Investigation of household drinking water quality in Dembia District, Tana Basin, Ethiopia

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Abstract

Access to safe and adequate drinking water is essential for human health, yet many communities in developing countries, including Ethiopia, still depend on water that is not microbiologically safe. Even improved water sources can become contaminated due to poor source protection, improper handling, and unsafe household storage. This study assessed the physicochemical and microbiological quality of household drinking water sources within multiple-use water systems in Dembia District, northwestern Ethiopia. A total of 22 water points from rural and urban kebeles were randomly selected and evaluated through sanitary inspections and laboratory analyses following WHO guidelines. Most physicochemical parameters met guideline values, with iron concentrations below 0.3 mg/L, manganese below 0.4 mg/L, fluoride below 1.5 mg/L, and chloride below 250 mg/L in all sources, except for one hand-dug well that showed a higher chloride level (185 mg/L). In contrast, turbidity and microbial contamination were key concerns, particularly in rural areas. Total coliforms were detected in 18.1% of urban and 36.4% of rural water points, while fecal coliforms were present in 9.0% of urban and 22.7% of rural sources, indicating potential fecal contamination and related health risks. Overall, although chemical water quality was largely acceptable, the presence of coliform bacteria in several sources highlights the need for improved source protection, routine chlorination, and household-level water treatment to ensure safe drinking water.

Keywords: Drinking water quality; WHO guidelines; physicochemical parameters; Microbial contamination; rural water supply; Water sustainability

1. INTRODUCTION

Access to safe and adequate drinking water is a fundamental human right and a cornerstone of public health protection. Nevertheless, water-related diseases remain a major public health challenge in many developing countries due to limited access to safe drinking water and improved sanitation services (UNICEF, 2018). Globally, more than 700 million people lack access to improved drinking water sources, and a significant proportion of water-related illnesses are attributable to microbiologically contaminated water (de Kort, 2016). Diarrheal diseases alone account for over 1.5 million deaths annually among children under five years of age, with the majority occurring in low-income countries (Alemayehu et al., 2020).

Ethiopia is often referred to as the "water tower of East Africa"; however, access to safe and reliable drinking water remains inadequate in many parts of the country (Muhammed & Hanie, 2016). Despite national commitments to the Sustainable Development Goals (SDGs) and substantial investments in water supply infrastructure, many communities continue to depend on unimproved or poorly managed water sources (UNDP, 2008). Even water obtained from improved sources is frequently recontaminated during collection, transportation, and household storage, thereby undermining the intended health benefits (Wright et al., 2004; Bain et al., 2014).

Drinking water quality is a critical environmental determinant of health, particularly due to the fecal–oral transmission of waterborne pathogens. Contamination may occur at the source, during abstraction, or at the point of use through unsafe handling and storage practices (WHO, 2011). Indicator organisms such as total coliforms and *Escherichia coli* are widely used to assess the microbiological safety of drinking water. According to WHO guidelines, drinking water should be free from fecal contamination, with zero coliform organisms per 100 mL (WHO, 2011).

In rural Ethiopia, water supply systems such as hand pumps and protected wells often suffer from inadequate maintenance, limited technical support, and poor sanitary protection, resulting in frequent system failure and compromised water quality (MoWE, 2007). Furthermore, seasonal water scarcity, long collection distances, and extended waiting times limit water availability for basic hygiene practices, increasing vulnerability to waterborne diseases (Sutton et al., 2012).

Dembia District, located in Northwestern Ethiopia, has benefited from various governmental and non-governmental water supply interventions. However, despite the presence of piped water systems and protected sources, many households continue to rely on traditional sources due to dissatisfaction with water taste, affordability issues, and service interruptions. Systematic assessment of drinking water quality and associated risk factors is therefore essential for understanding public health risks and informing sustainable water management strategies.

The main objective of this study was to assess the household drinking water quality in Dembia District, Northwestern Ethiopia. The specific objectives were to: (1) analyze physicochemical and microbiological drinking water quality parameters from selected water sources; (2) identify key factors contributing to drinking water contamination; and (3) assess accessibility and service sustainability of drinking water points in the district.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Dembia District is located in the Central Gondar Zone of the Amhara National Regional State, Northwestern Ethiopia, between 12°17′00″ N latitude and 37°26′00″ E longitude (Figure 1). The district capital, Kolladiba, lies approximately 750 km north of Addis Ababa and about 35 km southwest of Gondar town. Dembia District is bordered by Gondar town and Lay Armachiho District to the north, Gondar Zuria District to the east, Chilga and Takusa Districts to the west, and Lake Tana to the south.

