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Research Paper

Drinking water quality and health risk assessment of intake and point-of-use water sources in Tano North Municipality, Ghana

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ABSTRACT

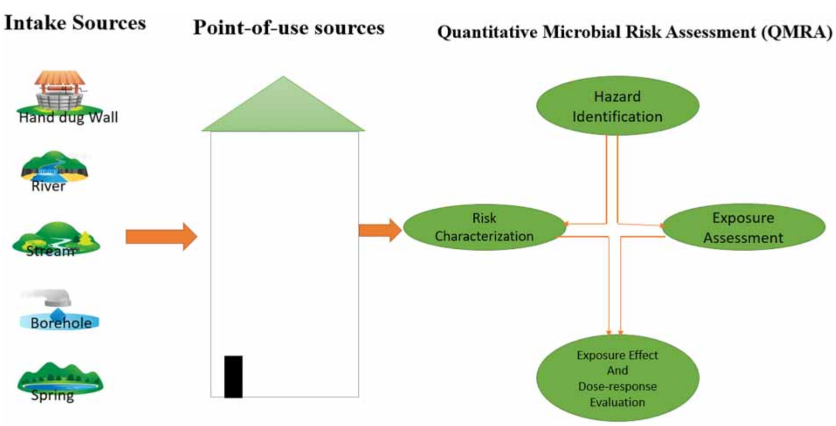
This study assessed the change in the quality of drinking water from the intake to point-of-use and the health risk to consumers of the water sources in a farming community in Ghana. Water samples were collected from five intake sources and point-of-use sources from 31 households. A quantitative microbial risk assessment (QMRA) was used to estimate the health risk. All the physicochemical parameters were found to be within the WHO guidelines except pH and water hardness. Again, none of the physicochemical parameters showed a significant difference between intake and point-of-use water sources. There were, however, significant differences in the mean total and fecal coliforms between the intake source and point-of-use source (3.63 vs 4.57 log CFU/100 mL and 1.38 vs 2.83 log CFU/100 mL, respectively). The results of the QMRA showed that the disease burden arising from exposure to river and spring water sources were above the WHO reference tolerable risk level of 1×10^{-6} Disability-Adjusted Life Years per person per year. The results of this study are expected to influence relevant stakeholders toward initiating plans that could mitigate the spread of waterborne diseases and avert the related economic implications in the study community.

Key words: Ghana, public health, QMRA, water quality, water-related diseases

HIGHLIGHTS

- This study is expected to improve health, sanitation and protect lives.
- This study is expected to influence stakeholders and local authorities toward initiating plans that mitigate the spread of waterborne diseases.
- This study seeks to achieve the SDG 6.
- This study also assesses the quality of drinking water and the health risk assessment of the water usage.
- This study will add up to existing knowledge on water quality.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Access to potable water remains a critical challenge in terms of protecting communities from waterborne diseases in the developing world. It may improve health, sanitation and food security as well as protect lives and reduce poverty (UNICEF & WHO 2015). Yet, it is estimated that 27% of the world's population still lacks access to safe drinking water and 2.3 billion people lack access to adequate sanitation (WHO 2020). Recent statistics indicate that water-related diseases account for 4 billion estimated cases of global disease burden and cause 3.4 million deaths annually, with 88% attributed to unsafe water drinking water supply and sanitation (Kahuho *et al.* 2019; WHO 2020). Accordingly, access to potable drinking water supply and improved sanitation, and reducing water-related diseases are key indicators in achieving the Sustainable Development Goal 6 as formulated by the United Nations. However, the effort required in accomplishing the set goals has been hindered by population growth, water source contaminations and poor sanitation coupled with industrial discharges and domestic wastes (Alemu *et al.* 2013).

In Ghana, access to drinking water is derived from a variety of sources depending on the local availability of surface water (rivers, streams, springs, lakes and ponds), groundwater (aquifers) and rainwater (Owusu *et al.* 2016). Most of these water bodies receive a varied range of pollution from point and or non-point sources by both natural and anthropogenic causes (Owusu *et al.* 2016). Water pollution occurs when harmful substances enter into receiving water bodies, being physical, chemical and/or biological agents, which alter the quality of water thus posing a threat to living organisms that depend on the water (Adekiya *et al.* 2020). Pollution activities introduce pollutants into the water and pose health threats to users if the water is not thoroughly treated (Sinharoy *et al.* 2019). There is, therefore, the need for consistent testing of water quality parameters to ensure compliance with recommended guideline values (WHO 2003).

