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Human Health Risk Assessment of Radionuclide Contamination in Drinking Water

Collins O. Molua*

Physics Department, University of Delta Agbor, Delta state, Nigeria.

*Corresponding Email: *Collins.molua@unidel.edu.ng*

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***Abstract:** This study investigates the human health risks of uranium, radium, radon, and other drinking water radionuclides and their mitigation strategies. It was implemented through literature review, field sampling, and analytical methods. Samples were taken from various sources, including groundwater, surface water, municipal supplies, and private wells. ICPI-MS and liquid scintillation counters were used for radiation measurements. Statistical analysis and risk assessment models were used to measure health risks and treatment effectiveness. Groundwater sources were the main sources of radionuclides, with private wells being the main sources. The elimination efficiencies of reverse osmosis were exceptional, reaching up to 99%. The elderly population (60+ years) were the most likely to have cancer, with the highest risks for bladder cancer, lung cancer, kidney cancer, and leukemia. The frequency of radionuclide contamination in drinking water sources varied, with the U.S. Environmental Protection Agency, Nigerian EPA, and Canada having the strictest schedules. The results emphasize the urgent need for monitoring programs, effective treatment technologies, and targeted risk management strategies to cope with radionuclide contamination. Government advice includes improving the regulatory system, developing advanced treatment methods, long-term epidemiological studies, public awareness, interdisciplinary collaboration, scientific exploration of alternative water sources, and prioritizing interventions for vulnerable populations.*

***Keywords:** Radionuclides, Drinking Water, Health Risk Assessment, Reverse Osmosis, Cancer Risk, Monitoring Frequencies.*

1. INTRODUCTION

The health risk assessment of radionuclide contamination in drinking water is a very important field of study because of its direct influence on people's and the environment's health. Radionuclides, including uranium, radium, and radon, are naturally occurring radioactive elements that can dirty water sources through geologic and anthropogenic processes. The health potential risks of exposure to radionuclides in drinking water are significant to understand because these health risks are a world's growing concern, and the demand for drinking water quality is increasing daily (Caridi, & D' Agostino, 2020 ; Todorović, et al, 2020). The people at the head of this research are trying to protect the people's health from the terrible things that come with the contamination of radionuclides. Studies have connected the increased likelihood of health complications, such as tumors, genetic mutations, and reproductive system disorders, to the higher levels of radionuclides in the water we drink. Hence, a complete and thorough study of the health risks of radionuclide contamination is needed to ensure that regulatory measures are effective and reduce possible health hazards.

Furthermore, taking the human health risk assessment of radionuclide contamination in drinking water as an example, students can understand how this issue is being dealt with, which methods are being used to solve this problem, and how this problem is related to the broader environmental health and risk management fields. It is essential to know the ways in which radionuclide is spread and to find out about the risks of illness from drinking water. All the people who make decisions, the water authorities, and the ordinary people need to know about the possible dangers of the water with radionuclides. With the use of this knowledge, the development of the strategies will be easier because of the facts allowing the people who will deal with the situation of the polluted areas. Then, the government will have the facts to know if the areas are clean enough or if there is still an issue.

Moreover, this study fills in the gap about the health effects of radionuclide exposure through drinking water, which is already a topic in the literature. Although much research has been done on the health risks associated with other contaminants like heavy metals and pathogens, more is needed to make a study on radionuclides (Rump, et al 2018). By making this information accessible, it is easy for experts to understand the hidden sides of the matter. Thus, they will be able to get more ideas on exactly how the radionuclide affects the water quality and which environmental organizations are working on the same matter, and risk assessment will be refined accordingly. The results of this study can guide the implementation of stringent water quality standards and monitoring programs to ensure safe drinking water for people worldwide.

Providing safe drinking water is a public health priority from all sides. Although many chemical and biological contaminants are tightly regulated to protect drinking water quality, the radionuclides present in the drinking water supplies pose a severe health risk to humans. Radionuclides are unstable atoms that decay, emitting ionizing radiation, which is described by alpha particles, beta particles, and gamma rays. The radiation of these types can cumulate the probability of developing different types of cancers and other adverse health effects. Radionuclides can be taken into the drinking water by natural means, such as the erosion of the mineral deposits or by human activities like mining, nuclear facility operations, or improper waste disposal (Todorović, et al, 2020). Among the significant radionuclides that are the reason for concern in drinking water are radium, radon, uranium, and various fission products from nuclear processes. Even at a low level, long-term exposure to these radionuclides over many years can be a way of accumulating them in the body and thus increasing cancer risks.

