Bacteriological and physical quality of Fiche drinking water from households and reservoirs, Oromia, Ethiopia

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Abstract

Drinking water is the major source of bacteria pathogens in developing countries along with poor sanitation and contamination of food with a pathogen. More than half of the population of the country uses unimproved sanitation facilities while 36% of them practiced open defecation. The aim of the study was to investigate the suitability of public water for drinking. The study is designed to include a survey of 90 respondents and experimental analysis of 170 water samples from households and reservoirs. Water quality parameters, such as temperature, electrical conductivity, turbidity, total dissolved solids, and bacteriological parameters like total coliforms (TC) and fecal coliforms (FC) were determined. Many of the respondents (88.8%) remarked that the water has no smells, tastes, and color. The experimental analysis confirmed that temperature (19.7 °C), electrical conductivity (269.63 µS/cm), turbidity (1.17 NTU), and total dissolved solids (134.3 mg/L) were found to be below the prescribed limit of World Health Organization guidelines for drinking water. Total coliforms (9.29 CFU/100 mL) and fecal coliforms (5.07 CFU/100 mL) were detected from pipe water sources during the wet season showing non-compliance with the guidelines. The reservoir samples were free from bacterial contamination. The main point of drinking water contamination was the household, where unsafe water handling practice was a common habit in the study area. Hence, awareness conception training on safe water handling practices is highly recommended for the communities.

Key words: drinking water, households, microbial, physical, reservoir

Highlights

- Water quality changes between the source and households.
- The physical quality of water does not explain the bacterial quality of water.
- Households were found to be the main source of microbial contamination.
- The result will certainly awaken people to amend their sanitations and water storage habits.
- The study will be primary source of information in the study area.

INTRODUCTION

Water harbors several microorganisms that may cause serious and fatal health problems. Water is highly vulnerable to pathogens because the water travels a long distance in the water cycle and it can be contaminated easily in any one of the many points in the way from sources to users (Keredin & Prasada 2016). Drinking water is the major source of microbial pathogens in developing countries of

the world along with poor sanitation and contamination of food with pathogens of the gastrointestinal tract. Contaminated water is responsible for 88% of diarrhea cases worldwide, and is accompanied by inadequate sanitation and poor hygiene (WHO/UNICEF 2009). Ingestion of polluted water with feces and urine from humans, animals, and avians is the main mode of bacterial contamination. Several pathogenic bacteria, viruses, protozoa, and helminths reside in feces that cause profoundly serious illness, such as cholera, typhoid, bacillary dysentery, adenoviruses, retroviruses, and other diseases (WHO 2017).

People who live in developing countries may suffer much due to a lack of sufficient clean water and sanitation services (Crampton 2005; Muhammed et al. 2016). Most developing countries are compelled to use unprotected and unsafe water sources following the depletion of freshwater sources. This may create much more pressure on the development of a country by the increasing number of infected population and deaths. In consequence, high pressure on health centers due to water-borne diseases and water quality is a concern (WHO 2010).

Countries of African and Asian continents are confronting water shortages, poor sanitation, and lack of access to clean and affordable water. Despite being naturally gifted with huge water resources that satisfy domestic, agricultural, and hydropower requirements, Ethiopia, as a developing county, has faced poor sanitation and unsafe drinking water services (Yasin et al. 2015; Gonfa et al. 2019; Alemnew & Seyoum 2020; Matusala et al. 2020). As of 2015, Ethiopia had a population of 99.4 million, of which about 45 million (about 56.7%) lack access to clean water and 51.4 million people (about 51.7%) do not have access to improved sanitation sources (World Bank 2018). Due to prolonged and repeated drought in the past decades, freshwater resources have dried up. This situation has forced people to use unsafe water sources that are contaminated with human and animal waste and worms (Crampton 2005).

