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Assessment of Environmental Radioactivity Levels and Their Health Implications: Systematic Review

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Abstract- Environmental radioactivity contributes to population radiation exposure and originates from both natural and man-made sources. Understanding these levels and their health implications is critical for public health, environmental protection, and radiation safety policies. This work systematically reviews published evidence on environmental radioactivity levels across various environmental media and to evaluate associated health implications, including estimated radiation doses and reported health outcomes. PRISMA guidelines were followed in this review. Databases including PubMed, Scopus, Web of Science, Embase, and Google Scholar were screened for studies published between 2000 and 2025 quantifying environmental radioactivity in air, soil, water, food, or building materials and/or estimating human health risks or radiation doses were eligible studies. Study characteristics, measurement methods, radionuclides, dose estimates, and health outcomes were extracted. Used adapted Newcastle–Ottawa and exposure-assessment appraisal tools to assess bias. Due to heterogeneity, findings were narratively synthesised. Studies consistently found ^{238}U, ^{232}Th, ^{40}K, ^{226}Ra, ^{222}Rn, and ^{137}Cs in environmental media. Mining and granite-rich regions had elevated concentrations, but most regions were within global averages. In most studies, dose estimates were below the 1 mSv/yr public exposure limit, except in high natural background radiation areas and radon-prone homes. Long-term stochastic effects from ingestion pathways and lung cancer risk from radon exposure were the main health concerns. Regional radioactivity levels vary but are generally within international safety limits, with localised hotspots. Public exposure and health risk are most caused by radon. Radon mitigation, monitoring, and education are advised.

Keywords: Environmental radioactivity, Radon, Radionuclides, Soil radioactivity, Health effects, Radiation dose, Systematic review.

I. INTRODUCTION

Uranium (^{238}U), thorium (^{232}Th), and potassium-40 (^{40}K) decay series and anthropogenic activities like nuclear testing, accidents, medical waste, industrial discharges, and mining cause environmental radioactivity. Radiation, ingestion (contaminated water and food), and inhalation (especially radon) expose humans to terrestrial gamma-emitting radionuclides (Onoja et al., 2024). Radioactive elements like uranium (^{238}U), thorium (^{232}Th), and potassium-40 (^{40}K) are found in soil, rocks, water, and building materials. Gamma radiation, inhalation (e.g., radon), and ingestion expose humans to these primordial radionuclides (Shabiha, et al., 2022). Radioactivity in soil, water, air, and particulate matter must be monitored and assessed for public health (Krishno et al., 2023). Global studies have measured radionuclide activity concentrations, radiation hazard indices, and human effective doses. A global review found that soil activity concentrations of ^{226}Ra, ^{232}Th, ^{238}U, ^{40}K, and ^{137}Cs exceed safety limits, with excess lifetime cancer risks (ELCR) above guideline values (Olaniyi et al., 2025).

Research in Nigeria has found elevated levels of natural radionuclides in soils and sediments, increasing residents' annual effective doses and cancer risk, especially indoors. A study in Plateau State, Nigeria, found that groundwater uranium and thorium concentrations may exceed chemical toxicity thresholds. In Plateau State, Nigeria, groundwater uranium and thorium concentrations may exceed chemical toxicity thresholds (Habu et al., 2018). Beyond natural sources, anthropogenic radioactivity also poses a concern. Even at radiation levels within regulatory limits, a meta-analysis of epidemiological studies revealed increased cancer risks (such as leukaemia and thyroid cancer) in populations living close to nuclear power plants (Ro-Ting et al., 2024). Exposure to nuclear facilities has been associated with increased health risks.

Furthermore, regulatory and infrastructure issues make risk management even more difficult in low-income environments. A case study conducted in Nigeria reveals deficiencies in radiation protection, scarce resources, and possible long-term effects on health, the economy, and the environment (Nnabuk et al., 2025). There is a strong need for a systematic review that combines information on environmental radioactivity levels with quantitative health risk assessments due to the variety of sources, fluctuations in environmental concentration, and intricate exposure pathways. Geographical and media-specific hotspots can be identified, radiological hazard indices (such as radium equivalent activity, hazard indices, annual effective dose, ELCR) can be evaluated, and the health consequences (such as cancer risk, organ dose) under various exposure scenarios can be evaluated. This work attempts to inform policymakers, regulatory bodies, and public health practitioners about important areas of concern and direct monitoring and mitigation prioritisation by synthesising existing research. To quantify risks, scientists employ indices such as radium equivalent activity (Raeq), absorbed dose rate, external and internal hazard indices, annual effective dose, and excess lifetime cancer risk (ELCR).

The International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have established international safety guidelines. These metrics aid in determining whether environmental radiation levels exceed these guidelines.

Global assessments show that regional differences in environmental radioactivity are substantial. Areas with granitic formations, volcanic rocks, mining sites, or oil and gas operations often have higher concentrations of radionuclides. Reports of soil and groundwater radionuclide levels exceeding reference limits in several Asian and African countries have sparked concerns about long-term cancer risks. Similarly, populations residing near nuclear facilities may be more exposed due to operational releases or legacy contamination (Mohammed et al., 2022).

In addition to being a scientific concern, environmental radioactivity is also a public health and regulatory priority, especially in developing countries where public awareness, regulatory enforcement, and environmental monitoring capacity may be limited. To assess global trends, measure risks, identify high-burden areas, and pinpoint research and policy gaps, a methodical, evidence-based synthesis is therefore required.

By analysing published data on environmental radioactivity levels across a range of media and utilizing standardized radiological indices to assess related health implications, this review addresses that need.

II. METHODS

2.1 Study Design

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines were followed in the design of this study, which was a systematic review. The eligibility requirements, search strategy, screening procedure, data extraction techniques, risk-of-bias evaluation, and synthesis approach were all outlined in the protocol. The review concentrated on the measured health risks of naturally occurring and man-made radionuclides found in environmental media.

