Assessing Microbial Contamination and Water Safety Risks in the Black Volta River Basin of Northern Ghana

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ABSTRACT

Microbial contamination of surface water remains a critical public health concern, particularly in low-resource settings with limited access to safely managed drinking water. This study evaluates the microbial quality of the Black Volta River, a key water source for Wa Municipality in Northern Ghana, and examines the implications for water safety and public health. Water samples were collected from raw, treated, and distributed sources during both dry and rainy seasons in 2021 and 2022. Microbial analyses assessed total viable count (TVC), Escherichia coli, and total coliforms, benchmarked against World Health Organization (WHO) standards. Results revealed that raw water consistently exceeded WHO limits, with TVC levels reaching 580 CFU/ml and 1000 CFU/ml in the dry and rainy seasons, respectively. Similarly, E. coli concentrations peaked at 250 CFU/ml (dry season) and 480 CFU/ml (rainy season). Treated and distributed water samples, however, consistently met WHO microbial quality guidelines, indicating effective disinfection by Ghana Water Limited. Seasonal dynamics significantly influenced contamination levels, with elevated microbial loads during the rainy season. Qualitative data from key informant interviews identified anthropogenic pressures, including open defecation, livestock grazing, and agricultural runoff along riverbanks, as major contributors to microbial pollution. Although the treatment system ensures compliance at the point of distribution, elevated raw water contamination levels increase operational burdens and treatment costs. The study underscores the need for integrated watershed protection, public sanitation education, and adaptive management strategies to safeguard water quality and public health in Ghana's rural and peri-urban communities.

Keywords: Black Volta, microbial contamination, water quality, agricultural waste, Escherichia coli, total coliforms, water treatment, sanitation practices

1.0 INTRODUCTION

Water is vital for human health and environmental sustainability, yet its quality is increasingly threatened by both natural and anthropogenic factors (Angelakis et al., 2023). The contamination of surface water, particularly rivers, poses significant risks to water safety and public health, especially in developing regions where water treatment systems may be inadequate (Islam et al., 2023; Singh et al., 2024). The Black Volta River, a crucial water source for many communities in Ghana, is similarly affected by microbial contamination resulting from agricultural runoff, open defecation, and land use practices such as illegal mining, locally referred to as "Galamsey" (Amengor, 2024; Faseyi et al., 2023). According to the United Nations Children's Fund and World Health Organization, microbial contamination, particularly from fecal matter, is a leading cause of waterborne diseases such as cholera, dysentery, and typhoid fever (UNICEF & WHO, 2024). The Black Volta River, serving both urban and rural populations, exemplifies these challenges and underscores the need for a comprehensive study of its microbial quality.

Recent research highlights the role of agricultural practices and inadequate sanitation in increasing surface water contamination. Zimmer-Faust et al. (2025) identified agricultural runoff, particularly in areas with shared animal grazing and fertilizer use, as a significant source of microbial pollutants. Similarly, Yang et al. (2025) found a strong correlation between open defecation and elevated levels of E. coli and total coliforms in rivers used for domestic purposes in sub-Saharan Africa. These findings are pertinent to the Wa Municipality, where the Black Volta River is similarly impacted. The implications of microbial contamination extend beyond public health to encompass broader water management challenges (Chen & Ding, 2024). The Ghana Water Limited (GWL) treats raw water from the Black Volta River to meet WHO standards; however, treatment effectiveness is often compromised by fluctuating microbial pollutant levels, particularly during seasonal transitions (Agodzo et al., 2023). Timmer (2023) reported significant seasonal variations in microbial contaminants, with higher concentrations observed during the rainy season, largely due to agricultural practices and open defecation along the riverbanks.