A recent study by Yeleliere *et al.* (2018) indicated that about 60% of water bodies in Ghana are polluted. Many activities including domestic use of water in river bodies, household and industrial waste, and agricultural pollution among others lead to the pollution of water bodies (Affum *et al.* 2015; Yeleliere *et al.* 2018). In response to this, several studies (Karikari & Ansa-Asare 2006; Affum *et al.* 2015; Saana *et al.* 2016; Mantey 2017) have been conducted to examine and evaluate the quality of drinking water in Ghana. These studies revealed that most of the drinking water sources were microbiologically contaminated and may cause water-related diseases such as typhoid, diarrhea and dysentery when consumed (WHO 2017).

According to the annual report of the Tano North Municipal (2018), about 65% of households in Subompan depend on borehole water sources for drinking. The study community has seven mechanized boreholes and no access to a pipe-borne water supply. Most of these borehole sources dry up especially during the dry season. This situation compels most of the inhabitants to depend on water from streams, springs and hand-dug well thus making them vulnerable to water-related diseases. However, in order to develop strategies to address these challenges appropriately with regard to access to potable water in the study area, an understanding of the existing conditions and magnitude of the problems is required. This study, therefore, assesses the physicochemical and microbial quality of drinking water as well as the health risk assessment of intake and point-of-use water sources in the Subompan community located in the Tano North Municipality.

2. MATERIALS AND METHODS

2.1. Study area

Tano North Municipality is one of the seven municipalities in the Ahafo Region of Ghana and shares boundaries with Offinso District and Ahafo-Ano North District both in the Ashanti Region, and also with Sunyani and Asutifi Districts of the Bono Region (Figure 1). The study area, Subompan, is one of the settlements in the Tano North Municipality and the 10th largest community in the municipality (Ghana Statistical Service (GSS) 2014). The municipality covers an estimated land area of 837.4 km^2 and has an approximate population of 107,647 (Tano North Municipal 2020). The population of Subompan is estimated to be 3,153 (Tano North Municipal Annual Report 2020). The main sources of water for drinking in the municipality are pipe-borne (53.7%), borehole (27.8%) and river/stream (11.6%) (GSS 2014). Recent water situation analysis in the municipality shows that of 301 communities in the municipality, only 92 and 176 of them have pipe-borne water supply and boreholes, respectively (Tano North Municipal Report 2018). The study area has seven mechanized boreholes and no pipe-borne water supply. Most of these borehole sources dry up especially during the dry season, so most people use water sources from streams, springs and hand-dug well thus making them vulnerable to water-related diseases. Water from these sources is mainly used for domestic (i.e. drinking, washing, cooking, bathing, etc.) and agricultural purposes (GSS 2014).

