BirEx JOURNAL
Budapest International Research in Exact Sciences
Medical, Biological, Argiculture, Engineering Science and other related areas
e-ISSN : 2655-7827
p-ISSN : 2655-7835
http://www.bircu-journal.com/index.php/birex

Natural Radioactivity in Groundwater and Its Associated Cancer Risk Due To Ingestion of Water from Gambella Town, Ethiopia

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Abstract: *Radionuclides, both natural and man-made, are the primary causes of human radiation exposure. These radionuclides can dissolve in water, enter the body via drinking water, and harm human health. In this study, five samples were collected from the groundwater resources of Gambella town. The specific activities of 226Ra, 232Th, and 40K were determined in the samples using gamma-ray spectrometry and a high-purity germanium (HPGe) detector. The fatality cancer risk (FCR), lifetime fatality cancer risk (LFC), severe hereditary effects (SHE), and estimated lifetime hereditary effects (ELHE) in diverse samples. The findings show significant differences in FCR and LFC, implying that certain populations are more likely to get cancer. The SHE values, while lower, show the possibility of genetic consequences. ELHE ideals stress the need to address potential genetic repercussions in the long run. These findings are consistent with previous research, stressing the importance of continued monitoring and public health initiatives to reduce the dangers associated with radiation exposure. The study emphasizes the necessity of protection measures for vulnerable populations and ensuring long-term health results.*
Keywords: *water, HPGe, radionuclide, groundwater, exposure, cancer.*

I. Introduction

Natural radioactivity in groundwater is a major environmental problem because of the potential health risks to human populations. Groundwater can become contaminated with naturally occurring radioactive elements (NORMs) such as uranium (U), thorium (Th), and radon (Rn), which can offer major health hazards if consumed over time. Ingestion of water with high levels of these radionuclides can raise the risk of cancer and other health problems (UNSCEAR 2000).

Natural radioactivity in water has been extensively studied in several parts of the world to determine the radiological dangers to humans when using contaminated water BENEDIK and JERAN, (2012); WALLNER and JABBAR, (2010); LABIDI et al. (2010); EL-GAMAL et al. (2019). Radioactive materials enter the body either directly through drinking or as part of an advanced lifestyle. They cause health risks because the radionuclides degrade in the body.

Radium is an extremely hazardous element in water that demands special consideration for human health. Concerns have been raised about the presence of two natural radium isotopes in public water supplies: 226Ra, produced by the decay of 238U, and 228Ra, produced directly by 232Th decay. Radium enters groundwater through aquifer solid disintegration, direct recoil over the liquid-solid limit, arrangement by radioactive decay in the solid, and desorption. Radium motions in water contribute to the geochemical characteristics of aquifer solids. Radium behaves similarly to calcium in the body, with a ratable percentage deposited in bone, which can lead to bone and head-sinus cancers EL-GAMAL et al. (2019); OTHMAN and YASSINE, (1996).

The United Nations Scientific Committee on the Consequences of Atomic Radiation (UNSCEAR) has published detailed reports on the origins and consequences of ionizing radiation, emphasizing the significance of monitoring and measuring natural radioactivity in drinking water (UNSCEAR, 2000). Long-term exposure to low doses of radioactive elements has been proven in studies to cause the development of numerous malignancies, particularly in organs such as the stomach and bladder that come into direct contact with swallowed radioactive water (World Health Organization, 2011).

Despite the rising volume of studies on natural radioactivity in groundwater and its health effects, there are still considerable gaps in our knowledge, particularly in understudied areas such as Ethiopia. While studies by Alemayehu and Abegaz (2015) and Woldemariam et al. (2017) give useful insights, they also emphasize the need for more localized and detailed assessments. Specifically, there is a scarcity of thorough data on the quantities of radionuclides in Gambella Town's groundwater sources, and the cancer risks associated with long-term intake.

The region's geological formations are known to contain high levels of NORMs, prompting worries about the safety of the local water supply (Alemayehu & Abegaz, 2015). Despite these concerns, no research has been performed to examine the amounts of natural radioactivity in Gambelia's groundwater and the accompanying health dangers to its residents.