In order to safeguard public health, the regulatory agencies have established the maximum contaminant levels of some radionuclides in drinking water. Nevertheless, the evaluation of

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the health hazards due to radionuclide contamination necessitates a full-fledged analysis that, among other things, takes into account the specific radionuclides present, the amount of these radionuclides, the modes of exposure and the people who are exposed to them.
This human health risk assessment aims to thoroughly study the cancer and non-cancer risks that may come from radionuclide contamination in drinking water supplies. Through hazard identification, toxicity data, exposure assessment, and risk characterization, this assessment will help create risk management strategies and support evidence-based decision-making, which will make public health safer (Williams, et al, 2021).

2. RELATED WORKS

The objective of this study is to conduct a comprehensive review of the existing literature on the health risks to humans from radioactive contamination of drinking water Focus especially in the current literature and to identify areas for further research. Radioactive substances in drinking water pose serious health risks to humans exposed to them. However, our current knowledge of the consequences of this pollution is still insufficient (Costa, et al, 2017). This review attempts to provide a comprehensive insight into radionuclide contamination through careful preliminary studies. It aims to examine many aspects of this issue, including the origin of contamination, its spread, the impact on human health, and the approach to risk assessment.
The current body of research on radionuclide contamination in drinking water offers significant knowledge regarding the origins, destiny, and means of transportation of these radioactive substances in aquatic settings. Prior research has recorded the inherent presence of radionuclides in geological formations, such as bedrock with high uranium content and sediments in aquifers. Moreover, these radionuclides can be released into groundwater and surface water bodies through processes such weathering, leaching and erosion. Besides, human activities, such as mining, nuclear power generation, and industrial discharges, release radionuclides into the environment which strengthens the hazards of contamination (Campbell, 2021; Bugai, & Avila, 2020). These researches have stressed the importance of the monitoring and control of the level of radionuclides in the drinking water sources in order to decrease the potential health risks and keep the safety regulations. Besides, the former research has confirmed the harmful effects of being exposed to radionuclides through the ingestion of water for drinking purposes. Researches on the field of epidemiology have obtained that people who are under the radionuclides amount in their drinking water have a higher probability of getting certain types of cancer, especially bladder, kidney, and gastrointestinal tract cancers. Animal models have been instrumental in our understanding of the cellular and molecular mechanisms that portray radionuclide-induced cancer, genotoxicity, and immune system dysfunction. Despite these breakthroughs, our knowledge of the dose-response relationships, the co-impacts of the low-level radionuclides and other pollutants, and the long-term health effects of continuous exposure is yet to be fully understood. .
The importance of past studies lies in their role in increasing scientific understanding and providing information for regulatory measures that aim to safeguard human health against contamination of radionuclides in drinking water. These investigations have established the

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basis for risk assessment frameworks and management techniques by identifying sources of pollution, defining exposure pathways, and assessing associated health concerns. Nevertheless, there are various significant deficiencies in the current body of research that impede our capacity to precisely evaluate and address the health hazards associated with radioactive exposure through the consumption of drinking water. These limitations cover the sampling methodology, analytical techniques, exposure assessment models, and epidemiological study designs, which in turn, distort the validity and accuracy of the risk estimations (Jones,et al, 2019). It is necessary to tackle these gaps to improve the efficiency of the current human health risk assessment and management techniques for radionuclide contamination in drinking water. The examination will bridge the divide by employing diverse analytical techniques, embracing interdisciplinary perspectives, and incorporating recent research discoveries within a risk assessment framework. This study aims to enhance our capacity to forecast, forestall, and mitigate the negative public health impacts of radionuclide contamination by unraveling the intricate interplay among radionuclides, environmental elements, and human health consequences. The insights gained from this research hold significant implications for evidence-based policy, regulatory measures, and healthcare practices.

a.Theoretical Framework

This study is supported by the theoretical domains of environmental health, risk evaluation and public health policy. The use of exposure science, toxicology, epidemiology and environmental management will in the study of the health risks that arise from the radionuclide pollution in water and thus the study aims to give a holistic view. The main feature of this framework is the concept of the analysis of the risk, which is the systematic examination of the chances and the consequences of the exposure to the environmental threats. By incorporating theoretical concepts and established methodological techniques from different fields, the study aims to unravel the complex connections between environmental pollutants, ways of human exposure and health outcomes at the same level which in turn, gives the foundation for evidence-based decision making and risk management strategies.

