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An Overview of the Measurements of Primordial Radionuclide Concentrations in Soil and Radon Concentrations in Water Samples

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Radiation physics has significantly improved health science, revealing the impact of radioactive materials on humans. These contaminants damage soil and water, leading to health issues like stomach, lung, and leukemia. Radon, a byproduct, poses a significant threat to human health, particularly lung and stomach cancer. Identifying radioactive soil sites is crucial for assessing health concerns among agriculture and construction workers, as natural radionuclides can cause radiological damage. Monitoring these materials can help to assess exposure-related health risks. The goal of this review is to overview and consolidate the works executed between 2007 and 2024 in several countries, including Romania, Turkey, Jamaica, Nigeria, Jordan, Serbia, Spain, Saudi

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Arabia, Armenia, China, Brazil, Sudan, India, Syria, Iraq, Tunisia, Pakistan, Qatar, and Yemen. Articles commonly employ (HPGe), RAD-7, and CR-39 techniques to measure primordial radionuclides and radon levels. The latest analysis revealed that Nigeria has a significantly higher average radon measurement of 36.1 Bq/L in its drinking water, above the global benchmark threshold of 11.1 Bq/L. The article also, reviews primordial radionuclides in soil research articles in 10 nations. Serbia has the highest 226Ra and 40K soil Bq/kg, which exceeded standards of 32, and 420 Bq/kg of 226Ra and 40K, respectively, while Turkey and Jordan have the lowest values. India has the highest 232Th, and health and safety concerns are addressed. This review work shows that naturally occurring background radiation from radionuclides in soil and radon concentrations in water samples typically has a substantial health impact, posing a major radiation risk to the residents of certain areas. Consequently, our analysis showed that residents should avoid some areas due to radiological hazards. Finally, this review evaluates and elucidates the several factors that influence the elevated and reduced levels of radon in consumption water and the primordial radionuclides activity in soil samples in each country.

Keywords: Drinking water; soil; radon; radioactivity; Gamm ray spectroscopy; RAD-7.

1. INTRODUCTION

Radiation can be delivered externally or internally to humans, causing health hazards. External exposure, such as near X-ray equipment or nuclear power plants, can damage skin. Internal exposure, resulting from inhalation, consumption, or wound absorption, can damage organs, tissues, and cells [1,2]. Radiation's effects depend on human exposure, measured by dosimetry. Factors like total dose, cell type, age, and health affect the body's effects. Nuclear radiation causes ionization, causing cell damage and potential long-term symptoms like radiation sickness, cataracts, or cancer [3]. Radiation-induced cellular changes can cause harmful tissue reactions and stochastic consequences [4,5-8]. Radioactive nuclides, including the natural series ^{238}U and ^{232}Th, as well as the non-series radionuclides ^{40}K, are the primary sources of background radiation and human exposure. They have been present on Earth since their inception and are widely distributed [9,10].

The International Atomic Energy Agency (IAEA) has identified uranium, thorium, radium, and radon as the predominant natural radionuclide component found in soil and water. The presence of radioactive materials can pose significant risks to human health when they exceed the established normal range [11]. Radiation infiltrates various organ tissues via ingestion, inhalation, and compromised skin. It has the potential to induce several forms of cancer [12]. Typically, soil, water, and several other substances contain trace amounts of naturally occurring radioactive elements like ^{238}U and ^{232}Th. These arise naturally as a result of the parent rock during the process of soil formation [13].

Human and environmental health depend on soil. Soil influences human and environmental health, either positively or negatively [14]. For billions of years, radionuclides have been the main source of radiation. Much of the of the radioactivity comes from soil deposition. Natural radionuclides in soil depend on geology. Soil radioactivity affects human and environmental health. Air, soil, water, and ecological system radionuclides result from radioactivity. Genetic change, lung cancer, and other health disorders show the impact [15]. Radionuclides in soil can harm water, soil, biodiversity, disrupt microbes, reduce plant development, and affect water quality and crop yield due to leakage into groundwater [16].

Water is essential to our ecosystem, but pollution, man-made activity, and an excess of radioactive materials can degrade it. Water quality must be assessed routinely using accurate scientific equipment [17]. Radioactive sources' total and individual radiation doses must be calculated to assess their health effects. These dosage calculations use water and soil radioactivity [13]. Radionuclide concentrations vary by region on Earth, with natural elements exposing only ten percent of the communal yearly dosage to the hominoid physique. Radioactivity is present in all Earth materials, and exposure can cause cancer in humans and animals [18].

Biomedical technology protects living things with biocompatible materials, yet pollution and radiation pose problems. Clean water is needed for drinking, industrial, and technological purposes. Radon and radium in the air, soil, and water can harm the body through inhalation and ingestion. Indoor and outdoor radiation levels are dangerous [19]. Radon in drinking water is limited by the EPA to 11 Bq/L. Uranium decays from alpha-producing ^{222}Rn to stable ^{210}Pb via ^{218}Po ($t_{1/2}$ = 3.11m) [20]. Half of annual radiation doses are radon [21,22]. The WHO says radon causes second-most lung and stomach cancer behind cigarettes. This study examines drinking water radon testing methods, data, and analysis for future research and planning. Radon indoors reduces shower water usage risk. Life requires water; hence radon and other radionuclides must be restricted. The European Commission recommends 1000Bq/L radon and alternative treatment above it. For sophisticated ^{222}Rn harm in ingestion water, the EPA recommends 11.1 Bq per L [23]. Radon from subsurface water can be released through soil. Geology can also cause it spontaneously. The WHO and IAEA can identify the initial radiation source and assess its public health impacts because radon is dangerous and must be controlled. Radon can be breathed [24]. Ingestion and inhalation of radon can injure humans [25]. Over 21,000 Americans die from lung cancer each year, twice as many as from vehicle accidents [26]. Most of the danger lies in the stomach. Radon in drinking water kills 129 people annually [27]. High exposure may impair the body's DNA repair systems, causing serious health issues and possibly cancer. Therefore, understanding how radiation damages and repairs DNA is critical to developing more effective methods and therapies to reduce radiation-induced toxicities and prevent cancer. Primordial radionuclides, including ^{226}Ra, ^{232}Th, and ^{40}K, in sediment, soil, water, and rock contribute to natural background radiation [28]. This radiation causes radioactivity levels to vary worldwide. Radioactivity is determined by geography and topography. Because of low exposure levels, background radiation in our surroundings is rarely a health hazard. The health risks of radionuclides vary depending on their type and duration. Radiation levels vary by location and decision. However, prolonged radiation exposure may harm your health [25].

