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Alpha and beta radioactivity concentration assessments in drinking water along the Kumbotso pipeline, Kano

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ABSTRACT
This study investigates the concentrations of gross alpha and beta activities in tap water samples collected from Kumbotso local government, reporting values ranging from 0.04 ± 0.01 BqL^{-1} to 0.9 ± 0.28 BqL^{-1} for gross alpha activities, and 0.7 ± 0.8 BqL^{-1} to 85.1 ± 11.7 BqL^{-1} for gross beta activities. The findings reveal that gross beta activities exceed their alpha counterparts across all tap water samples, with both surpassing the World Health Organization (WHO)-recommended thresholds of 0.1 BqL^{-1} for gross alpha and 1.0 BqL^{-1} for gross beta activities. This indicates an annual effective dose exceeding WHO's reference level of 0.1 $mSvy^{-1}$, highlighting a significant radiological risk to residents. The most vulnerable areas identified are Dorayi-1 and Gasau-2, where the annual effective dose rates are markedly higher than the recommended limits for adults and children. This work provides baseline radiometric data for tap and drinking water in the region, emphasizing the need for public awareness and immediate mitigation efforts to address these potential health hazards. Moreover, the findings underscore the importance of further research to confirm and expand upon these results, aiming to safeguard public health through informed policy and infrastructure improvements.

Keywords: alpha activity, beta activity, drinking water

INTRODUCTION
The sun and primordial radio nuclides existing in the lithosphere (Uranium and Thorium) are two significant sources (~96%) of radiation and radioactivity on land, in the atmosphere, as well as in water bodies or the marine environment.[1,2] Humans are exposed to such radiation in various ways, which include Direct exposure to sunlight or interacting with ionized particles (alpha and beta) emitted by the progeny of these radionuclides. This interaction can happen by physical exposure, inhalation (breathing in the air), or ingestion (food and water). The ionizing particles, when inhaled or ingested (especially alpha particles), can cause harm to humans. This is because some of such

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particles can possess energies sufficient (~10 eV) to affect humans at the cellular or DNA level, leading to severe illnesses or even death, depending on the type of exposure.[3] For this reason, organizations like the United Nations Scientific Committee on the Effects of Atomic Radiation are set to determine a worldwide average annual effective radiation dose with a typical value ranging from 0.2–1 $mSvy^{-1}$.[4,5]

Water is one of the most valuable resources for humans. As an estimate, an individual consumes a minimum of about 1 L daily. This is without considering the use for other purposes. In addition, an average person has a higher tendency to ingest water (in different forms) compared to eating. Therefore, determining the level of natural radioactivity present in drinking water originating from various sources becomes significant. Researchers[6] investigated the concentration of gross alpha and beta activities in bottled (mineral) water in Serbia. They found that the detected radioactivity levels are within the (0.1 – 1) BqL^{-1} limit recommended by the World Health Organization (WHO). Another study in the biggest city of the Turkish Black Sea region (Samsun) reported normal radioactivity levels in water collected from 19 different sample locations.[7] Many other studies have also reported normal radioactivity levels in drinking water.[8] However, radioactivity levels can vary depending on the geology and geochemistry of a given region. For example, storing water in drilled wells can lead to radioactivity.[1] Furthermore,[9] radioactivity that exceeded the WHO recommended levels was reported in water samples collected from boreholes and wells in Dutse, North-Western Nigeria. In this regard, one cannot determine whether the water consumed is safe unless it is reflected by radioactivity analysis. A study in South Africa measured levels of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) in 21 popular bottled water brands. Using gamma spectroscopy, researchers found all activity levels were within international safety limits, with ^{40}K being most abundant and ^{232}Th contributing the highest radiation dose. Infants were the most exposed age group. While the water is generally safe, a small lifetime cancer risk was estimated, underscoring the need for regular monitoring and strict regulation.[10]

Most of the mentioned studies and other studies in the literature focused on drinking water samples from sources other than those from a supply pipeline. A typical pipeline from a water processing plant to the city could span a length of one kilometer or even more. In most cases, it consists of multiple feeder outlets, which also lead to other channels. One pipeline (e.g., the one considered in this study) can be the source of drinking water for about a million individuals. The major concern is mostly attributed to old serving pipelines. Such pipelines may allow the accumulation of radioactive nuclides along their interior surfaces. As such, the need for radioactivity analysis in drinking water pipelines should be a priority. Following the above statements, this study is set to determine the levels of alpha and beta radioactivity in drinking water in an unexplored region, Kumbotso Local Government, Kano, Nigeria. We aimed to determine gross alpha and beta activity levels in drinking water collected from eight sample locations along the Panshekara-Dorayi pipeline (see Figure 1). In Section "DATA AND ANALYSIS", we discussed the Data collection and analysis methods. In Section "RESULTS AND DISCUSSION", we presented and discussed the results. We provide concluding remarks in the final section (Section "REMARKS").

