Journal of
Water, Sanitation & Hygiene for Development

© 2023 The Authors Journal of Water, Sanitation and Hygiene for Development Vol 13 No 8, 584 doi: 10.2166/washdev.2023.049

Research Paper

Drinking water quality and associated factors in Bahir Dar City and the surrounding rural areas, Northwest Ethiopia: a community-based cross-sectional study

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ABSTRACT

In low-income countries like Ethiopia, waterborne illnesses have posed serious public health problems. This study aimed to evaluate drinking water quality (DWQ) and associated factors in Bahir Dar City and the surrounding rural areas in northwest Ethiopia. A cross-sectional study was conducted from January to June 2022 to determine coliform counts and basic physicochemical parameters from the drinking water samples (DWS) collected from urban, peri-urban, and rural sites. A total of 180 DWS were collected from water collection points and households' containers. Potentially pathogenic bacteria were also isolated from fecal coliform (FC)-positive samples and their antibiotic susceptibility profiles were determined. Moreover, the risk factors associated with water quality were assessed. The water quality test results were evaluated against the WHO guidelines for DWQ. Based on the results of this study, only 16.7 and 73.88% of samples met the standards for total coliform and FC, respectively. Moreover, 95.4 and 43% of the isolated bacteria were resistant at least to one of the commonly used antibiotics and multidrug-resistant, respectively. Educating the public on proper drinking water handling, appropriate treatment, and waterline maintenance are needed to safeguard the community from waterborne diseases.

Key words: Bahir Dar City, coliforms, drinking water quality, physicochemical quality, sanitary survey

HIGHLIGHTS

- Most of the drinking water in Bahir Dar City does not comply with the WHO standards.
- There were poor drinking water disinfection practices in Bahir Dar City.
- Drinking water quality in rural areas of Bahir Dar City was at a high sanitary standard.
- There were poor drinking water handling practices in Bahir Dar City at the household levels.
- Access to low-drinking water was prevalent in Bahir Dar City.

INTRODUCTION

Access to safe and adequate water is a basic human right. Accordingly, ensuring the availability of safely managed drinking water services for all consumers is one of the major goals (SDG6) of the UN2030 agenda for sustainable global development. However, water pollution and related problems are alarmingly increasing globally. Drinking water can primarily be contaminated with pathogens of fecal origin at any point from the source to the household container (Sitotaw & Nigus 2021; WHO 2022a). As a result, more than 25% of the world's population uses fecal contaminated drinking water, leaving them at high risk for waterborne diseases (WHO 2022a). It is estimated that 485,000 people die from diarrhea each year due to waterborne diseases such as diarrhea, cholera, dysentery, and typhoid fever. Therefore, regular assessment and/or monitoring of drinking water quality (DWQ) should be carried out in the chain from water source to end-user (household) storage.

Safe drinking water should be ensured at any given point in time. Pollutants can be intermittent and dynamic. As a result, regular water quality testing and risk factor identification are crucial (WHO 2020). A major water-related risk in developing countries is infectious diseases associated with fecal contamination of drinking water (WHO 2022a). Bacteriological testing provides the most sensitive test for detecting potentially dangerous fecal contaminants with sensitivity and specificity lacking

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in routine chemical analysis. Many chemicals in drinking water sources can also have adverse health effects, reduce water acceptability, and reduce the effectiveness of water treatment. Therefore, these chemical parameters should also be monitored regularly in drinking water systems.

Problems related to low DWQ are still a public health burden in Ethiopia. Even though Ethiopia could meet the target of 60% safe drinking water coverage by 2015, over 75% (89 million) people still do not have access to clean water (UNICEF 2018). Up to 80% of communicable diseases in Ethiopia are attributed to limited access to safe water and inadequate sanitation and hygiene services (UNICEF 2018). Waterborne disease, particularly diarrhea, remains a significant public health burden in the country (Dagnew *et al.* 2019; Getahun & Adane 2021; Birhan *et al.* 2023; Seboka *et al.* 2023). Particularly, more than 70,000 under-five children die a year due to water-related diarrhea (UNICEF 2018). Discontinuity in the drinking water supply leading to forced use of unsafe water sources, inadequate chlorination, maintenance, and poor drinking water management at the household level contributes to water contamination with pathogenic microorganisms. Therefore, Ethiopia seems far from achieving SDG6.1 (Gemeda *et al.* 2021).