The district covers an estimated area of 1,490 km² and comprises 45 kebeles, including five urban centers. According to the 2007 national census, the total population of the district was 270,994, of which 247,643 resided in rural areas and 23,351 in urban areas. The average household size is approximately five persons, with a total of 49,528 rural households. The district experiences seasonal rainfall variability, which influences both water availability and quality.

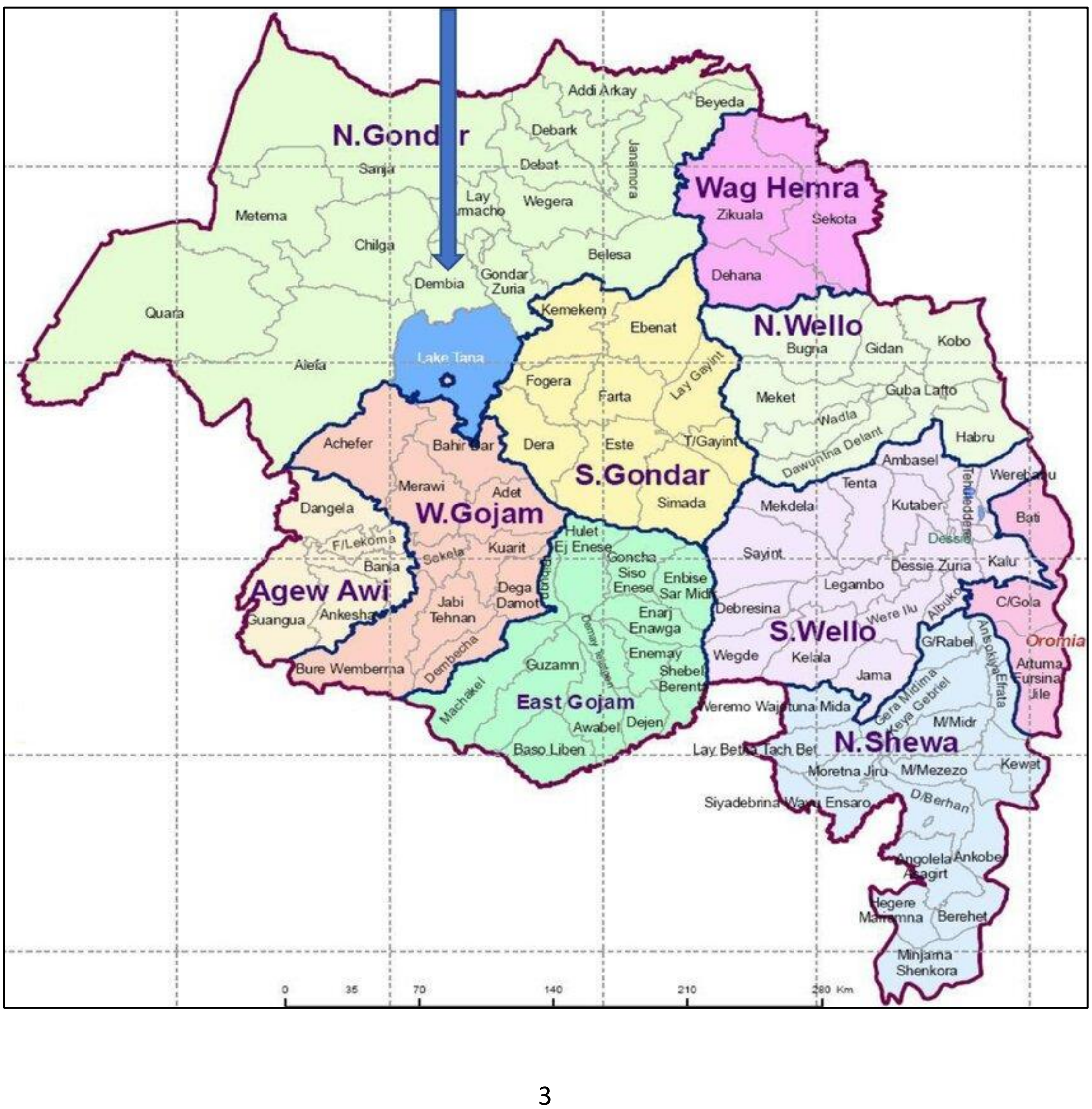

Figure 1. Map of the study area showing Dembia District within the Amhara Region, Ethiopia. Adapted from Research Gate (https://www.researchgate.net/figure/Map-of-Dembia-district-in-North-Gondar-zone-districts-in-Amhara-National-Regional-State_fig1_350057168).

