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EVALUATION OF NATURAL RADIONUCLIDE CONTENT IN POTABLE WATER IN SOME COMMUNITIES IN ABUAKWA SOUTH MUNICIPALITY, GHANA

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ABSTRACT

This research investigates naturally occurring radionuclides in household water supplies in some communities in Abuakwa South Municipality, Eastern region, Ghana, to provide understanding of probable radionuclide point sources in the region. Gamma spectrometry was used to determine the amounts of radionuclides (^{238}U, ^{232}Th, and ^{40}K) in water from hand-dug wells, boreholes, and pipe-borne sources. These concentrations were used to compute the excess lifetime risk and the annual committed effective dose. The study found differences in excess lifetime risk and annual committed effective dose among the different sampling locations. The Bunso pipe and well had higher doses, resulting in an increased excess lifetime risk. The average excess lifetime risk for all locations was 503.7×10^{-6}. The WHO average of 0.1 mSv/y for water was surpassed by the average yearly committed effective dosage, especially for infants below 1 year, and therefore suggests consumption of water in the area may pose a radiological risk. The Environmental Protection Agency and Abuakwa South Municipal should prioritise monitoring and mitigating risks in areas with elevated excess lifetime risk. Public awareness campaigns should be implemented to educate communities about the potential long-term health risks associated with drinking water from specific sources.

Keywords: Committed effective dose, health hazard, lifetime cancer, radioactivity.

INTRODUCTION

Around 70% of the world's population is exposed to ionising radiation from radioactive substances that occur naturally (NORM) (UNSCEAR, 1988). These materials include radionuclides consisting of uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K), which are naturally occurring elements of the Earth's crust and major sources of natural background radiation (Jibiri, Egwu & Adesiji, 2021). These radionuclides can infiltrate water systems through interactions between groundwater and geological formations, potentially posing radiological risks when consumed (Rajkhowa, Sarma, & Das, 2021). Long-term low-dose exposure to radiation can have negative health impacts, such as heightened cancer risk, genetic harm, and issues with the kidneys, heart, bones, and neurological system. This emphasises how crucial it is to keep an eye on and assess radionuclide levels in water sources for the sake of environmental safety and public health (Solomon, 2021; Wang & Tepper, 2021). Water resources in many parts of Ghana face significant contamination challenges, primarily from illicit small-scale gold mining activities, locally known as "galamsey." This is particularly evident in the Abuakwa South Municipality, where pollution from the Birim River has compelled communities to rely on alternative water sources such as boreholes, hand-dug wells, and treated water from municipal providers (Acquah, Appiah-Brempong & Anornu, 2025). However, these alternative sources are also susceptible to contamination, including the accumulation of naturally occurring radionuclides. Resolving these issues is in line with Sustainable Development Goal (SDG) 12, which places a strong emphasis on production and use that is sustainable. Understanding the concentration and distribution of naturally occurring radionuclides in domestic water supplies is crucial for evaluating potential radiological hazards associated with drinking water. Gamma spectrometry, a non-destructive and reliable analytical technique, is widely employed to quantify radionuclide concentrations and assess the effective radiation doses to consumers (Fathy *et al*., 2024). This study aims to measure the concentrations of uranium, thorium, and potassium in domestic water supplies within the Abuakwa South Municipality; determine compliance with international guidelines set by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO); estimate the effective radiation dose to residents consuming such water; and evaluate associated health risks. By providing a radiological baseline for the area, this study will aid in assessing the safety of drinking water sources, both surface and groundwater, in the Abuakwa South Municipality and its surrounding communities. A comprehensive evaluation of the annual committed effective dose and related excess lifetime risk is necessary for radiation exposure through drinking water, which is a critical component of public health (Anyimah-Ackah *et al*., 2021). This study investigates water samples from different locations, evaluating the impact of radionuclide concentrations on individuals' health over their lifetime. Over the years, numerous studies have investigated natural radioactivity in water and other media globally, revealing significant findings. For instance, research in Tanke-Ilorin, Nigeria, analysed radium isotopes (^{226}Ra and ^{228}Ra) in groundwater, reporting activity concentrations that exceeded WHO limits and posed potential health risks due to prolonged consumption (Nwankwo, 2013; Muhammad, Ismail & Garba, 2022). Similarly, studies in Finland and Turkey identified ^{122}Rn, ^{210}Po, and ^{210}Pb as significant contributors to the effective radiation dose from drinking water, with radionuclide concentrations varying by source and region. In Ghana, limited data exist on natural background amounts of radiation in water used for drinking. A study in the mining communities of Dumasi, Chujah and

Bogoso revealed that while most radionuclide concentrations were below global averages, infants consuming treated water were exposed to doses exceeding WHO limits, highlighting the vulnerability of specific demographic groups (Gbadago *et al*., 2011). This study fills critical data gaps and provide insights into the radiological safety of domestic water sources in the region.