DATA AND ANALYSIS

Data collection

Kano is one of the most populous cities in Nigeria. The metropolis is home to more than 3 million people. In addition, Kano is one of West Africa's rapidly developing cities.[11] A major drinking water processing plant (Callaway water board) is located at Kumbotso local government (Figure 1, left side). The feeder pipeline from the Callaway plant to the major distribution reservoirs in the city center passes through the Panshekara-Dorayi route (Figure 1, right side). This pipeline supplies over a million inhabitants with drinking water. The sample collection locations can be seen on the right of Figure 1. A total of 16 water samples were collected using 2 L plastic containers, which came directly from public taps (two containers from each sampling point). The first sample collection station (Panshekara-1) is less than 1 km from the Callaway water plant. All sampling points span about 8 km, starting from Panshekara-1, up to the final sample collection location (Dorayi-2, see Figure 1, right side). The distance between any two given sample collection locations is on average between 700 m and 1 km, as seen in Figure 1. The collection procedure is as follows. Each container is rinsed a few times with distilled water before collecting. To minimize interaction between the sample and the wall of the containing vessel, a 20 ml dilute HNO_3 is added after the collection. The samples collected are transferred to the Centre for Energy Research and Training, Zaria, Kaduna, Nigeria. The gross alpha and

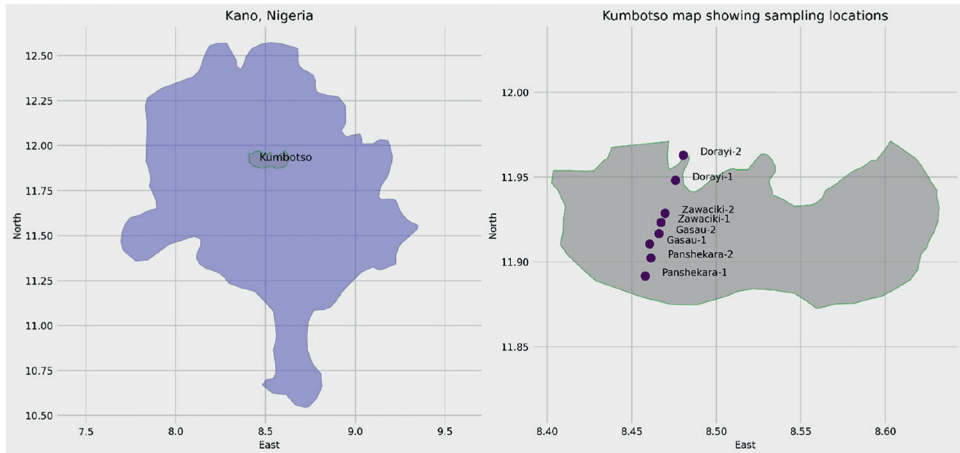

Figure 1. Map of Kano, North-Western Nigeria (left), and Kumbotso local government with data collection (sampling) location.

beta analysis procedure is done according to the International Standards Organization (ISO 9696 and ISO 9697: 1992E).[12]

Sample preparation and counting

A 100 ml "V_e" part of the sample is filtered and set to evaporate using a hot plate. This evaporation process is below the boiling temperature (to avoid excessive loss of residue). Evaporation continues until the sample volume is reduced to about half its original volume (about 50 ml). The sample is then transferred into a sterilized ceramic or petri dish, where the drying process is completed using an infra-red lamp. Next, the sample residue gets transferred into a planchet, and the mass of the residue (m_1) plus that of the planchet (m_2) is recorded in Eq. (1).

$$m_3 = m_1 + m_2 \tag{1}$$

A few drops of ethanol (C_2H_5OH) are added uniformly to the residue on the planchet surface. A Mylar film is used to cover it. It is left to dry out and is finally ready for counting. The sample efficiency S_e and sample volume V are estimated to be using Eqs. (2) and (3).