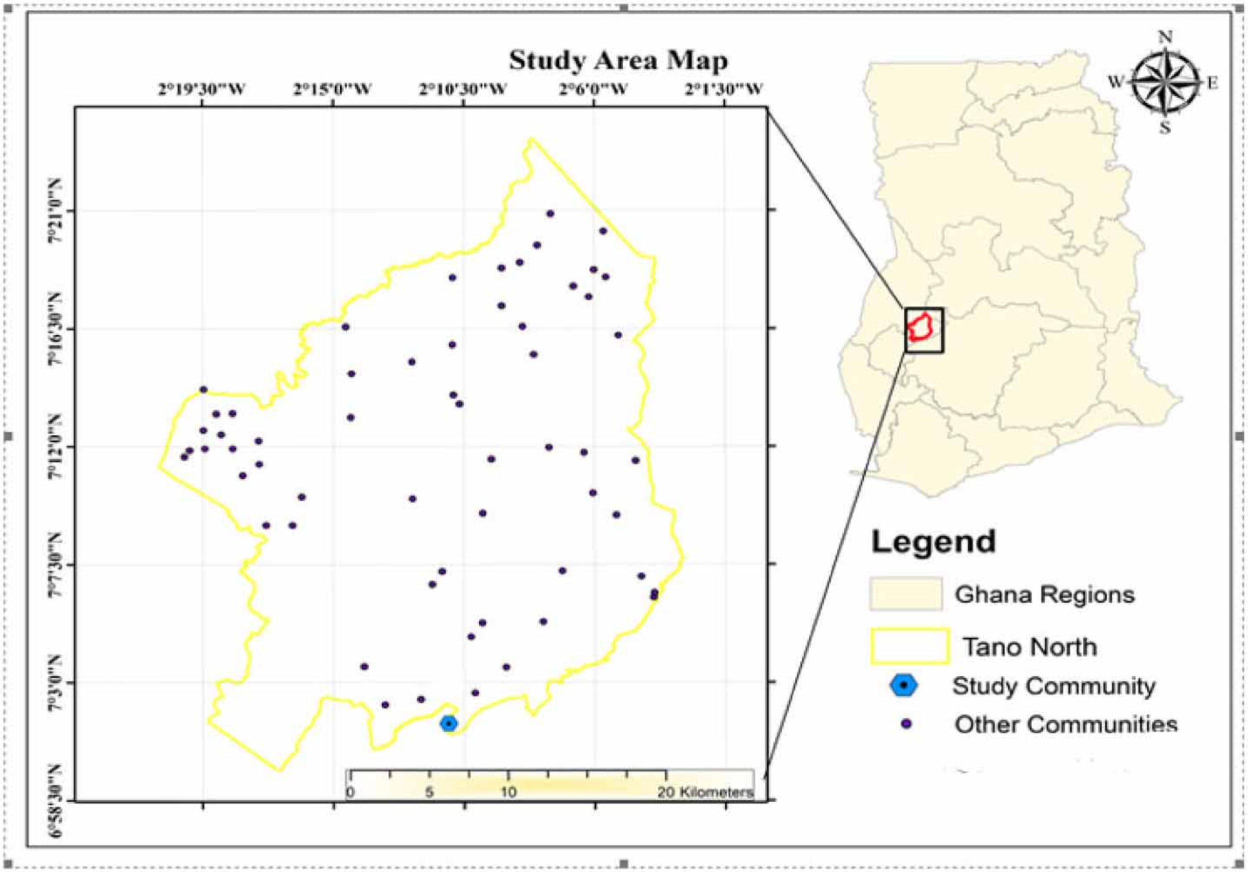


Figure 1 | Map of Tano North Municipality.

2.2. Study design and data collection

Data collection for the study was undertaken through the use of water quality sampling and laboratory analysis of physicochemical and microbial parameters. Secondary sources of data collection such as the census data and review of the related literature were also utilized. Water quality analysis at the intake sources and point-of-use source was carried out to determine the physicochemical and microbial quality of drinking water using standard methods by the American Public Health Association (APHA 1998, 2000, 2005). The microbial quality of the borehole water from household water storage containers was also analyzed. This was achieved through water sampling collected from five intake sources (boreholes, streams, spring, rivers and wells) and 31 point-of-use sources. A total of 38 drinking water samples were taken between March and April 2020. After sampling, all samples were sealed, labeled (showing sample type, location, identity number, date and time) and stored over ice in a thermo-insulated container at a temperature <4 °C prior to their transportation to the Chemistry Laboratory of the University of Energy and Natural Resources within 2–6 h (WHO 2012) for analysis.

To provide greater data confidence from the analytical procedure, appropriate quality assurance and quality control on water samples were ensured. The quality assurance and quality control were followed to ensure that the data recorded are of high quality and reproducible using control blind samples. Water quality parameters analyzed were pH, temperature, turbidity, conductivity, total dissolved solids (TDS), total suspended solids (TSS), phosphate, fluoride ions, chlorine, alkalinity, hardness, nitrate, total coliform, fecal coliform and *Escherichia coli*. However, *in situ* parameters such as water pH, temperature and conductivity were determined on-site using the HQ40D Portable Multi Meter. The instrument used for the *in situ* parameter analysis was calibrated using a specific calibration solution before each measurement (APHA 2005). TSS and TDS were separated gravimetrically by filtering the water through a 0.45-μm filter paper and determined according to the standard procedure (APHA 2005). Table 1 summarizes the various water parameters and the method used for the analysis of the water samples.

Table 1 | Water quality parameters and analytical methods

Parameters	Unit	Analytical techniques (method used)
Temperature	°C	Thermometer
pH		Electrochemical method using the pH Meter
Turbidity	NTU	Nephelometric meter
Conductivity	µS/cm	Electromagnetic induction method
TDS	mg/L	Gravimetric method
TSS	mg/L	Gravimetric method by the filtration process
Fluoride	mg/L	Potentiometric method
Nitrate	mg/L	Calorimetric (spectroscopy method)
Total hardness	mg/L	EDTA titration with an EBT as an indicator
Chlorine	mg/L	Iodometric method
Total alkalinity	mg/L	Titration (acid–base method)
E. coli	CFU/100 mL	Most probable number method
Fecal coliform	CFU/100 mL	Most probable number method
Total coliform	*E. coli*/100 mL	Most probable number method

2.3. Quantitative microbial risk assessment

We conducted a quantitative microbial risk assessment (QMRA) to estimate the potential risk of infection or illness due to exposure to pathogenic microorganisms in the drinking water sources. The QMRA addresses the quantitative approach through scenario modeling and simulations of hazards identification and characterization, exposure assessment, exposure effect and dose–response evaluation, and risk characterization (Haas *et al.* 1999; Medema 2013; Yunita *et al.* 2016). *E. coli* is considered as an indicator organism and it was used in this study to estimate the risk of infection to pathogenic microorganisms. The mean *E. coli* concentration of the point-of-use water sources was recorded to estimate the pathogenic content in the water sources (Katukiza *et al.* 2013; Yunita *et al.* 2016). However, data regarding the severity weight and the pathogenic content of the *E. coli* concentration were estimated according to previous studies (Haas *et al.* 1999; Havelaar & Melse 2003; Katukiza *et al.* 2013; Yunita *et al.* 2016). The health impact of the results was determined using the Disability-Adjusted Life Years (DALYs) (Haas *et al.* 1999; Katukiza *et al.* 2013).