2.2 Study Design and Water Source Selection

A cross-sectional water quality assessment was conducted to evaluate the physicochemical and microbiological quality of household drinking water sources in both rural and urban kebeles of Dembia District. A total of 22 drinking water points were selected using systematic random sampling. The sampled water sources were classified into three main categories: Category 1: Piped water supply systems (2 sources; 10%); Category 2: Boreholes equipped with hand pumps (10 sources; 45%); Category 3: Open hand-dug wells with concrete linings (10 sources; 45%). In each kebele (Figure 2), one to three commonly used drinking water sources were selected based on accessibility, functionality, and user dependence.

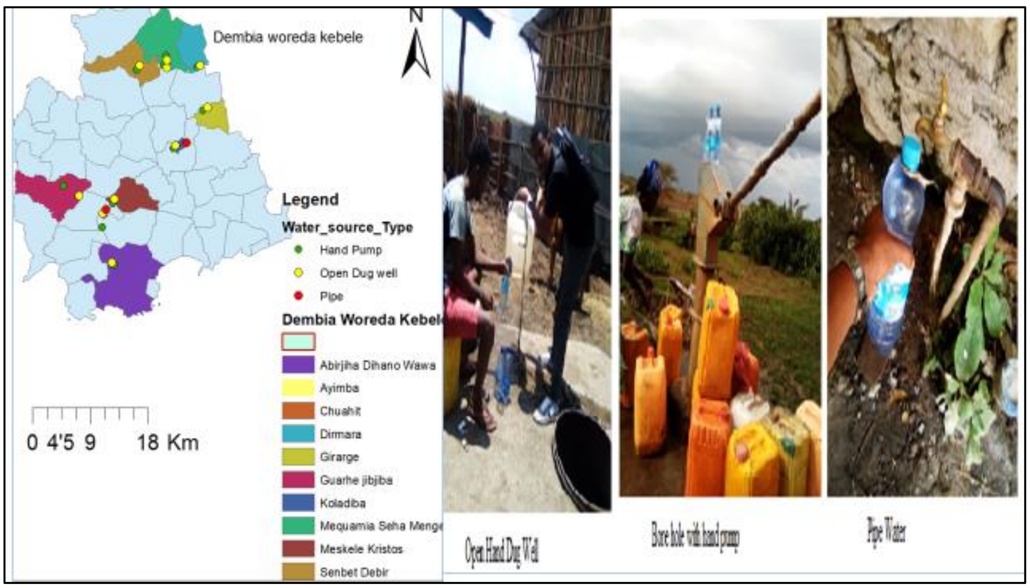

Figure 2: Locations of the target kebeles and water sampling sites in Dembia Woreda, Amhara Region, Ethiopia, with representative photos of the three water source categories.

2.3 Water Sampling Strategy

Water sampling was carried out during both rainy and dry seasons to capture seasonal variability. Sampling campaigns were conducted in: Rainy season: July 22–27, 2013 E.C. and Dry season: April 8–11, 2013 E.C. Grab water samples were collected from each water point following standard drinking water sampling procedures. For each site, 1,000 mL of water was collected for physicochemical analysis using clean polyethylene bottles, while samples for microbiological analysis were collected using sterile Whirl-Pak® sampling bags and sterile polyethylene containers.

All sampling containers were pre-cleaned, acid-washed (for chemical analysis), and rinsed with distilled water prior to sampling. Samples were immediately stored in ice boxes at approximately 4°C and transported to the Angereb Water Quality Analysis Laboratory in Gondar town within 6 hours of collection for analysis.

2.4 . Field Measurements

Physicochemical parameters that are subject to rapid change were measured in situ at each sampling point. These included: pH, Water temperature, Electrical conductivity (EC), Total dissolved solids (TDS) and Turbidity Measurements were performed using calibrated portable multi-parameter instruments, including HACH HQ40d, WTW PhotoFlex Turb Set, and Hanna HI-98129 meters. Instrument probes were immersed approximately 5 cm below the water surface, and readings were recorded once stabilized. All instruments were calibrated according to manufacturer specifications prior to field deployment.