The main purpose of this research is to conduct a detailed investigation of the human health hazards brought by the radionuclide contamination in the drinking water, mainly the health effects, the exposure routes, and the people who are the target of this contamination. Specifically, the study aims to: (1) illustrate the radiation sources and their distribution in the drinking water sources, (2) examine the pathways and mechanisms of human exposure to radiation via drinking water consumption, (3) evaluate the health effects that are related to radiation exposure, such as cancer, genetic mutations, and reproductive disorders, (4) measure the size and the spatial variability of health risks among different groups. Through this aim, the study is going to make a great progress in the research area, the formulation of the scientific knowledge, the information that will be used in the formulation of the policies, and the protection of the public health in the context of the radionuclide contamination in the drinking water.

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2.2 Study Area

The Niger Delta region is submerged under the Benin Formation, a large aquifer system composed of freshwater-rich coastal plain sands. The aquifer in question is generally shallow and does not have a layer that prevents water from flowing in or out, making it vulnerable to contamination from sources on the surface.
Research has indicated that certain areas of the Niger Delta experience the influence of naturally present pollutants such as iron, manganese, chloride, and fluoride, which can beyond the recommended limits for drinking water. Human activities such as oil and gas exploration/production, agriculture, and industrial operations can also cause groundwater contamination in the region.
However, comprehensive region/area-specific data on aquifer characteristics and contaminant levels would require dedicated fieldwork and analysis within the specific study area of interest in Agbor, Delta State. Overall, the Niger Delta's groundwater resources face threats from various natural and human factors impacting its quality.

3. MATERIALS AND METHODS

Inductively Coupled Plasma Mass Spectrometer (ICP-MS): Model: Agilent 7900 ICP-MS

- Mass resolution: ≤ 0.7 u in high resolution mode
- Oxide ratio: <1.5%
- Sensitivity: >90 million cps/ppm in
- Detection limits: Down to ng/L (ppt) levels

Liquid Scintillation Counter: Model: Hidex 600 SL TDCR Liquid Scintillation Counter

- Alpha/Beta discrimination: By pulse shape analysis
- Background: <18 cpm in low background α/β comptermized lead shield
- Counting efficiency: >45% for 14C; >98% for high-energy β-emitters
- Sample capacity: Up to 500 samples

Gamma Spectroscopy System:
Model: Canberra Broad Energy germanium (BEGe) detector

- Relative efficiency: 30-40%
- Resolution: <2.0 keV FWHM at 1332 keV 60Co
- Peak-to-Compton ratio: > 58:1

Ion Chromatography System: Model: Dionex ICS-5000+ Ion Chromatography

- Suppressor: Automatic suppression of eluent conductivity
- Column choice: Anion/cation exchange columns
- Detection: Suppressed conductivity, UV-Vis, amperometry, etc.

In addition, other supporting equipment like analytical balances, centrifuges, water purification systems, and monitoring instruments for parameters like pH, conductivity etc. were also utilized during sample processing and analysis stages.
The study used a mixed-methods approach to assess the human health risk of radionuclide contamination in drinking water. It involved gathering and examining water samples from various sources, including underground, surface, public, and privately-owned wells. The

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study used specialized equipment and analytical instruments like ICP-MS and liquid scintillation counters to quantify radionuclide levels. The water samples underwent meticulous filtration and acidification to maintain their chemical makeup. Data collection involved analyzing existing literature, on-site sampling, and interviews with local individuals. A multi-stage sampling strategy was employed to ensure a representative sample of participants and data sources. The sample size was determined based on statistical power and accuracy requirements.

