# Assessment of the Quality of Drinking Water Sources in Bahir Dar City, Ethiopia

Authors: Alemu, Agegnehu, Bitew, Woinitu, and Liyew Anteneh, Zelalem

Source: Air, Soil and Water Research, 17(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/11786221241301987

# Assessment of the Quality of Drinking Water Sources in Bahir Dar City, Ethiopia

Air, Soil and Water Research
Volume 17: 1–9

DOI: 10.1177/11786221241301987
Sage

Agegnehu Alemu[1,2], Woinitu Bitew[1] and Zelalem Liyew Anteneh[2,3]

[1]Department of Chemistry, College of Science, Bahir Dar University, Bahir Dar, Ethiopia. [2]Blue Nile Water Institute, Bahir Dar University, Bahir Dar, Ethiopia. [3]School of Earth Science, Bahir Dar University, Bahir Dar, Ethiopia.

**ABSTRACT:** This research investigates the quality of water supplied to Bahir Dar city, Ethiopia. The city gets water from 3 springs and 12 dug wells. Fifteen samples were collected from these water sources in the dry and wet seasons and examined according to standard procedures to determine their physicochemical and bacteriological qualities. The mean values of physicochemical parameters (dry and wet seasons) measured include: temperature (26.047 ± 0.71°C and 20.527 ± 0.586°C), pH (7.03 ± 0.58 and 7.13 ± 0.476), electrical conductivity (197 ± 53.78 and 119.144 ± 35.85 μs/cm), total dissolved solid (129.67 ± 34.87 and 70.97 ± 21.48 mg/L), fluoride (0.54 ± 0.263 and 0.21 ± 0.108 mg/L), phosphate (0.544 ± 0.214 and 0.47 ± 0.292 mg/L), nitrate ions (3.16 ± 0.897 and 3.12 ± 1.278 mg/L), total alkalinity (119.22 ± 41.254 and 127.49 ± 32.829 mg/L as $CaCO_3$), and total hardness (47.6 ± 20.797 and 41.47 ± 24.46 mg/L as $CaCO_3$) were safe and within the range of WHO and Ethiopian acceptable drinking water quality standards. The mean turbidity (3.37 ± 3.27 NTU) in the dry season was in the permissible limit of Ethiopia and WHO, but the mean turbidity in the wet season (6.88 ± 2.67 NTU) was above the drinking water guideline of WHO and Ethiopia. The bacteriological analyses of mean fecal coliform (10.6 ± 10.01 and 3.2 ± 2.344 CFU/100 mL) and total coliforms (56.8 ± 74.08 CFU/100 mL, too numerous to count CFU/100 mL) in the dry and wet seasons were beyond the WHO and Ethiopian permissible limit. This indicates that the water sources are not safe and consumers are at risk. Therefore, the water sources require treatment before it is distributed to the consumers.

**KEYWORDS:** Water quality, water sources, drinking water standards, dug wells, springs

**RECEIVED:** June 8, 2024. **ACCEPTED:** November 5, 2024.

**TYPE:** Research Article

**CORRESPONDING AUTHOR:** Agegnehu Alemu, Bahir Dar University, 79(6000) Bahir Dar, Ethiopia. Email: agegnehua@gmail.com

## Introduction

Water is essential for life and plays a crucial role in the world's economic development. Water sources can be of different type, including surface water (rivers, springs, and lakes), oceans, rain water, ground water and ice and snow. Drinking water is primarily obtained from two main sources: surface waters and groundwater. These water sources can be contaminated with geogenic, anthropogenic, and microbial contaminants. Natural factors like geology and geochemical processes also affect groundwater quality. Geogenic sources, in particular, significantly influence the chemical composition of groundwater, which can vary over time and across different regions (Davraz & Batur, 2021; Kazemi et al., 2022; Sener et al., 2022; Varol & Sekerci, 2018).

Groundwater contamination is increasing due to rapid population growth, urbanization, and economic development (Li et al., 2021; Zhang et al., 2019). Water sources can be contaminated with point and non-point sources including animal waste, sewage, septic tanks, and improperly disposed solid waste in open fields. Industrial wastewater and agricultural activities also contribute to chemical pollution (Al-Tabbal & Al-Zboon, 2012; Napacho & Manyele, 2010). Additionally, Climate change threatens water source quality by escalating pollutant and sediment runoff, lowering water availability through drought and saltwater intrusion, and impeding efforts to maintain water quality, which is essential to meet basic human needs (Dao et al., 2023; UN-Water, 2020).

Access to safe drinking water is a fundamental human right and essential for good health. However, freshwater is scarce in many regions across the globe. The availability of safe drinking water and adequate sanitation is a worldwide concern, particularly in developing countries like Ethiopia, where establishing reliable sources of clean drinking water and proper sanitation services has been a challenge (WHO, 2006). Many people still rely on vulnerable water sources such as rivers, springs, streams, and hand-dug wells, which are often exposed to flooding and contamination from human, animal, and bird waste. Additionally, human activities contribute to changes in the physical or chemical properties of these water bodies (Aremu et al., 2011). Surface water is often considered much dirtier than groundwater. However, groundwater quality is influenced by a variety of factors, including the discharge of industrial, agricultural, and domestic wastewater, land use practices, geological formations, rainfall patterns, and infiltration rates (Al-Tabbal & Al-Zboon, 2012). The main objective of hydrochemical testing is to gain a deeper understanding of the natural and human-induced processes that impact groundwater quality, helping to assess whether the observed water quality is suitable for its intended use.