A high concentration of pathogens is expected to present in an urban environment and can easily enter water systems at some point before consumption. All communities in the urban area, including the capital city of Ethiopia, are highly dependent on public water services and use storage, which is commonly called a 'jerry-can' (Zinabu et al. 2015). This material has a very narrow space through which enough oxygen cannot get in. The materials used to store water at home for days are highly suitable for the growth of anaerobic organisms. Several studies conducted in Ethiopia on the physicochemical and bacteriological quality of drinking water from various sources indicated that water sources were contaminated with pollution indicators such as fecal and total coliforms (APHA 1998; Mengesha et al. 2004; Birhanu 2007; Temesgen & Hameed 2009; Milkiyas et al. 2011; Solomon et al. 2011; Debasu et al. 2014; Yasin et al. 2015; Gonfa et al. 2019; Alemnew & Seyoum 2020; Matusala et al. 2020).

In poorly accessible and insecure areas, including the study area, where there are no water quality testing facilities, the community may be susceptible to waterborne diseases. So, frequent assessment is required to provide critical water quality information. The source of drinking water at Fiche is ground-water. The fecal coliforms found in the groundwater are a sign of contamination from human or animal sewage. More than half of the population of the country uses unimproved sanitation facilities while 36% of them practise open defecation (Keredin & Prasada 2016). In addition, the majority of the population of Fiche use jerry-cans and plastic extensions to store water at home for several days. Therefore, there may be a high chance of drinking water contamination both from sources and households. This study was, therefore, aimed at analyzing the status of basic physical and bacterial qualities of drinking water from sources to households in Fiche town.

MATERIALS AND METHODS

Study area

Fiche is the administrative town of the North Shewa Zone/Salale, Oromia, Ethiopia. The town has four kebeles occupying a total population of around 65,000 people. It is located about 114 km

north of Addis Abeba. Fiche has a latitude and longitude of 9 °48′N and 38 °44′E respectively (Figure 1). The Fiche town has an average altitude of 2,738 m (8,983 ft) above sea level. The source of drinking water in the town is a borehole and spring water.
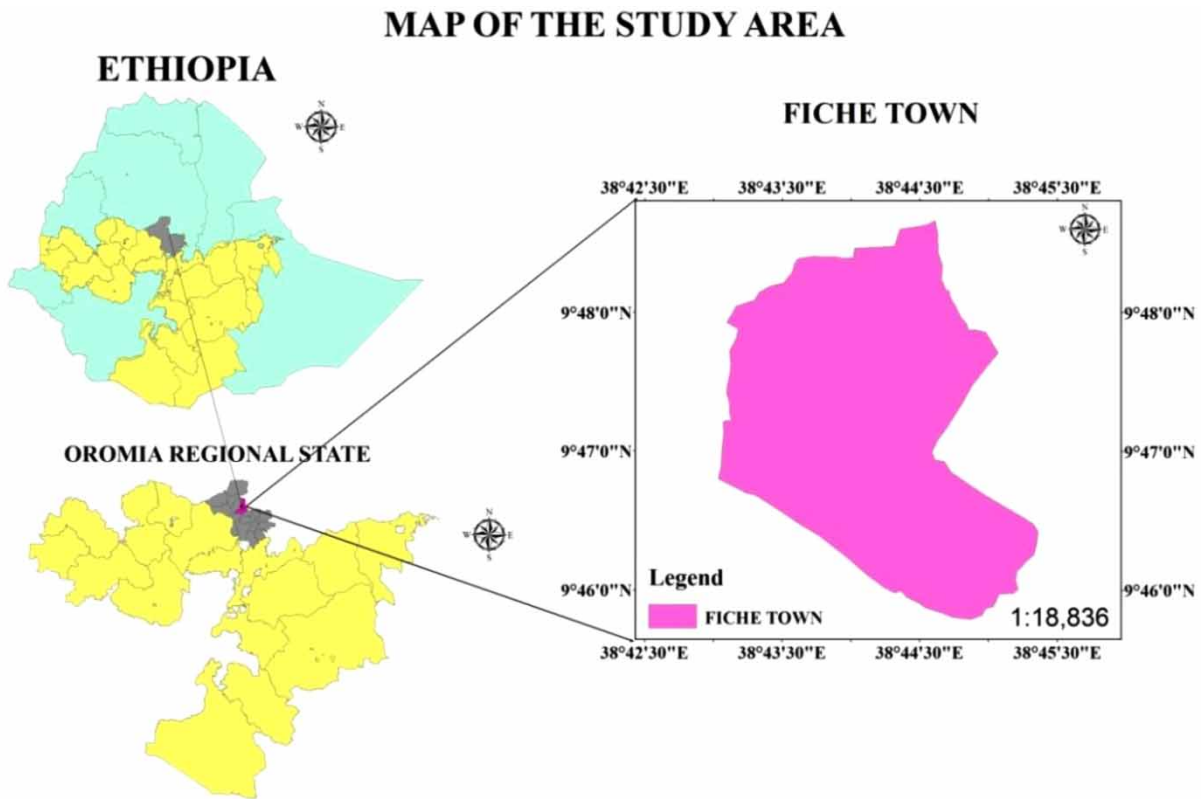