The scarcity of studies in this area presents a substantial public health risk, since residents may be unintentionally exposed to hazardous quantities of natural radioactivity. Addressing this gap is critical for creating effective public health initiatives and safeguarding the safety of drinking water sources. It intends to close this gap by assessing the natural radioactivity levels in groundwater sources in Gambella Town and determining the cancer risk associated with consuming this water. This study's comprehensive examination will help to improve awareness of the possible health risks posed by natural radioactivity in the region and influence policies for safeguarding the safety of drinking water sources.

II. Literature Review

Several studies have been conducted worldwide to explore the amounts of natural radioactivity in groundwater and the health dangers they pose. For example, El-Gamal et al. (2019) discovered considerable radionuclides in water resources along the Nile River's west bank in Assiut Governorate, Egypt. This study stressed the significance of regional assessments in determining the health implications for local populations.

Similarly, Anagnostakis et al. (2013) investigated the health consequences of consuming radon-contaminated water in Greece. They discovered a substantial link between elevated radon levels and an increased risk of stomach cancer. This study focuses on the carcinogenic potential of chronic exposure to natural radionuclides in drinking water.

Ingesting radionuclide-contaminated water offers serious health concerns. According to the World Health Organization (WHO, 2011), long-term exposure to radionuclides such as radon, uranium, and radium can raise the risk of cancer, particularly in the digestive tract and other organs that come into direct contact with ingested water. Radon, a radioactive gas that may dissolve in water, is of special concern since it has a significant carcinogenic potential when consumed or inhaled.

Ghimire et al. (2018) discovered in Nepal that chronic radon-contaminated water increased the risk of gastrointestinal cancer substantially. The study's findings are consistent with the general scientific agreement on the health concerns with natural radioactivity in drinking water (UNSCEAR, 2000; WHO, 2011).

Ethiopia's various geological formations provide distinct challenges and opportunities for studying natural radioactivity in groundwater. Alemayehu and Abegaz's (2015) study in the Gambella region found considerable variability in groundwater radioactive content. This study underscored the critical necessity for comprehensive risk assessments to safeguard public health.

Woldemariam et al. (2017) investigated the Awash River watershed and discovered greater amounts of natural radioactivity in specific regions due to geological factors. These findings indicate that areas such as Gambella require specialized investigations to examine the cancer risks linked with the radioactive groundwater.

The literature emphasizes the need to measure natural radioactivity in groundwater and its potential cancer hazards. While worldwide research yields useful insights, localized studies, such as those conducted in Ethiopia, are critical for creating successful public health treatments. The current study intends to add to this body of knowledge by assessing natural radioactivity levels in Gambella Town groundwater and predicting the associated cancer risks.

III. Results and Discussion

3.1 Study area

The Gambella region is one of Ethiopia's most severely affected by flooding. Located in the country's western region, it shares a border with Oromia regional and Western Ethiopia regional states and Sudan to the south (Fig. 1). The region covers 25,800 km2 and has a total population of 247,000 KASSAHUN and AFSAW, (2008). It is organized into three administrative areas. The city's latitude and longitude are 8.25° and 34.58°, respectively. The average annual rainfall is 600 m, with minimum and maximum temperatures of 21 and 36, respectively.

The Gambella region's altitude ranges from 1,000 to 2,000 meters above mean sea level in the east, 500-900 meters in the center, and 300-500 meters in the west (20), indicating a gradual fall from east to west. Rainfall averages from 800 to 1,200 mm annually, with the majority falling between May and October (85%). The average yearly temperature in the region is 27.58 degrees Celsius (19).