Assessing water quality in urban environments is crucial for sustainable management and supply, especially in developing countries. Monitoring water quality is vital to evaluate spatial and temporal variations, which aids in effective water management and pollution control (Melo et al., 2020). Globally, not everyone has access to safe drinking water. According to the WHO, around 785 million people lack basic drinking water services, and over 2 billion people consume water contaminated with feces. This contamination can lead to transmissible

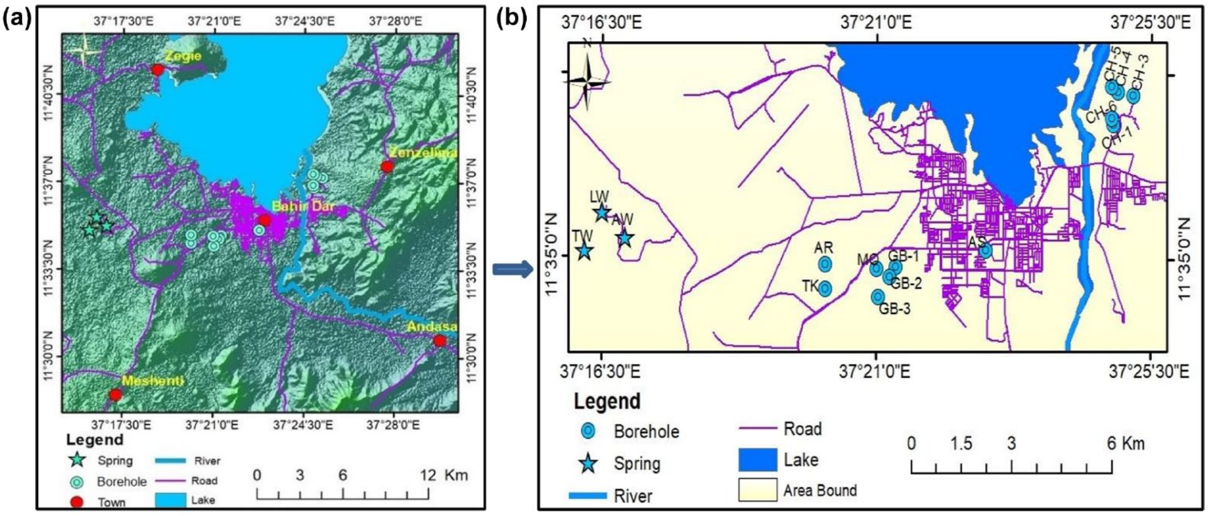


**Figure 1.** Map of the study area (a) and water sample collection sites (b).
*Note*. AW = Arekiwuha; LW = Lomiwuha; TW = Tikurwuha; TK = Tsehaykelem; AR = Agrostone; GB = Gudobahir; CH = Cherechera; AS = Addisu Stadium; MO = Moenco.

diseases such as diarrhea, cholera, dysentery, typhoid, hepatitis A, and polio (UN-Water, 2021).

The Central Statistical Agency of Ethiopia (2017) reported that 66% of the Ethiopian population relies on drinking water from improved sources, such as protected springs, tube wells, and dug wells, with access varying depending on the location. Over 60% of communicable diseases in Ethiopia are attributed to poor environmental health conditions, which stem from unsafe and inadequate water supplies, as well as poor hygiene and sanitation practices (UNICEF Ethiopia, 2018). Approximately 80% of the rural population and 20% of the urban population lack access to safe drinking water. According to Ethiopia's Ministry of Health, 6,000 children die each day from diarrhea and dehydration (UNICEF Ethiopia, 2018).

Bahir Dar city is indeed known for its natural beauty and serves as a hub for many tourist attractions in the Amhara Region of Ethiopia. The city is located near Lake Tana, the largest lake in Ethiopia, and the Blue Nile River, which contributes to its scenic landscapes. It is home to various historical sites, monasteries, and the stunning Blue Nile Falls. The city has been undergoing swift population growth and industrial expansion, presenting both opportunities and challenges. One challenge is the production of significant amounts of solid and liquid waste, for which the city lacks effective management systems. This waste may seep into the groundwater or contaminate nearby surface water bodies. Since the city's water supply comes from groundwater and springs, it is at risk of being polluted. Thus, the aim of this study was to evaluate the physicochemical and bacteriological quality of the water sources used in Bahir Dar City.

## Materials and Methods

### *Description of the study area*

This study was conducted in the capital city of Amhara National Regional State (ANRS) Bahir Dar, in Northwest Ethiopia from March to July 2021. Bahir Dar city is located at 11°36″North latitudes and 37°23″East longitudes (Figure 1). The city's name Bahir Dar means on shore or situated close to water. As its name refers, Bahir Dar is located on the shore of Lake Tana and Abbay River. The city's landscape consists mainly of flat plains, interspersed with a few scattered hills. Bahir Dar, located in this terrain, has an elevation ranging from approximately 1,786 m at the shore of Lake Tana to 1,886 m at the top of Bezawit Hill above sea level (Kasim et al., 2018). The weather shows high temperature from March to May and high rainfall from June to August. Bahir Dar is one of the fast-growing cities in the country with population number estimated to be 455,901 in 2022.

### *Water sample collection and preservation*

Water samples were collected from three spring water sources and twelve boreholes in the water sources of Bahir Dar City using properly cleaned and rinsed high-density polyethylene (HDP) plastic bottles (Figure 1). The samples were gathered during both the dry and wet seasons. For physicochemical analysis, the HDP bottles were first washed with detergent and tap water, soaked in 5% (v/v) nitric acid for 24 hr, and then rinsed with distilled water. The bottles were then air-dried, sealed with screw caps, and prepared for sample collection. Sterilized HDP plastic bottles were used for bacteriological analysis. After sample collection, the bottles were accurately labeled with details such as the abbreviated name, date, location, and collection time. They were stored in an icebox and transported to the laboratory. Bacteriological analysis commenced as soon as the samples reached the lab on the same day. For physicochemical analysis, the samples were kept in a refrigerator at 4°C in the dark until the analysis was completed within 24 hr (APHA, 2017).