Figure 1 | The map of study site in Fiche town (GIS database).

Study design

The study is designed to include a survey and analysis of the collected water samples. The design was intended to assess the physical and bacteriological quality of drinking water in Fiche town.

Sampling technique

A cross-sectional study was conducted to assess the bacteriological and physicochemical quality of drinking water from the source to distribution points. All reservoirs of the town were included in the study. The distribution points (end taps) were randomly selected. The survey questionnaires were filled by 90 households from all four kebeles of Fiche town. Using simple random sampling, a total of 22 households were selected from each kebele to fill questionnaire forms. And two city water service administrators were also purposively selected. The target population comprised different sorts of people. Selected respondents were distributed throughout the four kebeles of the town and included teachers, health professionals, merchants, drivers, lawyers, and people without apparent jobs. Information was gathered through observation, interviews, and focus group discussions. Generally, 170 samples of drinking water (85 samples in winter, 85 samples in summer) from households were taken for experimental analysis. And a total of 40 samples (20 samples in winter, 20 samples in summer) from the reservoir were taken for experimental analysis. The samples were collected three times from each sampling site within 20 day intervals.

Data analysis

The data were analyzed using descriptive statistics and analysis of variance at $p < 0.05$ significance level and a 95% confidence interval was used to compare the quality of water in reservoirs and distribution points. The quality parameters of tap and reservoir water samples were compared based on the season using one-way ANOVA. The post-hoc test was performed to find the real difference. Results of water analyses have been compared against standards set by the World Health Organization (WHO) and evaluated as acceptable or unacceptable.

Water sample collection and preparation

Water sample collection was done according to the WHO drinking water guidelines (WHO 2006), and the American Public Health Association guideline (APHA 1998). Samples were collected in sterilized glass bottles, and rinsed thoroughly with nitric acid and sterilized distilled water to avoid microbes and any dirty substances in the bottles. Samples of drinking water were collected from each sampling point in bottles for physical and bacteriological analysis. After sampling, bottles were kept in an ice box and immediately transported to Weliso Poly Technic College for analysis. The bacteriological tests were undertaken within 24 hours after collection to avoid the growth or death of microorganisms in the sample (WHO 2006).

Analytical methods/instruments

The water samples were taken at the selected sampling site and the physical and bacteriological characteristics of the water were analyzed according to the standard methods described by the American Public Health Association guideline. The physical characteristics of drinking water such as temperature, turbidity, electrical conductivity, total dissolved solids; and bacteriological parameters of total coliforms (TC) and fecal coliforms (FC) were analyzed by using the methods/instruments indicated in the table below (Table 1). Samples for bacterial indicators, TC and FC were analyzed by membrane filtration technique (APHA 1998). A sterilized pad dispenser was used to introduce the growth absorbent pads into the base of petri dishes, and the growth pads were saturated with the Lauryl Sulphate broth. A hundred ml of water sample was filtered using a membrane filter (0.45 μm) in a vacuum filtration apparatus, and all the filters were transferred to the absorbent pad, which was saturated with the broth. Then, plates for total coliform (TC) and fecal coliform (FC) counts were incubated at 37 °C and 44 °C, respectively, for 24 hrs, and colonies were counted and recorded.