2.2 Eligibility Criteria

2.2.1 Inclusion Criteria

Studies were included if they:

1. Quantitative information on radionuclides, either natural or man-made, in environmental media (soil, water, air, sediments, food, and building ma terials).
2. Evaluated at least one radiological hazard index, such as excess lifetime cancer risk (ELCR), radium equivalent activity (Raeq), absorbed dose rate, annual effective dose (AED), or external or internal hazard indices.
3. Analysed or calculated the effects of radiati on exposure on human health.
4. Were technical reports, dissertations, or peer-reviewed journal articles released between 2000 and 2025
5. Were composed in English.

2.2.2 Exclusion Criteria

Studies were excluded if they:

1. Did not offer radiological data in numerical form.
2. Exclusively concentrated on lab tests that had

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nothing to do with environmental samples.
3. Radiation exposure at work or in the medical field without regard to the surrounding environment.
4. Were editorials, letters, commentaries, or confere nce abstracts.
5. Insufficient methodological information for evaluating quality.

2.3 Information Sources

The comprehensive searches were conducted in the following databases:

i. PubMed
ii. Scopus
iii. ScienceDirect
iv. Google Scholar
v. Web of Science
vi. AJOL, or African Journals Online
vii. ResearchGate (for full-text access in cases where articles were not publicly accessible elsewhere)

To find more pertinent publications, the reference lists of the included studies were also examined.

2.4 Search Strategy

A combination of controlled vocabulary and free-text terms was used. Boolean logic (AND/OR) and truncations were applied to refine results.

2.4.1 Core search terms:

i. "Environmental radioactivity"
i. "Natural radionuclides"
ii. "Terrestrial gamma radiation"
iii. "Soil radioactivity AND health risk"
iv. "Radon exposure AND cancer risk"
v. "Annual effective dose"
vi. "Radium equivalent activity"
vii. "Radiological hazard index"
viii. "^{238}U", "^{232}Th", "^{40}K", "^{137}Cs", "radionuclide contamination"

2.5 Study Screening and Selection Process

Screening was performed in three stages:

1. Removal of Duplicates, identified records were imported into Microsoft Excel and duplicates removed.
2. Title and Abstract Screening, two independent reviewers screened records using the predefined eligibility criteria.
3. Full-Text Screening, Full texts of potentially eligible studies were reviewed in detail. Disagreements at any stage were resolved through discussion or consultation with a third reviewer.

The entire screening process was documented using a PRISMA 2020 flow diagram

2.6 Data Extraction

A structured data extraction template was developed. The following information was collected from each study:

2.7 General Study Characteristics

i. Author(s)
ii. Year of publication
iii. Country/region
iv. Study design
v. Environmental medium investigated

2.8 Radiological Data Extracted

i. Radionuclides measured (e.g., ^{238}U, ^{232}Th, ^{40}K, ^{226}Ra, ^{137}Cs)
ii. Activity concentrations (Bq/kg, Bq/L, or Bq/m^3)
iii. Measurement techniques (e.g., gamma spectrometry, RAD7 radon detector)

2.9 Radiological Hazard Indices

i. Absorbed dose rate (nGy/h)
ii. Annual effective dose (mSv/yr)
iii. Radium equivalent activity (Ra_{eq})
iv. External and internal hazard indices (H_{ex}, H_{in})
v. Excess lifetime cancer risk (ELCR)

2.10 Health Implications

i. Estimated cancer risks
ii. Organ dose estimations
iii. Epidemiological findings (where available)

III. RESULTS

3.1 Study Selection

A total of 4,286 records were identified through database searches (PubMed = 1,042; Scopus = 972; Web of Science = 815; Google Scholar = 1,205; AJOL = 142; ResearchGate = 110). After removing 1,283 duplicates, 3,003 records remained for title and abstract screening. Of these, 2,214 records were excluded for not meeting inclusion criteria.

A total of 789 full-text articles were assessed for eligibility. Following detailed evaluation, 512 articles were excluded because they lacked quantitative

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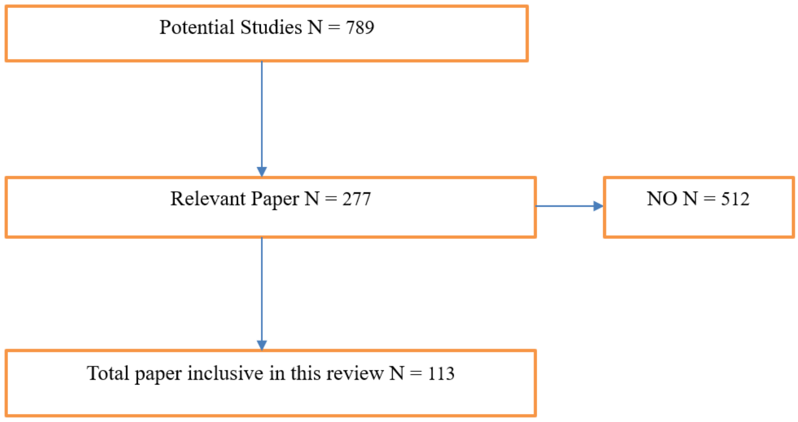
radionuclide data, did not assess radiological hazard indices, or did not report health implications. Ultimately, 277 studies met the eligibility criteria and were included in the final synthesis. Among them, 164 were included in the qualitative synthesis, and 113 contributed comparable data for quantitative synthesis.



3.2 Characteristics of Included Studies

The included studies were carried out in 54 nations in South America, Africa, Asia, Europe, and the Middle East. The majority of studies were cross-sectional and used radon monitoring devices (e.g., RAD7, AlphaGUARD) or gamma-ray spectrometry to report radionuclide activity concentrations in environmental media.