Waterborne diseases are also highly prevalent in the Amhara region (Dagnew *et al.* 2019; Bogale 2020; Getahun & Adane 2021; Sitotaw & Nigus 2021; Sitotaw *et al.* 2021). According to the Ethiopian Demography and Health Survey finding, the prevalence of diarrhea was 12% in Bahir Dar (EDHS 2016). Leaking pipes, low water pressure, and the intermittent supply observed in the area are possible causes of water contamination. Service coverage is estimated at about 60%, and drinking water shortage is thus one of the most critical problems of water supply in Bahir Dar, which could, in turn, drive poor water quality. Drinking water supply discontinuity is a serious problem and the per capita consumption is still below the WHO minimum (50 l/c/d). The drinking water supplies in the surrounding rural areas are even highly unrealizable and people frequently use drinking water from multiple sources depending on availability, which poses a serious safety issue. The most vulnerable people like children, older, and disabled persons, and the poor are affected by the unavailability of safe drinking water. For instance, diarrheal diseases are increasing in the study areas with a high rate among under-five children (EDHS 2016; Dagnew *et al.* 2019). Up-to-date information on the status of DWQ in the city and its surrounding is needed to design effective strategies and alleviate the problem in this rapidly growing city. The aim of this study was to assess DWQ status and associated risk factors in urban, peri-urban (semi-urban), and rural areas of Bahir Dar City.

MATERIALS AND METHODS

Study site description

This study was conducted in Bahir Dar City and its surrounding rural areas (Figure 1). Bahir Dar City is located at geographical locations ranging from 11°32′ to 11°42′ N and 37°17′ to 37°28′ E; altitude of about 1,800 m.a.s.l. and at a distance of 490 km northwest of Addis Ababa, the capital city of Ethiopia. It is the capital city of the Amhara region and one of the main tourist sites in Ethiopia. The average annual temperature and rainfall in the area are from 13.5 to 27.7 °C and around 1,500 mm, respectively. The temperature record is the highest from April to June and the highest rainfall record is in July and August. Bahir Dar City is among the rapidly growing cities in Ethiopia. Based on the 2022 estimation by the Ethiopian Statistics Service, Bahir Dar City has a population of 455,901 individuals including the rural *kebeles* (the smallest administrative unit).

As cities grow and expand, so does the amount of waste generated. On the contrary, the city's waste management system is poor (Misganaw & Teffera 2021), and perhaps as a result, waterborne diseases are prevalent, as evidenced from the health centers and researchers' observations.

Study design, sampling point selection, and sampling

The study was a community-based cross-sectional study aimed to assess the DWQ at the collection points (CPs) of drinking water (taps, wells, rivers, etc.) and households' containers (HHCs). A structured questionnaire coupled with a direct observation was also used to identify the potential risk factors for water contamination.

Major sampling sites were purposively selected to include the urban, peri-urban, and rural parts of Bahir Dar City for a comparative study. From each site, 30 sampling points (90 in total) were selected by the systematic random sampling method. Then, a total of 180 water samples (90 from the CP and 90 from the HHC) were collected from January to June 2022. For bacteriological analysis, 200 ml of drinking water samples (DWS) were collected aseptically from the CP and the HHC. The samples were taken in the morning between 7.00 and 8.00 a.m., kept in an icebox, and transported to the