### *Water sample analysis*

Water samples were analyzed according to the standard procedures outlined by APHA (2017). pH, electrical conductivity

(EC), and total dissolved solids (TDS) were measured directly at the sampling site. Temperature and pH were determined using pH meter (Jenway Model 370, England) after calibration with standard buffer solutions of pH 4, 7, and 10. EC and TDS were measured with a conductivity meter (CC-401, Poland) following calibration with a standard KCl solution. Turbidity was determined using a turbidity meter (H193703, Hungary), calibrated with standards ranging from 0 to 100 NTU. Fluoride, nitrate, phosphate, total hardness, and total alkalinity were measured using Palin test tablets with a 7100 photometer at specific wavelengths, applying the colorimetric method after blanking the samples. Each physicochemical measurement was conducted in triplicate, and the mean values along with their standard deviations were recorded.

Fecal and total coliforms in the water samples were analyzed using the membrane filtration method (APHA, 2017). A 100 mL portion from each water sample was filtered through a membrane with a 0.45 μm pore size using a vacuum pump. The filters were then placed in sterilized Petri dishes containing absorbent pads soaked in Lauryl Sulphate Broth. The Petri dishes were initially incubated at 37°C for 4 hr to revive physiologically stressed coliforms. For fecal and total coliform analysis, the samples were then incubated at 44°C and 37°C, respectively, for 24 hr. Bacterial growth was observed, and the colonies were counted. For colonies that were not visible to the naked eye, a desktop Colony Counter (CC-J2) was utilized to assist in the counting process.

*Data analysis.* The data for all parameters were analyzed using SPSS software version 27 and Microsoft Excel. Descriptive statistics like mean, standard deviation and range were used to describe the findings. To determine significant differences in water quality parameters across the sampling sites, a one-way ANOVA was employed. The analysis results were then compared with WHO and Ethiopian drinking water quality guidelines and standards, considering chemical, microbiological, and acceptability aspects such as taste, odor, and appearance.

## Results and Discussion

### *Physicochemical analysis*

*Temperature.* The temperature of water sources in Bahir Dar City varied from 24°C to 26.8°C (mean = 26.047 ± 0.71°C) during the dry season and from 19.9°C to 21.7°C (mean = 0.527 ± 0.586°C) during the wet season. The higher water temperature observed in the dry season compared to the wet season is attributed to the overall warmer conditions during that time. Water temperature has no objectionable guideline, but an increase in temperature can favor for biological activities and affect the quality of the water. This study aligns with the findings of Montoya-Pachongo et al. (2018), who reported a mean drinking water temperature of 26°C. Additionally, Eriksson (2012) reported a maximum temperature of 24.2°C for hand-dug well drinking water in the Koga irrigation area, and Horgby and Larson (2013) recorded 22.2°C for the same water source.

#### *pH*

The pH values of water sources in Bahir Dar city ranged from 6.47 to 8.97 (mean = 7.03 ± 0.58) in dry season and 6.7 to 8.74 (mean = 7.13 ± 0.476) in wet season (Figure 2(a)). The results indicated that 93.3 % the existing water sources in Bahir Dar City fell within the WHO recommended pH range of 6.5 to 8.5 (WHO, 2011). Daghara et al. (2019) reported pH values of drinking Water from springs in Palestine in the range of 7.08 to 8.19. In Ethiopia, Eriksson (2012) reported pH values ranging from 7.3 to 7.4 in hand-dug well drinking water samples from the Koga irrigation area. Yasin et al. (2015) also reported pH values in the range of 5.64 to 8.14 in the water sources of Jimma Zone, and Duressa et al. (2019) also reported pH values in the range of 6.8 to 7.03 in the water sources of Nekemte, Ethiopia. The Mean pH values of the water samples were within the safe range for drinking water quality. Statistically, there is no significance difference in mean values of pH in the water sources used in Bahir Dar City.

#### *Turbidity*

The turbidity level of water samples collected both in the dry and wet seasons are shown in Figure 2(b). Both in the wet and dry seasons, the turbidity values of water samples were in the range of 1.1 to 10.8 NTU. The maximum turbidity value was observed at MO (10.8 NTU) and the lowest turbidity value was observed at CH-5(1.1 NTU) in the wet season. Statistically, there was a significant difference in the mean turbidity values at the sampling sites ($p < 0.05$). Turbidity values were higher during the wet season compared to the dry season. This might be infiltration of surface run offs into the wells. All the turbidity values obtained at the sampling sites were beyond the maximum allowable permissible limit set by WHO (2011) and Ethiopian Standard (2001), which is 5 NTU (WHO, 2011). Yasin et al. (2015) reported that the turbidity of water sources of Jimma zone in Ethiopia in the range of 1.87 to 24.22 NTU. In this study about 29% of the analyzed samples were above the WHO water quality standards. This higher turbidity in the water, especially in the wet season may produce good condition for bacterial attachment and growth that can affect the health of the consumers.

#### *Electrical conductivity (EC)*

EC is the ability of a solution to carry an electrical current. Conductivity is an important component in determining water quality because it provides good information about dissolved ions in the water under investigation.

The EC of drinking water sources in Bahir Dar city range from 41.73 to 320 μs/cm during both the dry and wet seasons