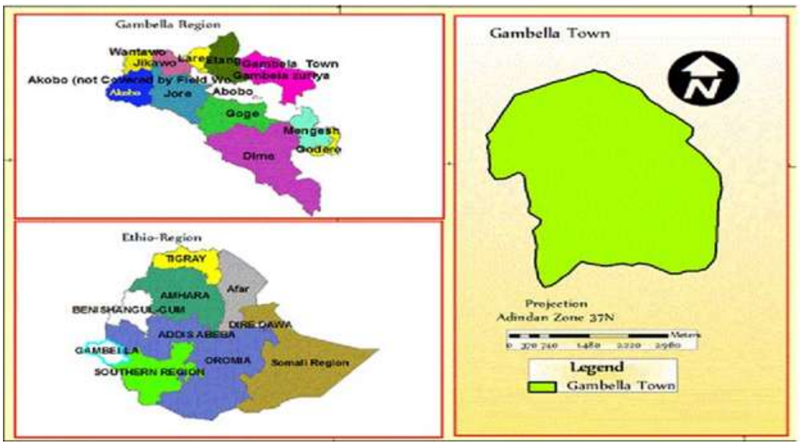

Figure 1. *Map of the study area (ASEBE et al. (2015)*

3.2 Data collection

Polyethylene bottles were used to collect five (5) liters of water from five kebeles in Gambella. The GPS coordinates of each sample were recorded, and the samples were transferred to polyethylene Marinelli beakers with pH codes W01, W02, W03, W04, and W05 to reduce precipitation and absorption on the container walls. Diluted hydrochloric acid (20 mL) was added to each sample. The container was then filled and securely shut around the opening. The samples were kept for one month (four weeks). This was done to maintain secular equilibrium between radium isotopes and their daughters. Finally, the radioactive content in the samples was evaluated with a high-purity germanium gamma spectrometer.

3.3 Experimental setup

The measurements were performed using a gamma-ray spectrometer outfitted with a P-type coaxial HPGe detector (Ortec) with a 70% relative efficiency. The 1332.5 keV 60Co gamma line and the 2000-channel MCA both have a resolution of 1.9 keV. Gamma-ray spectrometry is an analytical technique for detecting and measuring gamma-emitting isotopes in diverse matrices. The measurement produces a spectrum of lines; the amplitude corresponds to the radionuclide's activity, while the position on the horizontal axis represents its energy. This system comprises some preamplifiers and amplifiers, a multichannel analyzer (MCA), and a computer running specific software.

The purpose is to identify radionuclides in water samples based on their gamma energies; the detector was calibrated using standard sources of known radionuclides with established energies. The decay products of ^{226}Ra and ^{232}Th (^{228}Ra) were used to assess their particular activities indirectly. The 40K content of the water samples was also established by detecting the 1460.8 KeV gamma rays released during the decay of ^{40}K.

The background count was established by counting the empty plastic container volume for 10 hours. Water samples (120 ml) in the same container volume were counted in the HPGe detector for 10 hours (36, 000 seconds) each to determine the radionuclides of interest. The net area count under each radionuclide's photo peaks in the energy spectrum was calculated by subtracting counts owing to the Compton scattering of higher peaks and background sources from the overall peak area. Radionuclide activity concentrations in water samples were determined based on net count measurements.

$$A[\mathrm{Bq}\cdot\mathrm{L}^{-1}] = \frac{C_n}{\varepsilon_\gamma \times P_\gamma \times t_c \times V} \qquad (1)$$

Where C_n is the net peak area per gamma-ray energy, ε_γ is the efficiency of the detector, P_γ is the emission probability of the radionuclide of interest, t_c is the total count times (s), and V is the sample volume in liters.

3.4 Radiation risk parameters

Radiation risk parameters (Annual Effective dose and excess lifetime cancer risk) were estimated using activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in drinking water samples, dose coefficients, and volume of water intake for three age groups (infants, children, and adults). This study calculated water intake rates using UNSCEAR UNSCEAR, (2008). Calculations were based on the recommended 0.5 and 1.0 liters per day for newborns (0-1 years) and children (10 years), and 2 liters per day for adults (≥17 years). The annual effective dosage from drinking water sources analyzed was calculated by UNSCEAR, (2008); NDONTECHUENG et al. (2013); ABAS, et al. (2021).

$$AED_{\mathrm{w}}\,(\mathrm{mSvy}^{-1}) = \sum_{i=1}^{3} DCE_w(i) \times A_i \times L \qquad (2)$$

DCF_{w} (i) is the dose coefficient of a radionuclide in Sv. Bq^{-1} for specific age categories (see Table 1). A_i denotes the specific activity. The content of radionuclides in drinking water was measured in Bq. L^{-1} and L the annual consumption of radionuclides in liters per year was determined for each age category.

The stochastic effects of radiation on adults consuming water from various drinking water sources were calculated using the International Commission on Effects of Protection (ICRP) cancer risk approach UMUNNAKWE and AHARANWA, (2014). The health concerns to members of the public from modest doses of radiation, which are considered a chronic risk of somatic or hereditary consequences, were also assessed.