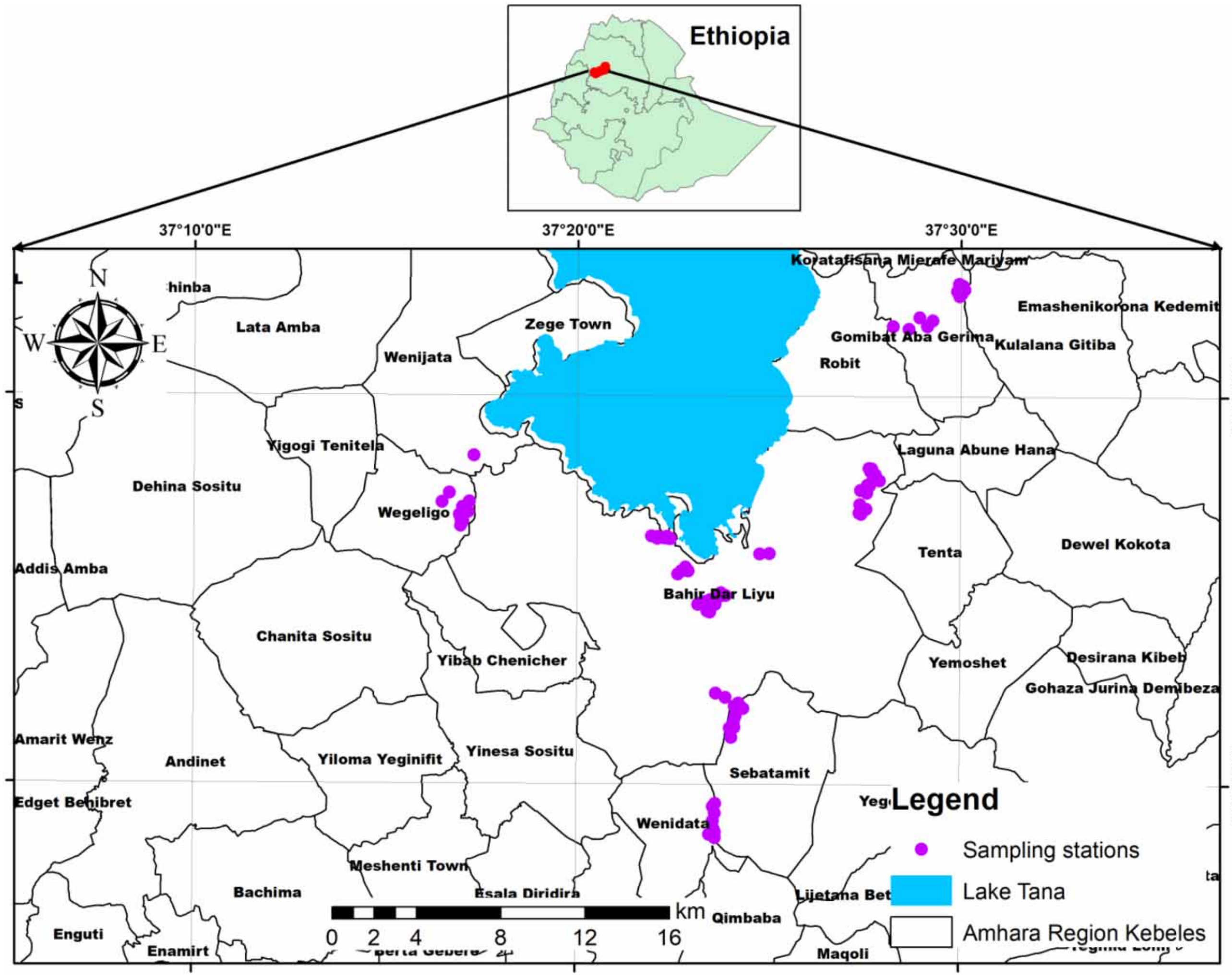

Figure 1 | Map of the study area showing the sampling sites in and around Bahir Dar City.

microbiology laboratory within 2 h. Bacteriological analysis was begun immediately after the sample had arrived at Microbiology Laboratory, Bahir Dar University, Ethiopia.

Microbiological analysis

Coliform counts were conducted as previously described by APHA (1998). Accordingly, the most probable number (MPN) method was used to quantify total coliform (TC) and fecal coliform (FC). For this procedure, 15 culture tubes were used per sample: five tubes of sterile 10 ml double strength and 10 tubes of 10 ml single strength lauryl tryptose broth (Blulux Laboratories Ltd, India). Inverted Durham tubes were carefully added to all tubes (avoiding air bubbles in the tubes). Using a sterile pipette, 10 ml of water sample was aseptically added to each of the first five culture tubes containing double-strength lauryl tryptose broth. Of the 10 tubes containing a single concentration of sterile lauryl tryptose, the five culture tubes were inoculated with a 1 ml sample, and the remaining five tubes were inoculated with a 0.1 ml sample. Tubes were gently shaken and incubated at 37 °C for 24 h to count TC. After 24 h of incubation, we observed a color change (acidification) or gassing of the cultures. For confirmatory studies, medium-filled loops from test tubes showing gas production were transferred to tubes of brilliant green lactose bile (BGLB) broth and incubated at 35 °C for 24–48 h. Tubes showing gas and growth were considered positive for TC. Finally, results were reported as the MPN per 100 ml of water sample (MPN/100 ml). The same procedure was followed for FC, except that the tubes were incubated at 44.5 °C for both the presumptive and confirmatory tests. Drinking water risk level (based on coliform counts) is calculated based on Tadesse (2014). Accordingly, fecal coliform counts of (MPN/100 ml) <1 no risk, 1–10 low risk, 11–100 high risk, and >100 very high risks were considered.

Isolation of some potentially pathogenic bacteria

Potentially pathogenic bacteria were isolated from FC-positive samples using respective selective or differential media. Accordingly, the presence of *Escherichia* spp. was checked on Eosin-Methylene Blue plate and incubated for 24 h at 37 °C. Similarly, *Salmonella* spp. and *Shigella* spp. were isolated on SS agar plates. Moreover, Campylobacter Selective Agar (CAMPY) for the isolation of *Campylobacter* spp., Pseudomonas Isolation Agar for the isolation of *Pseudomonas* spp., and thiosulfate–citrate–bile salts–sucrose agar for the isolation of *Vibrio* spp. were used. These isolates were identified to the genus level using colony characteristics, cell morphology, Gram test, and many other biochemical tests.

Antibiotic susceptibility tests

The standard Kirby–Bauer's disc diffusion method was performed to determine antibiotic susceptibility profiles of the isolates (Bauer 1966; Biemer 1973). Bacterial inoculum was prepared by suspending few morphologically identical colonies from each isolate in 5 ml nutrient broth (HiMedia, India) and incubated for 4 h at 37 °C. The bacterial suspension was compared with 0.5 McFarland turbidity standards to achieve about 1.5×10^8 CFU/ml. After adjusting the turbidity, the surface of the prepared Mueller Hinton Agar (MHA) medium (Accumix, India) was evenly inoculated three times using a sterile cotton swab while rotating the plate with the culture. The plates were left at room temperature for 15–20 min to let them dry.