2.3.1. Hazard identification and characterization

Hazard identification is the determination of pathogens associated with health effects in drinking water and the characteristics of pathogenic data and outbreaks (Medema 2013). Pathogenic *E. coli* (such as *E. coli* 0157:153 H7) is a major hazard for public health (Haas *et al.* 1999). The literature revealed that 8% of the total *E. coli* is pathogenic, so the *E. coli* concentrations recorded in the water sources were multiplied by 0.08 to estimate the dose of pathogenic *E. coli* (Haas *et al.* 1999; Katukiza *et al.* 2013; Yunita *et al.* 2016).

2.3.2. Exposure assessment

The potential exposure routes were identified to determine the critical points to quantify the microbial risk to human health. The hazard pathways identified were ingestion contact of indicator organisms through drinking water from the point-of-use sources. The potential exposed population was then determined. The volume of water ingested (mL per day) was multiplied by the concentration of pathogenic strain of *E. coli* 0157:153 H7 to obtain the dose of pathogens (Haas *et al.* 1999). The data regarding the frequency of water consumption per day and the exposure population to the drinking water sources were estimated from the study survey (questionnaire) and assumed for the entire study area population to estimate the exposed population in the study area (Yunita *et al.* 2016).

2.3.3. Dose–response assessment

The dose–response model was used to determine the number of pathogens ingested and the probability of an infection that may occur (Haas *et al.* 1999). The dose–response model used was the β-Poisson model for the *E. coli* O157:H7 concentration

(Haas *et al.* 1999; $\alpha = 0.49$ and $N_{50} = 59{,}600$). Pathogen ingestion was estimated and was based on the probability distributions for exposure assessment parameters using a standard equation (Haas *et al.* 1999).

Dose of pathogens

$$d = N \times V_{\mathrm{ing}} \tag{1}$$

Dose–response β-Poisson

$$P_1(d) = 1 - \left[1 + \left(\frac{d}{N_{50}}\right)(2^{1/\alpha} - 1)\right]^{-\alpha} \tag{2}$$

Annual risk of infection

$$P_{1(\mathrm{A})}(d) = 1–[1–P_1(d)]^n \tag{3}$$

where d is the dose of pathogens; $P_1(d)$ is the risk or probability of infection to a single pathogen dose d through dermal contact or ingestion. N is the pathogen concentration; V_{ing} is the volume of water ingested in one exposure; N_{50} is the microbial dose eliciting 50% infections in the exposed population; α is the pathogen infective constant.

2.4. Data analysis

The quality of the drinking water was evaluated according to the standards suggested by the WHO guideline values for drinking water. Minimum, maximum, mean and standard deviation as well as one-way analysis of variance with a comparison of the mean differences between the intake water source and household point-of-use source were determined using the SPSS Version (21) statistical tools. All statistical tests were estimated at a 95% level of confidence and a p-value of ≤ 0.05 was considered significant. The potential exposure routes to pathogenic microorganisms were identified to determine the critical points to estimate the microbial risk to human health using pathogenic *E. coli* as a reference pathogen for the QMRA. The dose–response model was used to estimate the dose and probability of infections that occur annually. Monte Carlo simulations were made for 10,000 iterations using the @Risk version 4.5 Professional edition (Katukiza *et al.* 2013; Medema 2013). The health impact of the results was determined using the DALYs (Haas *et al.* 1999; Katukiza *et al.* 2013).

3. RESULTS AND DISCUSSION

3.1. Drinking water quality

Results of water quality analysis carried out on the intake and point-of-use water sources in the study area indicated that the quality of most of these sources was compromised though these sources serve as the main sources of drinking water for the residents in the community.

3.1.1. Physicochemical quality of the borehole drinking water

Physicochemical parameters including pH, temperature, turbidity, conductivity, TDS, TSS, phosphate, fluoride ions, chlorine, alkalinity, hardness and nitrate were analyzed and compared to the WHO standards (Table 2).