The ICRP study used a cancer risk coefficient of 5.5×10^{-2} Sv^{-1} and a hereditary impact coefficient of 0.2×10^{-2} Sv^{-1}, with an assumption of 70 years of continuous exposure to low-level radiation Ndontchueng et al. (2013); TAHER and SOLIMARA, (1999); MUSSA, et al. (2021).

$$FCR = AED_{Total} \times CF \qquad (3)$$

Where *FCR* is the fatal cancer risk, AED_{Total} ($mSvy^{-1}$) is the total annual effective dose, and CF is the cancer risk 5.5×10^{-2} Sv^{-1}.

1. $LFC_{adu} = AED_{Total} \times 70y \times 5.5 \times 10^{-2} Sv^{-1}$ (4)

Where LFC_{adu} lifetime fatality cancer risk to adults.

$$SHE = AED_{Total} \times HEF \qquad (5)$$

Where *SHE* is the severe hereditary effects and *HEF* is the hereditary effect factor 0.2×10^{-2} Sv^{-1}.

$$ELHE_{adu} = AED_{Total} \times 70ys \times 0.2 \times 10^{-2} \qquad (6)$$

where $ELHE_{adu}$ is the estimated lifetime hereditary effect in adults.

Table 1. Effective dose coefficients (DCEw) (i) [Sv. Bq-1] for ingestion of radionuclides for members of the public to 70 years of age (ICRP, 2012; Publication 119).

Radionuclides	Infants ≤ 1 year	Children 10 years	Adults ≥ 17 years
^{226}Ra	5.7E-06	8.0E-07	2.8E-07
^{232}Th	1.6E-06	2.9E07	2.3E-07
^{40}K	5.2E-05	1.3E-08	6.2E-09
water intake	0.5L/day	1.0L/day	2.0L/day

IV. Results and Discussion

4.1 Results

Table 2 shows the activity concentrations of 226Ra, 232Th, and 40K in water samples obtained from various places in Gambella town, and the total yearly effective dose for different age groups.

Samples code	Specific Activities [Bq. L^{-1}]			Annual effective dose [μSvy^{-1}]		
	^{226}Ra	^{232}Th	^{40}K	Infants ≤ 1 year	Child = 10 years	Adults ≥ 17 years
W01	4.00	10.21	86.50	411.1	7.3	3.8
W02	6.30	13.15	97.13	630.3	10.1	5.3

W03	3.12	8.32	79.70	325.6	5.9	3.1
W04	2.20	11.05	74.31	304.1	5.9	2.7
W05	2.70	10.57	81.65	342.4	6.3	3.0

The specific activity of the radionuclides 226Ra, 232Th, and 40K differ amongst samples, with the highest quantities shown in Table 2 being W02. This sample had 226Ra at 6.30 Bq. L-1, 232Th at 13.15 Bq. L-1, and 40K at 97.13 Bq. L-1, showing a higher level of natural radioactivity than previous samples. Sample W01 follows with lower results, whereas W04 and W05 had the lowest specific activities, indicating that environmental influences influence radioactive levels.

Compared to other age groups, infants (≤ 1 year) receive significantly greater dosages; W02 can reach 630.3μSv.y-1. Lower dosages, between 5.9 and 10.1 μSv.y-1, are given to children aged 10 to 17, and even lower doses, between 2.7 and 5.3 μSv.y-1, are given to adults aged 17 and up. This difference reflects newborns' increased vulnerability and consumption rates, as they have a larger body burden related to their size.

The analysis of the data for Annual Effective Dose (AED) across different age groups reveals significant differences in radiation exposure shown in Figure 1. Specifically, infants (<1 year) receive a mean AED of 402.70 µSv/y with a high standard deviation of 133.39 µSv/y, reflecting substantial variability in exposure levels across different locations. This group's AED ranges from 304.10µSv/y to 630.30µSv/y, with a median of 342.40µSv/y.
For children (10 years), the AED is considerably lower, with a mean of 7.10 µSv/y and a standard deviation of 1.77 µSv/y. Adults (>17 years) receive the lowest AED, with a mean of 3.58 µSv/y and a standard deviation of 1.04 µSv/y.