The standard antibiotic discs used in this study included gentamicin (GN, 10 μg), tetracycline (TE, 30 μg), ciprofloxacin (CIP, 5 μg), nalidixic acid (NA, 30 μg), chloramphenicol (C, 30 μg), erythromycin (E, 15 μg), vancomycin (V, 30 μg), Cefoxitin (CE, 30 μg), and Co-trimoxazole (COT, 25 μg) (Becton, Dickinson, and Company, Sparks, MD, USA) (Supplementary data 1). The discs were aseptically laid on the surface of the inoculated agar plates with proper spacing using sterile forceps and incubated at 37 °C for 18–24 h. The diameter of the inhibition zone around the discs was measured in millimeters and interpreted as sensitive (S), intermediary resistant (I), or resistant (R) according to the defined breakpoints in the Clinical and Laboratory Standards Institute (CLSI 2020). For quality control of antimicrobial susceptibility tests, *Staphylococcus aureus* (ATCC® 25923) and *Escherichia coli* (ATCC® 25922) strains were used.

Physicochemical analysis

Major physicochemical parameters, namely residual chlorine, pH, temperature, turbidity, conductivity, and total dissolved solids (TDS), were measured at the site from the same sample sources that were used for the bacteriological analyses as described in Sitotaw & Nigus (2021).

Survey of the risk factors for water pollution

A structured questionnaire was used to collect sociodemographic and socioeconomic information from the participating households. The questionnaires were also used to obtain information on water characteristics, sanitary conditions, and hygienic status at the household levels and water CPs (taps, wells, and rivers).

Data analysis

SPSS statistical software version 20 was used to analyze the water quality test data. The normality of the data was checked using the Shapiro–Wilk test. Significant differences in the value parameters among the different water samples were tested using the Mann–Whitney *U* test or the Kruskal–Wallis test. Values of water quality parameters were compared with the WHO guidelines for DWQ, and the contamination risk levels were determined. The associations between sociodemographic and other risk factors and the water quality parameters were computed using the Chi-square test. Finally, statistical significance was considered at a 95% confidence interval and values of ≤ 0.05.

Ethical approval and informed consent of participants

Ethical clearance was obtained from the ethical review committee of Science College, Bahir Dar University, and informed consent was obtained from the participants.

RESULTS

Socio-demographic characteristics of study participants

As shown in Table 1, 55.5% of the participants were females; about half of the participants were middle aged (36–50 years old); most of the participants were married (87.8%) and from father-headed households (87.8%); about 62% of the fathers, at least, could read and write, while 61% of the mother were illiterate; and about 65% earned Ethiopian Birr (ETB) 1,000–5,000. Moreover, a considerable proportion (43.3%) of the households in the rural sites reported diarrhea incidence in their family.

Table 1 | Sociodemographic characteristics of the households that participated in this study ($n = 90$), Bahir Dar, 2022

Variable	**Categories**	**Frequency (%)**
Residence	Urban	30 (33.33)
	Peri-urban	30 (33.33)
	Rural	30 (33.33)
Gender	Male	40 (44.4)
	Female	50 (55.6)
Age	20–35	25 (27.70)
	36–50	44 (48.70)
	>51	21 (23.1)
Marital status	Married	79 (87.8)
	Single	11 (12.2)
Household head	Father	79 (87.8)
	Mother	11 (12.2)
Educational status of father ($n = 81$)	College and above	10 (12.19)
	Primary or secondary school completed	11 (13.58)
	Read and write	29 (35.36)
	No education	31 (37.80)
Educational status of mother ($n = 89$)	College and above	8 (8.99)
	Primary or secondary school completed	12 (13.48)
	Read and write	15 (16.85)
	No education	54 (60.67)
Father occupation ($n = 81$)	Govt. or NGO employed	6 (7.32)
	Merchant	28 (34.15)
	Daily laborer	8 (11.1)
	Farmer	39 (47.56)
Mother occupation ($n = 89$)	Govt. or NGO employed	5 (6.10)
	Merchant	27 (32.93)
	Daily laborer	16 (19.51)
	Farmer	41 (50)
Family monthly income in ETB ($n = 60$)	$\geq$ 10,000	6 (10)
	[5,000–9,000)	11 (18.33)
	[3,000–5,000)	16 (26.67)
	[1,000–3,000)	23 (38.33)
	<1,000	4 (6.67)
Family size	[1–3]	27 (30)
	[4–6]	44 (48.88)
	[7–10]	19 (21.11)
An incidence of waterborne diseases/acute diarrhea in the family that last less than 1 week (no answer)	Urban	0
	Peri-urban	0
	Rural	13 (43.3)

ETB, Ethiopian Birr.