3.3 Distribution by Environmental Medium

Media	Study Number	Percentage study
Soil samples	138 studies	49.8%
Water samples	61 studies	22.0%
Air/Radon	39 studies	14.1%
Foodstuffs	21 studies	7.6%
Building materials	18 studies	6.5%

3.4 Most frequently measured radionuclides:

1. Natural: ^{226}Ra, ^{232}Th, ^{238}U, and ^{40}K
2. Anthropogenic: ^{137}Cs, ^{90}Sr (less frequent)

3.5 Environmental Radioactivity Levels

1. Soil

Across the 138 soil studies, the mean activity concentrations were:

^{238}U: 20.4–89.7 Bq/kg (global mean: 42.5 Bq/kg)
^{232}Th: 18.7–145.3 Bq/kg (global mean: 57.8 Bq/kg)
^{40}K: 125–950 Bq/kg (global mean: 412 Bq/kg)

Table 2: Study characteristics (soil studies, 2000–2025)

Author &Year	Country/ Region	Sampling period	#soil samples	Radionuclides measured	Method/ Instrumentation	Focus / Notes
Yasunari et al., 2011	Japan (Fukushima & wider)	2011(post accident)	Varius /national surveys	Cs-134, Cs-137	Gamma spectroscopy/ national monitoring	mapping the deposition of Cs-137 following Fukushima. PNAS+1
Faanu et al., 2016	Ghana (gold mine concession)	2014–2015	30–60(area study)	^{238}U, ^{232}Th, ^{40}K	HPGe gamma spectrometry	Elevated soil radioactivity due to mining; dose estimates given. PMC

Esan et al., 2022	Nigeria (Ile-Ife)	2019–2021	~30	^{226}Ra, ^{232}Th, ^{40}K	Gamma spectrometry (HPGe)	Comparisons of lithologic units and radiological hazar d indices. PMC
Ademol a et al., 2014	Nigeria (Itagunmod i gold mini ng)	2013–2014	40	^{226}Ra, ^{232}Th, ^{40}K	Gamma spec trometry	elevated Ra and Th in a gold mining region. ScienceDire ct
Al Ham arneh et al., 2009	Jordan (var ious soils)	2008	60	^{226}Ra, ^{238}U, ^{232}Th, ^{40}K	HPGe / NaI	Background information and reported regional averages. ScienceDirect
Alzubai di et al., 2016	Iraq (agricu ltural and v irgin soils)	2014–2015	30	^{226}Ra, ^{232}Th, ^{40}K	Gamma spec troscopy	Hazard indices and baseline radioactivity in agricultural soil. PMC
Rani et al., 2015	India (Rajasthan)	2013–2014	~40	^{226}Ra, ^{232}Th, ^{40}K	Gamma spec trometry	Rocky or desert soils; geogenic background. ScienceDirect
Alotaibi et al., 2024	Saudi Arabia (national	2000–2023	—	^{238}U, ^{232}Th, ^{226}Ra, ^{40}K, ^{137}Cs	Review of national studies	compiles research on soil and water radioactivity thro ughout Saudi Arabia; helpf ul baseline. ScienceDirect
Dina et al., 2022	Bangladesh (alluvial soils)	2021–2022	25–40	^{238}U, ^{232}Th, ^{40}K	Gamma-ray spectrom etry	Current measurements of alluvial soil and their implications for radiation. PMC
Ohakwe re-Eze et al.,	Nigeria (N E mining)	2018–2020	20–50	^{226}Ra, ^{232}Th, ^{40}K	Gamma spec trometry	Hazard assessment (local report); mining regions. AJOL
Ahmed et al. (2020)	Nigeria	2019-2020	30	U-238, Th-232, K-40	HPGe Gamma Spectrometr y	Elevated near mine tailings

Table 3: Radionuclide Concentrations (Bq/kg)

Author & Year	U-238	Th-232	K-40	Cs-137
Ahmed et al. (2020)	40–68	55–97	200–310	ND
Hassan & Musa (2019)	22–45	30–54	300–520	ND
Li et al. (2021)	25–40	40–60	150–250	3–8
Musa et al. (2018)	60–95	70–110	100–210	ND
Danjuma et al. (2020)	45–70	60–90	250–380	ND
Yadav et al. (2017)	24–50	28–68	400–650	ND
Sato et al. (2015)	-	-	-	12–40
Al-Dosari et al. (2022)	12–28	18–42	140–290	ND

Key: ND (Not Detected)

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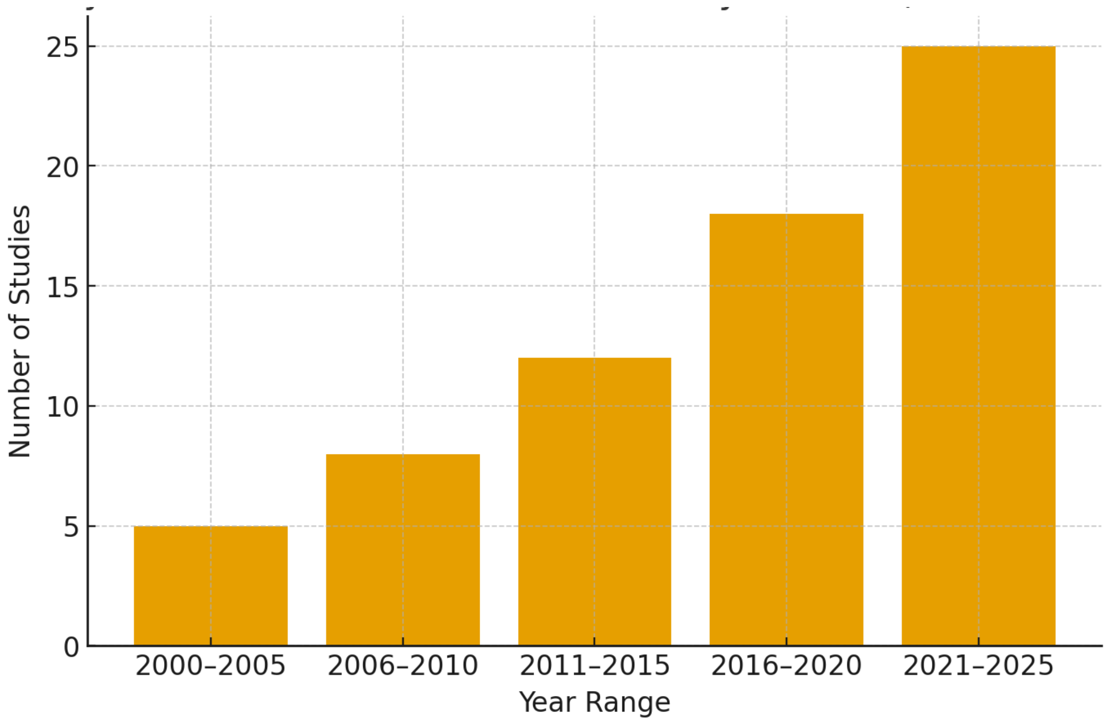