The study reveal that none of the physiochemical parameters showed a significant difference between intake and point-of-use water sources ($p > 0.05$). The mean values of pH measured from the intake and point-of-use water sources range from 5.96 to 6.28 and this fell below the WHO recommended limits of 6.5–8.5. This implies that the water samples are more acidic than those recommended for human consumption. Acidic water may result in serious health complications (Addo 2010). According to Kim *et al.* (2011), the pH of water determines the solubility of chemical constituents such as nutrients (phosphorus, nitrogen and carbon) and heavy metals (the amount that can be dissolved in the water) and biological availability (the amount that can be used by aquatic life). The average acidic pH values of water obtained corroborated with the pH of 6.24 in Kumasi (Amankona 2010) of borehole water from seven administrative town councils and the pH of 5.9 of groundwater quality in Cape Coast Municipality of Ghana (Quagraine & Adokoh 2010). These variations could be attributed to the geological conditions of the water locations (Mensah 2011).

The mean temperature of the water source did comply with both the WHO guidelines and showed no significant difference at the intake and point-of-use water sources ($p = 0.39$). The temperature values in the current study were higher than in other

Table 2 | Physicochemical quality for the borehole intake and point-of-use drinking water source

Parameters	Intake source ($N = 7$)		Point-of-use source ($N = 21$)		WHO guideline	*p*-value
	Mean ± SD	Min–Max	Mean ± SD	Min–Max		
pH	6.17 ± 0.11	5.98–6.28	6.14 ± 0.08	5.96–6.25	6.5–8.5	0.68
Temperature (°C)	36.0 ± 7.0	29–43	35.7 ± 2.70	29–41	22–29	0.39
E. Cond. (μS/cm)	270.0 ± 185	81.3–555	281.8 ± 163.2	7.9–688	1,500	0.15
Turbidity (NTU)	1.80 ± 1.50	0.3–3.3	2.80 ± 2.48	0.57–13	5	0.37
TSS (mg/L)	1.70 ± 0.81	0.50–3.0	2.24 ± 2.48	0.5–12	50	0.93
TDS (mg/L)	135 ± 72.5	84.0–294	134.2 ± 75.2	5.0–294	1000	0.17
Phosphate (mg/L)	0.025 ± 0.021	0.01–0.07	0.25 ± 0.0201	0.006–0.085	<1	0.08
Fluoride ions (mg/L)	0.0004 ± 0.00	0.00–0.00	0.005 ± 0.014	0.0002–0.06	1.50	0.12
Chlorine (mg/L)	24.31 ± 9.02	14.18–35.5	28.85 ± 16.26	10.27–92.17	250	0.23
Alkalinity (mg/L)	99.00 ± 55.30	34–201	103.5 ± 69.2	10.6–233.3	–	0.10
Hardness (mg/L)	245.2 ± 114.3	120–360	230.3 ± 121.2	40–620	350	0.05
Nitrate (mg/L)	0.49 ± 0.43	0.06–1.04	0.66 ± 0.43	0.077–1.334	10	0.20

studies in the country (Amankona 2010; Mensah 2011; Addo 2018). According to Mensah (2011), the climate is characterized by high temperature and rainfall and these factors might have contributed to the variations of the temperature values in the current study. The low levels of fluoride ions recorded in the present study met the WHO recommended limits of 1 mg/L for safe human consumption. This could mean that the water sources were not rich in fluoride-containing minerals (Saeed *et al.* 2020) perhaps due to the absence of industrial pollutions in the study area (Aloo *et al.* 2013). According to Aloo *et al.* (2013), fluoride ion concentrations >1.5 mg/L causes dental fluorosis and skeletal fluorosis.

Water hardness values varied completely from 120 to 360 mg/L for the intake water sources and 40 to 620 mg/L for the point-of-use water sources. This shows a significant difference ($p = 0.05$) between the intake water source and point-of-use water source. The relatively higher values recorded for the hardness of water from the water source may indicate the presence of higher concentrations of calcium and magnesium in the water sources (Aloo *et al.* 2013). Thomas & Cleever (1953) classify the degree of water hardness as follows: soft, 0 to <60 mg/L; medium, 60 to <120 mg/L and hard, ≥180 mg/L. Hence, the intake water sources in the study area could therefore be classified as hard water (245.2 mg/L).

Recent studies have indicated that a high concentration of nitrate results in adverse health risks on mankind (Kim *et al.* 2011; Nabi *et al.* 2019). The WHO proffered that water could be deemed potable when it contains nitrate components up to 10 mg/L. Nitrate reduces within the human body to nitrite which could result in methemoglobinemia or blue-baby syndrome (Dadzie 2012). The current study identified that the nitrate components of all the samples collected met the recommended standard. Both the intake and point-of-use water sources recorded no significant differences ($p = 0.15$). Increased nitrate levels in the drinking water could affect the water quality, which may suggest the presence of possible contaminants such as pathogens from inorganic and organic compounds and this could impair the health status of an organism (WHO 2012). The value recorded in this study was in line with a study conducted by Isah *et al.* (2015) and Mensah 2011 in Bauchi Metropolis in Nigeria and Tamale in Ghana, respectively.