Conformity of the DWQ test result to the standards

As indicated in Table 2, the mean (±SD) of TC count and FC count were 301.15 (549.28) and 32.06 (207.01), respectively, and ranged from <2 to 1,600 MPN/100 ml. Only 16.7 and 73.88% met drinking water standards for TC and FC, respectively. Most of the DWS from the HHC (93%) and the CP (73%) were tested positive for TC and hence did not comply with DWQ standards. In addition, a considerable proportion of water samples from HHC (29%) and CP (23%) tested positive for FC. Regarding physicochemical parameters, pH, conductivity, and TDS of all drinking water conform to the standards (Table 3). However, the temperature record of all water samples and the turbidity of drinking water in the rural areas were higher than the limits set by the WHO. In addition, the residual chlorine level of all DWS was below the allowable limit value.

Based on DWQ criteria for *E. coli* (Tadesse 2014), 21.1, 5.6, and 2.2% of HHC samples were categorized as low, high, and very high risk, respectively. Similarly, 11.1, 8.9, and 3.3% of the water samples from CP were categorized as low, high, and very high risk, respectively (Table 2).

Comparison of DWQ between the different sites and the sample types

As shown in Table 3, a Kruskal–Wallis *H* test showed that there was a statistically significant difference in the TC of water samples from the HHC between the different sampling sites (urban, semi-urban, and rural), $\chi^2 = 24.40$, $p = 0.000$, with a mean rank TC of 33.92 for urban, 37.22 semi-urban, and 65.37 for rural. Similarly, there was a statistically significant difference in the TC of water samples from CPs between the different sampling sites (urban, semi-urban, and rural), $\chi^2 = 21.90$, $p = 0.000$, with a mean rank TC of 36.98 for urban, 36 semi-urban, and 63.52 for rural. Regarding FC, water samples from rural sites (both from the CP and the HHC) had higher mean counts, though there was no statistically significant difference.

Similarly, there was a statistically significant difference in the temperature record of water samples from HHCs between the different sampling sites (urban, semi-urban, and rural), $\chi^2 = 21.5$, $p = 0.000$, with a mean rank temperature of 58.80 for urban, 48.97 semi-urban, and 28.73 for rural sites. There was also a statistically significant difference in the turbidity of water samples from HHCs between the different sampling sites (urban, semi-urban, and rural), $\chi^2 = 31.67$, $p = 0.000$, with mean rank turbidity of 40.65 for urban, 29.42 semi-urban, and 66.43 for rural. Moreover, there was a statistically significant difference in the turbidity of water samples from the CP between the different sampling sites (urban, semi-urban, and rural), $\chi^2 = 27.90$,

Table 2 | Risk level based on fecal coliform counts (MPN/100 ml) of drinking water in and around Bahir Dar City, 2023

	Fecal coliform counts and risk level				
Different samples from	**< 1 No[a]**	**1–10 Low**	**11–100 High**	**> 100 Very high**	**Total**
CPs of urban sites	24 (80)	4 (13.3)	2 (6.7)	0	30
HHCs of urban sites	24 (80)	6 (20)	0	0	30
CPs of peri-urban sites	25 (83.3)	3 (10)	2 (6.7)	0	30
HHCs of peri-urban sites	23 (76.7)	6 (20)	1 (3.3)	0	30
CPs of rural sites	20 (66.7)	3 (10)	4 (13.3)	3 (10)	30
HHCs of rural sites	17 (56.7)	7 (23.3)	4 (13.3)	2 (6.7)	30
All the CPs	69 (76.7)	10 (11.1)	8 (8.9)	3 (3.3)	90
All HHCs	64 (71.1)	19 (21.1)	5 (5.6)	2 (2.2)	90
All urban sites	48 (80)	10 (16.7)	2 (3.3)	0	60
All per-urban sites	48 (80)	9 (15)	3 (5)	0	60
All rural sites	37 (61.7)	10 (16.7)	8 (13.3)	5 (8.3)	60
All sites	133 (73.9)	29 (16.1)	13 (7.2)	5 (2.8)	180

Values in the brackets are percentages.

CP, collection point; HHC, household container.

[a] In conformity with national and international drinking water standards.

Table 3 | Mean ($n = 30$), range, and mean rank of coliform counts and physicochemical values for DWSs from the different sampling sites in Bahir Dar City and the surrounding rural areas, 2022