Table 1 | Tested water quality parameters and methods/instruments used

No.	Parameters	Unit	Method used/Instruments
1	Temperature	°C	pH/mV/temperature meter (PH-013)
2	Turbidity	NTU	Digital turbidity meter
3	Electrical conductivity (EC)	μS/cm	Digital electrical conductivity meter
4	Total dissolved solids (TDS)	mg/L	Digital total dissolved solids meter
5	Taste		Aesthetical
6	Odor		Aesthetical
7	Colour	HU	Color comparator
8	Total Coliforms	CFU/100 mL	Membrane filtration method
9	Fecal Coliforms	CFU/100 mL	Membrane filtration method

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RESULTS

Households reported using three types of treatment plans. From a total of 90 households, 28.89% were found to treat the water before drinking. Among these, 16.67% of the respondents exercise chlorine treatment. The rest use water filtering electronic devices (8.89%) and Wuha Agar (3.33%), which is a locally used Biocidal for further purification of the water. Many of the respondents (71.11%) never treat the water before drinking (Table 2).

Table 2 | Type of disinfections used by respondents in Fiche town

Type of disinfection	Responses (%)
Chlorine	16.67
Electronic filtering	8.89
Wuha Agar	3.33
Never treat	71.11

The households' experience was assessed on the smell, taste, and color of drinking water at Fiche town. Many of the respondents (88.8%) remarked that the water has no smells, tastes and color. Some reported experiencing foul smell (7.78%), taste (10.0%) and cloudy/dirty/color (15.54%) during the rainy season (Table 3).

Table 3 | Responses on non-microbial qualities, treatment plan and perception on the quality of drinking water

Survey on non-microbial qualities		Responses (%)
Smell	No smell	92.22
	Foul smell	7.78
Taste	Tasteful	10.00
	Tasteless	90.00
Color	Clear	84.44
	Cloudy	15.54
	Add chlorine	16.67
Treatment plan at home	Water filtering device	8.89
	Wuha agar	3.33
	No treatment	71.11
	Excellent	6.67
Perception on water quality	Good	66.67
	Fair	20.00
	Poor	6.66

More than a third of respondents (40%) had no primary knowledge of the meaning and process of chemical and bacteriological contamination of drinking water. Drinking water in the town was suspected (26.67%) to be contaminated at least sometimes and at some points. However, 33.3% spoke of their awareness of the process of both chemical and microbial (they did not know whether it was bacteria) contamination of drinking water and claimed that the town's drinking water is pure at all. And from Table 4, more than 42% of the respondents reported that they had encountered at least one medically confirmed waterborne illnesses.

Generally (Table 3), the quality of the drinking water at Fiche town was claimed to be good by the majority of respondents (66.67%), while the rest said the quality was fair (20%), excellent (6.67%) and poor (6.66%).

Table 4 | Knowledge of respondents on microbial qualities and exposure for waterborne illnesses

Survey on microbial qualities		
Contamination	Contaminated	26.67
	Pure	33.33
	Do not know	40
Had waterborne illness	Yes	42.22
	No	57.78

The physical assessments of drinking water started by measuring its temperature at the site of sample collection. The temperature ranged between 19.4–20.0 OC, and the water temperature average value was 19.7 OC. The electrical conductivity (EC) of tap water samples was from 200.3 to 210.1 μS/cm during the dry season. The wet season samples' conductivity ranged from 190.4 μs/cm to 420.2 μs/cm. Reservoir samples' conductivity was also found between 201.1 μs/cm and 210 μs/cm on the dry season and 225.5 μs/cm to 388.7 μS/cm on wet season. The average conductivity value in the dry and wet seasons was 206 μs/cm and 333.3 μS/cm, respectively (Table 5). There was a significant difference in electrical conductivity between the reservoir and tap water in both seasons (F = 57.14, $p < 0.05$); however, as the post-hoc test revealed, there is no EC difference between tap water and reservoir water sources during the wet season (t = 0.65< t critical, $p = 0.52$).