MATERIALS AND METHODS (METHODOLOGY)

Study Site Description of Apedwa, Kibi, Apapam, Asiakwa and Bunso

This study was carried out in Ghana's Eastern Region, specifically within the Abuakwa South Municipality, with Kibi serving as the capital (Adu, Tetteh, Puthenkalam & Antwi, 2020). Its coordinates are 6°10′0′′ north and 0°33′0′′ west. Located in the western semi-equatorial zone, the municipality experiences two distinct seasons of rainfall: the first, which lasts from May to June, and the second, which lasts from September to October.

Rainfall averages between 125 and 175 mm per year. With the primary season starting in November and ending in late February, the dry seasons are separate. Despite its detrimental effects on construction projects, which result in schedule and expense overruns on contracts, the favourable rainfall pattern encourages agricultural activity. From 26 °C in August to 30 °C in March, the temperature is observed to be quite consistent. The year-round relative humidity ranges from 75% to 80% during the rainy season and from 70% to 80% during the period of drought. Subsistence farming is typically the foundation of the local economy. The main crops cultivated in the area are plantains, cocoyams, cassava, and maize. Produced vegetables include tomatoes, cucumbers, okra, and garden eggs; fruits include bananas, pineapples, and citrus fruits. The majority of the local population makes their living from growing cash crops. Oil palm and cocoa are the two main cash crop plantations in the region (Ajagun *et al*., 2021). Small-scale mining continues to remain a significant source of revenue for the district, as it has for many years.

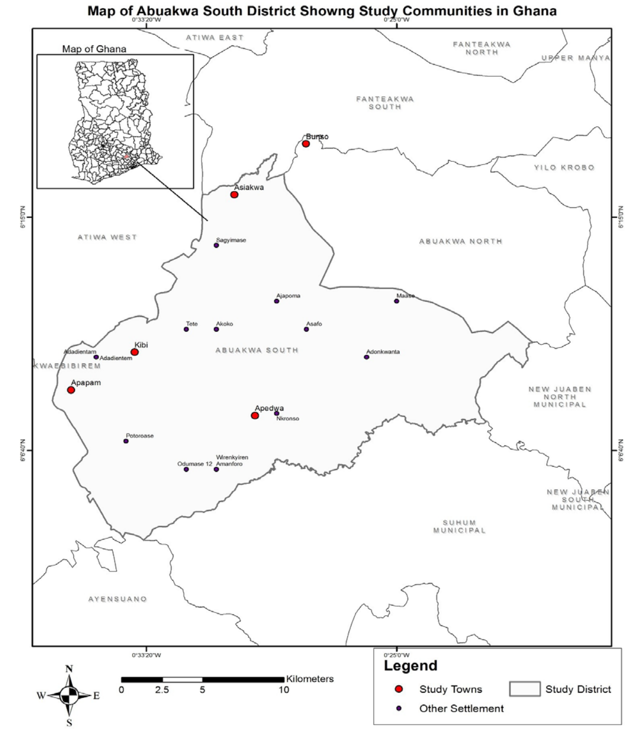

Figure 1: Map of study area showing sampling locations

Sample Collection, Preparation and Analysis

Five locations—Apedwa, Apapam, Kibi, Asiakwa, and Bunso—were selected based on geology, human activity, population density, and strategic positioning. A total of 14 water samples were collected, comprising well, borehole, and treated water from the Ghana Water Company. Wells were purged to ensure at least 95% aquifer water, and vials were rinsed with sample water before collection. Samples were stored in labelled 1.5 L bottles, acidified with 0.1N HNO_3 to prevent radionuclide adhesion, and transported to the GAEC laboratory, where they were refrigerated until analysis. Samples were filtered, transferred into 1 L Marinelli beakers, and analyzed with a High-Purity Germanium (HPGe) gamma detector connected to a Canberra S100 Multichannel Analyzer with Maestro-32 software. The detector, with a 36 mm crystal diameter and 10 mm thickness, was housed in an aluminium canister with a 0.5 mm beryllium window and shielded by 5 cm of lead. It operated at -196°C using liquid nitrogen cooling, with 1.8 keV resolution and 25% efficiency at 1332 keV. Energy and efficiency calibrations were performed using a mixed radionuclide standard, with background counts recorded for equal durations. Each sample was measured for 36,000 seconds to determine ^{238}U, ^{232}Th, and ^{40}K concentrations in Bq/L.