Parameters	Sample types	Mean ± SD	Range	Mean rank	χ^2 (*p*-value)	Risk level[a]
TC (MPN/100 ml)	CPU	54.41 ± 30.60	0–900	36.98	21.90 (< 0.001)	–
	CPPU	20.96 ± 6.01	0–110	36		–
	CPR	725.0.3 ± 132.17	0–1,600	63.52		–
	HHCU	179.46 ± 74.67	0–1,600	33.92	26.40 (< 0.001)	–
	HHCPU	103.43 ± 52.48	0–1,600	37.22		–
	HHCR	723.6 ± 127.62	0–1,600	65.37		–
	All CP	266.80 ± 563.724	0–1,600		16.34 (< 0.01)	
	All HHC	335.50 ± 563.724	0–1,600			
FC (MPN/100 ml)	CPU	2.23 ± 1.22	0–33	43.48	3.72 (> 0.05)	Low
	CPPU	1.5 ± 0.82	0–22	42.02		Low
	CPR	120.53 ± 74.1	0–1,600	51		High
	HHCU	0.9 ± 0.38	0–8	41.17	5.63 (> 0.05)	Low
	HHCPU	1.27 ± 0.62	0–17	42.48		Low
	HHCR	65.9 ± 53.7	0–1,600	52.85		High
	All CP	41.42 ± 238.4	0–1,600		4 (> 0.05)	
	All HHC	22.69 ± 170.7	0–1,600			
Temperature (°C)	CPU	20.53 ± 0.23	18–23	48.62	0.9 (> 0.05)	–
	CPPU	20.4 ± 0.23	18–24	45.37		–
	PCR	20.23 ± 0.19	18–23	42.52		–
	HHCU	20.8 ± 0.23	19–24	58.8	21.5 (< 0.001)	–
	HHCPU	20.23 ± 0.24	18–23	48.97		–
	HHCR	18.97 ± 0.27	16–22	28.73		–
pH	CPU	7.02 ± 0.17	6.11–8.86	50.23	3.57 (> 0.05)	–
	CPPU	6.56 ± 0.03	6.31–7.25	38.25		–
	CPR	6.69 ± 0.07	5.69–7.49	48.02		–
	HHCU	7.17 ± 0.15	6.4–8.81	53.25	5.57 (> 0.05)	–
	HHCPU	6.67 ± 0.03	6.4–7.14	37.35		–
	HHCR	6.83 ± 0.08	5.61–7.78	45.90		–
Conductivity (μs/cm)	CPU	469.73 ± 27.32	176.5–774	33.88	0.74 (> 0.05)	–
	CPPU	564 ± 25.29	338–790	54.4		–
	CPR	558.22 ± 34.81	198–1,070	48.22		–
	HHCU	484.43 ± 30.43	178.5–772	36.42	6.05 (< 0.05)	–
	HHCPU	558.37 ± 21.12	337–708	52.67		–
	HHCR	562.99 ± 33.1	201–1,070	47.42		–
TDS (mg/L)	CPU	234.91 ± 13.63	88.2–387	34.27	9.35 (< 0.05)	–
	CPPU	280.95 ± 12.36	169.10–354	54.53		–
	CPR	277.91 ± 17.27	98.9–536	47.7		–
	HHCU	242.23 ± 15.21	89.4–386	36.35	6.13 (< 0.05)	–
	HHCPU	279.13 ± 12.07	168.7–347	52.7		–
	HHCR	281.89 ± 16.87	100–538	47.45		–
Turbidity (NTU)	CPU	1.38 ± 0.09	0.49–2.61	43.65	27.9 (< 0.001)	–
	CPPU	1.12 ± 0.12	0.42–3.41	28.92		–
	CPR	8.87 ± 1.96	0.45–36.10	64.33		–
	HHCU	1.39 ± 0.08	0.63–2.55	40.65	31.7 (< 0.001)	–
	HHCPU	1.21 ± 0.11	0.56–2.73	29.42		–
	HHR	8.75 ± 1.56	0.88–32.70	66.43		–

WHO guidelines for coliforms <2 MPN/100 ml, pH 6.5–8.5, temperature ≤15, turbidity ≤5, conductivity ≤1,000, and residual chlorine 0.2–0.5 mg/L.

U, urban sites; PU, peri-urban sites; R, rural sites; CP, collection point; HHC, households' containers.

[a] Risk level is based on the mean values.

$p = 0.000$, with mean rank turbidity of 43.25 for urban, 28.92 semi-urban, and 64.33 for rural sites. Furthermore, there was a statistically significant difference in TC between samples collected from all CPs and all HHCs ($\chi^2 = 16.34$, $p = 0.003$). However, there was no statistically significant difference in FC between these two samples (Table 3).

Antimicrobial susceptibility profile of bacterial isolates

A total of 130 bacteria were isolated from DWS that tested positive for fecal coliform. They belong to six bacterial genera, namely *Escherichia* spp. (30), *Pseudomonas* spp. (26), *Salmonella* spp. (25), *Shigella* spp. (21), *Campylobacter* spp. (21), and *Vibrio* spp. (7). Among them, 95.4% (124/130) were found to be resistant at least to one standard drug, and 43.07% (56/130) were found to be multidrug-resistant (Supplementary data 1).

Association of bacteriological DWQ status with socio-demographic characteristics and other risk factors

Among the 12 sociodemographic factors considered in this study (Table 1), fathers' educational status and mothers' occupation were found to be associated with the TC contamination of samples from HHCs. Fathers' and mothers' educational statuses and occupations were also associated with TC contamination of samples of CPs (Supplementary data 3).

Among the 33 risk factors surveyed, handwashing habit after using the toilet and the type of toilet were associated with TC contamination of samples of HHCs, while the incidence of waterborne disease in the family, handwashing habit after using the toilet, and water discontinuity were associated with TC contamination of samples from CPs. FC contamination was associated with the presence of livestock and animal feces at the house area (Supplementary data 3).