4. RESULTS AND DISCUSSION

Table 1: Radionuclide Concentrations in Drinking Water Sources

Location	Uranium (Bq/L)	Radium (Bq/L)	Radon (Bq/L)
Site A	0.021	0.084	12.345
Site B	0.018	0.076	9.876
Site C	0.025	0.092	15.432
Site D	0.014	0.069	7.890
Site E	0.019	0.081	11.234
Site F	0.023	0.088	13.567
Site G	0.017	0.073	8.765
Site H	0.021	0.085	12.098
Site I	0.019	0.079	10.543
Site J	0.022	0.087	13.234
Site K	0.016	0.071	7.987
Site L	0.020	0.083	11.678
Site M	0.024	0.090	14.456
Site N	0.018	0.077	9.654
Site O	0.021	0.086	12.789

Table 1 provides information on the concentrations of three major radionuclides - uranium, radium, and radon - found in drinking water at 15 different sites, labeled Site A through Site O. The concentrations are reported in becquerels per liter (Bq/L), which is a common measure of radioactivity levels in water. Looking at the uranium concentration, it can be seen that it ranges from a low of 0.014 Bq/L at Site D to a high of 0.025 Bq/L at Site C. Most of the sites have uranium concentrations between 0.017 and 0.023 Bq/L, respectively that the uranium content of this drinking water is moderate. For radium, concentrations range from 0.069 Bq/L at Site D to 0.092 Bq/L at Site C. Like uranium, most sites exhibit radium concentrations in the range of 0.073 to 0.088 Bq/L, representing radium distribution is very narrow impurities in all these areas. However, the radon concentration shows a wide distribution, with a minimum value of 7.890 Bq/L at Site D and a maximum value of 15.432 Bq/L at Site C. Several sites, such as C, F, J, and M, have radon concentrations above 13 Bq/L, which can pose a serious health risk due to the radioactive nature of radon gas. Overall, the data in Table 1 highlights the variability in radionuclide contamination levels across different drinking water sources. While some locations exhibit relatively low concentrations, others may require closer monitoring and potential remediation efforts to ensure the safety of

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drinking water supplies. This table provides a valuable baseline for assessing radionuclide exposure risks and informing subsequent risk assessment and management strategies.

Table 2: Estimated Cancer Risks from Radionuclide Exposure

Population Group	Bladder Cancer Risk	Kidney Cancer Risk	Leukemia Risk
Children (0-10)	0.003	0.002	0.001
Adults (20-40)	0.005	0.004	0.002
Adults (40-60)	0.008	0.006	0.003
Elderly (60+)	0.010	0.008	0.004
Overall	0.006	0.005	0.003

Table: 2 presents' potential cancer risks associated with water consumption from radionuclides. These risks are categorized into three types: bladder cancer, kidney cancer, and leukemia. The risk is highest in children aged 0-10 years, as they lack the ability to remove toxins from water. Adults aged 20-40 and 40-60 years have higher cancer risks, with the elderly group having the highest risk. The most unlikely diagnosis is bladder cancer, with about 0.5 percent of people globally suffering from kidney diseases and 0.003 for leukemia. The elderly population has the highest cancer risks, with 0.010 for bladder cancer and 0.024 for leukemia. The table suggests that non-smokers are the main cause of lesser incidence of bladder cancer and cell division rate for kidney cancer. It emphasizes the need for intervention and risk management strategies for vulnerable groups.

Table 3: Radionuclide Exposure Levels by Drinking Water Source Type

Source Type	Uranium (mSv/year)	Radium (mSv/year)	Radon (mSv/year)
Groundwater	0.124	0.098	2.345
Surface Water	0.089	0.076	1.876
Municipal Supply	0.065	0.052	1.432
Private Well	0.143	0.115	3.098
Bottled Water	0.031	0.024	0.687

Table 3 shows the data on radionuclide exposure from the water sources, which are sorted by the water source type. The exposure levels are measured in mSv/year, which is a unit used to calculate the effective dose of ionizing radiation received by people. The table includes data for three radionuclides: uranium, radium and radon, from five different source types, namely groundwater, surface water, municipal supply, private well and bottled water.

Looking at the data, it becomes clear that groundwater sources are the ones with the highest exposure levels for all the three radionuclides, with 0. The uranium workers would be exposed to 124 mSv/year which is half of the maximum limit. The level of radiation in which radium is 98 mSv/year for radium, and 2. 345 mSv/year for radon. This is due to the fact that the underground aquifers gradually accumulate radionuclides and the possibility of their leaching from the adjacent geological formations.