$$S_e = \frac{m_3}{m_1} \times 100\% \tag{2}$$

$$V = \frac{V_e}{m_1} \times S_e \tag{3}$$

Counting and analysis

A portable gas-free MPC2000B-DP single-channel gross alpha and gross beta radiation detector is used to count. Sample efficiency S_e and volume V that produced the obtained mass of the residue, other calibrated values, and constants are programmed using the counting software. Vinyl acetate is added to the residue and is distributed evenly over the surface of the planchette. Each sample is counted for 45 minutes, five times (2700 seconds per cycle), and the average result is taken.[12] In both cases, i.e., for gross alpha and gross beta, the voltage was set at 1600 and 1700 V in alpha and beta mode, respectively. Results are usually displayed as raw counts, count rate (count/minute), activity, and standard deviation. The procedure involves entering the pre-set time, number of cycles, and counting mode. The raw counts (CPM) were repeated three times each for all the samples, and the average value was obtained for each. Below is the formula for count rate activity and other parameters:

$$\text{Count Rate for } (\alpha / \beta) = \frac{\text{Raw count}(\alpha / \beta)}{\text{Count time}(\alpha / \beta)} \tag{4}$$

$$\text{Activity } (\text{BqL}^{-1}) = \frac{\text{Raws counts (CPM)} - \text{Background (CPM)}}{(\text{Detector efficiency}) \times (60) \times (\text{sample volume})} \tag{5}$$

Table 1. Gross alpha and gross beta radioactivity levels from collected water samples.

Sample	Coordinates	WHO recommended (BqL^{-1})	Alpha activity (BqL^{-1})	Statistical error (±)	Beta activity (BqL^{-1})	Statistical error (±)
Dorayi-1	(8°28'32.84"E, 11°56'53.31"N)	0.1–1	0.906312	0.235188	85.10961	11.73762
Dorayi-2	(8°28'49.57"E, 11°57'46.73"N)	0.1–1	0.284252	0.081549	25.58074	4.460959
Zawaciki-1	(8°28'2.46"E, 11°55'24.31"N)	0.1–1	0.090239	0.040559	37.24151	3.569717
Zawaciki-1	(8°28'10.93"E, 11°55'43.41"N)	0.1–1	0.333382	0.08062	24.45434	3.734627
Gasau-1	(8°27'38.10"E, 11°54'38.37"N)	0.1–1	Below detection	Below detection	25.37696	2.432462
Gasau-2	(8°27'57.86"E, 11°55'0.53"N)	0.1–1	0.490475	0.155883	61.30365	9.485765
Panshekara-1	(8°27'28.42"E, 11°53'30.29"N)	0.1–1	0.074238	0.017953	0.735327	0.080551
Panshekara-2	(8°27'40.81"E, 11°54'8.54"N)	0.1–1	0.039565	0.010952	5.951022	0.592372

Effective calculation

Let $I(\alpha/\beta)$ be the rate at which an individual consumes water (L per day/year), $A(\alpha/\beta)$ be the gross alpha and beta activity concentration (BqL^{-1}), and dose conversion factors (IDF) be the annual effective dose conversion factor (Sv/Bq). Then, the annual effective dose equivalent (in Sv/year) can be calculated using the following relation:[7]

$$DR = A(\alpha/\beta) \times I(\alpha/\beta) \times IDF \tag{6}$$

RESULTS AND DISCUSSION

The estimated gross alpha and beta activity concentrations, as well as their uncertainties from collected water samples, are presented in Table 1. As seen, alpha activity concentrations vary from 0.04 ± 0.01 to 0.9 ± 0.2 BqL^{-1}. The observed gross beta activity varies from 0.7 ± 0.08 to 85.1 ± 11.7 BqL^{-1}. The highest alpha concentrations recorded are from Dorayi-1. In order of decrease in magnitude, this is followed by Gasau-2, Zawaciki-2, Dorayi-2, Zawaciki-1, Panshekara-1, and Panshekara-2, respectively (Table 1). The alpha activity at Gasau-1 is below the detection limit. Similarly, the highest beta activity concentration is recorded from Dorayi-1, followed by Gasau-2, Zawaciki-1, Dorayi-2, Zawaciki-2, Gasau-1, Panshekara-2, and Panshekara-1.