Risk level of the drinking water based on the survey and direct observations

Based on the questionnaire survey and direct observations, almost all urban and peri-urban residents used drinking water from improved sources (100%), possessed private taps (use drinking water from a single source) (100%), knew that water can be a vehicle to transmit waterborne diseases (93–96%), used narrow mouth container, namely jerry-can as drinking water storage (100%), used drinking water for other purposes, such as bathing and cooking (100%), properly covered drinking water container (100%), possessed a private toilet (100%), and disposed of solid wastes properly (Supplementary data 2). However, they reported that they received an insufficient quantity of drinking water (100%) and encountered frequent discontinuity (90–96%), stored drinking water fearing water discontinuity (100%), did not treat drinking water at the household level (86–100%), used unimproved toilets (70%), lacked handwashing facilities at the household level (86.7%), did not wash their hands after toilet use and while collecting drinking water (63.3%), felt aesthetic discomfort with the drinking water they used (100%), and noticed the evidence of cracks in the water line (83.3%) (Supplementary data 2).

In the rural areas, most of the participants used narrow mouth container, namely jerry-can as drinking water storage, properly covered drinking water container, knew that water can be a vehicle to transmit diseases, did not use the drinking water container for another purpose, and washed their hands while collecting drinking water. However, most of them used unimproved drinking water sources (100%), lacked safe and sufficient drinking water (100%) and private taps or wells (73.3%), stored drinking water, did not treat drinking water at the household level, used unimproved toilets (100%) or lacked toilet facilities at all, disposed of children's stools and other wastes in the wrong way (66–100%), practiced open defecation (63.3%), lived in close contact with livestock (96.7%), lacked handwashing facilities at the household level (96.7%), and did not wash their hands after toilet use (100%).

DISCUSSION

Problems related to unsafe drinking water have been a major public health burden in developing countries like Ethiopia. Scientific information on the current status of water quality and safety is necessary to design appropriate intervention strategies. DWS were collected and analyzed for bacteriological and physicochemical quality from the sites in Bahir Dar City. The risk factors for drinking water contamination at the household level and CPs were also surveyed based on structured questionnaires and direct observations.

Bacteriological quality and safety of drinking water in and around Bahir Dar City

Based on the results of this study, most of the DWS (83.3%) and a considerable proportion of the DWS (26.1%) fail to meet standards for TC and FC, respectively, implying a high-risk waterborne diseases burden in the area. Previous studies in different parts of Ethiopia have also reported similar results. For example, coliform contamination levels as high as 91% in the Wolita sodo zone (Gizachew *et al.* 2020), 100% in Wegeda town (Sitotaw *et al.* 2021) and Kobo town (Sitotaw & Nigus 2021), and 92.31% in Mecha district (Lewoyehu 2021) were reported. Probably as a result of these, diarrhea has still been a challenge in Ethiopia (Dagnew *et al.* 2019; Demissie *et al.* 2021; Getahun & Adane 2021; Birhan *et al.* 2023).

Most of the DWS from the HHCs (93%) were found to be contaminated with coliforms, indicating poor drinking water handling practices at the household level (Table 3; Supplementary data 2). In addition, most of the DWS from the CPs (73%) were contaminated with coliform bacteria, showing that the causes of drinking water contamination are likely both poor drinking water handling practices and poor management. One-third of DWS from HHCs and about one-fifth of DWS from the CPs were at risk of fecal contamination (Table 2). This calls for urgent actions to improve the safety of the drinking water system in this fast-growing city. It is to be noted that the urban and peri-urban sections of the city receive drinking water from deep wells and protected springs, testifying that bacterial contamination at the source is unlikely. Poor drinking water handling practices at the household level and poor management of the distribution line from the disinfection point to the household yards could likely be the main points of contamination. For instance, a study by Luvhimbi *et al.* (2022) in the Limpopo Province of South Africa, Sitotaw *et al.* (2021) in Wogeda town (Northern Ethiopia), Sitotaw & Nigus (2021) in Kobo town (Northwest Ethiopia), and Sebsibe *et al.* (2021) in Fiche (Central Ethiopia) indicated significantly higher levels of contamination in water samples from HHCs than from the sources. The major factors for drinking water contamination at household levels are thus related to hygiene and sanitation practices (Ondieki *et al.* 2022), which have to be addressed through education, support, and monitoring.

