

Research Paper

Bacteriological and physicochemical quality of drinking water in Kobo town, Northern Ethiopia

Baye Sitotaw and Molla Nigus

ABSTRACT

Despite drinking water supply in Kobo town is from a borehole through pipes, a high incidence of waterborne diseases are frequently reported. Hence, this study aimed to assess the bacteriological and physicochemical drinking water quality in Kobo town. One hundred and twenty water samples were collected from four sampling sites (the source, reservoir, taps, and households' containers) from February to April 2020. Total and fecal coliforms were counted from the water samples using membrane filtration while selected physicochemical parameters were determined using standard methods. The mean counts of total and fecal coliforms ranged from 3.9 to 22.9 and 1 to 13.6 CFU/100 mL, respectively. Hence, all water samples did not satisfy the WHO guidelines and national standards. There were statistically significant differences in the coliform counts between the different sampling sites, and the counts were significantly higher in the taps and households' containers compared to the counts in the source and reservoir ($p < 0.05$). All physicochemical parameters, except for temperature, were within the recommended acceptable limits. High coliform count in the water system demands proper maintenance of the distribution line and good hygiene practices at household level to improve the microbiological quality of drinking water in Kobo town.

Key words | bacteriological quality, coliforms, drinking water, Kobo town, physicochemical parameters

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HIGHLIGHTS

- Drinking water in Kobo town had high risk score.
- Coliform counts in drinking water of Kobo town fail to comply with WHO standards.
- Physicochemical water quality parameters in Kobo town comply with WHO standards.
- Poor sanitation and water handling practices were observed in the community of Kobo town.
- Preventing human activities around the water source and reservoir are highly recommended.

INTRODUCTION

Delivering adequate and potable water to all citizens is among the top priorities of governments in all nations.

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Goal 6 of the Sustainable Development Goals (SDGs) focuses on ensuring access to water and sanitation for all, and almost all countries in the world have promised to achieve SDGs (WHO 2017a). Despite the efforts, drinking water pollution continues to pose health threats to communities in low-income nations. Drinking water can be polluted

at any point along the way from the source to the point of consumption. Several human pathogens can be transmitted via polluted drinking water (WHO 2017b). Worldwide, water-related diseases account for about 80% of all illnesses and diseases; 785 million people use unimproved water sources; 144 million people rely on surface water for drinking; and about 2 billion people use drinking water contaminated with feces (WHO 2019).

Waterborne diseases are very common in poor communities, where drinking water can easily be polluted due mainly to lack of awareness about appropriate sanitary practices and low water supply. For instance, Wright *et al.* (2004) pointed out that drinking water pollution in developing nations is mainly caused by poor handling practices and lack of knowledge about keeping drinking water safe. Several studies conducted in developing nations including in Kenya and Vietnam (Grady *et al.* 2015) and southwestern Nigeria (Bisi-Johnson *et al.* 2017) reported high risks of drinking water contamination with pathogens that greatly compromised public health.

The Ethiopian government has given considerable attention to the supply of adequate and safe water to the people. As a result, Ethiopia met the target of 60% safe drinking water coverage by 2015 (WHO/UNICEF 2017). However, water quality deterioration is still a serious health and development issue in Ethiopia. Basic water and sanitation services are very low, and water-related diseases are highly prevalent in Ethiopia. Safe drinking water coverage is about 66%, and only 6.3% of households have access to improved sanitation (Beyene *et al.* 2015; CSA 2017; UNICEF Ethiopia 2018). Moreover, over 80% of people do not practice improved hygiene behaviors and live in unhealthy environments (UNICEF Ethiopia 2018). As a result, communicable diseases related to limited access to safe water, inadequate sanitation, and poor hygiene services accounted for 60–80% of all illnesses and diseases in Ethiopia (UNICEF Ethiopia 2018).