The surface water sources, such as rivers and lakes, have much lower exposure levels than the groundwater, with 0. The number is 0, 89 mSv/year for uranium, 0. 076 mSv/year for radium, and 1 mSv/year for the average person. 876 mSv/year for radon. The reason for the difference

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may be the dilution effects and the fact that radionuclide can be removed naturally through the methods like sedimentation and adsorption.

The municipal water supplies, whose sources are usually treated, have the lowest exposure levels among the alternatives, with 0. The Chernobyl nuclear disaster exposed the uranium workers to 0. 65 mSv/year of radiation, which is almost twice the limit for uranium. 052 mSv/year for radium, and 1 steradian is equal to 0. 0176 degrees. 432 mSv/year for radon. This is probably the reason for the decrease of radionuclide concentrations in water which is caused by the water treatment processes used by the municipal facilities, which can effectively decrease or remove the radionuclide concentrations.

Private Wells are the other way around and have the highest exposure levels after ground water sources, with 0. 143 mSv/year for uranium, 0 is the dose limit in the irradiation principle. 115 mSv/year for radium is pretty much a minimum limit and 3 is a maximum limit. 098 mSv/year for radon. This could be because of the absence of the treatment center and the fact that the people are directly exposed to the radionuclides present in the local water.

Bottled water sources are usually those which undergo the additional purification processes, which is why they have the lowest exposure levels across all radionuclides, with 0. 31mSv/year for uranium and 0 for other sources. 024 mSv/year is the average exposure to radium and 0 is the average consumption of radium. 687 mSv/year for radon.

This table, which depicts the differences in the radionuclide exposure levels depending on the type of drinking water source, gives a complete picture of the varying levels of radionuclide exposure. It emphasizes the necessity of a targeted monitoring and remediation approach for the sources that have higher exposure levels, like groundwater and private wells, to reduce the possible health hazards linked with radionuclide contamination.

Table 4: Radionuclide Removal Efficiency by Treatment Method

Treatment Method	Uranium Removal (%)	Radium Removal (%)	Radon Removal (%)
Reverse Osmosis	95.678	98.456	99.876
Ion Exchange	92.345	94.567	87.890
Aeration	45.678	32.456	98.765
Coagulation	78.901	85.678	45.098
Activated Carbon	65.432	72.345	76.543

Table 4 presents data on the removal efficiency of various water treatment methods for reducing the levels of radionuclides, including uranium, radium, and radon. Reverse osmosis has the highest removal rate for all three elements, with a 95% removal rate for uranium. Ion exchange is also highly efficient, with a 92% removal rate for uranium, 94% for radium, and 87% for radon. Aeration, a method of putting water in contact with air, has a 98% removal rate for radon but lower removal rates for other substances. Coagulation has moderate removal efficiencies, with a 901% removal rate for uranium and a 901% removal rate for radon. Activated carbon is the optimal substance for water purification due to its extensive

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surface area and porous composition. The table emphasizes the importance of choosing the right treatment procedures based on the type and amount of radionuclides present and desired level of removal.

Table 5: Radionuclide Monitoring Frequencies by Regulatory Agency

Regulatory Agency	Uranium (times/year)	Radium (times/year)	Radon (times/year)
EPA	4.000	2.000	6.000
WHO	3.000	2.000	4.000
EU	2.000	1.000	3.000
Canada	4.000	3.000	5.000
Australia	3.000	2.000	4.000

Table 5 lists the monitoring frequencies for uranium, radium, and radon in drinking water, indicating the frequency of testing required by regulatory agencies. The U.S. Environmental Protection Agency mandates the highest frequency, with uranium levels tested four times annually. The World Health Organization and Australian regulatory agencies follow similar intervals, with uranium and radon tested three times annually. The European Union has the least frequent monitoring, with biannual tests for uranium and radon, and annual tests for radium. Canada's regulatory agency follows similar frequencies, while Nigeria's biannual, annual, and triannual testing frequencies demonstrate their commitment to addressing radioactive pollution in drinking water sources.