Table 5 | Physical parameters of Fiche town drinking water (mean ± standard error)

	Temperature (°C)	EC (μs/cm)	Turbidity (NTU)	TDS (mg/L)
Dry season (tap water)	19.8 ± 0.01	208.57 ± 0.4	1.08 ± 0.05	104.3 ± 0.2
Wet season (tap water)	19.6 ± 0.01	341.07 ± 11.9	1.3 ± 0.05	170.53 ± 6
Dry season (reservoir)	19.8 ± 0.01	203.37 ± 1.2	1.03 ± 0.04	101.62 ± 0.6
Wet season (reservoir)	19.6 ± 0.00	325.5 ± 15.08	1.28 ± 0.07	160.75 ± 8.5
Mean of mean	**19.7 ± 0.01**	**269.63 ± 7.14**	**1.17 ± 0.05**	**134.3 ± 3.82**

The analysis indicated that the turbidity of all the samples was 1.17 NTU (Table 4). There was difference in the cloudiness of water caused by a variety of particles among samples (F = 4.2, $p < 0.05$). The real turbidity difference was found between the dry and wet season for tap water (t = −11.04, $p < 0.05$) and dry and wet season for reservoir water (t = −2.8, $p < 0.05$).

The total dissolved solid of samples was in the range between 95 and 210 mg/L. The average value TDS was 134.3 (Table 5). The maximum value of TDS was found during the wet season. The number of dissolved solids was higher in the tap water than in reservoir sources (~7 mg/L changes). There was a higher difference among samples collected from tap and reservoir sources (F = 54.9, $p < 0.01$). Post analysis showed a higher difference was found between seasons ($p < 0.01$) and between sample collection sites ($p < 0.01$) except reservoir samples in the wet season ($p = 0.4$). The correlation coefficient index showed a very strong positive relationship between electrical conductivity and total dissolved solids (r = 0.99) in both tap water and reservoir water samples. Values of temperature (19.7), electrical conductivity (269.63), turbidity (1.17), and total dissolved solids (134.3) were found to be below the prescribed limit of World Health Organization guidelines for drinking purposes. No sample was detected to have color. Every sample was inodorous and has no objectionable taste (Table 6).

Among 210 water samples analyzed from pipe and reservoir in Fiche town, 37.14% and 25.71% were contaminated with total coliforms (TC) and fecal coliforms (FC) respectively. All water samples taken from the reservoir were free from both TC and FC in both seasons (Table 7).

Table 6 | Outputs of qualitative physical parameters

	Color	Odor	Taste
Dry (tap water)	Colorless	Inodorous	Not objectionable
Wet (tap water)	Colorless	Inodorous	Not objectionable
Dry (reservoir)	Colorless	Inodorous	Not objectionable
Wet (reservoir)	Colorless	Inodorous	Not objectionable

Table 7 | Seasonal prevalence of indicator organisms detected in the drinking water samples

	Dry season		Wet season	
Indicator organism	Pipe ($N = 85$)	Reservoir ($N = 20$)	Pipe ($N = 85$)	Reservoir ($N = 20$)
TC [n (%)]	9 (11.76)	0	53 (62.35)	0
FC [n (%)]	5 (5.88)	0	39 (45.88)	0

During the dry season, out of the samples of water taken from the pipe, TC and FC were detected in 9 (11.76%) and 5 (5.88%) samples, respectively. Higher TC counts were observed particularly in pipes connected to plastic tubes in homes selling water to others. Out of the positive samples, three samples were the most contaminated of all, in which 'too numerous to count' (TNTC) TCs were detected. On the other hand, out of 20 samples of water taken from the reservoir, neither total nor fecal coliforms were detected (Table 8).