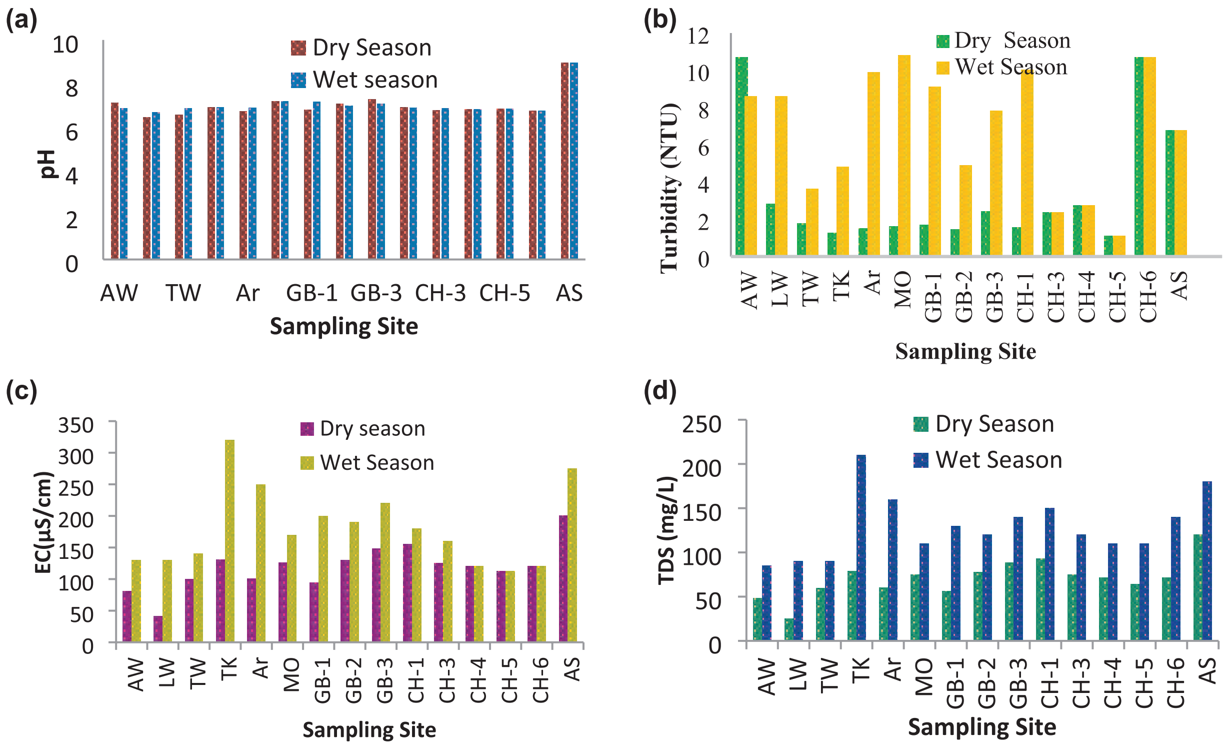


**Figure 2.** Water quality sources of Bahir Dar City: (a) pH, (b) turbidity, (c) electrical conductivity, and (d) total dissolved solids during dry and wet seasons as compared with the WHO Maximum Permissible Limit.

**Table 1.** Classification of the EC of Water Samples at 25°C Based on Rajankar et al. (2011).

| RANGE OF EC (µS/CM) | WATER QUALITY CLASSIFICATION | PERCENTAGE OF SAMPLES IN THE DS | PERCENTAGE OF SAMPLES IN THE WS |
|---|---|---|---|
| <250 | Excellent | 100% | 80% |
| 250–750 | Good | — | 20 |
| 750–2,000 | Permissible | — | — |
| 2,000–3,000 | Doubtful | — | — |
| >3,000 | Unsuitable | — | — |

(Figure 2(c)). The water samples are very weakly mineralized water and acceptable for drinking (Detay & Carpenter, 1997). According to water quality classification (Table 1), the EC of water samples taken from Bahir Dar City water sources were found excellent in the dry season. In the wet season, 80 % of the water samples were classified excellent, while 20% were considered good quality (Rajankar et al., 2011). The EC values in the study area were lower compared to those reported by Yasin et al. (2015) in Ethiopia. According to single factor ANOVA, the average EC value in the water sources show significant variations ($p < 0.05$) at the sampling sites.

### *Total dissolved solids (TDS)*

In this study, the TDS values ranged from 24.9 to 120 mg/L with mean 70.97 during the dry season, and 85 to 210 mg/L with an average of 129.67 during the wet season (Figure 2(d)). The higher TDS values in the wet season compared to the dry season could be attributed to agricultural runoff, urban wastewater discharge, and other human activities.

According to Todd's (2009) categorization of groundwater, all the water samples fall into the fresh water class (Table 2). The low level of TDS in the water samples indicated the water is applicable for drinking, agricultural, and other domestic purposes. The TDS values in the study areas were within the permissible limits set by WHO (2011) and Ethiopian Standards (2001), which specify a maximum of 1,000 mg/L.

The TDS values obtained in water samples were below the values reported by Annalakshmi and Amsath (2012) in Tamil Nadu, India (221–3,534 mg/L) and Uddin et al. (2021) in Bangladesh tube well water (258–261 mg/L). Lewoyehu (2021) reported similar findings in the Amhara Region, Ethiopia,

**Table 2.** Groundwater Quality Classification Based on the TDS Values (Todd, 2009).

| TDS (MG/L) | WATER CLASS | NO. OF SAMPLES ($n$=30) | % OF SAMPLES |
|---|---|---|---|
| 10–1,000 | Fresh water | All | 100 % |
| 1,000–10,000 | Slightly–brackish water | — | — |
| 10,000–100,000 | brackish | — | — |
| >100,000 | Brine water | — | — |

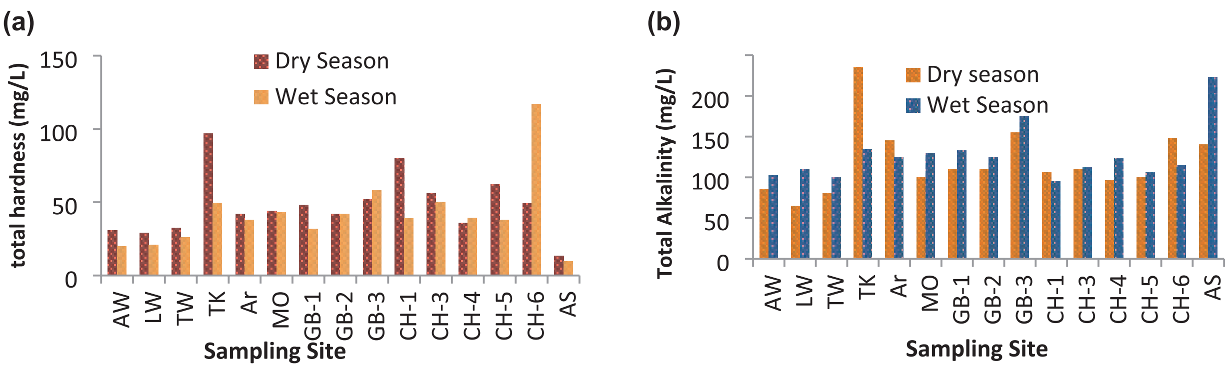


**Figure 3.** The quality of water sources of Bahir Dar City; total hardness (a), total alkalinity (b) during the dry and wet seasons.