Scientific information about drinking water quality from different settings is vital in tackling water-related problems. The two principal activities in water quality assessment are observational techniques (sanitary survey and qualitative visual inspection) and water quality analysis (both biological and physicochemical). If carefully applied, sanitary inspection (SI) tools well complement water quality test results

for a comprehensive management of drinking water systems (Kelly *et al.* 2020). SI helps identify potential risks, provide information on possible causes of both past and future pollution and actions necessary to manage future water quality. Bacterial pathogens are commonly used biological parameters, and selected physicochemical parameters can be included depending on the specific objective of a study. While the number of different pathogens can be large in a contaminated water sample, load of pathogens from fecal contamination is usually too small to detect. It is, therefore, difficult and even unsafe to test for pathogens in a large number of water samples. Alternatively, pathogens can be quantified indirectly by testing for an ‘indicator’ organism such as coliform bacteria. The quantification of coliform bacteria has thus been serving as indirect evidence for quantitatively estimating pathogenic bacteria in drinking water samples (Bartram & Balance 1996; WHO 2017b).

Coliform bacteria originate from the same sources as pathogenic bacteria do. They are relatively easy to identify, are usually present in larger numbers than the pathogens, and respond to the environment and water treatment similarly to many pathogens (Bartram & Balance 1996). As a result, counting coliform bacteria has been a standard method to estimate the load of pathogenic bacteria in a sample. Total coliforms include bacteria that are found in the soil as well as in human or animal waste. Fecal coliforms, on the other hand, are members of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. Because the origins of fecal coliforms are more specific than the origins of the more general total coliform group of bacteria, they are considered a more accurate indication of animal or human waste than the total coliforms.

World Health Organization (WHO) guidelines as well as Ethiopian standards for drinking water quality do not allow any detection of coliforms in 100 mL of drinking water. Even though a high count of total coliforms may not directly indicate pathogenic bacteria contamination, this at least shows that chlorination has not been properly done, which in turn, could lead to bacterial contamination of drinking water. However, a high count of fecal coliforms is direct evidence for fecal contamination (WHO 2017b).

Several studies on the bacteriological quality of drinking water have been conducted in many locations in Ethiopia.

In southern Ethiopia, Alemayehu *et al.* (2020) reported that 44.7% and 50.9% of the drinking water samples were contaminated with *Escherichia coli* and *Enterococcus*, respectively, and had a high-risk score. Similarly, Gizachew *et al.* (2020) reported that 44 and 91% of drinking water samples collected from different sources and households, respectively, were positive for fecal coliforms. In western and southwest Ethiopia, Yasin *et al.* (2015) indicated that all drinking water samples were positive for total and fecal coliforms. Likewise, Duressa *et al.* (2019) reported 100% total coliforms and 37% fecal coliform contamination rates of drinking water samples in Nekemte town. In north and northwest Ethiopia, Tabor *et al.* (2011) reported that 77% of the drinking water in Bahir Dar city was positive for total coliforms and had a high-risk score, and Feleke *et al.* (2018) reported that 82.1–86.8% of drinking water in Wogera town was contaminated with fecal coliforms. However, no study has ever been conducted in the Kobo area.

The majority of the population in Kobo town (7,000 of 85,000 households) obtains drinking water from a borehole through pipes. The remaining 1,500 households obtain drinking water directly from another well by hand pumping.

According to official reports from the health sector of the town, water-associated diseases were among the top ten causes of illness in the community. For instance, 5,864 people in 2017 and 6,037 people in 2018 were sick from waterborne diseases such as diarrhea, amoebiasis, or other intestinal bacterial pathogens. The recent quarterly report (from July to September 2019) showed that 1,620 children under the age of five were affected by waterborne diseases. The overall aim of this study was thus to gain insight into the possible health risks due to drinking water quality deterioration in Kobo town, with the following specific objectives: water quality evaluation against guidelines and standards and assessment of possible risks based on sanitary surveys.