This review used multiple datasets from 2007–2024 research projects in different nations. Each study measured drinking water radon and radioactivity concentrations in soil samples at different locations. The review relies on gamma spectroscopy to quantify radionuclide concentrations in soil and water. This entails the use of NaI (Tl) and HPGe detectors, as well as a CR-39 detector for passive detection and a RAD7 detector for active detection. Additionally, the investigations looked into the causes of radon in water and primordial radionuclides in soil. It also emphasizes the importance of adhering to radiation safety rules to reduce radionuclide hazards, consumer contamination, and transfer.

2. MEASUREMENT SYSTEMS

As part of the literature review, thallium-doped sodium iodide, the trace detector (CR-39), high-purity germanium, and the solid-state detector (RAD7) were used to measure the number of radionuclides. Thallium-doped sodium iodide (NaI (Tl)) detectors are often used as scintillation detectors in several fields, such as natural radiation tracking, gamma spectroscopy, nuclear medicine, environmental monitoring, and national safety concerns. These detectors are highly efficient at detecting gamma rays [29] We will delve deeper into these detection systems in the upcoming sections.

2.1 Gamma Ray Spectroscopy

Gamma spectrographic analysis is a highly prevalent scheme employed for the quantification and examination of radioactivity in various environmental materials. The present investigation provides evidence that prior studies have employed conventional material methods to ascertain the concentration of natural radionuclides in household dinnerware [30-32]. The widely employed technique is referred to as high-purity germanium (HPGe) (Fig. 1). Gamma spectrometers use (HPGe) detectors because of their great resolution, despite their poor count efficiencies that might change depending on crystal volume.

The vertical closed-end coaxial germanium detector from PGT (Princeton Gamma Tec-PGT Company, USA) is highly pure. The product has these features: The crystal is 7.06 cm wide and 0.707 cm long. The FWHM resolution of ^{57}Co is 0.0011 MeV at 0.122 MeV and 0.00197 MeV for ^{60}Co at 1.332 MeV. Energy is 73.8% efficient. The ratio of the peak to the Compton number at 1332 keV is 75 per one. The energy range of P-type HPGe coaxial detectors spans from 40 keV to 10 mV, making them well-suited for a diverse range of applications.

During operation, the liquid nitrogen auto-fill system cools the detector. Among the components of this system are a liquid nitrogen level control device, a liquid nitrogen storage dewar with a capacity of fifty liters, and a dewar with a capacity of thirty liters. The primary objective of this system is to reduce leakage current and thermal noise [33].

Also, the NaI (Tl) technique is another gamma-ray spectrometer extensively utilized as an inorganic scintillation substance. It has a high degree of working adaptability. The photomultiplier tube (PMT) links to the crystal. The pulses created are extremely small and cannot be detected until they are processed by electronic filters, such as a preamplifier, amplifier, and multichannel analyzer. These filters amplify and transform the electrical pulse into a digital signal that can be recognized. NaI (Tl) is an economical substance that functions at normal room temperature and provides outstanding luminosity. It is accessible in many different forms and dimensions. The crystal displays unfavorable attributes such as fragility, susceptibility to temperature variations, moisture absorption, and insufficient energy resolution [34]. Fig. 2 illustrates the primary elements of the NaI (Tl) gamma-ray spectrometry apparatus.

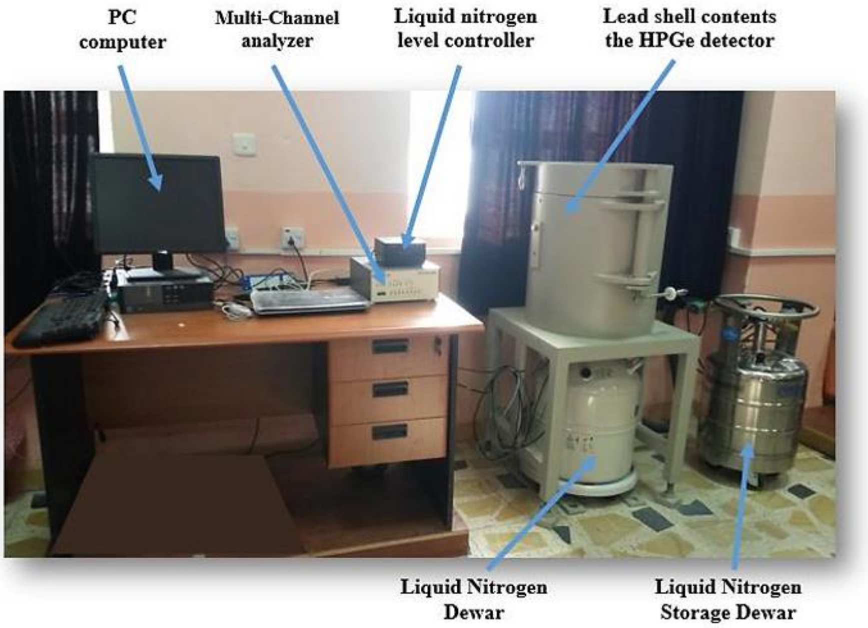

Fig. 1. Gamma-ray spectrometry system used to measure the activity concentration of radioactive nuclides