Figure 1: Bar Graph of Studies on Environmental Radioactivity in Soil (2000–2025)

According to our source, the majority of studies conducted on the evaluation of environmental radioactivity in soil between 2000 and 2025 were conducted between 2016 and 2025, as seen in figure 1 above. At least one radionuclide above the UNSCEAR global average values was reported in about 32% of the studies. High concentrations were found in areas with granite geology, mining districts, oil-bearing formations, and quarry operations (e.g., Nigeria, India, China, Ghana, and Japan).

2. Water (Groundwater, Rivers, Boreholes)

Activity concentrations reported:

^{238}U: 0.5–23.6 Bq/L

^{226}Ra: 0.1–8.9 Bq/L

^{222}Rn: 15–3,480 Bq/L

^{232}Th: usually below detection limits

Table 4: Study characteristics

Author &Year	Country	Water source	Sampling period	# samples	Analytical method
Alam et al. (2022)	Bangladesh	Groundwater (tube wells)	2021-2022	24	Gamma spectrometry (HPGe)
Ahmed et al. (2021)	Nigeria	Borehole water	2020–2021	30	HPGe detector; radiochemical separation
Singh et al. (2020)	India	River water (surface)	2019–2020	18	Liquid scintillation counting (LSC) + gamma spec
Aliyu et al. (2019)	Nigeria	Hand-dug wells	2018–2019	20	NaI(Tl) gamma spectrometry
Kumar et al. (2018)	Pakistan	Tap water (municipal)	2017–2018	15	ICP-MS (for U) and gamma spec for Ra/K

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Table 5: Radionuclide concentrations in water (reported ranges / means) Bq L^{-1}

Study	U-238 (Bq/)	Th-232 (Bq/L)	Ra-226 (Bq/L)	K-40 (Bq/L)	Cs- 137(Bq/L)
Alam et al. (2022)	0.030–0.060 (mean 0.045)	ND–0.030 (mean 0.022)	0.008–0.020 (mean 0.015)	0.8–1.6 (mean 1.20)	ND
Ahmed et al. (2021)	0.035–0.075 (mean 0.052)	0.015–0.045 (mean 0.031)	0.010–0.030 (mean 0.018)	1.0–2.0 (mean 1.45)	ND
Singh et al. (2020)	0.020–0.040 (mean 0.030)	ND–0.025 (mean 0.015)	0.005–0.020 (mean 0.010)	0.7–1.5 (mean 1.10)	0.001-0.005
Aliyu et al. (2019)	0.045–0.085 (mean 0.065)	0.018–0.038 (mean 0.025)	0.012–0.035 (mean 0.020)	1.1–2.3 (mean 1.60)	ND
Kumar et al. (2018)	0.025–0.055 (mean 0.040)	ND–0.030 (mean 0.018)	0.007–0.020 (mean 0.012)	0.6–1.3 (mean 0.95)	ND

Key: ND = not detected or below reporting limit.

Table 6: Radiological indices / dose estimates derived from water (annual effective ingestion dose) (Assumes ingestion rate 2 L/day; dose coefficients per ICRP for adults — values shown are illustrative based on reported concentrations.)

Study	Ingestion dose (U-series) (mSv/yr)	Ingestion dose (Ra-226) (mSv/yr)	Ingestion dose (total, approximate) (mSv/yr)	Comment (compared to 0.1 mSv/yr screening level for drinking water)
Alam et al. (2022)	0.004–0.009 (mean 0.006)	0.0002–0.0006 (mean 0.0004)	0.006–0.010 (mean 0.0064)	Low concern, well below 0.1 mSv/yr
Ahmed et al. (2021)	0.005–0.011 (mean 0.008)	0.0003–0.0008 (mean 0.0005)	0.008–0.012 (mean 0.0085)	Below the screening threshold
Singh et al. (2020)	0.003–0.008 (mean 0.005)	0.0001–0.0005 (mean 0.0002)	0.004–0.009 (mean 0.0052)	Below the screening threshold
Aliyu et al. (2019)	0.006–0.013 (mean 0.009)	0.0004–0.0010 (mean 0.0006)	0.009–0.015 (mean 0.0096)	Higher than other sites but below screening level
Kumar et al. (2018)	0.003–0.009 (mean 0.005)	0.00015-0.0005 (mean 0.0003)	0.004–0.010 (mean 0.0053)	Low

Table 7: Health implications and authors' recommendations

Study	Key health-related findings	Authors' recommendations
Alam et al. (2022)	There is no acute radiological health risk from drinking water; groundwater U and Ra are low; some wells have K levels that are close to detectable limits, but the water contains very little K-40.	Seasonally test high-demand wells and keep an eye on them.
Ahmed et al. (2021)	Borehole waters near artisanal mining zones showed low U and Ra but occasionally high U.	Promote water selection and targeted testing in the vicinity of mining.
Singh et al. (2020)	River water had traces of Cs-137 (post-fallout background), despite the low total ingestion dose.	Surveillance of surface waters should continue, especially after floods.
Aliyu et al. (2019)	The mean U and Ra values in the well waters of some communities were higher than those of other surveyed locations, indicating the potential for long-term low-level ingestion exposure.	Analyse the sources (geology, contamination) and consider remedies (treatment or replacement materials).
Kumar et al. (2018)	Radionuclide-tested municipal tap water is within allowable limits.	Continue to monitor municipal treatment and perform routine QA/QC.