MATERIALS AND METHODS

Study area description

This study was conducted in Kobo town, Kobo district, north-east Ethiopia (Figure 1). This town is situated some 570 km northeast of Addis Ababa, the capital city of Ethiopia. The

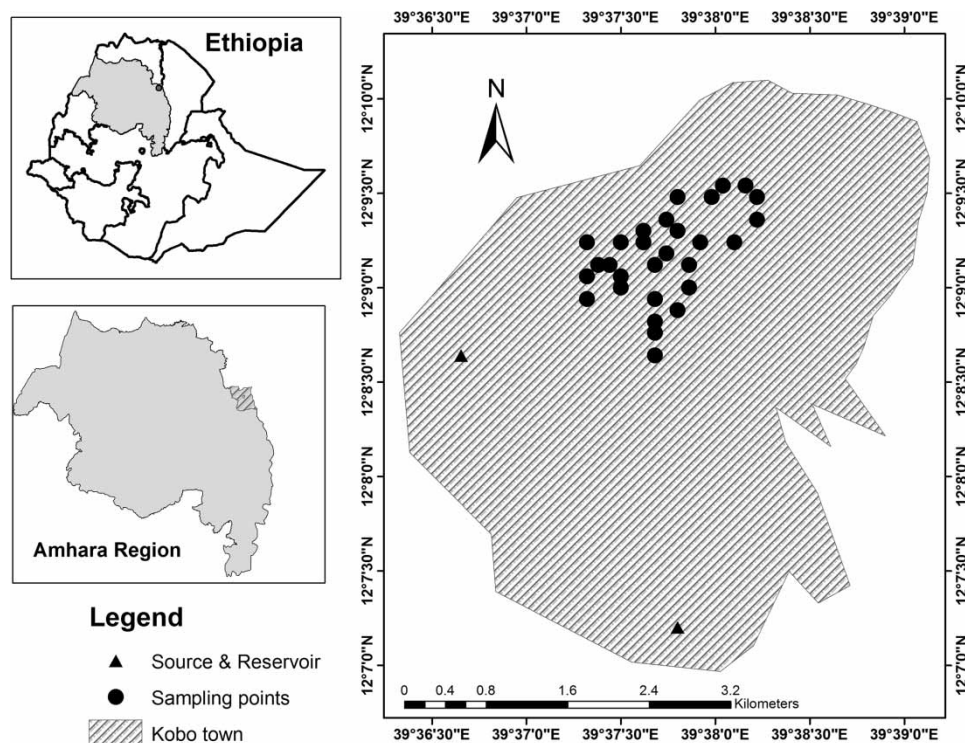


Figure 1 | Map of the study area (the sampling points at each household are from the urban sites).

town is located at the latitude of 12°09 N, longitude of 39°38 E, and at an elevation of about 1,500 meters above sea level. The town is part of a mid-altitude (lowland) area where the annual mean temperature is 24–32 °C, and the mean annual rainfall is about 500 mm. The primary wet season extends from June through September, of which July and August are the wettest months. The town has an estimated total population of 49,724 of which 24,812 (49.9%) were males and 24,912 (50.1%) were females (CSA 2008).

The current drinking water supply coverage of this town is estimated to be 78.3%. This is calculated based on the criteria stated in the Ethiopian government first Growth and Transformation Plan (GTP I). The criteria demanded the provision of 20 liters of clean water per person in a day within a radius of 0.5 kilometer in urban areas, and the target coverage in urban areas was a clean drinking water supply of 91% (official document of Kobo district water sector, 2019). Chlorination of the water system in Kobo town is done at the reservoir using calcium hypochlorite powder (at the concentration of 2.5 mg/L of water), which contains 65–70% available chlorine. However, chlorination was performed inappropriately. Based on the information obtained from the responsible person (personal communication), less contact time, irregular chlorination, frequent breakage in the distribution line, and not checking free chlorine before distributing the water were major limitations.

Study design

A cross-sectional study was conducted to evaluate the microbiological and physicochemical quality of drinking water in Kobo town from February to April 2020. Four out of five *kebeles* (the smallest administration level), which obtained tap water piped from the borehole, were included in the study. One *kebele* was excluded from the study as it was located a little farther from the others and the residents used hand dug well water for drinking. Before sample collection for water quality analysis, sanitary assessment was conducted at the source, reservoir and 364 households, which were selected through systematic random sampling technique. Next, 30 households who used taps were selected (sub-sampled) again through systematic random sampling technique. Then, water samples from the source, reservoir, and the 30 households (both from their taps and water

containers) were collected for bacteriological and physicochemical analyses.