In Ghana, the prevalence of waterborne diseases is closely linked to water microbial quality, particularly in rural areas with limited access to treated water (Yeboah et al., 2024). The contamination of the Black Volta River exemplifies the broader challenges of managing microbial pollutants in resource-limited settings (Agodzo et al., 2023). The presence of microbial contaminants such as total coliforms and E. coli in drinking water is a critical public health concern, as these indicators of fecal pollution can lead to severe health consequences if consumed without proper treatment (Agodzo et al., 2023). Access to quality water resources is a critical public health issue in Wa Municipality, where rural communities face significant challenges related to water quality and availability. Studies indicate that while groundwater sources in the region, such as boreholes and wells, often meet WHO standards for certain contaminants, issues persist with microbial contamination, particularly from human activities like open defecation and agricultural runoff (Kpoda & Darimani, 2022; Bowan, 2022). The reliance on untreated water sources increases the risk of waterborne diseases, which disproportionately affect vulnerable populations, including children and the elderly (Husein et al., 2023). Furthermore, inadequate sanitation infrastructure and limited community engagement in water management exacerbate these challenges, leading to public water rationing and reliance on private suppliers (Kosoe & Osumanu, 2015; Mangai & Vries, 2018). The interplay of these factors highlights the urgent need for comprehensive water quality monitoring and community involvement in water resource management to enhance public health outcomes in Wa Municipality (Willis et al., 2022; Oteng-Peprah et al., 2020).

This study aims to examine the microbial quality of the Black Volta River and its implications for water safety in the Wa Municipality. Specifically, it assesses the concentrations of microbial contaminants in raw, treated, and distributed water, the effectiveness of water treatment practices, the need for enhanced mitigation strategies, and the influence of community activities on microbial loads in the Black Volta River and the need for public participation. This research contributes to the growing body of literature on water quality management in sub-Saharan Africa, providing valuable data for policymakers and water management authorities in Ghana and beyond, and highlighting the necessity for integrated approaches to water resource management that consider both human activities and environmental factors affecting water quality.

2.0 METHODOLOGY

2.1 Study Area

The study was conducted in the Wa Municipality of Ghana, focusing on the Black Volta River. The river serves as a vital source of water for domestic, agricultural, and industrial purposes in the Municipality and surrounding areas. The study area is characterized by a mix of urban, suburban, and rural settlements, with significant anthropogenic activities such as farming, grazing, and open defecation along the riverbanks. These activities contribute to microbial contamination, making the Black Volta River an essential subject for water quality assessment**.** The Black Volta River, a crucial transboundary water source flowing through Ghana, Côte d'Ivoire, Burkina Faso, and Mali, significantly influences the Wa Municipality in Ghana's Upper West Region. The area experiences a tropical savannah climate with distinct wet and dry seasons, receiving an average annual rainfall of 900–1,200 mm, primarily between May and October, peaking in August and September. River flow patterns align with these rainfall variations, with increased discharge and surface runoff during the rainy season contributing to heightened microbial contamination, while the dry season (November to April) sees diminished flow, concentrating pollutants. Temperatures in the region range from 20°C to 40°C, with March and April being the hottest months, and harmattan winds during the dry season exacerbate evaporation and sediment deposition. These climatic and hydrological conditions directly impact water quality, microbial contamination, and seasonal variations in the Black Volta River, which serves as a vital water source for domestic, agricultural, and industrial uses in the Wa Municipality.

2.2 Study Design and Sampling Strategy

This study employed a quasi-experimental research design to evaluate the microbial contamination levels in water samples collected from the Black Volta River and their potential public health implications. This design facilitated an investigation of cause-and-effect relationships between anthropogenic activities and water quality, employing both quantitative and qualitative methods (Das, 2025). The dependent variable was surface water quality, while the independent variables included microbial contaminants influenced by activities along the riverbank.

A randomized sampling approach was adopted to ensure representative data. Water samples were collected from three designated locations:

1. Raw water at the river intake point (Group A),
2. Treated water at the treatment facility (Group B),
3. Distributed water at the end-user points (Group C).

The selection of the three sampling points (intake treatment, and distribution sites) represent the comprehensive dynamics of the Black Volta River's contamination and treatment processes. The intake site reflects upstream contamination from activities such as farming, open defecation, and runoff, providing a baseline for assessing seasonal microbial loads. The treatment site evaluates the effectiveness of disinfection and filtration processes in meeting WHO standards for potable water, highlighting the treatment facility's ability to mitigate pollutants. Finally, the distribution site examines the quality of water delivered to consumers, identifying potential issues like recontamination during transport. Together, these points capture the entire water supply chain, from contamination sources to treatment efficacy and consumer safety. Sampling was conducted during the dry (February–April) and rainy (July–September) seasons of 2021 and 2022 to capture seasonal variations in contamination levels.