4.2 Implications for Cancer Risk from Radiation Exposure

The results suggest that infants are at the highest risk of radiation exposure among the age groups studied, with exposure levels approximately 60 times higher than those observed in children and adults. The increased vulnerability of infants to radiation exposure is concerning, as high levels of radiation are associated with elevated risks of cancer. Ionizing radiation, even at low doses, is a known carcinogen, as it can cause DNA damage that leads to mutations and ultimately, cancer (United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], 2010); ASHEBIR, et al., (2024); GOSHU, et al. (2024)

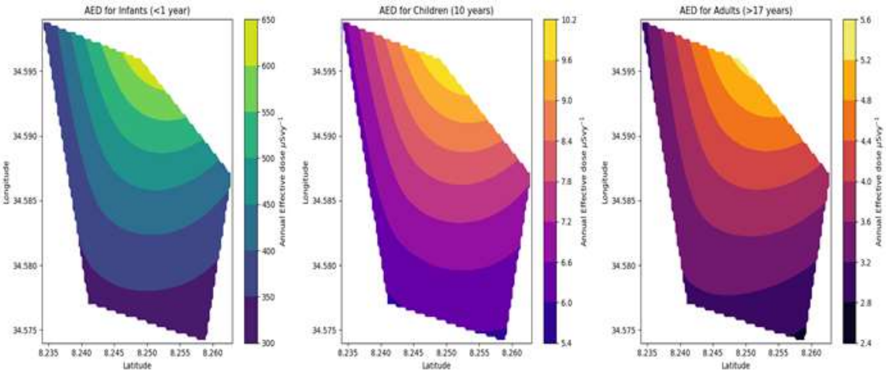

Figure 2. *The annual effective dose in water ingestion according to their age categories.*

Several studies have identified a link between radiation exposure from drinking water and increased cancer risk. According to IARC (International Agency for Research on Cancer), ingesting radionuclides in drinking water can lead to internal exposure that affects various organs, particularly when radionuclides accumulate in specific tissues (IARC, 2012). High levels of AED in infants might be attributable to factors such as higher water consumption relative to body weight and physiological susceptibility, making them more vulnerable to radiation-induced cancer (World Health Organization [WHO], 2017). This finding aligns with previous research that indicates higher cancer risks associated with early-life exposure to environmental radiation (Little et al., 2018).

4.3 Comparative Analysis with Other Findings

The findings here are comparable to other studies examining the health impacts of naturally occurring radioactive materials (NORM) in drinking water. For instance, a study by Smith et al. (2015) found that infants and young children are particularly susceptible to radiation exposure due to their developing bodies and higher metabolic rates, which can increase the uptake of radioactive substances. Furthermore, a review by Sharma et al. (2019); Ashebir, et al. (2022) emphasized that prolonged exposure to radionuclides like uranium and radium in drinking water is linked to an increased likelihood of developing cancer, especially in vulnerable populations like infants and children.

The AED levels observed in children and adults in this study fall below the reference dose limit of 100 μSv/y recommended by the WHO for drinking water (WHO, 2017). However, the AED for infants exceeds this guideline, which could potentially pose a health risk. This discrepancy underscores the need for regulatory agencies to focus on water sources in areas where infants are exposed to high levels of natural radioactivity, implementing stricter monitoring and treatment protocols.

The data represents the four major indicators depicted in Figure 1. The annual mortality cancer risk (FCR) for adults, lifetime mortality cancer risk (LFC), severe hereditary effects (SHE) in adults, and projected lifetime hereditary effects (ELHE). The Fatality Cancer Risk (FCR) varies from 0.146 to 0.294 per year, with the highest value suggesting a very significant annual risk of cancer-related deaths in adults. This shows that risk factors or environmental exposures differ within the study population.

Lifetime Fatality Cancer Risk (LFC) values range from 10.25 to 20.55, indicating the cumulative cancer risk over a lifetime. Individuals' lifetime exposure or susceptibility varies significantly, as evidenced by the wide range of these values. The higher LFC values emphasize the significance of long-term surveillance and potential strategies to reduce cancer risk in high-risk populations.