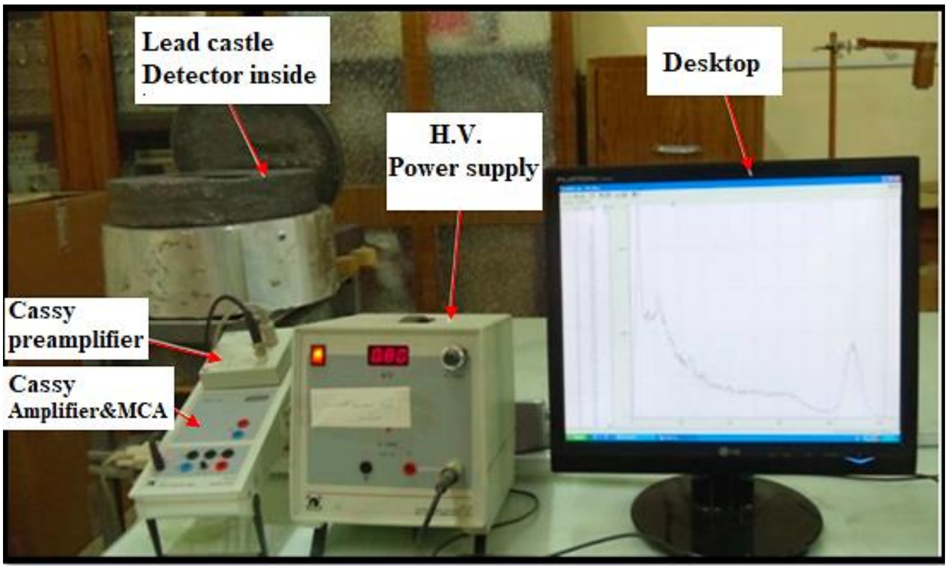

Fig. 2. The components of NaI (Tl) gamma-ray spectrometry system

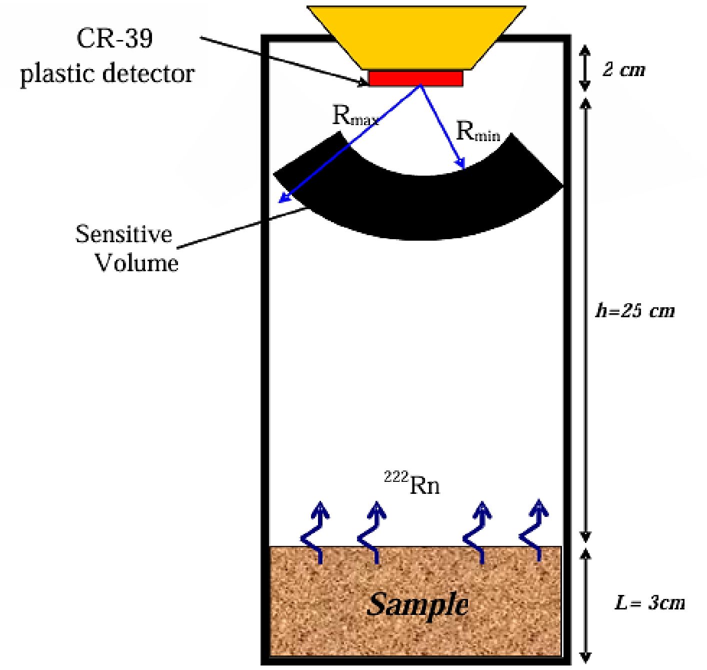

Fig. 3. Experimental setup for the measuring of radon exhalation [35]

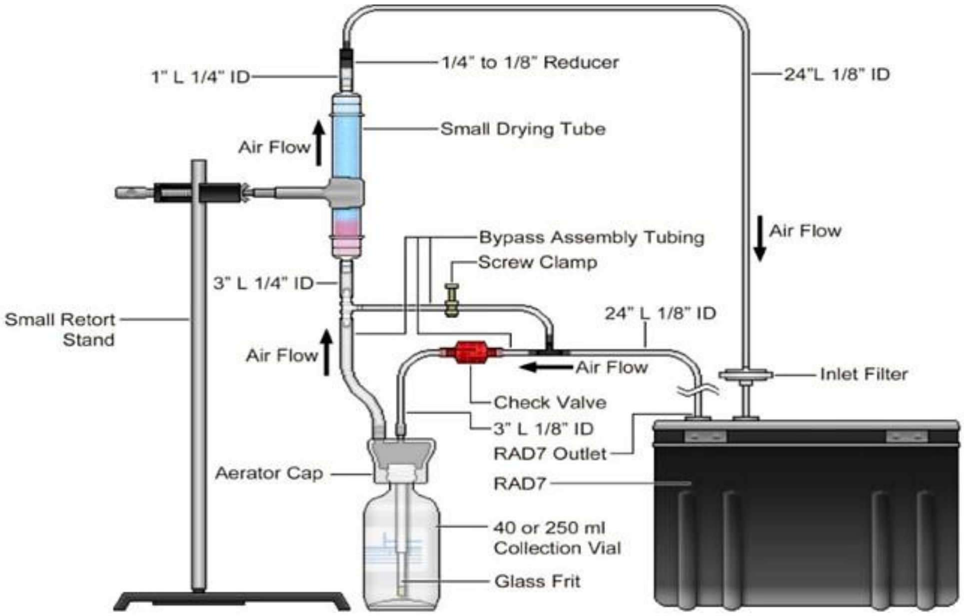

Fig. 4. RAD-7 experimental setup to measure the concentration of radon activity [36]

Nuclear detection equipment's accuracy in detecting natural radioactivity relies on various parameters, including reagents, detector type, efficiency, and radiation energy. Radiation. Understanding these aspects and employing appropriate calibration and standardization methods are crucial for accurate measurements in environmental monitoring and radiation protection. HPGe detectors are sensitive [29]. Calibration is essential for measuring detector efficiency using energy information at various energies. Gamma spectrometers calibrate their energy gain efficacy using typical radioactive sources such as ^{60}C0, ^{133}Ba, ^{60}Co, ^{152}Eu, ^{226}Ra, ^{137}Cs, and ^{22}Na, or at least three energy peaks. This calibration technique ensures precise power readings. To determine emitter energy, we will compare measured and known energies [37,38].