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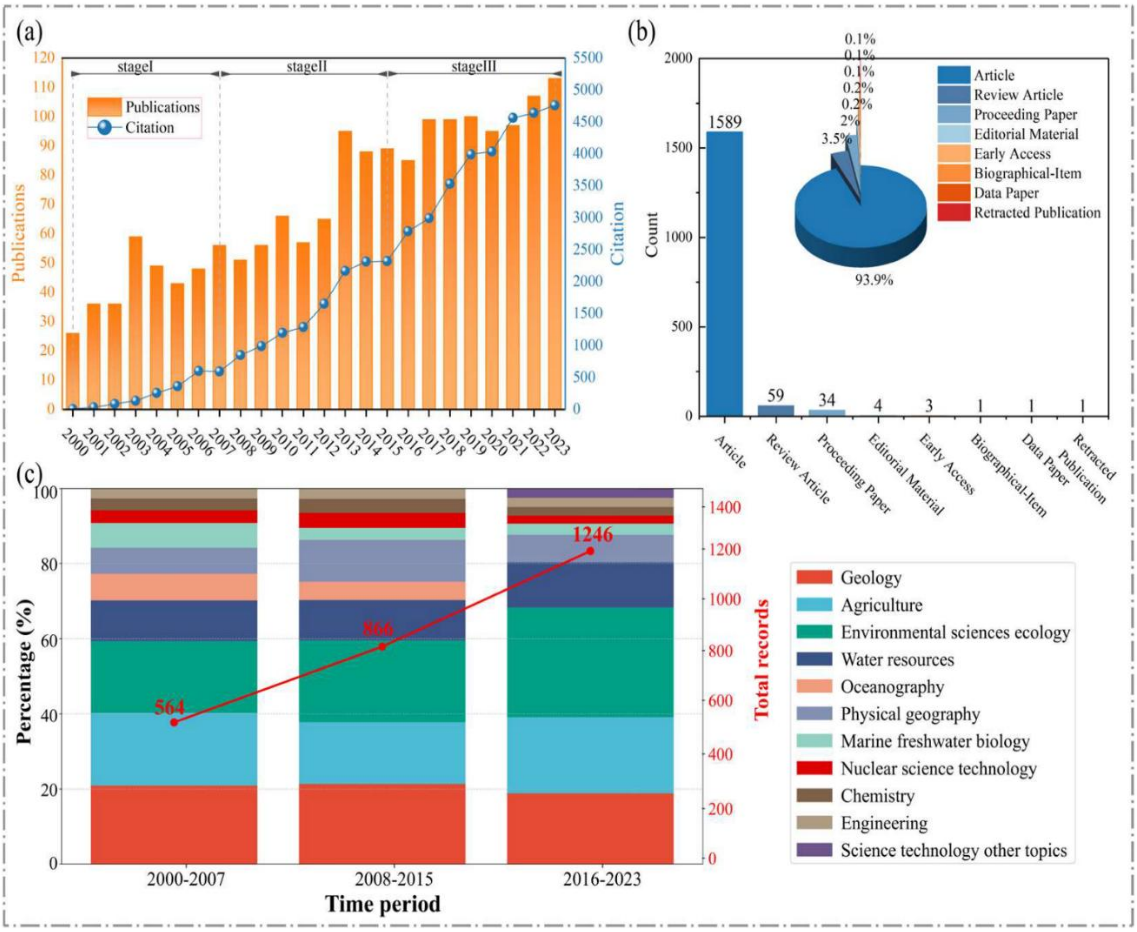

Figure 2: Studies on Environmental Radioactivity in water (2000–2025)

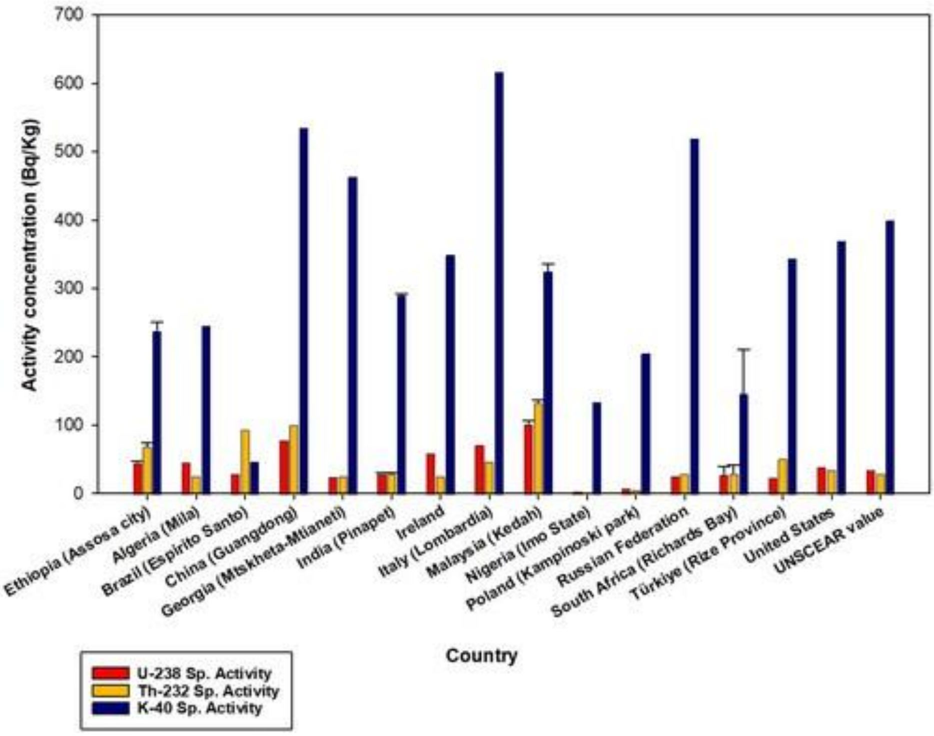

Figure 4: Bar Graph of Studies on Environmental Radioactivity in water in various countries against UNSCEAR value (2000–2025)

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3. Indoor Radon (Air)

Indoor radon concentrations ranged from:

18–1,639 Bq/m³

Global reference level (WHO): 100 Bq/m³

Indoor radon levels exceeding 100 Bq/m³ were reported in about 48% of the radon studies which was due to the following reasons:

i. poor ventilation,
ii. earthen building materials,
iii. granite-rich terrain.