2.5 . Laboratory Analysis of Physicochemical Parameters

Laboratory-based analyses were conducted for selected chemical parameters, including Chloride, Fluoride, Ammonia, Iron and Manganese. Samples for metal analysis were preserved by acidification with concentrated nitric acid to achieve a $pH < 2$. Chemical analyses were performed using a HACH DR 500 UV–Visible spectrophotometer, following standard procedures outlined in the HACH Water Analysis Manual (2010).

2.6 Microbiological Analysis

Microbiological water quality was assessed by analyzing total coliform (TC) and fecal coliform (FC) bacteria using the membrane filtration technique, following standard methods for the examination of water and wastewater (APHA, 2003). For each sample, appropriate dilutions (1 mL, 0.1 mL, and 0.01 mL) were prepared using sterile buffered water. A measured volume of sample was filtered through sterile 0.45 μm membrane filters, which were then placed on m-Endo LES agar media in labeled Petri dishes. The plates were incubated at 35 ± 0.5°C for 22–24 hours. After incubation, characteristic coliform colonies pink to dark red colonies with a metallic sheen were counted using a colony counter. Results were expressed as colony-forming units per 100 mL (CFU/100 mL).

2.7 Sanitary Inspection and Water Handling Assessment

Sanitary inspections of each water point were conducted using a standardized checklist adapted from WHO guidelines. The inspection assessed factors such as source protection, proximity to contamination sources, drainage conditions, and maintenance status. Household water handling practices were evaluated using 14 criteria, including container cleanliness, hand washing before collection, covering of storage containers, and method of water withdrawal, household water treatment practices, and storage duration. Good water handling practice was defined as a score above the average threshold (>8 criteria met).

2.8 Quality Assurance and Quality Control

All laboratory equipment, glassware, and culture media were sterilized prior to use. Blank samples and duplicate analyses were performed to ensure analytical accuracy. Instruments were calibrated daily, and all procedures followed laboratory quality assurance protocols.

2.9 Data Analysis

Collected data were entered, cleaned, and analyzed using SPSS version 23 and Microsoft Excel. Descriptive statistics (minimum, maximum, mean, and standard deviation) were used to summarize water quality parameters. Results were compared with World Health Organization (WHO) drinking water quality guidelines to assess compliance. Inferential analyses, including correlation and analysis of variance (ANOVA), were conducted where appropriate.

Table 1: Water Quality Parameters and Analytical Methods for Water Source Evaluation

No	Parameter	Method of Analysis	Type of Analysis
1	Conductivity	Direct instrumental measurement using a conductivity meter	On-site
2	Temperature	Instrumental measurement	On-site
3	Turbidity	Nephelometric method	On-site
4	Total Dissolved Solids (TDS)	Gravimetric method	On-site
5	pH	Electrometric measurement using a pH meter	On-site
6	Ammonia	Spectrophotometric method using reagent and test tube	Laboratory
7	Fluoride	Potentiometric method	Laboratory
8	Chloride	Photometric method	Laboratory
9	Manganese	Photometric method	Laboratory
10	Iron	Photometric method	Laboratory
11	Total Coliform	Membrane filtration method	Laboratory
12	Fecal Coliform	Membrane filtration method	Laboratory

3. RESULTS AND DISCUSSION

3.1 Physicochemical Characteristics of Drinking Water and Seasonal Variability

Temperature: Water temperature varied from 21.5–26.3 °C during the rainy season (RS) and 24.1–26.9 °C during the dry season (DS) (Figure 3). The highest temperatures were recorded at Stations 11 and 8 during RS and DS, respectively. Overall, water temperature increased from the rainy to the dry season, and significant spatial variation among stations was observed (ANOVA, $p < 0.05$). The observed temperature range is comparable to, or slightly lower than, previous reports for the Lake Tana basin (26–32 °C). Seasonal variation reflects meteorological conditions, sampling time, and exposure of water sources. Temperature influences dissolved oxygen solubility and microbial activity, thereby indirectly affecting water quality and ecosystem health, particularly in shallow groundwater systems.