2.2 CR-39 as a Passive Methos

The present investigation showcased the utilization of conventional material techniques in prior research to ascertain the radon levels in meals and cocking dishes [39,35]. The CR-39-type Solid-State Nuclear Track Detectors (SSNTDs) are commonly used as a passive approach. The CR-39 plastic detector is classified as an organic detector and is specifically designed as a polyester carbonate multi-carbon detector. The polymer is commercially known as CR-39; however, it is more frequently referred to as SSNTD [40]. Solid state nuclear track detectors monitor isotope concentration and spatial arrangement by detecting heavy nuclear particle emission. They detect alpha particles within the radon nuclide energy range, causing damage along their trajectory. When radon decays, alpha particles collide with detector surfaces, generating a latent track. This leads to scissions or fragmented polymer chains, and localized melting, disrupting the chain and creating novel endpoints [41]. Fig. 3 shows the experimental setup occupied with CR-39 detector of measuring radon gas within soil samples.

2.3 Rad 7 Detector as an Active Method

The RAD 7 detector, as depicted in Fig. 4, is a widely employed technique for measuring radon concentration. Fig. 1 illustrates the schematic diagram of the RAD7 detector. The device possesses an enhanced detector capable of detecting radon, accompanied by a rapid data recording mechanism that occurs at 30-minute intervals. Additionally, RAD7 can be conducted in both laboratory and field settings because of its ease of use and superior design quality in measurement. We attribute this to its ability to organize using superiority performances and its high correctness in assessing ^{222}Rn and isolates within a short timeframe [19,42].

Researchers employ RAD7 in laboratory, research area, and home settings, as it yields more dependable data in comparison to alternative detectors.

The RAD-7 equipment is manufactured by Durriadge Business, Inc. It employs a semiconducting material to convert alpha-particle directly into an electronic indication. This process accurately detects any alpha particles and isotopes (^{218}Po, ^{214}Po) that are generated by the radiation. Additionally, it distinguishes between seniors radon, recent radon, and radon that originates afterward automatic sound disruptions [19,42]. The RAD7 device uses a conductor and semiconductor to separate radon from water, a radioactive nuclide with a half-life of 3.83 days. It detects radon concentrations in drinking water, which is a critical concern for public health [13]. Radon levels can vary significantly, making some countries unfit for drinking water. To reduce radon exposure, awareness and action are crucial. Radon measurement methods vary but must meet WHO standards. E-DWD suggests trustworthy methods based on standards. Accurate samples must be collected from various locations and methods, considering the volume of the water [24]. CR-39 and RAD7 detectors are used for radiation detection and dosimetry involving high-mass, electrically charged particles. These particles cause ionization in the medium they traverse, allowing for examination after exposure. Chemical etching is a widely used method to dissolve materials along ionization routes, using potassium or sodium hydroxide solutions [43]. The size and shape of a track provide information on a particle's mass, charge, energy, and trajectory. Solid-state nuclear track detectors (SSNTDs) offer unique advantages, including comprehensive particle data, improved track longevity, and a simple, economical design. Optimizing these parameters is crucial for precise measurements and unambiguous trajectories [44].

3. LITERATURE REVIEW

3.1 Radon Concentration in Drinking Water

Table 1 presents compiled data on ^{222}Rn concentrations from multiple research studies conducted in different nations. The ^{222}Rn gas is considered a significant contributor to lung cancer, second only to smoking. Table 1 records and organizes the ^{222}Rn activity content in drinking water from various countries worldwide between 2008 and 2024.

Ismail and Haji conducted a study in Kurdistan in 2008, measuring ^{222}Rn activity in ingestion aquatic in the Erbil province and its districts. The results showed varied levels, with the highest concentration in the Hugran region at 9.61 Bq/L and the lowest in Haji Omaran city at 2.01 Bq/L. The study also assessed the impact of radon concentration on indoor radon levels. The study found no radon issues compared to EPA limit, ensuring the safety of the drinking water. Located in Romania in 2012. Nita et al. evaluated ^{222}Rn in northern and western ingestion aquatic. The investigation used well, spring, tap, and surface water. Measurements were done with the LUK-VR. Radon was highest in spring water (68.9 Bq/L) and lowest in surface water (0.9 Bq/L). The mean activity level was 10.65 Bq/L, below the recommended range [23]. From China in the year 2014. Wu et al. conducted a study in Beijing City to evaluate the levels of radon in surface and ground drinking water. They employed a straightforward technique that involved utilizing an air monitor to assess radon. The measured ^{222}Rn levels vary from 4.63 to 5.87 Bq/L, which is below the recommended limit of 11 Bq/L set by the EPA for drinking water. ^{222}Rn levels in 38 drinking water samples in Shimoga district were quantified [45].

Erdogan et al in 2014 used alpha guard detectors to measure the radon content in 16 well water samples taken from city center of Konya in Turkey. The study found that radon levels in water are directly affected by seasons and vary little with depth. 11 out of 16 well water samples had concentrations below the EPA's standard, but all were significantly below the WHO standard [46]. Also, Turhan et al. in 2023 found radon level in 39 bottled water samples with an average 0.0157 Bq/L below the suggested limit [47].