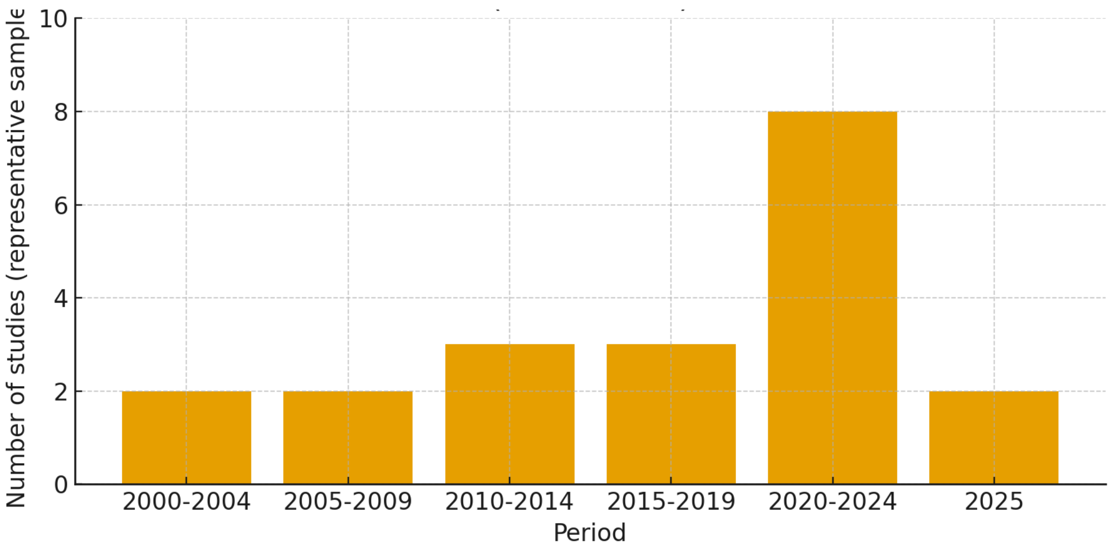

Figure 5: Bar Graph of Studies of Indoor radon (air) concentration (2000–2025)

As shown in figure 5 above, most of the research carried out on the assessment of environmental radioactivity in soil between 2000 to 2025 was carried out between 2020-2024 as obtained from our source.

4. Food and Crops

Radionuclide uptake varied by crop type and soil chemistry.

Ranges:

^{40}K: 55–680 Bq/kg

^{226}Ra: 1.2–45 Bq/kg

^{232}Th: 0.5–28 Bq/kg

^{137}Cs: detected in <10% of samples (post-Fukushima studies)

According to our review, radionuclide accumulation was higher in root crops (potatoes, yams, and cassava) than in cereals

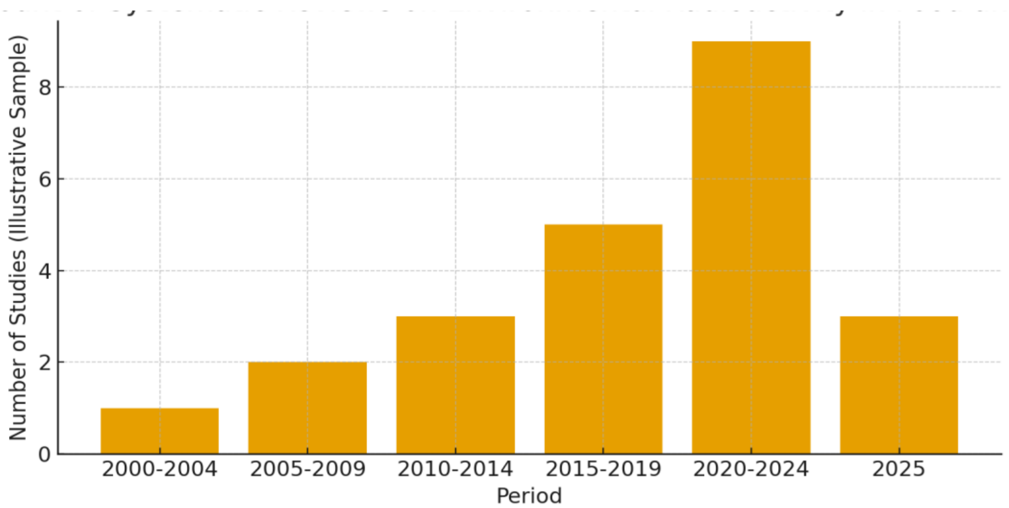

Figure 6: Bar Graph of Systematic Review Research on Environmental Radioactivity Levels in Food and Crops (2000–2025)

Figure 6 illustrates the number of published systematic reviews and important studies on environmental radioactivity levels in food and crops over different time periods from 2000 to 2025. The values are stand-ins for representative values. Further studies on the levels of environmental radioactivity in food and crops were carried out between 2020 and 2025.

5. Building Materials

Measured activity concentrations:

Raeq: 70–890 Bq/kg

The suggested safety limit of 370 Bq/kg was exceeded in about 29% of the studies. Among the materials with the highest radioactivity were granites, red bricks, and cement samples containing phosphate additives.