2.3 Water Sampling and Laboratory Analysis

Water samples were collected using sterilized 1-liter bottles, sealed, labelled, and transported under refrigeration (< 4 °C) to the Ghana Water Limited (GWL) laboratory for analysis within 4 h. Microbial parameters assessed included:

- Total Viable Count (CFU/ml, at 37 °C for 48 h)
- *Escherichia coli* (CFU/ml, at 37 °C for 48 h)
- Total Coliforms (CFU/ml, at 37 °C for 48 h)

Chromocult nutrient enrichment agar was employed as the culture medium. After sampling, all samples were sealed, labeled, and stored over ice in a thermo-insulated container to maintain the samples at a temperature below 4 ºC prior to their transportation to the Chemical/Biological Laboratory of the Ghana Water Limited within 2 – 4 h (WHO, 2024) for analysis.

Results were benchmarked against WHO standards for potable water. To ensure data validity and reliability, the study implemented robust Quality Assurance/Quality Control (QA/QC) measures, including sterilization of all sampling equipment through autoclaving, duplicate sampling at each site to verify results, and the use of field and lab blanks to detect contamination during handling and analysis. Samples were transported in sterilized bottles under 4 °C and analyzed within 4 hours to maintain microbial integrity. Positive and negative controls were used to validate microbial culture accuracy, while all procedures adhered to WHO and ISO standards (e.g., GS ISO 6222 for total viable counts). Triplicate tests for microbial parameters enhanced statistical reliability, and equipment calibration ensured measurement accuracy. Detailed documentation and trained personnel minimized errors, and statistical tests, including paired t-tests, validated observed patterns, ensuring robust, reproducible findings on the Black Volta River's microbial contamination.

2.4 Qualitative Data

Key informant interviews were conducted with GWL officials and local community members to ascertain human activities contributing to microbial pollution. The interviews explored agricultural practices, sanitation habits, and local perspectives on water quality challenges.

2.5 Data Analysis

Quantitative data from laboratory analyses were processed using SPSS (Version 20). Descriptive statistics highlighted contamination levels across seasons, while paired t-tests assessed significant differences between sampling groups and seasons. Correlation analysis examined relationships between microbial contaminant levels and human activities. Qualitative data were transcribed and coded thematically to triangulate findings from the laboratory analyses and provide contextual understanding of contamination sources.

3.0 RESULTS

This study evaluated the water quality of raw, treated, and distributed water samples from the Black Volta collected during the dry and rainy seasons, benchmarking the results against WHO recommended limits. Key microbiological contaminants, such as total viable count, *E. coli,* and total coliforms, are presented to highlight variations across different water treatment stages and seasons. The findings presented not only provide insights into the effectiveness of GWCL's treatment processes but also underscore the challenges of maintaining safe, high-quality water standards in the region.

3.1 Microbial Contamination Levels and their Seasonal Variations Across Sampling Points

The microbial contaminants assessed in this study included Total Viable Count (CFU/ml, at 37 °C for 48 h), E. coli (CFU/ml, at 37 °C for 48 h), and Total Coliform (CFU/ml, at 37°C for 48 h). These parameters were benchmarked against WHO guidelines for potable water and are summarized in Figure 1 and Table 1. Table 1 suggests that the Total Viable Count (TVC) in raw water (RW-21) was significantly above the WHO recommended limit of ≤ 500 CFU/ml, with concentrations of 580 CFU/ml during the dry season and 1000 CFU/ml during the rainy season. In contrast, treated water (TW-21) and distributed water (DW-21) had 0 CFU/ml during both seasons, indicating the effectiveness of the treatment process. For *E. coli*, raw water samples (RW-21) showed concentrations of 250 CFU/ml in the dry season and 480 CFU/100ml in the rainy season, exceeding the WHO guideline of 0 CFU/ml. Treated water (TW-21) and distributed water (DW-21), however, consistently met the WHO standard with 0 CFU/ml in both seasons, demonstrating effective disinfection by the Ghana Water Company Limited (GWL). Similarly, Total Coliform concentrations in raw water (RW-21) were 330 CFU/ml during the dry season and 390 CFU/ml during the rainy season, both exceeding the WHO guideline of 0 CFU/ml. Treated water (TW-21) and distributed water (DW-21) maintained 0 CFU/ml, reflecting the adequacy of the treatment process. These findings underscore the effectiveness of the water treatment system in mitigating microbial contamination. However, the elevated levels of microbial contaminants in raw water highlight the need for enhanced source protection, especially during the rainy season when contamination levels are markedly higher due to surface runoff and anthropogenic activities along the riverbanks.