The percentage distribution for the detected alpha and beta concentrations is given in Figure 2. According to these results, Dorayi-1 has the highest alpha and beta concentration counts. It covers about 41% (alpha) and 32% (beta) of the overall recorded activities. Interestingly, Gasau-2 follows with about 22% (for alpha) and 23% (for beta) in the overall counts. Besides these two sampling locations, all other percentages differ in recorded alpha and beta concentrations. The relationship is decent as Figure 3a suggests a reasonable correlation between the alpha and beta concentration counts (R-squared~0.8). The uncorrelated ones are Zawaciki-1 and Zawaciki-2. These two sampling locations are separated by less than half a kilometer, as their locations almost overlap on the map (Figures 3a and b). Unfortunately, these results imply that the gross alpha and beta activities are respectively higher than the 0.1 and 1.0 BqL^{-1} recommended by WHO. This is a significant concern as prolonged exposure to these radionuclides increases the likelihood of cancers, organ damage, and developmental issues, especially among vulnerable groups like children and pregnant women. Areas such as Dorayi-1 and Gasau-2, with the highest recorded levels, face heightened risks from chronic exposure. Moreover, contamination may affect agriculture, introducing radionuclides into the food chain.

Adamu et al. recently published a similar report on gross alpha and beta concentrations in borehole and well water samples in Kaduna State, northern Nigeria. A portable single-channel gas-

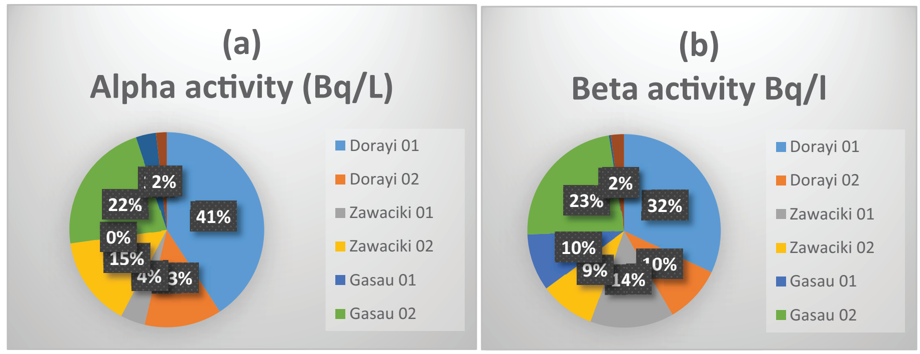

Figure 2. Percentage activity by location for gross alpha (a) and beta (b) concentrations.

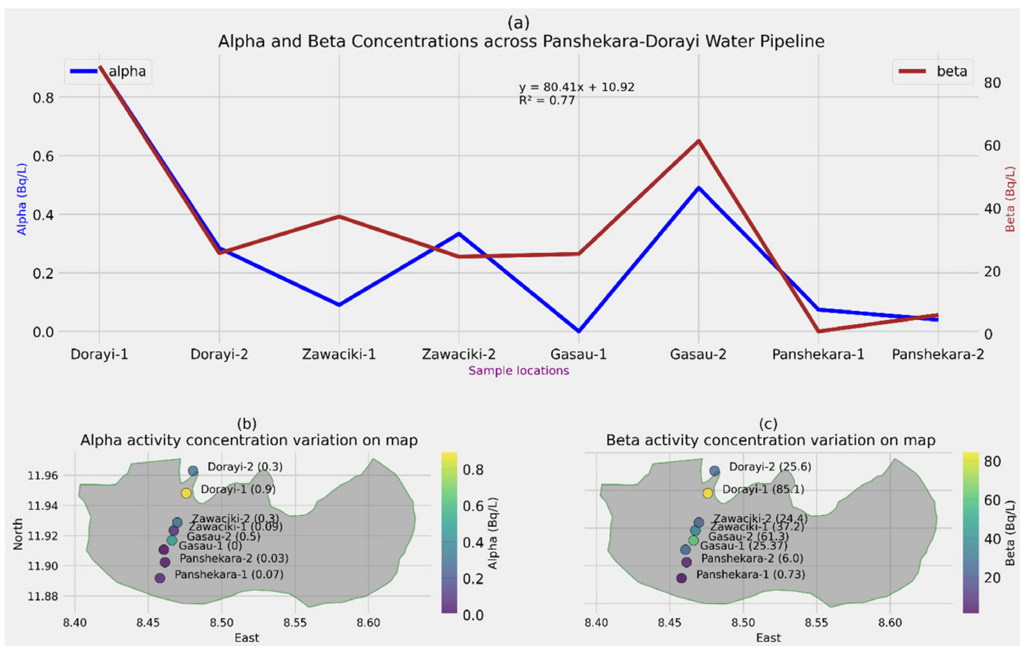

Figure 3. (a) Gross alpha and beta variations across the Panshekara-Dorayi pipeline, (b) Spatial heatmap for gross alpha concentrations across sample collection points, and (c) Spatial heatmap for gross beta concentrations across sample collection points. The heatmaps represent the magnitudes of the detected radioactivity (BqL⁻¹).