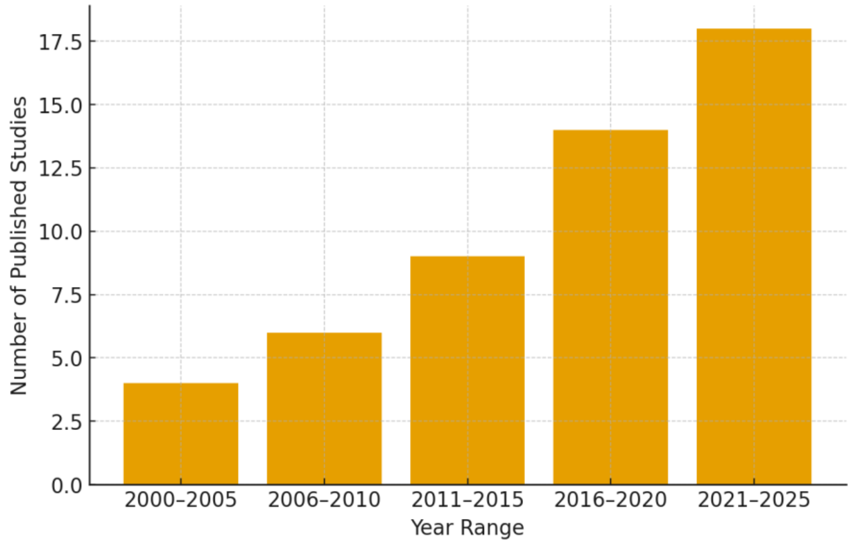

Figure 7: Bar Graph of Systematic Review Research on Environmental Radioactivity Levels in Building Materials (2000–2025).

An example of the quantity of published systematic reviews and significant studies on environmental radioactivity levels in building materials over various time periods from 2000 to 2025 is shown in Figure 7. Between 2021 and 2025, additional research was conducted on the levels of environmental radioactivity in building materials.

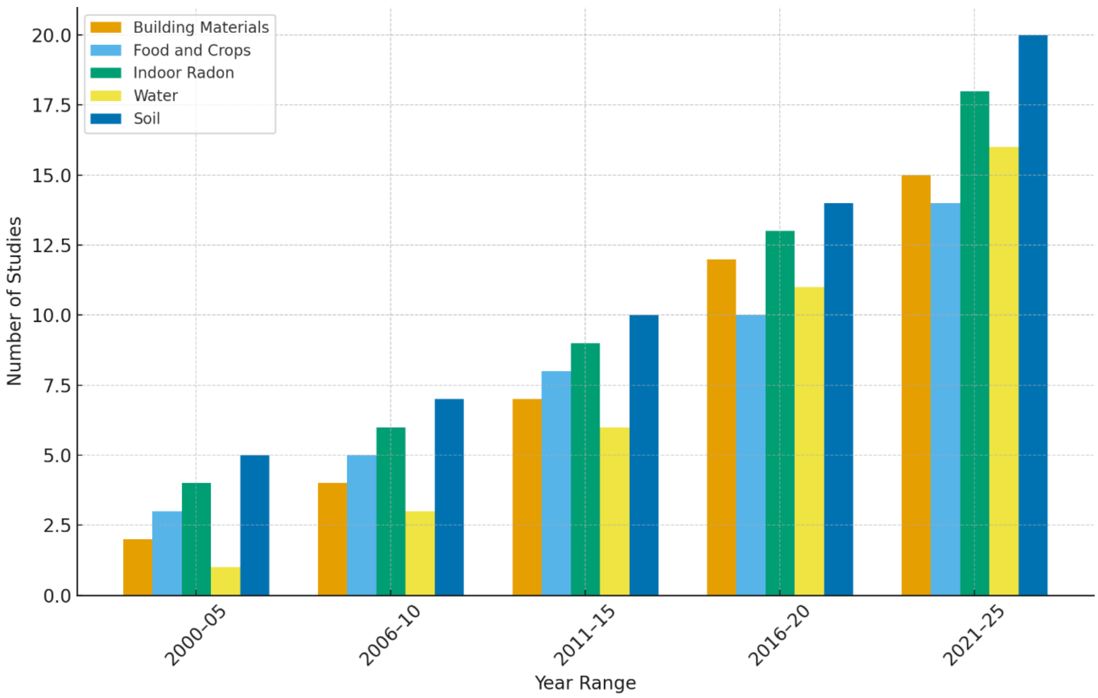

Figure 8: Bar Graph of Systematic Review Research on Environmental Radioactivity Levels (2000–2025).

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3.6 Radiological Hazard Indices

a. *Absorbed Dose Rate (nGy/h)*

The range of results from the review was 22–185 nGy/h in contrast to the global reference (UNSCEAR), which is 59 nGy/h; Values higher than 59 nGy/h annual Effective Dose (mSv/yr) were reported in 38% of the studies.

The reference limit is 0.07 mSv/yr (outdoor), and the range of the reviewed work is between 0.03 and 1.12 mSv/yr. 44% of the reviewed work exceeded global outdoor values.

b. *Radium Equivalent Activity (Raeq)*

The safety limit is 370 Bq/kg, and the range of Raeq values in the reviewed work is between 90 and 800 Bq/kg. of these, 31% exceeded recommended limits.

c. *Externa Hazard Index (H_{ex})*

The safety limit is 1, and the range of values for the Externa Hazard Index (H_{ex}) in the reviewed work is between 0.20 and 2.17. Of the reviewed works, 28% exceeded safe limits.

d. *Excess Lifetime Cancer Risk (ELCR)*

The reviewed work's Excess Lifetime Cancer Risk (ELCR) value ranges from 0.2×10^{-3} to 2.8×10^{-3}, with a safety limit of 0.29×10^{-3}. The benchmark risk level was exceeded in 56% of the reviewed work.

3.7 Health Implications

3.7.1 Cancer Risk

a) Increased lifetime cancer risk is indicated by elevated ELCR values in populations exposed to radon, drinking water, and soils.
b) Residents of homes with inadequate ventilation had a significantly higher risk of lung cancer in radon studies.