Sanitary assessment of drinking water from source to the household level

Prior to water quality analysis, assessment of the sanitary status of the drinking water source, reservoir, and distribution lines was carried out through visual inspection following recommendations in WHO/UNICEF (2012). Structured questionnaires were used to obtain information on the sanitary condition at the household level that may affect drinking water quality. The questionnaires were first developed in English and translated into Amharic (a local language) and then the responses were translated back into English. Three hundred and sixty-four households, including the 30 households chosen for water quality analyses, were selected through systematic random technique from four *kebeles* in the study area for the preliminary assessment of the risk factors for water contamination. The sample size ($n = 364$) was determined using single population proportion formula for cross-sectional surveys (i.e., $n = \frac{z^2 p(1-p)}{d^2} = \frac{1.96^2 0.7(1-0.3)}{0.05^2} = 322 + 10\%(32) = 364$ students) assuming that 70% of the households in the community had poor sanitary conditions, and with 10% addition to compensate for the non-respondents.

Sample size, sampling, and sample handling for water quality analysis

Among the 364 households selected for a preliminary assessment, 30 households were sub-sampled as mentioned earlier, and from these, drinking water samples were collected from their taps and water containers. Water samples were thus collected from the source (borehole), the disinfection point (reservoir outlet), taps at the residence of each household, and households' containers. A total of 120 water samples, 30 samples from each sampling site (the source, reservoir, taps, and households' containers), were collected from the urban sites of Kobo town. A 1-liter water sample was collected aseptically using sterilized glass bottles for bacteriological examination, while samples for chemical analyses were collected using 1-liter acid-washed polyethylene

bottles. The samples were collected in the morning between 7.00 and 8.00 a.m., kept in an icebox and transported to the microbiology laboratory within 3 hours. The analyses started immediately after the samples had arrived at the water quality laboratory of Water Supply and Development Sector, North Wollo Zone, Ethiopia.

Bacteriological quality analysis of the water samples

Coliform count was performed using membrane filtration technique following procedures described in APHA (2005). The absorbent pads were aseptically placed into Petri plates and saturated with Lauryl Sulphate Broth (HiMedia). A 100-mL water sample was filtered through a 0.45- μm membrane filter (HACH company), and the filter papers were put onto the absorbent pad. The plates were then incubated at 37 °C and 44 °C for 24 hours for total coliforms and thermotolerant coliform count, respectively. After 24 hours of incubation, colonies with yellow color were counted and recorded.

Determination of physicochemical parameters

Basic physicochemical parameters in the water samples were measured following standard methods described in APHA (2005). Temperature (using Bio abron student mercury thermometer), pH (using Wagtech pH meter, model CP 1000 Singapore), turbidity (using Wagtech turbidity meter model Wag-WT 302, Singapore) and conductivity (using TDS/Conductivity meter, Wagtech 534000, Singapore) were measured *in situ*. Residual chlorine and nitrite were determined by photometric methods using Palintest Photometer 7100 (Wagtech, Thatcham, UK).

Data analysis

Data were analyzed using SPSS statistical software (version 23). The normality of the data and homogeneity of variance for dependent variables within sampling sites were checked using Kolmogorov–Smirnov test and Levene test, respectively. The data were found not normally distributed, and as well, the distribution of the values of each dependent variable for each sampling site was not identical. As a result, to compare mean ranks and to show significant differences in the measured parameters among the different sampling sites

Kruskal–Wallis H test was conducted. The values of bacterial counts and physicochemical parameters of the investigated water samples were compared with WHO guidelines and Ethiopian standards for drinking water quality. In addition, water samples were categorized into the different risk levels according to the risk classification for thermotolerant coliforms of water supplies, as suggested by Tadesse (2014). In all cases, statistical significance was set at 95% confidence interval and a p -value of ≤ 0.05 .

