Scientific Annexes. United Nations, New York*.

Unscear (United Nations Scientific Committee on the Effects of Atomic Radiation)., 2000. *Sources and Effects of Ionizing Radiation, Report to the General Assembly, with Scientific Annexes. United Nations, New York*.

Unscear (United Nations Scientific Committee on the Effects of Atomic Radiation)., 2008. *Sources and Effects of Ionizing Radiation, Report to the General Assembly, with Scientific Annexes. United Nations, New York*.

Wais, T.Y., Namq, B.F., Najam, L.A., Othman, S.Q., Hussein, Z.A., Al-Taii, H.A., Sayyed, M.I., Yuness, M., Mostafa, A., Živković, M.P., Mansour, H., and Kumar A., 2025. Investigation of natural radionuclide transfer from soil to wheat. *Scientific Reports,* 15(1), p.35785.

Yousuf, R.M., and Abullah, K., 2013. Measurement ofnatural radioactivity in soil collected from the Eastern of sulaimany governorate in Kurdistan Region, Iraq. *ARPN Journal of Science and Technology,* 3(7), pp.749-757.