3.1.2. Microbial quality of drinking water

The WHO recommended guideline values for fecal and *E. coli* coliform bacteria are none detectable per 100 mL and total count not exceeding 500 CFU/100 mL (WHO 2004). The levels of fecal and total coliforms in the water sample were well above the WHO recommended limit (Figure 2). With this high amount of fecal and total coliforms, consumers are likely to be infected with waterborne diseases like cholera and diarrheal diseases (Monney *et al.* 2001). The high levels of fecal and total coliforms could indicate that the water tends to be more exposed to more dangerous disease-causing organisms such as protozoa, bacteria and viruses. Total and fecal coliforms recorded at the intake sources and household point-of-use sources varied significantly. The mean total coliform of 3.63 and 4.57 log CFU/100 mL of the water samples was found to be significantly different ($p = 0.004$) between the intake and point-of-use water sources, respectively. The mean

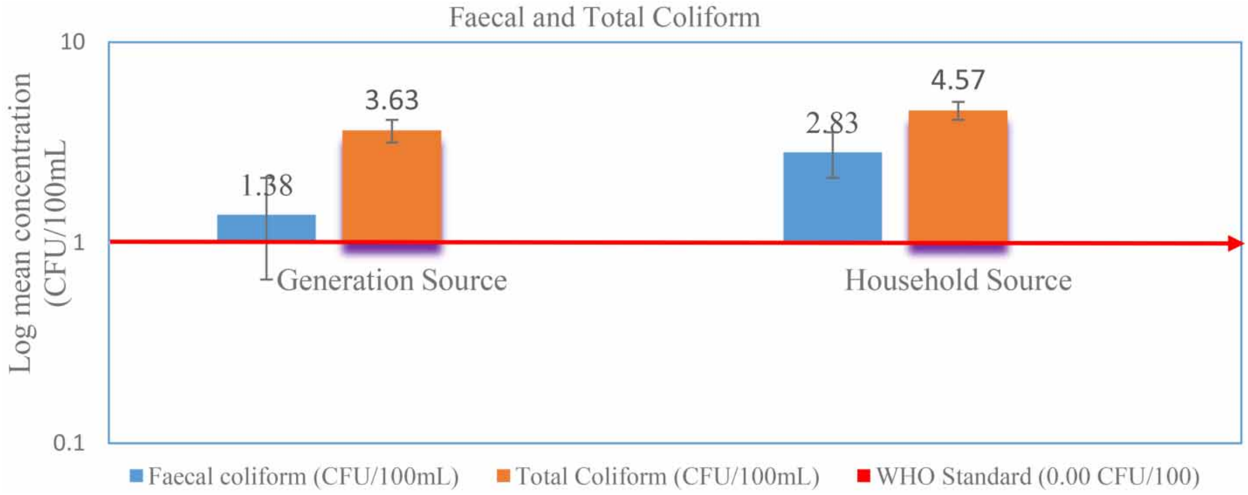


Figure 2 | Total and fecal coliform concentrations of borehole intake and point-of-use water sources.

fecal coliform between the intake and the point-of-use water samples was also found to be significant ($p = 0.033$). According to a study by Addo *et al.* (2014) on hygiene practices, drinking water may be contaminated during the time of collection and/or water storage as a result of poor personal hygiene. The results of this study were consistent with the findings by other authors (Osiemo *et al.* 2019). The fecal contamination of the water sources could be the effect of unsanitary handling of the water during collection and transportation to homes (WHO 2010; Figure 3).

3.1.3. Microbial quality of the borehole water from point-of-use water storage containers

The household drinking water storage containers varied extensively in storage container type and capacity. Of the 21 water samples, the most common type of storage containers used were jerry cans ('Kuffour gallons') (42.9%) followed by the plastic barrel (23.8%) and veronica bucket (23.8%). The least was recorded for clay pot (9.5%). For storage capacity, the most common one was the plastic barrel that was relatively larger than the jerry cans. During the analysis, the veronica bucket recorded the highest level of total coliform and fecal coliform in the household borehole water sampled (Figure 4). High levels of microbial contamination were found in storage containers mostly uncovered. These storage containers were found to be susceptible to the introduction of cups, hands and other materials that can convey fecal contamination. Biofilm formation was observed in the household water storage containers. This could be a result of improper cleaning practices