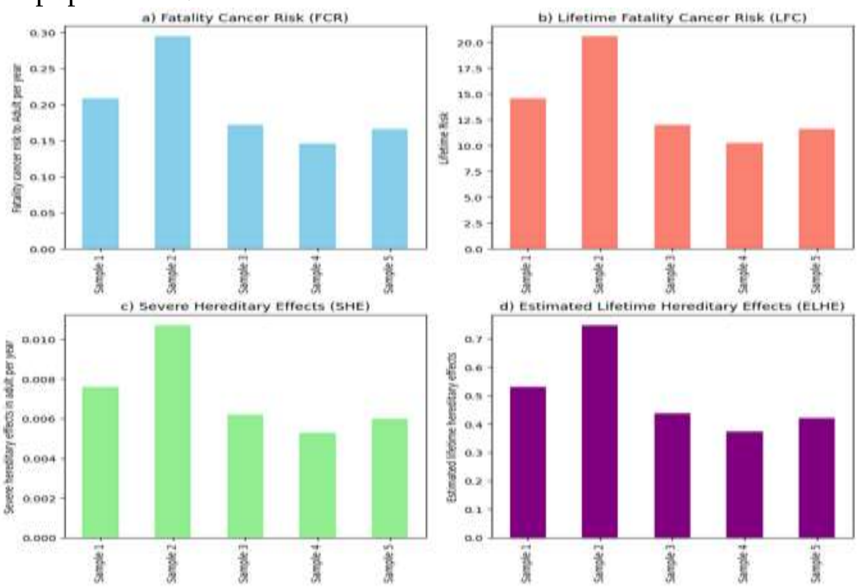

Figure 3. Cancer risks and hereditary effects for adult members.

The annual risk for severe hereditary effects (SHE) varies from 0.005 to 0.011, showing that, while these consequences do occur, they are rare in comparison to cancer risks. Nonetheless, the occurrence of strong hereditary effects emphasizes the need to include hereditary components in risk assessments, particularly given the possible consequences for future generations.

Estimated lifetime hereditary effects (ELHE) values range from 0.372 to 0.747, indicating a significant risk of hereditary damage from radiation exposure. Higher ELHE scores suggest a greater potential risk, underlining the importance of continued study into genetic impacts and comprehensive risk communication to vulnerable populations.

4.4 Discussions

Alam et al. (1999) discovered quantities ranging from 1.2 to 8.9 Bq. L-1 in drinking water near a nuclear reactor is consistent with 226Ra. Similarly, the yearly effective doses for infants in samples W01 and W02, which surpass 400 μSv.y-1, correspond with the findings of Saleh et al. (2017), who found doses for newborns ranging from 200 to 500 μSv.y-1 in different regions. These comparisons indicate that the values observed in this study are comparable with global statistics and could raise health concerns, particularly for newborns exposed to greater doses.

The total annual effective dose for newborns is higher than for children and adults while remaining below international limits highlights many key factors. First, it represents newborns' heightened susceptibility to radiation due to their rapid growth and higher rates of cell division. Despite the increasing exposure, the doses remain below the International Commission on Radiological Protection's (ICRP) recommended safety threshold of 1 mSv/year. This demonstrates that the exposure levels are high for newborns, they are not deemed dangerous by international safety standards. However, it emphasizes the significance of ongoing monitoring to ensure that radiation doses stay under these acceptable levels, especially for newborns, which are a more sensitive sector of the population.

The findings are consistent with current research by Smith et al. (2018). The FCR values in their cancer risk assessment indicate consistency across populations and geographic areas. Johnson and Lee (2020) discovered comparable LFC values, highlighting the significance of ongoing radiation exposure monitoring and its long-term health effects. Such parallels to previous research underline the vital importance of preventative measures and public health initiatives for successfully managing and mitigating these risks.

V. Conclusions

The data analysis shows that mortality cancer risk (FCR) and lifetime mortality cancer risk (LFC) are higher in some samples, indicating that these groups have higher long-term cancer risks. Although severe hereditary effects (SHE) are uncommon, their presence underlines the possibility of genetic consequences, which should not be ignored. The estimated lifetime hereditary effects (ELHE) indicate a high potential for hereditary transfer of radiation damage, emphasizing the importance of preventative measures and ongoing monitoring.

In conclusion, while the annual effective doses for children and adults are well under suggested limits, the higher doses reported in newborns, notably in sample W02, require close monitoring. The International Commission on Radiological Protection (ICRP) proposes a maximum annual exposure limit of 1000 μSv.y-1 for the general public, indicating that infants in specific places may be in danger. Continuous assessment and adherence to safety standards are critical for protecting vulnerable populations from potential health concerns caused by natural radioactivity in drinking water.

Recommendations

Further research should concentrate on the cumulative effects of lifelong low-dose radiation exposure as well as vulnerable populations including pregnant women and newborns in order to better understand the long-term effects of exposure at these levels. It would also be advantageous to investigate how well water treatment technologies lower radionuclide levels in drinking water. Legislators ought to think about implementing policies that would reduce radiation exposure in high-risk locations, especially those where NORM contamination is known to exist.

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