Activity concentration

The activity of ^{238}U in the samples was determined by analyzing the 609.31 keV energy peak associated with ^{214}Bi and 351.9 keV from ^{214}Pb. Likewise, the activity of ^{232}Th

was calculated based on the 911.21 keV peak of ^{228}Ac, 238.6 keV of ^{212}Pb, and 583 keV of ^{208}TI. The activity of 40K was derived from the energy measurement of 1460.83 keV. The analytical model employed to compute the activity in Bq/L for water samples is depicted in equation (1) (Faanu *et al.*, 2016).

$$A_{sp}=\frac{N_{D^{e^{\lambda ptd}}}}{P.Tc.\eta(E).m} \quad \text{eqn 1}$$

Where: A_{sp}= Activity concentration; P= probability of gamma-ray emission (yield of gamma ray); N_D= net counts of the samples' radionuclides; td= time delayed between sampling and counting; η(E)= the absolute counting efficiency of the detector system; Tc= time taken to count sample; $\exp(\lambda_p t_d)$= factor of decay correction for the delay between the time of sampling and counting; λp= decay constant of the parent radionuclide; and m= mass of sample (kg) or volume (L).

The Annual Committed Effective Dose of Individuals Due to Drinking Water Injection

The annual committed effective dose quantifies the total radiation exposure an individual receives over a year, considering the varying sensitivity of different organs and tissues to radiation. It provides a measure of the potential health risk from radiation exposure to the entire body. The annual effective dose is expressed in millisieverts (mSv). To determine the Annual Committed Effective Dose, the activity concentrations of radionuclides were analysed in relation to the Annual Water Consumption Rate for adults, which is estimated at 730 liters per year (Pintilie-Nicolov et al., 2021). This value is derived by multiplying the daily water intake (2 litres per day) by 365 days. The annual total committed effective dose (D), measured in mSv per year ($mSvy^{-1}$), can be calculated using the following equation (IAEA, 1996;Gbadago et al.,2011):

$$\mathbf{D} = \mathbf{W_c}\boldsymbol{CE_g} \quad \text{eqn 2}$$

D is the annual dose in mSvy; W_c is the water consumption per annum for each age group; C is the specific radionuclide concentration of the decay chain in mBql; and E ($_g$) is the specific radionuclide ingestion dose conversion factor.

Calculation of Cancer Risk from Water Injection

Cancer risk refers to the probability of developing cancer due to exposure to ionizing radiation. This type of radiation can damage cellular DNA, leading to genetic mutations and uncontrolled cell growth (Nguelem et al., 2013). The likelihood of radiation-induced cancer depends on factors such as dose, dose rate, age, sex, and the type of radiation. According to the International Commission on Radiological Protection (ICRP), a radiation dose of 1mSv carries an estimated lifetime cancer risk of approximately 0.003% (1 in 20,000), while the excess cancer risk at this dose is about 0.004% (4 in 100,000). The radiation risk to the population was assessed by determining the quantitative relationship between dose and risk. Since radiation exposure follows a linear relationship at low doses, doubling the dose results in twice the risk over several years. This assumption, known as the linear-no-threshold (LNT) model, suggests that even small radiation doses carry some level of risk. ICRP 60 estimates that the lethal dose for cancer is approximately 0.05 Sv^{-1}. The risk factor indicates that for a total body dose of 1 Sv, the probability of an individual developing fatal cancer increases by 5% over a lifetime. To estimate an adult's cancer risk, the annual committed effective dose from water samples was used, assuming a 5% probability per 1 Sv lifetime dose. The cancer risk was determined using an equation based on the estimated average annual committed effective dose, D (Sv/y), from the water samples (Qureshi et al., 2014; AL-Alawy et al., 2018 and ICRP 2012).