Rangaswamy et al. (2015) used the emanometry method in India. Radon activity varied from 3.1 to 38.5, with an average of 13.6 Bq/L, slightly greater than the EPA action level of 11 Bq/L. A RAD 7 detector was used to analyze aquatic sample from Brazil [48]. The results indicate that all bottled drinking water is safe, except for AQUA VIVA sample, which had a ^{222}Rn level of 1463 Bq/L, exceeding the acceptable range. The high content was linked to the volcanic water supply. Shweikani and Raja [49] assessed ^{222}Rn levels in 12 drinking water categories based on their hometowns and Syrian origins. The researchers used gas extraction to take the measurements. Results indicate radon concentrations ranged from 2800 to 15300 mBq/L in houses and 7500 to 284000 mBq/L in water sources. Observations reveal a major difference between residential water and its sources. The study found that drinking water in households and water sources met international standards. We measured the radon concentration. Ahmed, Saridan, and Jafir. The year is 2016. 164 Darbandikhan Lake drinking water samples from Northeastern Iraq's Kurdistan Region were examined for seasonal ^{222}Rn changes. The measurements used an electronic RAD7 detector. Mean radon concentration throughout four seasons was 1.999 Bq/L. All samples were below the average criterion, except for two places that exceeded the safety level.

Table 1. Quantified levels of radon in drinking water between the years 2008 and 2024

No	Location	Radon concentration (Bq/L)	Year	References
1	Iraq/Erbil	4.693	2008	[50]
2	Romania	11.4	2013	[23]
3	Turkey	2.29-27.25	2014	[46]
4	China	5.87 - 4.63	2014	[45]
5	Brazil	15.4	2014	[48]
6	Syria	10.8 ± 2.5	2015	[49]
7	Iraq	8.158	2016	[51]
8	Yemen	3.306	2016	[52]
9	Jamaica	18 ± 2	2017	[24]
10	India	13.6	2020	[53]
11	Nigeria	36.1	2020	[54]
12	Iran	0.92 – 17.12	2020	[55]
13	Iraq/ Kurdistan	0.15–7.48	2023	[56]
14	India	0.26 ± 0.02	2024	[57]
15	Qatar	20.6	2023	[58]
16	Turkey	0.0157	2023	[47]
17	Pakistan	12	2024	[59]
18	Standard limit	11.1	2004	[60]

Table 2. Arranges 2007–2023 soil samples from various nations by natural radio activity

No	Location	Activity concentrations (Bq/Kg)			Year	References
		^{226}Ra	^{232}Th	^{40}K		
1	Turkey	20.8	24.95	298.6	2007	[61]
2	Jordan	42.5	26.7	291.1	2009	[62]
3	Iran	38.8	43.4	555.1	2013	[63]
4	Serbia	249	69	960	2014	[64]
5	Spain	35	38	448	2014	[65]
6	Iraq/ Nineveh	33.55	21.54	326.74	2015	[66]
7	Iraq/Erbil	1.9–38.2	4.5–52.4	12.6–388.6	2019	[12]
8	Saudi Arbia	23.2	7.73	278	2019	[4]
9	Iraq/ Basrah	35.5	20.3	337	2018	[67]
10	Armenia	45.69	37.25	294.35	2021	[68]
11	Romania	197.21	16.21	543.21	2022	[69]
12	India	31	188	471	2023	[70]
13	Iraq/Kirkuk	34.4-44.1	12.5-28.1	206.5-332.2	2024	[71]
14	Tunisia	27	13	264	2024	[72]
15	Nigeria	61.55	72.65	1134.9	2024	[73]
16	Worldwide	32	45	420	2008	[11]

Abdurabu [52] assessed the levels of ^{222}Rn activity and the associated well-being danger in underneath aquatic tasters collected in, Yamen. The RAD7 detector conducted the measurements. The measured levels of ^{222}Rn diverse from a tiniest of 1±0.2 Bq/L to a extreme of 896±0.8 Bq/L. 57% of groundwater samples violated USEPA limits. In 2017, Smith and Voutchkov measured ^{222}Rn in 22 Jamaican consumption aquatic holes using RAD-7 equipment. Detective ^{222}Rn activity ranged from 11.1 ± 1 to 49.932 Bq/L, averaging 18.2 ± 1 Bq/L. Values exceeded recommendations. Alluvium, white limestone, and geographical changes caused significant data fluctuations. In a study conducted in Nigeria in 2019, Bello et al. used a scintillation counter to quantify the annual effective dosage resulting from ^{222}Rn in eight superficial ingestion aquatic tasters obtained from gilded withdrawal areas. The mean recorded concentration of ^{222}Rn was 18000 mBq/L, which exceeds the established security threshold. Shamsaddini et al. [55] conducted a study in Iran to estimate the ^{222}Rn content in fifty-one examples of intake aquatic. For this purpose, they used a RAD7 detector. The concentration of ^{222}Rn varied between a low of 920 mBq/L and a extreme of 17120 mBq/L. Changes in the geographical features of the area surrounding the structure can explain these oscillations in the data.

Yashaswini et al. conducted the study in 2020. Yashaswini et al. conducted measurements of the ^{222}Rn content in thirty-six distinct places of underneath and consumption aquatic in India. They employed the performance of emanometry. The highest observed radon level was 38500 mBq/L, while the lowest was 1100 mBq/L. The geometric average of the radon activity was 8500 mBq/L, a figure lesser than the reported accepted level.