With regards to the microbiological contaminants, despite being within the acceptable limit of (500 CFU/ml) for the total viable count during the dry and wet seasons for both TW-22 and DW-22, RW-22's concentration points in Table 2 were higher than those of TW-22 (380 CFU/ml) and DW-22 (135 CFU/ml), which were far less concentrated. Regarding E. coli and total coliform, the results indicated significant concentration levels for RW-22 (120 & 12 CFU/ml) and (260 & 93 CFU/ml) for both the dry and wet seasons, respectively, as opposed to TW-22 and DW-22 (0 CFU/ml), which were within the WHO standard requirement since the water has been treated (Table 2). Figure 1 confirms the differences in microbial contamination between raw and treated water samples from the Black Volta River Basin.

The raw water plate shows visible microbial colony growth, indicating substantial microbial contamination before treatment and supporting the quantitative results reported for total viable count, *E. coli*, and total coliforms. The presence of *E. coli* and coliform bacteria in water is widely used as an indicator of fecal contamination and potential public health risk, particularly where surface waters are affected by sanitation deficiencies, runoff, livestock activity, and other human pressures (Pitkänen et al., 2010; Mohan et al., 2022; Yang et al., 2025). In contrast, the treated water plate shows a near absence of detectable colonies, demonstrating the effectiveness of the treatment and disinfection process in reducing microbial loads to levels consistent with potable water safety expectations. This observation is consistent with studies showing that effective coagulation, filtration, and disinfection processes can substantially reduce *E. coli* and total coliform concentrations in treated water (Marois-Fiset et al., 2016; WHO, 2024). The contrast between the two plates reinforces the importance of Ghana Water Limited's treatment system in protecting public health, while also emphasizing that high microbial loads in raw water can increase treatment demands, operational costs, and the need for stronger watershed protection measures.

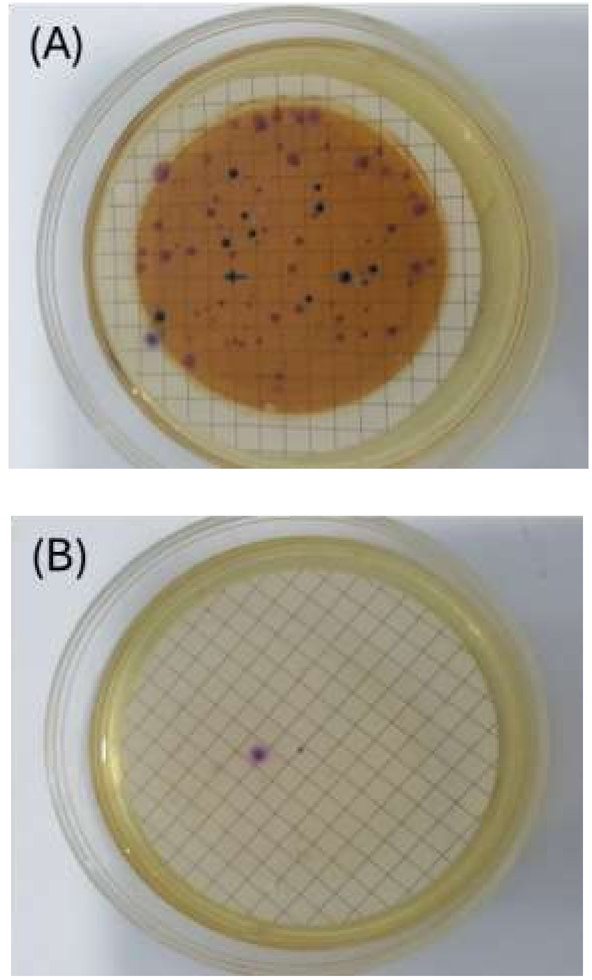

Figure 1*:* Representative microbial culture plates showing microbial contamination levels across sampled water sources from the Black Volta River Basin during laboratory analysis.
(A) Raw water sample showing high total viable count and coliform growth;
(B) Treated water sample showing near absence of detectable microbial colonies after disinfection;

Table 1: Microbiological contaminants in raw, treated, and distributed water

Determinants	**WHO Standard**	**2021 (Dry Season)**			**2021 (Rainy Season)**		
		Raw Water	**Treated Water**	**Distributed Water**	**Raw Water**	**Treated Water**	**Distributed Water**
Total viable count, CFU/ml, at 37 ºC for 48 h	500	580	0	0	1000	0	0
E. coli, CFU/ml	0	250	0	0	480	0	0
Total Coliform, CFU/ml	0	330	0	0	390	0	0