free MPC-2000B-DP detector was employed to record the data.[13] Although the findings showed that alpha levels in all samples were below the WHO limit of 0.5 BqL^{-1}, 11% of the samples exceeded the 1.0 BqL^{-1} WHO limit for beta activity. The authors attributed the high beta concentrations to industrial, agricultural, and medical activities in the area. Further, an investigation from Langa et al. performed on various water samples (tap, dam, water reservoir) at Gombe, Northeastern Nigeria, indicated that alpha and beta nuclide concentrations are well below the tolerable limit of the WHO. The experiment results recommend that the examined water samples be safe for drinking.[14] The European Euratom has, however, provided guidelines legislation S.I. No. 160/2016[15] for the screening level. When a gross alpha and gross beta activity are found to respectively exceed 0.1 and 1.0 BqL^{-1} analysis for specific radionuclide should be conducted. Techniques such as liquid scintillation counting (LSC) often serve as complementary methods for characterization. It measures the energy and intensity of radioactive decay events, especially beta-emitting isotopes, under low radionuclide levels. Such as ^{210}Po, ^{210}Pb, ^{235}U, ^{234}U, ^{238}U, ^{90}Sr etc. Recently, in some advanced countries such as Singapore, gross alpha and beta as well as titanium levels were studied in tap and bottled water, and the results show that titanium and gross alpha were below minimum detectable limits, while that for beta in tap water ranged from

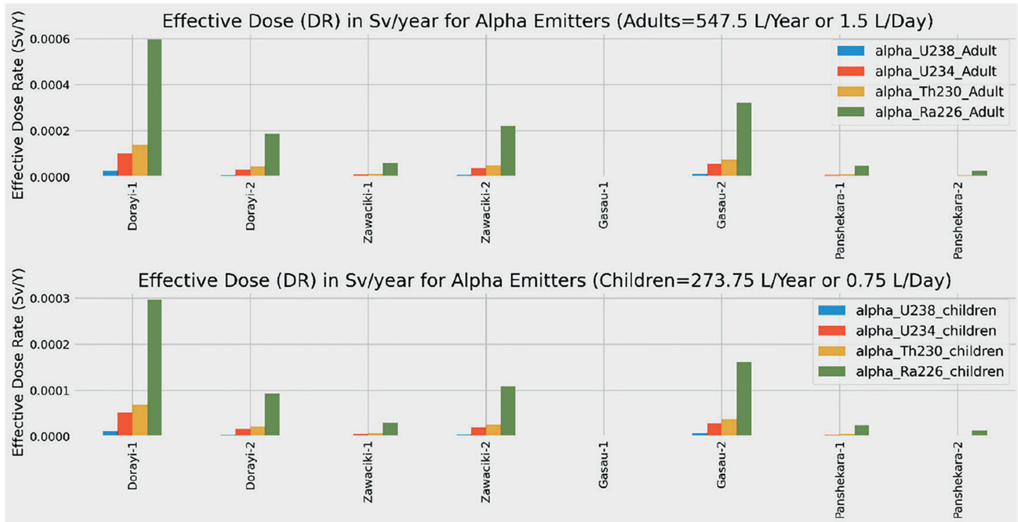

Figure 4. Effective dose rate for alpha emitter radionuclides (Uranium, Thorium, and Radium) calculated for adults (top panel) and children (bottom panel) using the data in Table 1.

0.228 to 0.258 BqL^{-1}. In bottled water, tritium, gross α, and gross β levels ranged from below detection limits to 1.59, 0.437, and 1.33 , respectively.[16]

To properly visualize this concentration variation across sampling locations, a heatmap is presented in Figures 3a and b. The sampling location is sorted by increasing distance relative to the Callaway water plant. As seen, concentrations are lower in sampling locations near the Callaway plant (Panshekara-1 and 2) and increase with distance. This can be explained if we consider the possibility of a higher shear force (pressure gradient) on the water molecules in locations near the Callaway plant compared to the rest of the sampling locations. For this reason, the radioactive nuclides in the pipe (uranium, thorium, radium, and lead) have easier settling and accumulation opportunities due to the presence of a near steady state condition. In addition, such a long supply pipe is not horizontal throughout the supply route. There are bents, inclinations, and declinations. This could potentially favor the settling of the radioactive molecules in some sampling locations compared to others, and thus, a possible reason for the inverse trajectories between alpha and beta curves observed in Zawaciki-1 and Zawaciki-2 sampling stations Figure 3a.