**Table 3.** Classification of Water Samples for Various Ranges of Hardness (Prakash & Somashekar, 2006).

| TOTAL HARDNESS IN MG/L | DEGREE OF HARDNESS | NO. OF SAMPLES ($n$=30) | % OF SAMPLES |
|---|---|---|---|
| 0–75 | Soft | 27 | 90 |
| 75–150 | Moderately hard | 3 | 10 |
| 150–300 | Hard | — | — |
| >300 | Very hard | — | — |

with TDS values ranging from 11 to 152 mg/L, comparable to the results of this study. Water with a TDS level below 600 mg/L is generally considered to have good palatability, while drinking water becomes increasingly unpalatable at TDS levels exceeding around 1000 mg/L (WHO, 2011). The Analysis of TDS in the water samples showed levels below 600 mg/L. Thus, the TDS values for the water sources in Bahir Dar City suggest that the water is of good quality.

### *Total hardness*

The total hardness of this study ranged from 13.3 to 97 mg/L with an average of 47.6 mg/L during the dry season. In the wet season, the total hardness in water samples ranged from 9.67 to 117 mg/L with a mean value of 41.47 mg/L as $CaCO_3$ (Figure 3(a)). Higher total hardness values were observed at TK (97 mg/L) and CH-1(80 mg/L), during the dry season, and at CH-6 (117 mg/L) during the wet season, which are classified as moderately hard water (Prakash & Somashekar, 2006). About 90% water samples showed total hardness values below 75 mg/L, which is classified as soft water (Table 3). According to WHO (2011) and Ethiopian Standard (2001), the maximum acceptable total hardness in drinking water is 300 mg/L. Therefore, the water sources supplied to the city are safe for human consumption. The total hardness observed in this study is lower than the levels reported in other studies, such as Daghara et al. (2019) in Palestine (199–485 mg/L) and Salem et al. (2022) in Sebha city, Libya (600–810 mg/L). Statistically, one factor of ANOVA showed a significance p value of 0.007, which is less than the $p$=0.05. This indicated the presence of significant variation in the mean of total hardness at the sampling sites of water sources used in the city.

### *Total alkalinity*

In this study, the total alkalinity varied from 65 to 235 mg/L $CaCO_3$ during the dry season and 95 to 223 mg/L $CaCO_3$ during the wet season (Figure 3(b)). Higher alkalinity

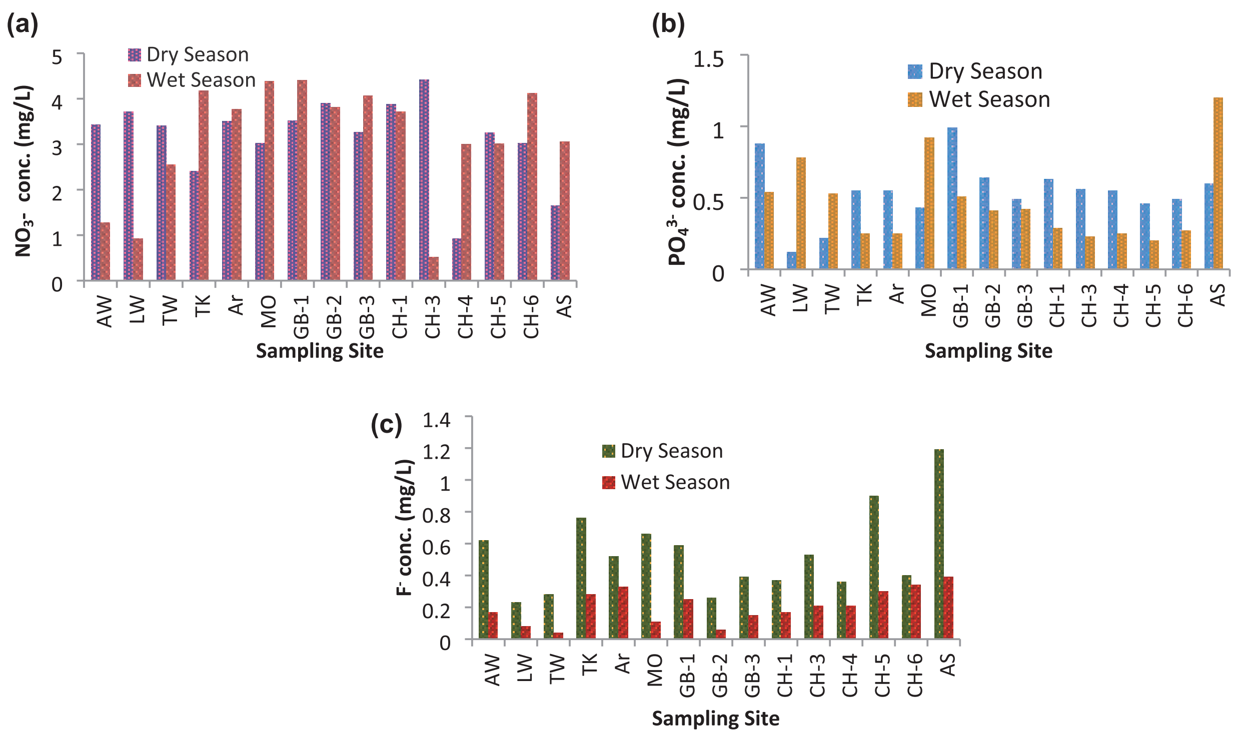


**Figure 4.** The quality of water sources of Bahir Dar City: phosphate concentration (a), nitrate concentration (b), and fluoride concentrations (c) during the dry and wet seasons.