Table 2: Microbiological contaminants in raw, treated, and distributed water

Determinants	**WHO Standard**	**2022 (Dry Season)**			**2022 (Rainy Season)**		
		Raw Water (RW-22)	**Treated Water** (TW-22)	**Distributed Water** (DW-22)	**Raw Water** (RW- 22)	**Treated Water** (TW-22)	**Distributed Water** (DW-22)
Total viable count, CFU/ml, at 37 ºC for 48 h	500	380	0	0	135	0	0
E. coli, CFU/ml	0	120	0	0	12	0	0
Total Coliform, CFU/ml	0	260	0	0	93	0	0

3.2 Impacts of microbiological pollutants

Paired sample t-test analyses with a 95% confidence interval were carried out to determine the statistical difference between samples taken during the dry and wet seasons with relation to the impact of the microbiological parameters, Total coliform, E. coli, and Total Viable Count, on water quality as presented in Table 3. The outcome demonstrates that while there was no difference in microbiological contaminants according to the parameters tested in treated and distributed water (i.e., statistics were not calculated because results were zero), positive correlation were observed but were not statistically significant correlation differences between 2021 and 2022 results (correlation coefficient = 0.812, *p*-value = 0.396) and samples from the dry season and rainy season (correlation coefficient = 0.932, *p*-value = 0.237), and (correlation coefficient = 0.991, *p*-value = 0.087), respectively, within the years (Table 3).

The results of paired sample analysis (Table 4) highlight year-to-year and seasonal variations in microbial contamination levels in raw water. While differences between 2021 and 2022 contamination levels showed a mean increase of 225.56, this was not statistically significant (p = 0.081). Seasonal differences in 2021 (dry vs. rainy) also showed higher contamination during the rainy season (mean difference = -236.67), but this difference was not statistically significant (p = 0.151). In contrast, 2022 exhibited a significant seasonal variation, with higher contamination during the rainy season (mean difference = 173.33, p = 0.049) (Table 4).

Table 3: Paired Samples Correlations of microbiological variables of samples between dry and rainy seasons

	Paired sample	**N**	**Correlation**	***p*-value**
Pair 1	Mean, raw water (2021) & Mean, Raw Water (2022)	3	0.812	0.396
Pair 4	Raw Water (Dry – 2021) & Raw Water (rainy – 2021)	3	0.932	0.237
Pair 5	Raw Water (Dry – 2022) & Raw Water (rainy – 2022	3	0.991	0.087

Table 4: Paired Samples t-Test analysis of microbiological variables: raw, treated, and distributed water in dry and rainy seasons between 2021 and 2022

	Paired sample	Paired Differences: Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper	**t**	**Df**	**p-value**
Pair 1	Raw Water 2021 – Raw Water 2022	225.55556	118.52910	68.43281	-68.88706	519.99817	3.296	2	0.081
Pair 4	Dry Season (RW 21) vs Rainy Season (RW 21)	-236.667	180.093	103.976	-684.041	210.708	-2.276	2	0.151
Pair 5	Dry Season (RW 22) vs Rainy Season (RW 22)	173.333	68.719	39.675	2.625	344.041	4.369	2	0.049

4.0 DISCUSSIONS

The implications of microbial contamination findings in the Black Volta River are significant, particularly given the observed variations in water quality driven by human activities and seasonal dynamics. Key indicators such as *E. coli*, total coliforms, and total viable counts serve as critical markers of water quality and public health risks associated with consuming untreated water. The Ghana Water Limited faces challenges in ensuring a safe water supply, particularly due to these microbial pollutants. Recent studies have highlighted the fluctuations in total coliform and fecal coliform levels in various water bodies, indicating a direct correlation between human activities and water quality degradation. For instance, in the Achankovil River, total coliform concentrations ranged from 100 to 840 MPN/ml, with fecal coliform levels between 10 and 220 CFU/ml, underscoring the health risks posed by consuming untreated water, which can lead to gastrointestinal diseases and other health complications (Mohan et al., 2022). *E. coli* in the Black Volta River indicates fecal contamination, primarily attributed to human activities such as open defecation and agricultural runoff, which are prevalent in the region (Habib, 2024).