As presented in Eq. (6), it is possible to estimate the risk associated with these detected radioactive levels on the population at the individual level. In the calculation process, it is assumed that alpha emitter radionuclides present in the water supply pipeline are U238, U234, Th230, and Ra226 and the beta emitters are Pb210, and Ra228. The IDF are taken as recommended by WHO, 4.5×10^{-5} $mSvBq^{-1}$ for ^{238}U, 4.9×10^{-5} $mSvBq^{-1}$, for ^{234}U, 2.1×10^{-4} $mSvBq^{-1}$ for ^{230}Th, 2.8×10^{-4} $mSvBq^{-1}$ for, ^{226}Ra, 1.2×10^{-3} $mSvBq^{-1}$ for ^{210}Po, and 6.9×10^{-4} $mSvBq^{-1}$ for ^{228}Ra.[7] For simplicity, the estimations were made for two categories of consumers. The first category is for adults (>18 years), while the second category is for children (<18 years). It is also assumed that the children consume half of what adults consume annually. The final assumption is that an average adult consumes about 1.5 L of water daily, and 365 days make up a year. With this in place, Figures 4 and 5 give the annual effective dose estimations for adults and children across sample locations. Following the previous discussion, it is obvious that Dorayi-1 $mSvy^{-1}$ and Gasau-2 would have the highest effective dose rate per individual for both alpha and beta emitter concentrations. Let us consider Radium-226 as a major alpha emitter in the sample. The data in Figure 4 (top panel) indicates the annual effective doses for the adults in Dorayi-1 (0.5 $mSvy^{-1}$). Gasau-2 (0.3 $mSvy^{-1}$) and Zawaciki-2 (0.2 $mSvy^{-1}$) have exceeded the WHO recommended reference level of 0.1 mSvy–1 for tap, spring and river water samples. A similar outcome is observed in Figure 4 (bottom panel). The data suggests that annual effective doses for children in Dorayi-1 (0.3 $mSvy^{-1}$), Gasau-2 (0.2 $mSvy^{-1}$) and Zawaciki-2 (0.3 $mSvy^{-1}$) have exceeded the WHO recommended reference level.

It is possible that U^{238}, U^{234}, and Th^{230} dominate as alpha sources compared to Radium in the water samples. In this case (apart from Dorayi-1), the annual effective dose rates for adults and children vary within the acceptable range recommended by WHO. A limitation of this study is that only the alpha

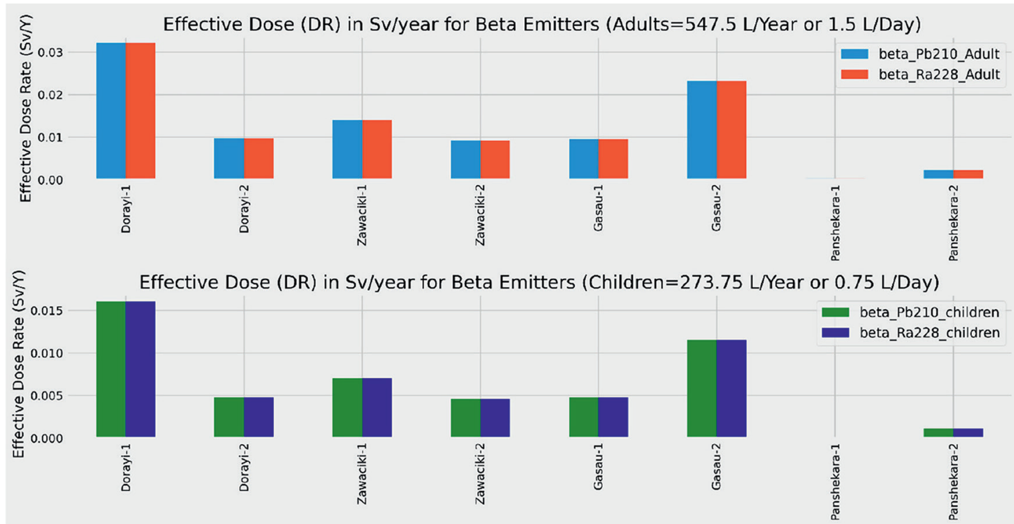

Figure 5. Effective dose rate for beta emitter radionuclides (Lead and Radium), calculated for adults (top panel) and children (bottom panel) using the data in Table 1.