Ethical approval and informed consent of participants

Before collecting the data, the ethical review committee of Science College, Bahir Dar University, cleared the study, and a letter describing the objectives of the research was written to water and health offices in the administration of Kobo town. In addition, informed consent was obtained from the participants selected for this study after explaining the purpose of the study.

Limitations of the study

The presence of *E. coli* could have been tested in all water samples as this is a highly recommended microbial indicator for recent fecal pollution. Moreover, the self-administered questionnaires might have biased the results.

RESULTS

Bacteriological quality of drinking water in Kobo town

In this study, 95.8% (115/120) of the drinking water samples were positive for total coliforms (TC) and did not comply with the WHO guideline or national standard. Comparing each sampling point, 93.3% (28/30) of water samples from the source, 90% (27/30) of water samples from the reservoir, and 100% of water samples from households (both from the taps and containers) were positive for TC. The highest (22.9 CFU/100 mL) and the lowest (3.9 CFU/mL) mean TC counts were recorded in the water samples taken from households' containers and water samples taken from the reservoir, respectively (Table 1).

Table 1 | Mean count ($n = 30$), range, and mean rank of total and fecal coliform bacteria (CFU/mL) of drinking water samples from the different sampling points in Kobo town, 2020

Indicators	Sampling points	Mean \pm SD	Range	Mean rank*	Risk level
Total coliforms	B (Borehole/sources)	7.5 \pm 3.7	0–15	44.7	–
	R (Reservoir/disinfection) point	3.9 \pm 2.7	0–12	23.2	–
	T (Taps at each household)	18.9 \pm 10.8	6–40	80.5	–
	H (Households' containers)	22.9 \pm 7.7	10–38	93.6	–
Fecal coliforms	B (Borehole/sources)	1.8 \pm 1.9	0–7	38.7	Low
	R (Reservoir/disinfection) point	0.5 \pm 0.9	0–4	24.8	Low
	T (Taps at each household)	13.5 \pm 8.4	1–29	87.9	High
	H (Households' containers)	13.6 \pm 6.4	2–27	90.5	High
Res.Cl ₂ (mg/L)	B (Borehole/sources)	0.00	–	15.5	–
	R (Reservoir/disinfection) point	0.37 \pm 0.07	0.3–0.5	101.2	–
	T (Taps at each household)	0.19 \pm 0.10	0.01–0.4	66.	–
	H (Households' containers)	0.15 \pm 0.09	001–0.4	59.3	–

SD, standard deviation.

WHO guideline value for residual chlorine = 0.2–0.5 mg/L.

Regarding fecal coliforms (FC), 74.2%(89/120) of the water samples were positive for FC and hence did not conform to the WHO guidelines and Ethiopian standards. Of these, 63.3% (19/30), 33.3% (10/30), and 100% of the water samples from the sources, reservoir, and households (taps and containers), respectively, were positive for FC.

A Kruskal–Wallis H test showed that there was a statistically significant difference in TC between the different sampling sites, $\chi^2 = 77.8$, $p < 0.01$, with mean rank TC of 44.7 for borehole, 23.2 for reservoir, 80.5 for taps, and 93.6 for households' containers. Similarly, there was a statistically significant difference in FC between the different sampling sites, $\chi^2 = 85.9$, $p < 0.01$, with mean rank FC of 38.7 for borehole, 24.8 for reservoir, 87.9 for taps, and 90.5 for households' containers.

Concerning the residual chlorine, the mean value was within the expected range in the reservoir while it was lower than the expected value in the taps and households' containers (Table 1).

According to Tadesse (2014), risk classification for thermotolerant coliforms (based on mean count of fecal coliforms), water samples from households' containers and taps were in the high-risk category while those from the source and reservoir fell into the low-risk category (Table 1). However, if all the 30 samples for each sampling site is considered, 63.3% of the water samples from the

households' containers and 50% from the taps fell into the high-risk category, while the rest of the samples from these two points were in the low-risk category. On the other hand, 63.3% and 33.3% of the water samples from the source and reservoir fell into the low-risk category while the rest fell into the no-risk category.