$$\mathbf{CR} = \mathrm{D} \times \mathbf{LE} \times \mathbf{RF} \qquad \text{eqn 3}$$

Where: CR is Cancer Risk; D (Sv/y) = mean annual committed effective dose; LE = Life expectancy (66years); RF = Fatal Risk factor per sievert (0.05 Sv^{-1}) as per ICRP 60

RESULTS AND DISCUSSIONS

This study assessed the annual committed effective dose (ACED) and the excess lifetime cancer risk of naturally occurring radionuclides (^{238}U, ^{232}Th, and ^{40}K) in domestic water sources across selected communities (Apedwa. Kibi, Apapam, Asiakwa and Bunso) in the Abuakwa South Municipality. These radionuclides are of radiological concern due to their presence in geological formations and potential health risks from long-term exposure. Residents in the study area rely on pipe-borne water, hand-dug wells, and boreholes, making it crucial to understand the radiological quality of these sources.

Table 1: Annual committed effective Dose for various age groups

		Annual Committed Effective Dose (µSv/y)					
Water Type	**Sample Location**	< 1	1-2 y	2-7 y	7-12 y	12-17 y	>17
Pipe Borne	Apedwa	576	132	100	89	127	131
	Apapam	358	116	82	71	99	96
	Asiakwa	432	118	85	75	104	105
	Kibi	611	147	112	102	148	148
	Bunso	896	198	152	138	198	203
	Mean	575	142	106	95	135	137
	Range	358-896	116-198	82-152	71-138	99-198	96-203
Well	Apedwa	509	134	101	93	137	132
	Apapam	732	191	142	127	181	180
	Kibi	666	168	126	115	167	165
	Asiakwa	649	160	119	107	151	153
	Bunso	586	139	105	96	137	138
	Mean	628	158	119	107	155	154
	Range	509-732	134-191	101-142	93-127	137-181	132-180
Borehole	Apedwa	569	142	106	97	139	138
	Apapam	570	125	95	86	121	126
	Kibi	609	137	104	95	136	139
	Asiakwa	750	175	135	124	183	181
	Bunso	770	197	150	138	205	198
	Mean	654	155	118	108	157	156
	Range	569-770	125-197	95-180	86-138	121-205	126-198

Annual Committed Effective Dose by Age Group and Water Source

The annual committed effective dose (ACED) from radionuclide consumption via drinking water varies significantly with age, water source, and geographic location. Table 1 shows ACED estimates (in µSv/y) for six age groups across three water types (pipe-borne, well, and borehole) gathered from five communities in the study area. The study provides insight into the radiological health concerns connected with water consumption in various demographic groups, notably children, who are more vulnerable to radiation-induced biological impacts.

Variations in Dose Estimates Based on Age

In all water types and locations, newborns (<1 year) consistently received the highest dose, whereas children aged 7-12 years received the lowest dose. This pattern is consistent with recognized radiological protection literature, which states that dose coefficients for ingestion are higher in newborns due to physiological reasons such as higher water consumption per unit body mass, higher metabolic rate, and developmental sensitivity to radiation (ICRP 2012). Among pipe-borne water drinkers, newborns (<1 y) have a roughly six-fold greater mean dose (575 µSv/y) than children aged 7-12 years (95 µSv/y). The similar diminishing pattern with increasing age is seen in well and borehole water, albeit with variability between sample locations.

Excess Life Cancer Risk

The excess lifetime cancer risk was estimated for the Pipe Borne with Apapam recording the least of 317 x10^{-6} and Kibi recording the highest of 670 x 10^{-6}. The average is 451 x 10^{-6}, which is below the WHO (2004) guidelines of 1450 x 10^{-6}. In the case of Well water, the least was 436 x 10^{-6} for Apedwa, and the highest was 594 x 10^{-6} for Apapam, with an average of 507 x 10^{-6}, which is below the WHO (2004) guidelines of 1450 x 10^{-6}. In the case of Borehole water, the least was 416 x $10^{-6}$for Apapam, and the highest was 653 x 10^{-6} for Bonsu, with an average of 516 x 10^{-6}, which is below the WHO (2004) guidelines of 1450 x 10^{-6}. Figures 2A, 2B and 2C Compare cancer risk with the WHO average.