(235 mg/L $CaCO_3$) was observed during the dry season at TK sampling site, and during the wet season (223 mg/L $CaCO_3$) at AS sampling site. The higher value of total alkalinity at TK might be due to pollution of groundwater from the nearby Tsehay Kelem paint industry wastewater discharged to the environment. The mean values of the total alkalinity of the water samples in the dry (119.22 mg/L) and wet (127.49 mg/L) seasons were below the maximum permissible limit set by WHO and ES (200 mg/L $CaCO_3$). These values are greater than the alkalinity values reported by Oljira (2015), which is 12 to 132 mg/L. Statistically, there is a significant difference ($p = 0.008$) in total alkalinity to the samples taken at the water sources.

### *Phosphate ($PO_4^{3-}$)*

Phosphate analysis of Bahir Dar City drinking water sources indicated in the range of 0.2 to 1.2 mg/L (mean 0.544 mg/L) in the wet season and 0.12 to 0.99 mg/L (mean = 0.47 mg/L) in the dry season (Figure 4(a)). Maximum phosphate concentrations were observed at AS (1.2 mg/L), MO (0.91 mg/L) during the wet season and GB-1(0.99 mg/L) during the dry season. This may be due to dissolution of minerals containing phosphate minerals, agricultural fertilizer, and infiltration of municipal wastewater. These values are less than the phosphate values reported by Oljira (2015), which is 0.12 to 5 mg/L and greater than the values reported by Eriksson (2012). Single factor ANOVA indicated that there is no significant difference in the mean value of phosphate ($p = 0.865$) at the sampling site of water sources used for Bahir Dar City.

### *Nitrate ($NO_3^-$)*

The $NO_3$–N concentration in the water sources of Bahir Dar City ranged from 0.52 to 4.41 mg/L(mean = 3.12) and 0.92 to 4.42 mg/L(mean = 3.16) in wet and dry season's, respectively (Figure 4(b)). The $NO_3$–N concentrations during wet and dry seasons were much less than the maximum permissible limit of Ethiopian Standard (2001) and WHO (2011), which is 10 mg/L $NO_3$–N .This revealed that water sources in the study area are safe in terms of the $NO_3$–N level for drinking and other domestic applications. Salem et al. (2022) reported higher nitrate concentrations in the range of 3.1 to 24 mg/L $NO_3$–N in the groundwater sources of Sebha city, Libya. The nitrate level in the studied water samples were below the nitrate concentration reported by Akale et al. (2018), which is 1.4 to 15.8 mg/L $NO_3$–N. Statistically, there was no significant difference ($p = .312$) in the mean concentrations of nitrates in the water sources of the city.

### *Fluoride ($F^-$)*

In this study, the fluoride concentrations were found in the range of 0.23 to 1.19 mg/L (mean = 0.54) during the dry season and 0.04 to 0.39 mg/L (mean = 0.21 mg/L) during the wet season (Figure 4 (c)). Higher $F^-$ concentrations were found at AS (1.19 mg/L) and CH-5 (0.9 mg/L) during the dry season. The

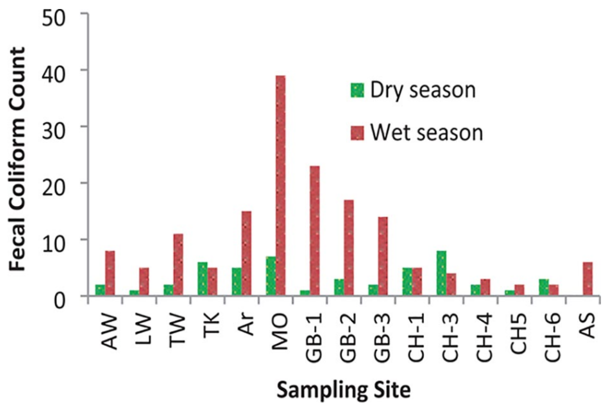


**Figure 5.** Fecal coliform count (CFU/100 mL) during the dry and wet seasons in the water sources collected in Bahir Dar City.

F– concentrations during dry season were higher than the wet season; this might be due to dilution during recharging of the groundwater with rain water. Statistical analysis indicated that there was significant difference ($p = 0.002$) in the mean fluoride concentrations at the water sources used in the city. The analysis of fluoride in the water sources of Bahir Dar city were below the maximum permissible limit set by Ethiopian Standard (2001) and WHO (2011) that is 1.5 mg/L. The fluoride concentrations in this study were lower than the values reported by Oljira (2015) and Demelash et al. (2019). Therefore, the water source of Bahir Dar city has no fluoride health risk to the consumers.

### *Bacteriological test analyses*

*Fecal and total coliforms.* In this study, fecal coliforms(FC) were found in the range of 2 to 39 CFU/100 mL (mean = 10.6) in the wet season and 0 to 8 CFU/100 mL (mean = 3.2) in the dry season (Figure 5), which exceed the WHO and ES (0 CFU/100 mL) permissible limit except sample AS (0 CFU/100 mL). About 60% of the water samples were categorized in the low risk and 40 % in the moderate risk in the wet season (Table 4). In the dry season, 6.67 % categorized in the no risk and 93.33 % in the low risk grades. The analysis indicated that the water sources were highly polluted with fecal coliforms in the wet season compared with the dry season. This might be due to contamination of the water sources with animal or human wastes infiltrated to the ground water from the municipal water run offs or poor sanitary septic tanks.

The total coliforms (TC) count of this study were in the range from 1 CFU/100 mL to 241 CFU/100 mL in the dry season and too numerous to count in the wet season in 100 mL sample (Table 5). TC bacteria are not acceptable as an indicator of the sanitary quality of water supplies, particularly in tropical areas, where many bacteria of no sanitary significance occur in almost all untreated supplies (WHO, 2011). The FC and TC concentrations in this study were in agreement with the values reported by Lora-Ariza *et al.* (2024). In general, the fecal coliforms and total coliforms levels of this study indicate that regular addition of chlorine in the reservoirs is needed to assure a better quality of drinking water.