In 2023, Abdullah et al. conducted a study to achieve this. They collected 25 spring water samples from Erbil and Iraqi Kurdistan. Annual efficiency: Erbil residents swallowed spring water samples to measure radon gas intake. The RAD7 detector is used. Doli Akoyan and Gale Faqeyan had the uppermost ^{222}Rn level. This measurement was near the proposed contamination threshold of 11.1 Bq/L, unlike all other radon activity levels below it. In 2024, Pervin et al. found ^{222}Rn activity in 20 Dhaka-branded bottled waters using RAD7 and HPGe detectors. The results showed lower concentrations compared to global studies and the US-EPA limit. Drinking water containing ^{222}Rn had an annual effective dose below WHO and International Commission on Radiological Protection criteria. In 2023, Manawi et al. measured ^{222}Rn concentration 48 ground water samples from different locations throughout the Qatar using RAD-7. Radon levels ranged from 2.7 to 60.7 Bq/L, with an average value of 20.6 Bq/L, surpassing the US EPA's maximum contamination threshold of 11 Bq/L. Approximately 65% of the analyzed samples exceeded the maximum contaminant level (MCL) criteria set by the United States Environmental Protection Agency (EPA). In 2024, Shah et al. conducted a study in Pakistan where they measured the radon activity. The 30 water samples obtained for drinking purposes showed a variation in ^{222}Rn levels, with the minimum, maximum, and mean values being 2.6, 23.0, and 12.0 Bq/L, respectively [59].

3.2 Concentration of Primordial Radionuclides in Soil from 2007 to 2023

Table 2 shows primordial radionuclide concentrations from several research studies in different countries with varied soil sources.

Bozkurt et al. conducted the study in Turkey in 2007. Bozkurt et al. collected 45 soil samples to measure the levels of radioactive isotopes. The measurements of the study region were conducted using gamma radiation spectrographic analysis. The average activities of the natural primordial radioactive elements ^{226}Ra, ^{232}Th, and ^{40}K were determined to be 20.8, 24.95, and 298.6, respectively. The soil radioactivity concentrations obtained in this investigation illustration that the radiation level is in the accepted range of ambient radiation.

In 2013, Asgharizadeh et al. conducted a high-resolution gamma-spectrometric study on Tehran's surface soil samples, evaluating natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K). The results showed radon and daughter product exposure, with average concentrations matching several nations' levels. The study also found that outdoor air-absorbed dose rates were unsafe, with effective exposure rates ranging from 0.06 to 0.11 mSv per year. Tehran residential areas have normal background radiation levels.

In 2014, Moreno et al. studied radon levels in volcanic materials in Spain's volcanic region. They found that quaternary sedimentary deposits have the highest average concentrations of ^{40}K, ^{226}Ra, and ^{232}Th (448.70 Bq/Kg, 35.5 Bq/Kg, and 38.5 Bq/Kg, respectively). The study also measured terrestrial radiation-absorbed dose rates in the air to understand the area's radiological properties. The results clearly showed a link with the make-up of geological formations, with the highest rate of gamma radiation being absorbed on land being found over Quaternary sedimentary deposits.

In 2009, Al-Hamarneh and Awadallah conducted a study in Jordan to assess primordial activity levels in superficial soil tasters from various geological formations in urban areas of the northern highlands. The study, surveying 70% of the population, revealed that limestone used for construction materials primarily formed the soils. We found the average concentrations of radionuclides ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K to be 42.5, 49.9, 26.7, and 291.1 Bq/Kg, indicating secular equilibrium. The study also measured levels of uranium, thorium, and potassium in the geological characteristics of the research sites.

In 2015, Najam and Younis conducted a study on the levels of natural radioactivity in the soil of Mosul utilizing a scintillation method. The measured concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{226}Ra were within the range of 21.25-58.13 Bq/kg (with an average of 41.24 Bq/kg), 11.22-31.63 Bq/kg, 206-509.56 Bq/kg and 17.02-40.98 Bq/kg, respectively. The information was determined to be below the globally acceptable standards.

In 2019, Hussein utilized an HPGe detector to quantify the levels of primordial radionuclide content in soil examples collected from Erbil province. The levels of the activities of ^{232}Th, ^{40}K, and ^{226}Ra varied between 4500 mBq/kg and 52400 mBq/kg, 12600 mBq/kg and 388600 mBq/kg, and 1600 mBq/kg and 38200 mBq/kg, respectively. Upon comparing data with various countries, it was determined that the level of natural radioactivity is below the internationally suggested threshold. However, the natural radioactivity does not indicate any range of health risks.

In 2018, Ahmed et al. conducted a study on the levels of primordial radionuclide content in soil examples taken from nadirs ranging from zero to sixty cm in 2 boroughs of Basra. They used an HPGe indicator for their measurements. They measured the concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{226}Ra in the Abu Al Khasib district to be 43600 mBq/kg, 19400 mBq/kg, 321800 mBq/kg, and 58440 mBq/kg, respectively. The average concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{226}Ra in the Ad Dayer district were determined to be 35500, 20300, 337000, and 45710 mBq/kg, respectively. The soil's concentrations were discovered to fall within the typical global level.

Pemmaraju et al. conducted a study in 2023 in India, measuring the levels of naturally occurring radioactive elements in soil samples collected between 2013 and 2018 near the Bhabha Atomic Research Centre (BARC) in Visakhapatnam, Andhra Pradesh. The study used high-purity germanium gamma-ray spectrometry to analyze the soil activity and annual effective dose (AED) resulting from extraterrestrial radiation. There were 29.8 ± 8 Bq/kg of activity in 238U, 31.81 ± 1 Bq/kg of activity in ^{226}Ra, 188.82 ± 2 Bq/kg of activity in ^{232}Th, and 471.10 ± 10 Bq/kg of activity in ^{40}K. The yearly effective dosage (AED) ensuing from extraterrestrial radiation in the examined region ranged from 0.37 to 2.5 mSv/y, with an average of 0.9 mSv/y. The average external exposure index was close to the safe criteria limit of one.