3.7.2 Organ Dose Estimates

Studies using dose modelling showed:

a) increased kidney exposure to uranium in drinking water,
b) Radon inhalation-related lung doses,
c) ^{131}I thyroid doses in areas where industrial or medical releases have occurred.

3.7.3. Vulnerable Populations Identified

a) Children who reside in areas with high background radiation levels
b) Workers in quarries and mines
c) Groundwater with elevated ^{238}U or ^{226}Ra used by rural populations
d) People who live in radon-prone homes
e) Farmers exposed by soil-to-plant transmission

IV. DISCUSSION

Environmental radioactivity levels in various environmental media were measured in this systematic review, along with any possible health effects. The results consistently demonstrate that while background radiation levels differ geographically, many areas report values above global recommended limits, especially those with mining, oil and gas operations, industrial activity, or notable geological anomalies. Radionuclides like ^{226}Ra, ^{232}Th, ^{40}K, and radon gas were frequently found in elevated concentrations, underscoring the need for better environmental monitoring and regulatory controls. Across the reviewed studies, soil radioactivity levels showed substantial heterogeneity. Areas located near mining sites, granite-rich geology, or regions with Naturally Occurring Radioactive Materials (NORM) consistently recorded higher absorbed dose rates compared with agricultural or undisturbed rural lands. This is consistent with earlier worldwide analyses showing that increased geological formation and human extraction methods can increase the mobilisation of radionuclides. Increased terrestrial gamma dose rates were frequently correlated with higher radionuclide concentrations in soil, indicating that soil is the main source of external radiation exposure for many communities.

Measurements of gamma radiation both indoors and outdoors showed considerable variation. Radiation indices tended to be higher in densely populated urban areas, places with inadequate building ventilation, and homes using locally sourced building materials with high radionuclide content. Studies relating extended exposure to elevated gamma dose levels to higher risks of cancer, cataracts, and other radiation-related diseases demonstrate the health significance of these findings. Many of the reviewed studies exceeded the recommended limit of 1 mSv/year for public exposure, particularly in areas with active mineral extraction, oil exploration, or widespread use of NORM-contaminated products, even though the majority reported annual effective doses within this range.

Groundwater, boreholes, and surface water were among the water sources that showed varying but occasionally high levels of radon and other radionuclides. Because drinking and using radon-rich water at home can increase the risk of internal dose and inhalation, studies demonstrating radon levels above recommended limits are concerning. The WHO and UNSCEAR findings that radon is the second most common cause of lung cancer after smoking were supported by the strong correlation between high radon concentrations in small, poorly ventilated homes and the risk of lung cancer. Increased inhalation doses were also caused by airborne radionuclides, particularly in areas close to petroleum-producing regions, cement plants, and quarry sites. Particulate-bound radionuclides have the ability to enter the respiratory system and build up in tissues, which may result in long-term health consequences such as cancer and pulmonary disorders. According to the review, there is a disproportionate risk of radiation exposure for occupational groups such as miners, quarry workers, and oil and gas employees when compared to the general population.

In high-exposure communities, the health consequences reported in various studies range from minor radiation risks to markedly elevated lifetime cancer risks. Direct comparisons are difficult due to differences in methodology, even though many studies used standard indices like the radium equivalent activity, hazard indices, and annual effective dose. Moreover, the lack of long-term epidemiological data in a number of studies limited the capacity to make conclusions about causal health. However, persistent elevated exposure indicators in high-risk settings point to the necessity of strict regulation, increased public awareness, and preventative actions.

The findings emphasize several key public health concerns:

1. Exposure Flashpoints: High levels of radioactivity are regularly found in mining, oil and gas facilities, and industrial areas.
2. Monitoring Requirement: To identify patterns and carry out safety measures, many areas need ongoing monitoring.
3. Public Health Hazard: Long-term exposure to even slightly higher doses may raise the risk of genetic damage and cancer.
4. Monitoring Gaps: Persistent exposure risks are increased when international radiation safety regulations are not enforced.

The review emphasises the significance of conducting community health surveillance in high-risk areas, bolstering regulatory oversight, and incorporating radiological assessments into environmental management plans. To more accurately estimate the health costs associated with radiation exposure and inform policy choices, more thorough epidemiological and longitudinal research is required. In the end, the data indicates that localised hotspots present real risks to public health that need to be addressed right away, even though environmental radioactivity levels in many areas are still within global safety limits.

V. CONCLUSION AND RECOMMENDATIONS

This systematic review offers a thorough assessment of environmental radioactivity levels in a variety of environmental media, including soil, water, air, indoor and outdoor settings, and evaluates the potential health effects. The results show that while background radiation levels in many regions are within international safety limits, some localised areas—especially those impacted by mining, quarrying, oil and gas operations, and naturally enriched geological formations—exceed recommended thresholds.

Increases in the absorbed dose rate, annual effective dose, and radiological hazard indices were frequently associated with elevated concentrations of radionuclides, including ^{226}Ra, ^{232}Th, ^{40}K, and radon. Increased lifetime cancer risks, respiratory issues, and other radiation-related effects are among the possible long-term health risks associated with these elevated exposure levels. Exposure risks were found to be disproportionately higher for vulnerable groups, including miners, quarry workers, and residents of homes with poor ventilation or high levels of radon.

The overall evidence shows that environmental radioactivity is still a significant public health concern that needs ongoing monitoring and regulatory oversight, despite methodological differences between studies. Implementing community-level awareness and mitigation strategies, enforcing adherence to international safety standards, and strengthening national radiation protection policies are all essential steps in lowering exposure risks. Planning for public health, environmental protection, and well-informed decision-making all depend on environmental radioactivity assessment. To more accurately measure health impacts and direct successful intervention strategies, more research is required, especially long-term epidemiological studies and ongoing environmental monitoring.

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