## Conclusion

This study was conducted to analyze the quality of drinking water sources supplied to Bahir Dar City in the dry and wet seasons to the level that is safe and acceptable to the customers. The physicochemical parameters examined, including temperature, pH, TDS, EC, $PO_4^{3-}$, $NO_3^-$, $F^-$, total alkalinity, and total hardness were found to be within the acceptable limits set by WHO & Ethiopian drinking water standards across all sampling sites. However, turbidity and bacteriological analyses (fecal coliforms and total coliforms) exceeded the recommended guidelines. The contamination of these water sources is likely due to human activities, animal presence, livestock grazing, and other anthropogenic factors near the water sources. This contamination poses a risk of exposure to pathogenic microorganisms for consumers. Therefore, it is essential to implement long-term monitoring strategies, assess the potential effects of climate variability on water quality, and ensure the protection from contamination and proper disinfection of water sources before distribution to consumers.

**Table 4.** Classification of Water Samples for Fecal Coliforms (CFU/100 mL) According to Degree of Risk (WHO, 2004).

| TOTAL COLIFORM (CFU/100 ML) | RISK GRADE | PERCENTAGE OF SAMPLES IN THE DRY SEASON | PERCENTAGE OF SAMPLES IN THE WET SEASON |
|---|---|---|---|
| 0 | No risk | 6.67 | — |
| 1–10 | Low risk | 93.33 | 60 |
| 11–100 | Moderate risk | — | 40 |
| 101–1,000 | high risk | — | — |
| >1,000 | Very high risk | — | — |

**Table 5.** Total Coliform (CFU/100 mL) in Wet and Dry Season Compared with WHO Permissible Limit.

| SAMPLING SITE | TC IN THE WET SEASON | TC IN THE DRY SEASON |
|---|---|---|
| AW | TNC | 241 |
| LW | TNC | 1 |
| TW | TNC | 85 |
| TK | TNC | 17 |
| AR | TNC | 160 |
| MO | TNC | 17 |
| GB-1 | TNC | 167 |
| GB-2 | TNC | 48 |
| GB-3 | TNC | 49 |
| CH-1 | TNC | 4 |
| CH-3 | TNC | 16 |
| CH-4 | TNC | 24 |
| CH-5 | TNC | 16 |
| CH-6 | TNC | 1 |
| AS | TNC | 6 |

*Note*. TNC = too numerous to count, CFU = colony forming unit.

## Acknowledgements

The authors are grateful to Bahir Dar University for the financial support of lab analysis of this study.

## Author Contributions

Agegnehu Alemu: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. Woinitu Bitew: Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Zelalem Liyew Anteneh: Draw Sampling sites With ARC GIS, Edit manuscript.

## Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

## ORCID iD

Agegnehu Alemu https://orcid.org/0000-0003-3640-7665

## REFERENCES

Akale, A. T., Moges, M. A., Dagnew, D. C., Tilahun, S. A., & Steenhuis, T. S. (2018). Assessment of nitrate in wells and springs in the North Central Ethiopian Highlands. *Water*, 10(4), Article 476.

Al-Tabbal, J. A., & Al-Zboon, K. K. (2012). Suitability assessment of groundwater for irrigation drinking purpose in the northern region of Jordan. *Journal of Environmental Science and Technology*, 5(5), 274–290.

Annalakshmi, G., & Amsath, A. (2012). An assessment of water quality of river Cauvery and its tributaries Arasalar with reference to physico-chemical parameters at Tanjore DT, Tamilnadu, India. *International Journal of Applied Biology and Pharmaceutical Technology*, 3(1), 269–279.

Aremu, M. O., Olaofe, O., Ikokoh, P. P., & Yakubu, M. M. (2011). Physicochemical characteristics of stream, well and borehole water sources in Eggon, Nasarawa State, Nigeria. *Journal of Chemical Society of Nigeria*, 36(1), 131–136.

APHA. (2017). *Standard methods for the examination of water and wastewater* (23th ed.). American Public Health Association. Retrieved May 15 2021, from https://www.aphabookstore.org

Central Statistical Agency of Ethiopia. (2017). *Drinking water quality in Ethiopia–results from the 2016 Ethiopia socioeconomic survey*. A Report by the Central Statistical Agency of Ethiopia in Collaboration with the Ministry of Water, Irrigation and Electricity (MOWIE), LSMS, World Bank, UNICEF, WHO, and JMP.

Daghara, A., Al-Khatib, I. A., & Al-Jabari, M. (2019). Quality of drinking water from springs in Palestine: West Bank as a case study. *Journal of Environmental and Public Health*. Advance online publication. https://doi.org/10.1155/2019/8631732

Dao, P. U., Heuzard, A. G., Le, T. X. H., Zhao, J., Yin, R., Shang, C., & Fan, C. (2023). The impacts of climate change on groundwater quality: A review. *Science of the Total Environment*, 912, 169241.

Davraz, A., & Batur, B. (2021). Hydrogeochemistry characteristics of groundwater and health risk assessment in Yalvac–Gelendost basin (Turkey). *Applied Water Science*, 11(4), Article 67.

Demelash, H., Beyene, A., Abebe, Z., & Melese, A. (2019). Fluoride concentration in ground water and prevalence of dental fluorosis in Ethiopian Rift Valley: Systematic review and meta-analysis. *BMC Public Health*, 19, Article 1298.

Detay, M., & Carpenter, M. (1997). *Water wells: Implementation, maintenance and restoration*. Wiley.

Duressa, G., Assefa, F., & Jida, M. (2019). Assessment of bacteriological and physicochemical quality of drinking water from source to household tap connection in Nekemte, Oromia, Ethiopia. *Journal of Environmental and Public Health*. Advance online publication. https://doi.org/10.1155/2019/2129792

Eriksson, S. (2012). *Water quality in the Koga Irrigation Project, Ethiopia: A snapshot of general quality parameters*. Geotryckeriet Uppsala University.