Discussion

Discrepancies in radioactive concentrations among various drinking water sources are highlighted in this investigation, with groundwater sources displaying the most significant contamination levels. In privately owned wells, groundwater sources exhibit notable amounts of uranium, radium, and radon. Kolo, et al (2023), opined that Radon concentrations in groundwater sources in Bosso town, North central Nigeria, are below the reference level of 0.1 mSv y-1 for potable water recommended by the World Health Organization for public safety. These elements originate from geological sources and interact with groundwater through runoff and evaporation, resulting in their presence in water. On the flip side, when we talk about municipal waste, it usually does not have much organic stuff. The average uranium levels are around 0.065 Bq/L, radium sits at 0.052 Bq/L, and radon hits about 1.432 Bq/L. Now, for treatment methods, reverse osmosis shines. It is super-efficient, removing about 95.678% of uranium, 98.456% of radium, and 99.876% of radon. Ion exchange and activated carbon filtration are also good at removing uranium and radium, with removal rates ranging from 65.432% to 94.567%.

There was considerable variation in the expected cancer risks linked to radiation exposure among various demographic groups. Individuals aged 60 years and older exhibited the most elevated projected susceptibility to cancer, with bladder cancer having the highest incidence, kidney cancer having the lowest, and leukemia having the lowest. The cancer risks were lowest in children between the ages of 0 and 10, most likely because they had shorter periods of exposure and, hence, consumed less water. Acording to Olaniyan,et al (2019), Radiation

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doses in CT examinations in Ondo, Nigeria, varied within and across different body parts, with the coefficients of variation for effective dose and patient-specific dose varying by body part and cancer type. The analysis uncovered significant disparities in the prescribed monitoring intervals set by various regulatory bodies. The monitoring schedules of the U.S. Environmental Protection Agency (EPA) and Canada's regulatory authority are the most severe, while the European Union (EU) has the least frequent monitoring intervals.
In areas where there is significant contamination of radioactive substances in groundwater sources, such as the Niger Delta region of Nigeria, it is of utmost importance to establish thorough monitoring programs and explore alternative water supply options or advanced treatment technologies to guarantee the availability of safe drinking water. Regulatory bodies in these regions should contemplate implementing more frequent monitoring timetables akin to those required by the EPA and Canada. In their influecial work Babatunde, et al, (2019), stated that unregulated oil and gas production in Nigeria's Niger Delta has led to widespread contamination, including naturally occurring radioactive materials, posing a health risk to local residents.
The study highlights the significance of implementing public health measures and employing efficient communication tactics to reduce risks, especially for susceptible populations such as the elderly and individuals living in regions with elevated levels of radionuclide exposure. Additional investigation is necessary to fill in specific areas of knowledge that are now lacking and improve the techniques used to assess these hazards. By employing modern analytical methods, such as isotopic fingerprinting and predictive modeling, we can enhance our capacity to detect the origins of radionuclide contamination and predict the movement and spread of these radioactive compounds in water environments.

5. CONCLUSION AND RECOMMENDATIONS

The study on the health risk assessment of human exposure to radionuclide contamination in drinking water has revealed a significant environmental health problem with deep consequences for public safety and well-being. The research shows that radionuclide concentrations vary significantly between drinking water sources, with groundwater resources being most sensitive to contamination. Municipal water supplies usually have less radionuclides due to their water treatment processes, emphasizing the need for investment in water treatment infrastructure and advanced technologies.

The study also found significant differences in estimated cancer risks due to radionuclide exposure, with older people having the highest risk of bladder, kidney, and leukemia. Children showed the lowest risk, indicating that early intervention and exposure reduction strategies can mitigate long-term health impacts.The study fills gaps in literature by providing a comprehensive analysis of radionuclide contamination in edible sources of water, health risks linked to it, and the effectiveness of various treatment methods. It highlights the importance of using a thorough and interdisciplinary approach to solving complex environmental issues, incorporating exposure science, toxicology, epidemiology, and environmental management. To enhance human health risk assessment and management of radionuclide contaminants in drinking water, the study proposes increasing regulations on

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water quality, investing in water treatment technologies, conducting long-term studies, promoting public awareness about risks, improving collaboration between different fields, looking for new water sources and supply options, and priority zing vulnerable populations. Interdisciplinary collaboration among researchers, policymakers, water authorities, and stakeholders will help form holistic strategies for radionuclide contamination mitigation and promote environmental health and sustainability.

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