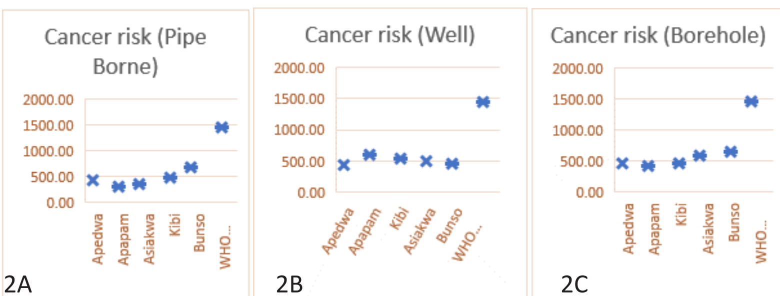

Figure 2A: Comparison of Excess lifetime cancer risk of pipe borne water with WHO average.

Figure 2B: Comparison of Excess lifetime cancer risk of well water with WHO average.

Figure 2C: Comparison of Excess lifetime cancer risk of borehole water with WHO average.

The estimated lifetime cancer risk values for all five sampling locations for the three main water sources fall within the acceptable risk range recommended by WHO. The excess lifetime risk estimates highlight the potential long-term health implications of radionuclide exposure in drinking water. Individuals residing in areas with higher excess lifetime risk may face an increased likelihood of developing radiation-related health conditions over time. These findings are critical for regulatory agencies, as they emphasize the need for intervention strategies to reduce excess lifetime risk and safeguard public health.

STATISTICAL ANALYSIS

A two-way ANOVA was conducted to examine the effects of water source (pipe-borne, well, borehole) and location (Apedwa, Apapam, Kibi, Asiakwa, Bunso) on Annual committed effective dose (ACED). There were significant main effects of water source, $F(2, 45) = 10.20$, $p < 0.001$, and location, $F(4, 45) = 6.80$, $p < 0.001$. A significant interaction was observed, $F(8, 45) = 2.97$, $p = 0.015$, indicating that the effect of source differs by location (e.g., borehole water in Bunso and Asiakwa produced notably higher ACED). Post-hoc Tukey tests indicated that borehole sources produced significantly higher ACED than pipe-borne sources (mean difference = 79 μSv/y, $p < 0.001$). The partial eta-squared for the model was 0.30, indicating a large effect size. Residuals were approximately normal and Levene's test indicated homogeneity of variances ($p = 0.12$). Given these results, location-specific mitigation and continued monitoring are recommended.

LIMITATIONS OF THE RESEARCH

The study faced several limitations, including limited sampling coverage, which excluded some towns in the Abuakwa South Municipality, possibly missing areas with high radionuclide contamination. Seasonal variations were not considered, as sampling occurred during a single timeframe. The Gamma Spectrometer used had limited sensitivity, potentially missing trace radionuclide levels and underestimating contamination. Spatial variations in natural radionuclide levels due to geological differences may not have been fully captured. Resource constraints affected sample size, analytical methods, and training. Additionally, community resistance and low awareness hindered access to private water sources and local participation. Addressing these issues requires better planning, funding, and stakeholder involvement.

CONCLUSION

The study measured the annual committed effective dose (ACED) and the excess lifetime cancer risk of ^{238}U, ^{232}Th, and ^{40}K in domestic water sources across the Abuakwa South Municipality, Ghana. The data indicated that infants and younger children were disproportionately affected by ingestion-related radiation dose from water consumption, with borehole and well water sources contributing the highest levels of committed effective dose. Findings revealed variations in the annual committed effective dose and excess lifetime risk among different sampling locations. Notably, water samples from the Bunso pipe and well exhibited higher doses, resulting in an increased excess lifetime risk. The average excess lifetime risk across all sites was recorded at 503.7×10^{-6}. The annual committed effective dose exceeded WHO average of 0.1 mSv/y, especially for infants below 1 year, and therefore suggests consumption of water in the area may pose a radiological risk. Environmental Protection Agencies (EPA) and the Abuakwa South Municipality should prioritize continuous risk monitoring and mitigation efforts, particularly in high-risk areas. The findings underscore the importance of age-sensitive dose assessments in public health evaluations and the need for targeted water quality interventions, especially in areas like Bunso and Asiakwa. Additionally, public awareness initiatives should be implemented to educate residents on the potential long-term health risks associated with consuming water from specific sources. Further geological research is also necessary to better understand the factors influencing radionuclide concentrations, which will aid in developing effective strategies for reducing exposure and ensuring water safety.

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