Ethiopian Standard. (2001). *Drinking water quality standard* (2nd ed.).

Horgby, A., & Larson, K. (2013). *Effects on drinking water quality due to irrigation in the Koga area of Merawi, Ethiopia*. Geotryckeriet, Uppsala universitet.

Kasim, O. F., Abshare, M. W., Mukuna, T. E., & Wahab, B. (2018). Land use and ambient air quality in Bahir Dar and Hawassa, Ethiopia. *Air, Soil and Water Research*, 11,1178622117752138.

Kazemi, A., Esmaeilbeigi, M., Sahebi, Z., & Shooshtari, S. J. (2022). Hydrochemical evaluation of groundwater quality and human health risk assessment of trace elements in the largest mining district of South Khorasan, Eastern Iran. *Environmental Science and Pollution Research*, 29(54), 81804–81829.

Lewoyehu, M. (2021). Evaluation of drinking water quality in rural area of Amhara Region, Ethiopia: The case of Mecha District. *Journal of Chemistry*. Advance online publication. https://doi.org/10.1155/2021/9911838

Li, X., Zhang, Y., Li, Z., & Wang, R. (2021). Response of the groundwater environment to rapid urbanization in Hohhot, the provincial capital of western China. *Journal of Hydrology*, 603, Article 127033.

Lora-Ariza, B., Piña, A., & Donado, L. D. (2024). Assessment of groundwater quality for human consumption and its health risks in the Middle Magdalena Valley, Colombia. *Scientific Reports*, 14(1), Article11346.

Melo, D. C., Anache, J. A., Almeida, C. D. N., Coutinho, J. V., Ramos Filho, G. M., Rosalem, L. M., Pelinson, N. S., Ferreira, G. L., Schwamback, D., Calixto, K. G., & Wendland, E. (2020). The big picture of field hydrology studies in Brazil. *Hydrological Sciences Journal*, 65(8), 1262–1280.

Montoya-Pachongo, C., Douterelo, I., Noakes, C., Camargo-Valero, M. A., Sleigh, A., Escobar-Rivera, J. C., & Torres-Lozada, P. (2018). Field assessment of bacterial communities and total trihalomethanes: Implications for drinking water networks. *Science of the Total Environment*, 616, 345–354.

Napacho, Z. A., & Manyele, S. V. (2010). Quality assessment of drinking water in Temeke District (part II): Characterization of chemical parameters. *African Journal of Environmental Science and Technology*, 4(11), 775–789.

Oljira, G. (2015). *Investigation of drinking water quality from source to point of distribution: The case of GimbiTwon in Oromia regional State of Ethiopia, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia* (pp. 34–54). Addi s Ababa University.

Prakash, K. L., & Somashekar, R. K. (2006). Groundwater quality assessment on Ankeltaluk, Bangalore urban district, India. *Journal of Environmental Biology*, 27(4), 633–637.

Rajankar, P. N., Tambekar, D. H., & Wate, S. R. (2011). Groundwater quality and water quality index at Bhandara District. *Environmental Monitoring and Assessment*, 179(1–4), 619–625.

Salem, M. A., Sharif, O. A., Alshofeir, A. A., & Assad, M. E. H. (2022). An evaluation of drinking water quality in five wells in Sebha city, Libya, using a water quality index and multivariate analysis. *Arabian Journal of Geosciences*, 15(18), Article 1519.

Şener, E., Varol, S., & Sener, S. (2022). Hydrochemistry and geogenic pollution assessment of groundwater in Aksehir (Konya/Turkey) using GIS. In *Computers in earth and environmental sciences* (pp. 477–490). Elsevier.

Todd, D. K. (2009). *Groundwater hydrology*. Wiley.

Uddin, M. R., Khandaker, M. U., Abedin, M. J., Akter, N., Molla Jamal, A. S. I., Sultana, R., Sultana, S., Hasan, M., Osman, H., Elesawy, B. H., & Sulieman, A. (2021). Quality assessment of bottled and unbottled drinking water in Bangladesh. *Water*, 13(15), Article 2026.

UNICEF Ethiopia (2018). Water, sanitation and hygiene (WASH). In: United Nations Children's Fund (UNICEF) [Internet]. [Cited 23 May 2024]. https://www.unicef.org/ethiopia/water-sanitation-and-hygiene-wash

UN-Water. (2020). Water and climate change. *The United Nations World Water Development Report*. UNESCO. https://unesdoc.unesco.org/ark:/48223/pf0000372985/PDF/372985eng.pdf.multi

UN-Water. (2021). Summary progress updates 2021: SDG 6 - water and sanitation for all. https://www.unwater.org/sites/default/files/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf

Varol, S., & Şekerci, M. (2018). Hydrogeochemistry, water quality and health risk assessment of water resources contaminated by agricultural activities in Korkuteli (Antalya, Turkey) district center. *Journal of Water and Health*, 16(4), 574–599.

WHO. (2004). *Guidelines for drinking water quality* (3rd ed.).

WHO. (2006). *WHO guidelines for the safe use of waste water excreta and grey water* (Vol. 1).

WHO. (2011). *Guidelines for drinking-water quality* (4th ed.). Retrieved May 17, 2021, from https://apps.who.int/iris/bitstream/handle/10665/44584/9789241548151_eng.pdf?sequence=1

Yasin, M., Ketema, T., & Bacha, K. (2015). Physico-chemical and bacteriological quality of drinking water of different sources, Jimma zone, Southwest Ethiopia. *BMC Research Notes*, 8, 1–13.

Zhang, Q., Miao, L., Wang, H., Hou, J., & Li, Y. (2019). How rapid urbanization drives deteriorating groundwater quality in a provincial capital of China. *Polish Journal of Environmental Studies*, 29(1), 441–450.