Table 8 | Bacteriological count of drinking water among all water samples (mean $\pm$ SE)

	Dry season		Wet season	
Indicator organisms	Pipe ($N = 85$)	Reservoir ($N = 20$)	Pipe ($N = 85$)	Reservoir ($N = 20$)
TC (CFU/100 mL)	3.93 ± 0.81	0.00	9.29 ± 1.45	0.00
FC (CFU/100 mL)	1.00 ± 0.21	0.00	5.07 ± 0.79	0.00

In the wet season, out of 85 samples of water taken from pipes, TC and FC were detected in 53 (62.35%) and 39 (45.88%) respectively. Out of 53 positive TNTC, TCs were detected in seven samples. As in the dry season, samples collected from reservoirs in the wet season were free from both total coliforms and fecal coliforms (Table 8).

Tap water sources from pipes in both seasons had overall mean TC and FC counts of 6.61 and 3.04 CFU/100 mL, respectively. Analysis of variance of the mean counts (CFU/100 mL) revealed that there was a statistically significant difference ($p < 0.05$) among the mean counts of both TC and FC in both seasons. The present study showed that both TC and FC counts obtained from tap water were higher in the wet season than in the dry season (Table 6). Generally, total coliforms (9.29 CFU/100 mL during the wet season, 3.93 CFU/100 mL- during the dry season) and fecal coliforms (5.07 CFU/100 mL- during the wet season; 1.00 CFU/100 mL- during the dry season) were detected from pipe water sources, indicating non-compliance with the WHO water quality guideline.

DISCUSSION

As the survey part of the study revealed, most of the respondents remarked that the water has no smell (99%), no taste (90%), and no color (84.44%); the majority of the respondents remarked that the

overall quality of drinking water at Fiche town is good (66.67%). Consequently, many (71.11%) of the households did not treat the water at home before drinking. The main reason for letting the water be untreated before drinking is the expectation of the societies that the water may not be contaminated. It was possible to conclude that Fiche town communities' information about water treatment before drinking is comparable with the research result observed at Bona District (73%) and Dire Dawa Town (87%), where the majority of the households never treat water at home before drinking (Amenu *et al.* 2013; Berhanu & Hailu 2015).

The drinking water aesthetic parameters such as appearance, color, taste, and odor indicate the hygienic state of water and the risk of water-borne infections (Tamungang *et al.* 2016) and affect the water's acceptability to consumers. Under this study, the water had no color, no taste, and no odor, and an acceptable value of turbidity was recorded. Turbidity is the cloudiness or haziness of the water caused by suspended solid particles (Khanam & Singh 2014). Turbidity within the WHO acceptable value was recorded in this study, which is also supported by the households' response. High amounts of turbidity particles in the water can shield pathogenic organisms from being attacked by disinfectants (Behailu *et al.* 2017), and thus drinking such water can have health risks (Yasin *et al.* 2015). The value of turbidity recorded under this study was in the range of 0.6 to 1.9, an annual average of 1.18. This value is less than the 5 NTU value recommended by WHO (WHO 1997), and the value is lower than the turbidity value (2.1–2.9 NTU) reported in Jimma town of Ethiopia (Chalchisa *et al.* 2017).

The temperature of the water affects the rate of chemical reactions and solubility of gases in the water body, and thus affects the color and taste of the water (Olajire & Imeokparia 2001). The average value of the temperature of drinking water at Fiche town was 19.7 °C, and the result is comparable with the study reported in Bahir Dar town (15–20 °C), in Ethiopia (Milkiyas *et al.* 2011). All the recorded values of temperature were very close to the recommended limit (20 °C) for drinking water (Garoma *et al.* 2018).

Electrical conductivity (EC) is mostly influenced by the number of salts dissolved in the water and is responsible for its conductivity of an electric current (Duressa *et al.* 2019). The measured values of EC are excellent indicators of TDS in the water (Werkneh *et al.* 2015). EC and TDS have a strong relationship (ESS 2016), and this relationship has been supported by their positive correlation coefficient index, $r = 0.99$, recorded under this study. The electrical conductivity values were ranged between 190.4 and 420.2 μS/cm. The average recorded values of EC (269.63 μS/cm) were a little higher than the WHO Standard EC measures (<250 μS/cm) and within the Australian Standard EC measures (<800 μS/cm), which indicate good quality of drinking water (NHMRC/NRMMC 2011). The EC of the water, 190.4 to 420.2 μS/cm, recorded in this study was similar to that of the drinking water in Jimma town (EC of 30.77 to 727.67 μS/cm) (Yasin *et al.* 2015), and that of Shambu town (80–248.96 μS/cm) (Garoma *et al.* 2018).