Physicochemical drinking water quality in Kobo town

Except for temperature, all other physicochemical parameters of drinking water in Kobo town were found to be within the permissible limits recommended in WHO guidelines and national standards (Table 2). Maximum mean values of pH, temperature, turbidity, and nitrite were recorded in water samples from households' containers, while the minimum mean values of the same parameters were recorded in water samples from the source (borehole). Mean temperature values ranged from 21.6 (borehole) to 25.9 °C (households' containers). The minimum and maximum mean conductivity values ($\mu\text{s}/\text{cm}$) were recorded in taps (360) and borehole (403). A Kruskal–Wallis H test showed that there were statistically significant differences in all physicochemical parameters between the different sampling sites (Table 2). Generally, mean pH, temperature, turbidity, and nitrite showed an increasing pattern from

Table 2 | Mean ($n = 30$), range, and mean rank of physicochemical values for drinking water samples from the different sampling points in Kobo town, 2020

Parameters	Sampling points	Mean \pm SD	Range	Mean rank	Chi-square
pH	B	6.8 \pm 0.32	6–7.3	30.9	75.1
	R	7 \pm 0.51	6–8	39.8	
	T	7.5 \pm 0.08	7.4–7.7	70.6	
	H	7.9 \pm 0.21	7.5–8.3	100.7	
Temperature ($^{\circ}$ C)	B	21.60 \pm 1.19	19.5–23.5	20.9	101.8
	R	22.78 \pm 0.52	22–23.7	40.6	
	T	24.22 \pm 0.52	23.5–25.6	76.8	
	H	25.78 \pm 0.75	24–27	103.9	
Turbidity (NTU)	B	0.61 \pm 0.40	0.01–1.07	24	98.9
	R	0.89 \pm 0.27	0.04–1.1	37	
	T	3.87 \pm 0.59	2.4–5	78.1	
	H	4.97 \pm 0.57	3.8–5.8	102.8	
Conductivity (μ s/cm)	B	403.4 \pm 21.8	350–436	88.4	43.4
	R	393.7 \pm 39.9	345–468	71.8	
	T	360.13 \pm 10.7	339–379	34.7	
	H	369.5 \pm 18.7	339–412	47.1	
NO ₂ (mg/L)	B	0.024 \pm 0.014	0.01–0.06	24.9	92.8
	R	0.04 \pm 0.03	0.01–0.16	36.1	
	T	1.05 \pm 0.44	0.4–1.9	85	
	H	1.39 \pm 0.52	0.4–2.9	96	

B = borehole/source, R = reservoir, T = taps, H = households' containers.

WHO guidelines or Ethiopian standards are for pH 6.5–8.5, temperature \leq 15, turbidity \leq 5, conductivity \leq 1,000, and nitrite 3.

the source to household samples while mean conductivity slightly decreased from the source to household samples.

Sanitary assessment at the source, distribution line, and household level

Results from sanitary inspection at the source, reservoir, and the distribution system indicated that the source, including the line to the reservoir, had a 61.5% (8/13) risk score while the reservoir, along with the distribution line to the taps, had a 50% (5/10) risk score. Based on the sanitary inspection risk score described in WHO (2012), the source and the distribution line to the reservoir were at the high-risk level. On the other hand, the reservoir and the distribution line to the taps were at the intermediate-risk level (Supplementary Material, data 1).

In addition, a total of 17 questions was presented to the 364 selected households to obtain preliminary information about the sanitary conditions at the household level

(Supplementary Material, data 2). Of the respondents, 88% did not wash their hands before drawing water from the storage, 73% rarely washed drinking water storage containers, 70% had waterborne disease of at least one family member in the last three years, 70% had drinking water collecting container inadequately covered, 68.4% did not wash their hands after using the toilet, and 60.2% had cracked or unclean drinking water storage.