The findings from the Black Volta River align with the work of Kothari et al. (2021), who developed an association matrix indicating that total coliform, fecal coliform, and total iron concentrations significantly impact the water quality index. However, the study also revealed a lack of statistically significant correlation between microbiological pollutants and overall water quality, a finding that resonates with other studies that reported no significant relationships between microbial levels and overall water quality indicators. This discrepancy highlights the complexity of assessing water quality and the multifaceted nature of microbial contamination. The seasonal dynamics of microbial contamination are particularly pronounced, with higher concentrations observed during the rainy season due to increased runoff from agricultural and urban areas. Research supports this observation, indicating that rivers in regions with significant human activity often exhibit elevated microbial levels during wet seasons, thereby increasing the risk of waterborne diseases (Islam, 2024).

In the Black Volta River, the seasonal influx of contaminants exacerbates the challenges faced by GWL in maintaining water quality, especially as treatment costs rise in response to increased microbial loads. Moreover, the study revealed a statistically significant difference in microbial contamination levels between dry and rainy seasons, emphasizing the critical role of seasonal variations in water quality management. Studies (Le et al., 2021; Liu et al., 2025; Salma et al., 2025;) have corroborated this finding, noting that tropical water bodies typically experience heightened microbial contamination during rainy seasons due to surface runoff. This seasonal fluctuation necessitates continuous monitoring and adaptive management strategies to mitigate contamination risks effectively. Community practices also play a vital role in influencing water quality. Key informant interviews indicated that activities such as open defecation and farming near the river significantly contribute to microbial pollution. Research (Atemoagbo et al., 2024; Singh, 2024) have found similar results, highlighting the impact of poor sanitation infrastructure in rural areas on surface water contamination. These findings underscore the urgent need for improved sanitation practices and community engagement to protect water sources from further degradation. The correlation between *E. coli* and total coliform levels in raw water samples further emphasizes the health risks associated with untreated water consumption.

WHO has consistently warned about microbial contamination, particularly from fecal sources, which can lead to severe waterborne diseases such as cholera and typhoid (Mwevura et al., 2021). In the Wa Municipality, where many residents rely on the Black Volta River for drinking water, the high levels of microbial contamination present significant public health challenges, particularly for vulnerable populations. Despite GWL's successful treatment of water to meet WHO standards, the high microbial load in raw water complicates treatment processes and increases operational costs. Elevated microbial levels necessitate more intensive treatment methods, further straining resources for water treatment facilities. This situation is exacerbated by seasonal variations in contamination levels, particularly during the rainy season when runoff increases. The study's findings call for proactive measures to address the sources of microbial contamination in the Black Volta River. Community education on the importance of protecting water sources, stricter enforcement of regulations regarding agricultural practices near water bodies, and the implementation of better land-use practices are essential to reduce runoff during the rainy season. Emphasizing the importance of maintaining the integrity of water distribution systems to prevent recontamination of treated water is crucial for ensuring safe drinking water (Zheng et al., 2020).

5.0 CONCLUSION

In conclusion, the assessment of microbial contamination in the Black Volta River reveals significant public health risks associated with untreated water consumption. The findings indicate that human activities and seasonal dynamics play critical roles in influencing water quality. While GWL effectively treats water to meet WHO standards, the high levels of microbial pollutants in raw water necessitate ongoing monitoring and adaptive management strategies to mitigate contamination risks and protect public health. While treated and distributed water samples met WHO microbial quality standards, the elevated microbial loads in raw water, driven by anthropogenic activities such as open defecation, livestock grazing, and farming near the river, pose significant challenges for water treatment facilities, increasing both the complexity and cost of disinfection. The findings emphasize the critical need for upstream source protection, strengthened enforcement of environmental regulations, and sustained community engagement on hygiene and sanitation practices. Addressing these upstream risks through integrated water resource management and public health interventions is essential to ensuring the long-term safety and sustainability of drinking water systems in Ghana’s rapidly urbanizing secondary cities.

DECLARATIONS

Author Contributions: All the authors conceived, designed the study, and contributed to the questionnaire preparation. JK and ADM collected the data in the field, while EAK supervised the process. JK, EAK, and MCO analyzed the data, interpreted the results, and wrote the first draft of the manuscript. All the authors contributed to subsequent drafts and approved the final draft. All authors have read and agreed to the published version of the manuscript.

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