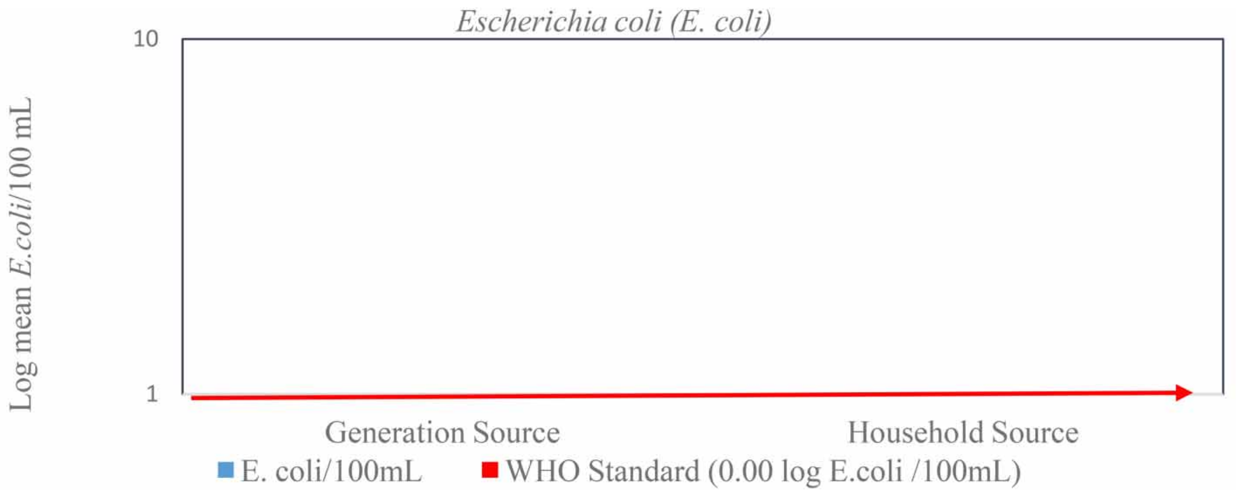


Figure 3 | *E. coli* concentrations of the borehole intake and point-of-use water sources.

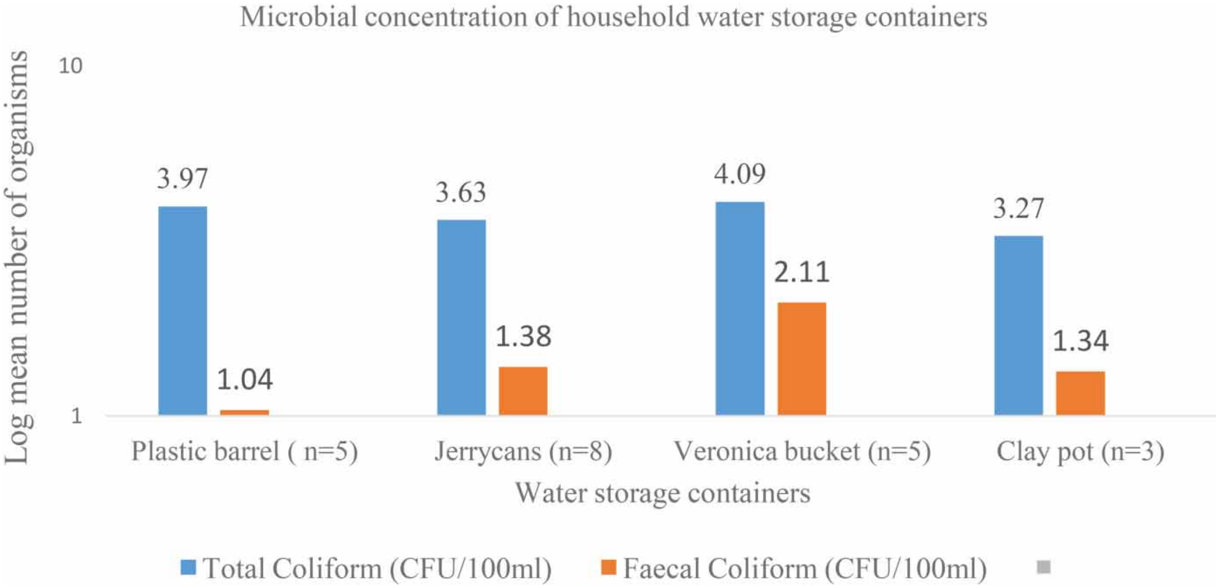


Figure 4 | Microbial quality of water from point-of-use water storage containers.

which enable the growth of likely pathogenic microorganisms (Addo 2018). The current study was in line with the study done by Seino *et al.* (2008) that recorded higher levels of microbial contamination for uncovered storage containers.

3.2. Health risk analysis

3.2.1. Concentration of pathogen and indicator organisms

The sources of microbial contamination identified were the drinking water sources for the spring and the river. Pathogen hazards of the spring well and river waters showed *E. coli* contaminations, which might be caused by unsanitary and improper maintenance of the water sources. Poor sanitation and point-of-use water handling practices were observed in most households which might lead to higher levels of coliform bacteria (Gyasi *et al.* 2018). The mean concentrations of 5.0×10^{-1} log *E. coli*/100 mL and 1×10^{0} log *E. coli*/100 mL of *E. coli* were recorded in river and spring point-of-use drinking waters, respectively. However, there was no detectable level of *E.coli* contamination in the other water sources (Table 3).