In 2021, Belyaeva et al. conducted a study in Yerevan, Armenia, analyzing the spatial distribution of (NORMs) and manmade ^{137}Cs. They used soil samples from Yerevan's multifunctional geochemical survey and a gamma spectrometry device to determine the activity concentrations in urban soils. The study found that soil-forming rocks significantly influence the distribution of NOR elements in urban soils. The study concluded that Yerevan's urban soils are radiologically safe, but igneous rock-produced soils are the primary source of exposure.

In 2024, Amoduin et al. used a sodium iodide detector in Nigeria. They investigated soil samples' primordial radionuclide activity. The findings indicate that the average activity concentration values for ^{226}Ra, ^{232}Th, and ^{40}K were 61.55 ± 3.71, 72.65 ± 4.45, and 1134.99 ± 38.12 Bqkg^{-1}, respectively. These values exceed the acceptable limits set by international standards [73]. Shaker et al. [71] conducted a study in Iraq to investigate natural radioactivity in soil samples using an HPGe detector. The measured activity concentrations (in Bq kg^{-1}) of ^{226}Ra, ^{232}Th, and ^{40}K ranged from 23.4 ± 2.8 to 44.1 ± 6.1, from 12.5 ± 0.9 to 28.1 ± 4.3, and from 206.5 ± 12.8 to 332.2 ± 7.2, respectively. The findings have been compared to the global mean values and found to be below the recommended thresholds [71]. In 2024, Machraoui et al. conducted a study in Tunisia to examine the levels of natural radioactivity in soil samples. The researchers used an HPGe detector to assess the concentrations of primordial radionuclides using gamma spectrometry. The average values of ^{40}K, ^{226}Ra, and ^{232}Th concentrations were 264, 27, and 13 Bq kg^{-1}, respectively. The findings were below the global average values [72].

4. DISCUSSION

This review used multiple 2007–2024 research datasets from different nations. At different locations, each study assessed drinking water radon and primordial radionuclides in soil samples. The measures have a crucial impact on humanoid well-being, as soil and water are essential for human survival. Excessive levels of radionuclide materials in the human body can lead to the development of many types of cancer. Scholars from various locales and nations have reported data over the past decade. Life needs water. Water sustains life; hence, life without it is meaningless. Water contaminated with radioactive nuclides can cause several cancers. Radon in drinking water above 11.1 Bq/L can harm health. Not all drinking water is radon-contaminated. However, surface water from lakes, rivers, or underground sources may contain radon before reaching your home. A civilization that provides reliable and accessible drinkable water benefits individuals financially and time-wise. Having a reliable drinking water source ensures good health and reduces the need to search for clean water, eliminating personal dangers. Children who cannot attend formal school suffer long-term disadvantages and sometimes contribute to national poverty. Poorer countries are unaware of radioactivity in their drinking water, while developed countries regulate it. This study investigates radon concentration in drinking water research articles from 2008 to 2024 in a certain country. Radon concentrations fluctuate across the country due to geological structure and rock type. This study is critical for informing society about radionuclides in drinking water, particularly radon. It also discusses health dangers and precautions. Romania, Brazil, Iran, India, Jamaica, and Nigeria exceeded acceptable radon levels. The data is in Table 1. The ^{222}Rn level in China, Iraq, Syria, and India is under the recommended level. In Nigeria, the extreme mean radon content was 36100 mBq/L, which is greater than the EPA value due to abundant granitic stones and geological formations.

The ^{222}Rn is a notable gas because of its ability to decay and form offspring isotopes such as (^{218}PO) and (^{214}PO). However, it differs in its hazardous nature and severe impact on the human body. Apart from its primary function of causing cancer, radon carriages a noteworthy danger to humanoid well-being. Some individuals residing in the radioactive zone hold the belief that ^{222}Rn has significant impacts on the hominoid physique, particularly in the lungs, where it can be deadly and induce chronic interstitial fibrosis. Additionally, radon exposure can also lead to the development of malignant melanoma in the skin. Radon is a primary cause of cancer. The (IARC) avowed in 1989 that radon has the ability to cause cancer in humans. The World Health Organization (WHO) later validated this finding by classifying radon as a carcinogen. Within the United States, there is a lack of awareness about race, age, and education level. Furthermore, there is a notable deficiency in understanding radon, with many individuals lacking information about its impacts. Certain nations, especially those with high levels of development, cannot view the problem of drinking water contamination solely as a matter of international politics. Additional measures, such as reducing the population residing in radioactive areas and disseminating information to enhance awareness about radiation, are necessary because this is a matter of public concern. However, the most crucial approach is implementing a program to reduce radon levels. The Environmental Protection Agency (EPA) is the governing body responsible for monitoring and ensuring water quality. They are also responsible for addressing the drinking water problem. Additionally, the EPA aims to raise awareness among individuals and provide them with relevant information, as this issue directly affects the general public. Date-specific variations can occur when measuring data. Specifically, on cold days, the temperature tends to fall. This is because radon activity increases on cold days, typically resulting in the highest measurements in wells. New York State researchers surveyed 1000 people from 1995 to 1997. Many participants failed to reply 2 queries: "Have you heard about radon?" Various society reacted negatively, indicating radon ignorance. Without further knowledge, only 21% had heard about radon. A 2004 study raised awareness of radon, albeit with an inadequate understanding of its impacts. Some responders thought radon caused cancer, while others thought it caused headaches, a symptom of carbon monoxide poisoning. Thus, radon reduction requires a thorough understanding. We need research and thorough investigations to educate people and reduce the health risks associated with radon. All countries worry about radon, with variable exposure. You can't ignore radon.