Thirty out of the 364 households were selected for water quality analysis, and to find out the association between the risk factors listed in Supplementary Material data 3 with the level of water contamination. However, the association using chi-square test was not analyzed, because the expected value of the number of sample observations in each level of the variable was less than 5. As a result, only description statistics were employed.

Most of the respondents (86.7%) from the 30 households were females; between 41 and 60 years old (86.7%); cannot

read and write or just primary school completed (80%); farmers (70%); earned Ethiopian Birr <2,000 monthly (96.6%); and had a family size of 5 and above (70%). Among the 30 households interviewed and/or inspected, some 22 (73.3%) washed their water storage containers rarely; 26 (86.7%) did not wash their hands or washed sometimes after using the toilet; 20 (66.7%) placed their finger inside the tap to allow adequate water flow; 20 (66.7%) had cracked or unclean water storage containers; and 19 (63.3%) covered their water storage container inadequately.

DISCUSSION

Waterborne disease, as the result of low supply of potable water, has been among the major public health challenges in low-income countries like Ethiopia. Clinical information, preliminary sanitary survey data, and general observation in Kobo town indicated possibilities for high risks of drinking water pollution. This study aimed to assess the microbiological and physicochemical quality of drinking water and some associated risk factors in Kobo town. Drinking water samples from the source, reservoir, taps, and households' containers were analyzed for microbial and physicochemical water quality parameters.

Bacteriological quality of drinking water in Kobo town

Based on the mean count of TC and FC, all water samples from the four sampling sites fail to satisfy WHO guidelines and Ethiopian standards for drinking water quality. Considering all samples, almost all samples (95.8%) also did not comply with WHO guidelines and Ethiopian standards for drinking water quality in terms of TC (ESA 2013; WHO 2017b). Similarly, TC contamination rate of 100% by Duressa *et al.* (2019) in Nekemte town (western Ethiopia) and Yasin *et al.* (2015) in Jimma zone (southwest Ethiopia), and 77% by Tabor *et al.* (2011) were reported. Although the detection of TC may not necessarily show the presence of pathogens, it at least implies inadequate chlorination that, in turn, leads to pathogenic contamination of the drinking water.

The mean FC (CFU/100 mL) of water samples in the taps (13.5) and households' containers (13.6), and TC contamination of 74% of all water samples recorded in this

study were in agreement with previously reported results in Jimma zone (southwest Ethiopia) (Yasin *et al.* 2015), in Wogera town (northern Ethiopia) (Feleke *et al.* 2018), and in Wolaita zone (southern Ethiopia) (Gizachew *et al.* 2020). The presence of FC in drinking water implies fecal contamination and hence a high risk of pathogenic bacteria contamination (WHO 2017b). It is strongly suggested that Kobo town health and water sector should take appropriate measures to control drinking water pollution.

Generally, drinking water at the household level (both in taps and water containers) were found to be highly contaminated with coliforms compared to the source and the reservoir (Table 1). This result is in agreement with previous reports from Boloso Sore District in southern Ethiopia (Gizachew *et al.* 2020) and from southwestern Nigeria (Bisi-Johnson *et al.* 2017), but was in contrast to the report from Shambu town (western Ethiopia) (Garoma *et al.* 2018) where water samples were shown to have lower TC counts compared to the sources and the reservoir.

Based on the result of this study, poor water handling practices at the household level and possible pollutant leakages at some point(s) in the distribution line from the reservoir to the taps (Supplementary Material, data 1) were highly likely reasons for the observed contamination. Similarly, Wright *et al.* (2004), in their systematic review of microbiological contamination between source and point-of-use in developing countries, and Gizachew *et al.* (2020), in their study in southern Ethiopia (Boloso Sore District), identified poor drinking water handling practices at household level as a major factor for microbial contamination of drinking water. The results of this study suggest an awareness raising campaign on best drinking water handling practices for the community in Kobo town.