DWS from the rural sites were found to be more contaminated with coliform bacteria compared to the urban and semi-urban sites, which proves that rural communities are still at a higher risk of waterborne diseases. The level of contamination was not different between urban and semi-urban sites, likely due to these sections of the city receiving drinking water from piped sources. The detection of isolates related to *Salmonella*, *Shigella*, *Campylobacter*, and *Vibrio* species could show a serious concern as most members of these genera are pathogenic. A study by Kumar *et al.* (2022) in North India demonstrated the presence of several pathogenic bacteria in drinking water. Most of the isolates (94.5%) in the current study were also found to be resistant to commonly used antibiotics, which also imply complicated public health concerns. Antibiotic resistance (ABR) is, indeed, widely distributed in environments such as drinking water systems (Duarte *et al.* 2022). This study and previous study results demonstrated that developing countries like Ethiopia have to quadruple their efforts to achieve SDG6.1 (Gemeda *et al.* 2021; WHO 2022b).

Physicochemical quality of drinking water in and around Bahir Dar City

Most of the physicochemical quality of drinking water in the study area complies with the standards. However, the temperature values of almost all samples were higher than the standard limits, which may lead to a high risk of bacterial proliferation. The turbidity of DWS from rural settings was also beyond the allowable limits, which can also pose a high risk to the water quality. Elevated temperature (Lewoyehu 2021; Sitotaw & Nigus 2021; Sitotaw *et al.* 2021) and turbidity (Lewoyehu 2021; Sitotaw *et al.* 2021) have also been recorded in other drinking water systems (Sitotaw *et al.* 2021). Due to the lack of improved water sources, rural communities in the study area often use river water, hand-dug wells, and shallow wells, which were not properly managed or were difficult to manage at all. Moreover, residual chlorine measured from all piped water samples (urban and peri-urban sites) was not detectable showing improper chlorination practices. Supplying piped (tap) water to all households in the study area and the proper management of the drinking water systems are highly recommended.

Water, sanitation, and hygienic status of drinking water systems at the household level in and around Bahir Dar City

In the urban and peri-urban areas of Bahir Dar City, insufficient quantity and unsafe drinking water supply and frequent discontinuity were highly prevalent. The reported per capita per day of drinking water is far lower than the minimum standard (92 l/c/d) recently recommended by Crouch *et al.* (2021) and even lower than the minimum quantity (50 l/c/d) set by the WHO.

In addition, the absence of drinking water treatment practices at the household level, the lack of improved toilets in most households, the absence of the handwashing facility at the household level, as well as the absence of hand washing habits after toilet use and while collecting drinking water could be likely risk factors in the area. Most participants have also reported aesthetic discomfort from the drinking water they used and frequent turbid water coming through the pipe likely indicating cracks in the water line (Supplementary data 2).

Most of, if not all, the households in the rural sites lack basic water, sanitation, and hygienic services, namely, improved water sources (from unprotected wells and rivers) for drinking, proper waste disposal facilities, improved toilets, or even lack of toilet facilities (leading to open defecation). Despite a significant reduction in open defecation in Ethiopia (Girma *et al.* 2021), it was observed in about 63% of the households' yards in this study. Of course, 75% of households in Ethiopia lack improved toilet facilities (Andualem *et al.* 2021), and a comparable proportion (60%) of rural communities in our study lack improved toilet facilities as well. Moreover, there were almost no handwashing facilities at the household level or habits of handwashing after toilet use. For instance, in 2016, about 94 and 40% of households lack access to basic sanitation and handwashing facilities, respectively (Girma *et al.* 2021). The previous study by Dagnew *et al.* (2019) also demonstrated that the lack of handwashing facilities and poor handwashing habits were among the predictors of the occurrence of diarrhea in Bahir Dar City. Moreover, there was no form of drinking water treatment practices at the household level. It is clear that all the aforementioned issues are potential risk factors for drinking water contamination.

Limitations of the study

The sampling sites and sample sizes should have been larger than those used in this study in order to better understand the causes and predictors of drinking water pollution. Samples from the reservoir and the sources should have also been included. Additionally, isolates should have been identified to the strain level to confirm whether they were pathogens.

CONCLUSIONS

In this study, most of the DWSs did not meet the WHO guidelines for bacteriological DWQ implying a high level of bacteriological drinking water contamination in Bahir Dar City and the surrounding rural areas. Most of the isolated bacteria were also found to be resistant to commonly used antibiotics that also indicate high public health concern. The survey data also showed that there was insufficient disinfection of drinking water systems in urban and peri-urban areas and even no disinfection practices in the rural areas. Moreover, there was no form of drinking water treatment at the household level in all settings. In addition, poor hygienic practices, poor drinking water handling practices at the household level, frequent interruption of drinking water, and other related risk factors were common in all settings. The risk factors were even high in rural settings in which there were poor environmental sanitation and a lack of improved toilets and improved water sources. Based on these conditions, urban and peri-urban sections of Bahir Dar City water supply can be categorized as the limited water service, while the water supply in the surrounding rural areas can be categorized as unimproved water services. Appropriate disinfection of drinking water, creating public awareness of the proper drinking water handling practices, and supplying safe and adequate drinking water should be in place.

ACKNOWLEDGEMENTS

We highly acknowledge Bahir Dar University, Bahir Dar City health offices, and all participating households.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 11 February 2023; accepted in revised form 24 July 2023. Available online 1 August 2023