TDS is the amount of dissolved inorganic salts and organic matter in the water solution. Under this study, the amount of TDS in the water was found to be in the range of 95 to 210 mg/L. The average value of TDS was 134.3 mg/L. The maximum value of TDS was found during the rainy season. According to World Health Organization standards, the desirable limit amount of TDS in drinking water is between 600 and 1,000 mg/L (WHO 2017). The high amount of TDS in drinking water may affect people who have kidney and heart disease (Werkneh *et al.* 2015). In terms of balancing body ions and energy from dietary contribution, this water is considered to have poor mineral content and is unacceptable in this regard, which is similar to another study conducted in Shambu town, Ethiopia (Garoma *et al.* 2018).

In Ethiopia, access to improved water supply and sanitation has been very low and hence the majority of the communicable diseases are associated with unsafe and inadequate water supply (Duressa *et al.* 2019). The bacteriological quality analysis of household water samples of the study area shows that, of 170 samples of water collected from a pipe in both dry and wet seasons,

62 were positive for TC with 3-TNTC CFU/100 mL and 44 were positive for FC with 7-TNTC CFU/100 mL. This is higher than the study conducted by Eliku & Sulaiman (2015), in Adama, in which out of 52 pipe water samples eight (15.38%) were positive for FC ranging from 1–10 CFU/100 ml. However, this is much lower than the study conducted by Haddis *et al.* (2017) in Shashemane, in which TC and FC were 90.5% and 42.8% respectively. Another study conducted in Serbo town, southwest Ethiopia, showed that 50% of samples had fecal coliforms, of these 35.7% had E. coli (Solomon *et al.* 2011). In the study area, it has been observed that fecal coliforms were higher in drinking water collection and storage containers water than from sources, suggesting that contamination may occur due to bacterial growth in unclean pieces of storage equipment. This study concurrently agreed with a study that showed that water collection containers affected household water quality in India (Eshcol *et al.* 2009). This study has limitations in identifying specific strains of responsible pathogens, so we recommend that other researchers may conduct a study concerning the issue.

In the current study, tap water obtained from a pipe connected to a plastic tube showed greater contamination with total coliforms than from those who did not use plastics for an extension. They take the water directly from installed metallic pipes. Seasonal variation was also observed in water samples obtained from pipes in which a higher bacterial count was recorded in the wet season than in the dry season. However, both TC and FC were not detected in all samples collected from reservoirs in both seasons. This is probably due to free residual chlorine applied at the disinfection point of the treatment system (Werkneh *et al.* 2015). In general, from a total of 210 water samples of both collection points, 107 (50.95%) were found to have zero TC and FC per 100 ml which is at the acceptable limit of WHO and national standard. But this is lower than the study conducted by Eliku and Sulaiman (Eliku & Sulaiman 2015) in Adama, in which out of 52 pipe water samples 43 (82.69%) were found to have zero TC and FC per 100 ml of water.

CONCLUSIONS

Following the results of the survey and experimental analysis, physical characteristics of the town's water were found to be within the WHO guidelines' permissible level. Uncountable bacterial contamination was found at the households that were using more plastic tubes connected to the pipeline. The majority of households never treat the water before consumption. The pipes and water storing equipment are not frequently washed and cleaned. The authors recommended that water development and public health offices must collaborate to organize theoretical and practical training programs to create awareness to households on the prevention of drinking water contamination and water-borne illnesses. In addition, it is very advisable to treat water at home before consumption at least to eliminate the common waterborne pathogenic microorganisms introduced into the drinking water through the pipeline at some points. This study highlights the need for continuous monitoring and quality assessment of groundwater and modernizing purification processes throughout the water distribution system.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

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

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