Given that the source of drinking water for Kobo town is a borehole (relatively considered as the safest water source), the detection of coliforms is unexpected. This may be due to poor sanitation status around the borehole as indicated in the sanitary survey data (Supplementary Material, data 1). This evidence of contamination in the source is likely due to agricultural activities in the vicinity, poor protection, exposure to contamination by wastes from humans, animals, and the surrounding environment. Similar to the result of this study, 40% (35/88) of boreholes in the southern region of Ethiopia were found to be contaminated with FC

(Alemayehu *et al.* 2020). Similarly, TC (up to 12 CFU/100 mL) were detected at the disinfection point although the FC count was low (>4 CFU/100 mL). High coliform count in the reservoir (disinfection point) was also previously reported from Shambu town drinking water supply (Garoma *et al.* 2018).

In this study, high coliform counts in the water system can also be accounted for by the inadequate chlorination (Table 1), which was also reported from Bahir Dar town drinking water system (Tabor *et al.* 2011). Low residual chlorine level implies that the water system is vulnerable to bacterial contamination, and the impact on public health can be devastating as the result of pathogenic bacteria contamination. The town water sector should strictly conduct proper chlorination.

Sanitary conditions at the water source, reservoir, and household level in Kobo town

Adequate water supply, sanitation, and hygienic condition are mandatory to secure access to safe drinking water. In contrast, the sanitation coverage in Ethiopia is very low, and was 52.1% during 2014 and far lower than the national plan set to reach 60% by 2015 (Beyene *et al.* 2015). Kobo town is not an exception to the low sanitary coverage in the country. Results from the sanitary inspection around the water source indicated a high-risk level (Supplementary Material, data 1), which more or less agrees with a previous report from the southern region of Ethiopia (Alemayehu *et al.* 2020). Lack of vegetation cover, animal access, poor protection, and various human activities around the source are the possible factors for the observed poor sanitary status. The reservoir was also shown to be at an intermediate-risk level (Supplementary Material, data 1) due to the observation of animal access, open defecation, and waste disposed around it. Drinking water handling practices at the household level in Kobo town can be considered as poor due to the observation of many people with poor hand-washing habits (88% did not wash their hands when they draw water from the container and 68% did not wash their hands after using the toilet) and unsafe drinking water containers (Supplementary Material, data 2). In line with the results of this study, Bisi-Johnson *et al.* (2017) (southern Nigeria) and Gizachew *et al.* (2020) (southern

Ethiopia) reported that drinking water samples at the household level were more contaminated compared to that of the source. In addition, drinking water at the household level was found to be more contaminated by coliforms compared to water from taps due to poor sanitation and hygienic practice (Tabor *et al.* 2011).

Physicochemical quality of drinking water in Kobo town

Generally, the Kobo town drinking water system can be considered safe with regard to the documented physicochemical water quality parameters. However, the temperature of drinking water samples was higher than the permissible limit, and this can be conducive for the proliferation of aerobic mesophilic bacteria, and in turn, may contribute to the high microbial count observed. In fact, in several studies elsewhere in Ethiopia, temperature records have been higher than the standard limit (e.g., Tsega *et al.* 2013; Yasin *et al.* 2015; Duressa *et al.* 2019), even in water systems where pollution level was very low. This could mean that it might not be due to some problem related to water pollution or might not produce a serious problem by itself. Rather, the temperature limit value in the tropics may need a revision.

CONCLUSIONS

Microbial drinking water quality in Kobo town fails to comply with WHO guidelines and national standards. The presence of the high counts of the coliform bacteria observed suggested that the drinking water pollution in Kobo town is likely a threat to public health. This study also confirmed that there were poor sanitation and water handling practices in the community. The most probable risk factors for water quality deterioration include unhygienic water handling practices at the household level and poor environmental conditions around the source, reservoir, and distribution line. The town administration, health and water offices should take immediate actions including preventing human activities and waste disposal around the water source and the reservoir, as well as regular inspection and maintenance of the distribution lines. In addition, educational campaigns on environmental sanitation and hygienic

practices are of paramount importance in raising public awareness in Kobo town, thereby reducing the impact of water-related health burdens among the community.

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DATA AVAILABILITY STATEMENT

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

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