This review also, evaluates the existence of primordial radioactive elements in soil research articles published between 2007 and 2024 in a specific country. Serbia has recorded the uppermost content of ^{226}Ra and ^{40}K in soil, measured in Bq/kg. On the other hand, Turkey and Jordan exhibit the lowest values of ^{226}Ra and ^{40}K, respectively. The soil in India had the highest concentration of ^{232}Th, whereas Saudi Arabia had the lowest recorded content. Natural radioactivity levels vary throughout the country due to differences in geological structure and rock composition. This work is crucial for enlightening people regarding the presence of radionuclides in soil. Additionally, it addresses the potential health hazards and necessary safety measures. Romania, Nigeria, Serbia, Iran, India, and Spain surpassed the global thresholds of 32, 45, and 420 Bq/kg for ^{226}Ra, ^{232}Th, and ^{40}K, respectively [11]. The data can be found in Table 2. The activity concentrations in other countries are lower than the suggested threshold. Serbia has recorded the highest average concentration of activities above the declared amount, mostly due to the presence of abundant granitic rocks and geological formations. Furthermore, the location in Serbia has verified that the area known as the former uranium mine 'Gabrovnica' exhibits heightened levels of natural radioactivity. Most of the adjacent houses are vacant in this abandoned region. Only a few residences see periodic use throughout the year. The study sheds light on ^{226}Ra, ^{232}Th, and ^{40}K values in soil samples. It compares global standards with actual facts to show parallels and differences. This study underlines the necessity to gather and analyze empirical data from several places to better understand regional radionuclide concentrations. The content is useful for improving global models and standardizing techniques. The data indicate that ^{226}Ra is more prevalent in the studied areas than globally. Compared to worldwide standards and empirical data, Serbia, Romania, and Nigeria have significant average concentration variations. ^{40}K concentrations vary widely compared to global levels and observed data. The geographical and geological characteristics of the research location, wind patterns, humidity levels, temperature variations, and the materials under investigation are the main factors affecting the results of the aforementioned prior investigations. Potassium has a greater specific activity than radium and thorium due to geological factors at past study locations. In some studies, due to muddy conditions and a lack of sedimentary or igneous rocks, thorium has greater specific activity than radium. The average radium and thoron concentrations in some countries were within UN Scientific Committee on the Effects of Atomic Radiation guidelines. Due to the research area's agricultural landscape and abundant water supplies, uranium activity or radon gas concentration may be low. In most samples, the study location's high humidity reduces radon. The measurement may have taken place in the winter. Most countries had average radon concentrations within the EPA's guidelines. Due to the research area's agricultural landscape and abundant water supplies, uranium activity or radon gas concentration may be low. In most samples, the study location's high humidity reduces radon. The measurement may have occurred in winter.

This article review anticipates a more extensive collection of studies to develop a comprehensive radiological database mapping the presence of radionuclides in water and soil across Iraq and other countries, with a particular focus on the Kurdistan region. Therefore, I suggest doing further investigations to encompass all provinces.

5. CONCLUSION

This review investigates soil radionuclides such as ^{226}Ra, ^{232}Th, and ^{40}K, as well as global water radon concentrations. We conducted this article to gain a deeper understanding of the history and current status of contamination. Radiation is ubiquitous on Earth, exposing all people to ionizing radiation from various sources. Most indoor radon comes from soil gas migration. Radon is difficult to detect in air, water, and soil. As the second-leading source of malignancy, it is dangerous despite its short lifespan. We also need greater knowledge on how to protect ourselves from radiation levels above the recommended threshold. This overview compares radon in twelve countries' drinking water. Iranian and Chinese values were lower than claimed, whereas Nigeria, Jamaica, and Brazil reported greater levels. Due to geological structure and rocks, research region parameters vary. Radiation affects multiple countries. US car accidents kill 21,000 people annually, twice as many. Such complex evidence cannot be ignored. People misunderstand radon, the second-leading cause of lung cancer. Additionally, this assessment examines primordial radionuclides in soil research articles from 2007 to 2024 in eleven nations. Serbia has the greatest concentrations of ^{226}Ra, but Nigeria possesses the highest recorded levels of ^{40}K in soil (measured in millibecquerels per kilogram). Jordan and Turkey have the lowest ^{226}Ra and ^{40}K levels. India had ^{232}Th the most, while Saudi Arabia had the least. Rock and geology have an impact on natural radioactivity nationwide. This endeavor necessitates an education about soil radionuclides. Safety and health risks are covered. Romania, Serbia, Nigeria, Iran, India, and Spain exceeded 32, 45, and 420 Bq/kg global parameters for ^{226}Ra, ^{232}Th, and ^{40}K. The study examines ^{226}Ra, ^{232}Th, and ^{40}K values in soil samples, comparing global standards with actual data. It highlights the need for empirical data to understand regional radionuclide concentrations. Results show ^{226}Ra in some countries is more prevalent in studied areas than globally, with significant average concentration variations in Serbia, Romania, and Nigeria. Factors influencing results include geographical and geological characteristics, wind patterns, humidity levels, temperature variations, and materials under investigation. Potassium has greater specific activity than radium and thorium due to geological factors.

This review work shows that naturally occurring background radiation from radionuclides in soil and radon concentrations in water samples typically has a substantial health impact, posing a major radiation risk to the residents of certain areas. Consequently, our analysis showed that residents should avoid some areas due to radiological hazards. Finally, the review discovered variations in primordial contents and physio-chemical constraints in soil and aquatic samples, providing insights into geographical establishment and factors, weather circumstances, and soil category. Oil refinery regions have also quantified naturally occurring radioactivity, but the assessment is limited. Since exposure to naturally occurring radionuclides is the primary cause of most exposures, further investigation is necessary to construct a new base map for the Kurdistan region.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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