activity levels are measured. It is not possible to directly infer a given radionuclide as the main source of alpha/beta levels. This should be considered in future research. However, radium is a probable candidate because, compared to other alpha emitters, radium is regarded as a prominent source of alpha radiation. The reason is that the decay and the decay of its progeny (Radon, polonium, lead, and bismuth) are considered a major source of natural alpha and beta particle sources in soil and the lower atmosphere.[17] As such, elevated levels of alpha radiation, particularly from ^{226}Ra and its decay products, would pose significant health risks. Adults consuming water from Dorayi-1, Gasau-2, and Zawaciki-2 would be exposed to doses exceeding WHO limits, increasing the likelihood of bone cancer and kidney damage over time. The risks are even higher for children, as developing tissues are more vulnerable. Prolonged exposure to such radiation levels underscores the need for immediate intervention to mitigate health impacts on the population.

However, the data presented in Figure 5 (top panel) and (bottom panel) imply that most of the annual effective dose for beta activity levels across the sampling locations are greater than WHO recommended 0.1 mSvy^{-1} for tap, spring, and river water samples. Panshekara-1 and Panshekara-2 seem to have the lowest levels compared to other sample collection points. However, their effective annual dose for adults is greater than the WHO recommended values, while that of the children is within the limit. In alpha and beta cases, the inhabitants using water from Dorayi-1 and Gasau-2 stations are most vulnerable. These findings highlight a critical concern for the health and safety of inhabitants relying on water from Dorayi-1, Gasau-2, and other stations with elevated alpha and beta radiation levels. The vulnerability of adults and children to radiation-related health risks demands immediate attention, as prolonged exposure to such levels can result in severe long-term health consequences, including cancer and organ damage. To address this pressing issue, it is essential to build on the current study by expanding the scope of research. A detailed radioactivity analysis of water from the Callaway River, which may be a potential source of contamination, should be conducted to understand the extent and origin of the radioactivity. Investigating the integrity of the existing pipeline infrastructure, identifying and repairing leaks, or replacing sections of the pipeline may be necessary to prevent further contamination. Additionally, implementing regular monitoring programs for alpha and beta radiation levels in drinking water, alongside public awareness campaigns, can help mitigate health risks. If the elevated radiation levels are confirmed through further studies, decisive measures such as upgrading water treatment facilities to remove radioactive contaminants or switching to alternative water sources should be considered. These steps are crucial to safeguarding public health and ensuring sustainable access to safe drinking water for the affected communities.

REMARKS

The concentrations of gross alpha and beta activities in tap water from Kumbotso local government exceed WHO-recommended limits, with the highest annual effective doses recorded at Dorayi-1 and Gasau-2. The detected alpha and beta activities suggest a significant radiological risk to residents, particularly from radium-226 and its progeny, which are known to contribute prominently to natural radioactivity. This study's findings indicate that the population is potentially exposed to elevated health risks, including cancer and organ damage, necessitating immediate attention and action. To address these issues, it is imperative to expand the scope of research by conducting a comprehensive radioactivity analysis of water sources, such as the CALLAWA River, to trace the origin of the contamination. Infrastructure evaluations to identify and repair leaks, replace faulty pipelines, and improve water treatment facilities are crucial steps. Regular monitoring of radiation levels, public awareness campaigns, and enforcing stringent water safety standards should also be prioritized. If future studies confirm these elevated levels, decisive measures such as switching to alternative water sources or upgrading treatment processes must be implemented without delay. Although current research employs a simple method to determine the radioactive alpha and beta concentrations, a more in-depth spectroscopic analysis of isotope-specific (such as alpha and gamma spectrometry) is underway. This is crucial due to its precision in identifying the isotope, which can be used to trace the source of contamination. This work provides critical baseline data that will facilitate evaluating future changes in radiometric levels and their implications for public health. By building on these findings, researchers and policymakers can collaboratively develop sustainable solutions to ensure the safety and well-being of affected communities.

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Conflicts of interest

None.

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