3.2.2. Risk of infection

The probability of infection from *E. coli* diseases was determined for all sources of contamination using the concentration of pathogenic strain of *E. coli* (Haas *et al.* 1999). The highest risk of infection was recorded from the spring well 6.9×10^{-6} (Table 4). The risk of infection of all the contamination sources was within the WHO level of tolerable risk to human health from pathogenic bacteria of 10^{-5} DALYs per person per year (WHO 2004). The results from this study were consistent with the findings by Katukiza *et al.* (2013) that recorded the highest risk of infection, that is, 3.28×10^{-2} of *E. coli* O157:H7 in drinking water collected from river sources. Health outcomes from exposure to a pathogen depend mostly on the exposure route by ingestion (Haas *et al.* 1999). However, the human health effect from exposure to a hazard upsurges with the

Table 3 | *E. coli* concentrations of the point-of-use drinking water

Water sources	*E. coli* concentration (log *E. coli*/100 mL)
Stream water	0.00 log *E. coli*/100
Borehole water	0.00 log *E. coli*/100
River water	5.0×10^{-1} log *E. coli*/100 mL
Hand-dug well	0.00 log *E. coli*/100
Spring well	1×10^{0} log *E. coli*/100 mL

Table 4 | Quantity ingested, exposed population and the estimated risk of infection at the point-of-use water sources

Sources of contamination	Microorganism (mean)	Quantity ingested (mL)	Exposed population	No. of exposure to single-dose per year	Dose (d)	Probability of infection $P_1(d)$	Annual probability of infection $P_{1(A)}(d)$
River water	*E. coli* (0.5)	3,360	132	365	1.3	3.3×10^{-6}	1.2×10^{-3}
Spring well	*E. coli* (1.0)	3,360	284	365	2.7	6.9×10^{-6}	2.5 x10^{-3}

Table 5 | Distribution of disease burden by different contamination sources (risk exposure estimates were made using Monte Carlo Simulations)

Sources of contamination	Risk exposure estimates per year	Proportion of the total no. risk exposure estimates per year (%)	Disease burden DALYs per year	Disease burden DALYs per person per year	Proportion of the total no. of disease burden (%)
River water	6	28.6	1	7.6×10^{-3}	69.1
Spring	15	71.4	1	3.5×10^{-3}	30.9
Total	**21**	**100**	**2**	$\mathbf{1.1 \times 10^{-2}}$	**100**

pathogen dose (Katukiza *et al.* 2013). Table 4 summarizes the quantity of water ingested (mL), exposed population and the estimated risk of infection.

3.2.3. Disease burden

The total risk exposure estimates per year of infection from *E. coli* pathogens in the sources of contamination in the QMRA was 21 (Table 5). This, however, accounted for 1.2×10^{-2} DALYs per person per year. The disease burden of 1.2×10^{-2} DALYs per person per year in the study area was higher compared to the WHO reference level of tolerable risk of 1×10^{-6} DALYs per person per year. The outcome of this study was consistent with the disease burden of 0.5 DALYs per person per year obtained by Machdar *et al.* (2013) in the Nima slum of Accra. Again, the highest disease burden contribution was from the river water (59.8%) (Table 5). Similarly, Machdar *et al.* (2013) found that 52% of the disease burden was recorded from the point-of-use river drinking water source. Higher pathogenic concentrations increase the risk of infection as well as the disease burden per person (Haas *et al.* 1999; Machdar *et al.* 2013).

4. CONCLUSION

This study was conducted to assess the drinking water quality and health risk assessment of intake and point-of-use water sources in the Subompan community located in the Tano North Municipality of Ghana. The microbiological quality of the drinking water sources revealed the presence of coliforms and *E. coli* concentrations in the river and spring water sources. Using *E. coli* as a proxy for the presence of pathogens in water, it can be concluded that the microbiological quality of the spring and river water used as sources of drinking water in the study area was found to be rather poor, posing a potential threat to human health if consumed untreated. The results of the study also revealed significant microbial differences between the intake sources and point-of-use sources. Still, the assumption holds that the recorded poor water quality of the spring and the river water contributes to the high microbiological quality consumed in the area but further research is required for more valid inferences. The QMRA revealed that the disease burden arising from exposure to river and spring water sources was above the WHO reference level of tolerable risk of 1×10^{-6} DALYs per person per year. The findings of this study are relevant to the Tano North Municipal Assembly and other stakeholders toward making decisions on measures to reduce water-related diseases and infection risk. These infection risks can be reduced by sustainable management of human excreta in addition to hygiene awareness campaigns at household and community levels.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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