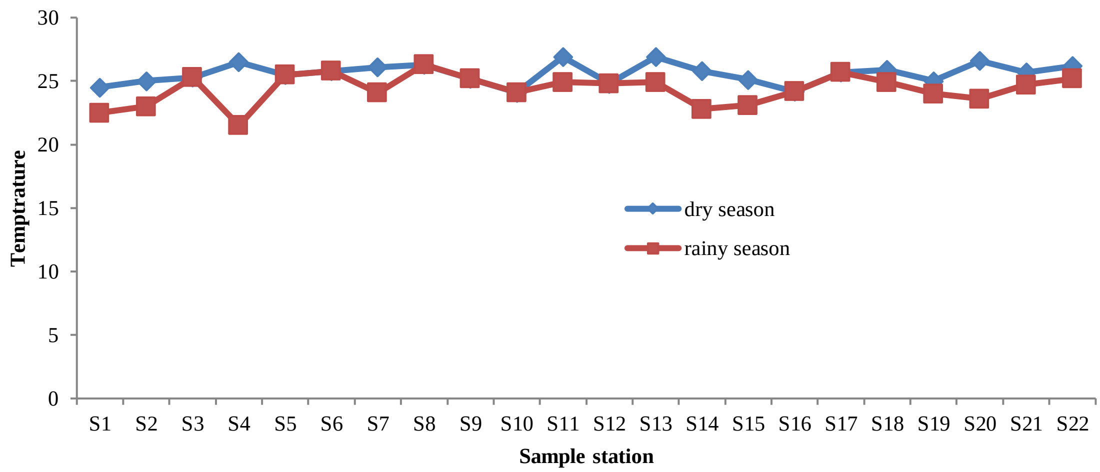

Figure 3. Temperature Variation between Dry and Rainy Seasons

pH: pH values ranged from 6.06 to 7.90 in the rainy season and 6.63 to 8.75 in the dry season (Figure 4). The lowest pH value was observed at Station 17 during RS, while the highest value (8.75) was recorded at Station 3 during DS. Most samples fell within the WHO recommended range of 6.5–8.5, although isolated exceedances were recorded during the dry season.

No statistically significant difference in pH among sampling stations was detected ($p > 0.05$). Slightly elevated pH during the dry season may be attributed to reduced dilution and increased photosynthetic activity, which consumes dissolved carbon dioxide. Overall, pH conditions were suitable for drinking and aquatic life.

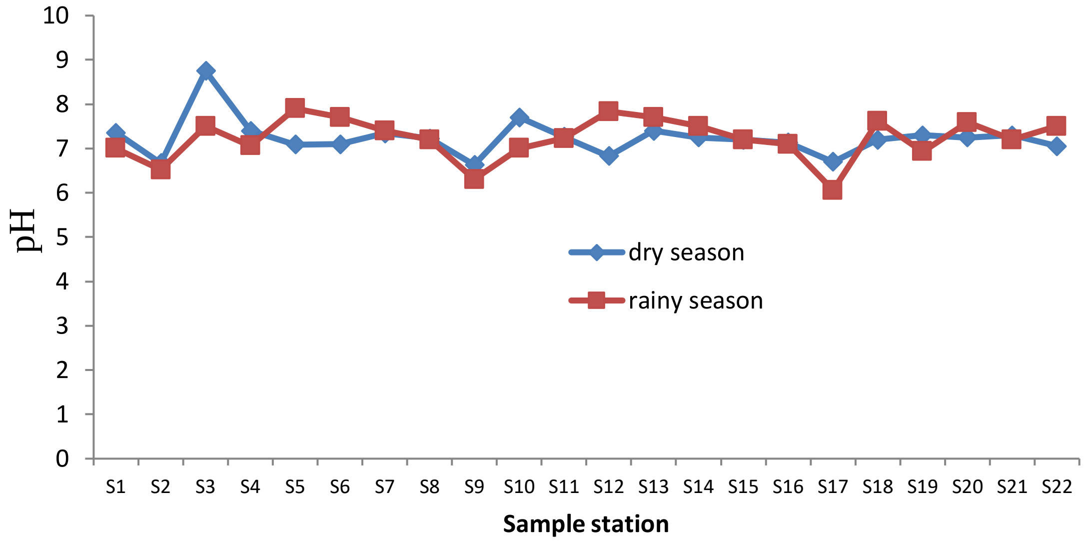

Figure 4. pH Variation Between Dry and Rainy Seasons

Electrical Conductivity (EC): Electrical conductivity ranged from 36–95 µS/cm during RS and 35–75 µS/cm during DS (Figure 5). All values were well below the WHO guideline limit of 1000 µS/cm, indicating low levels of dissolved ionic constituents. No significant seasonal or spatial differences were observed ($p > 0.05$). The low EC values reflect limited mineral dissolution and relatively low anthropogenic influence, although localized agricultural runoff and geological conditions may contribute to minor variations among stations.

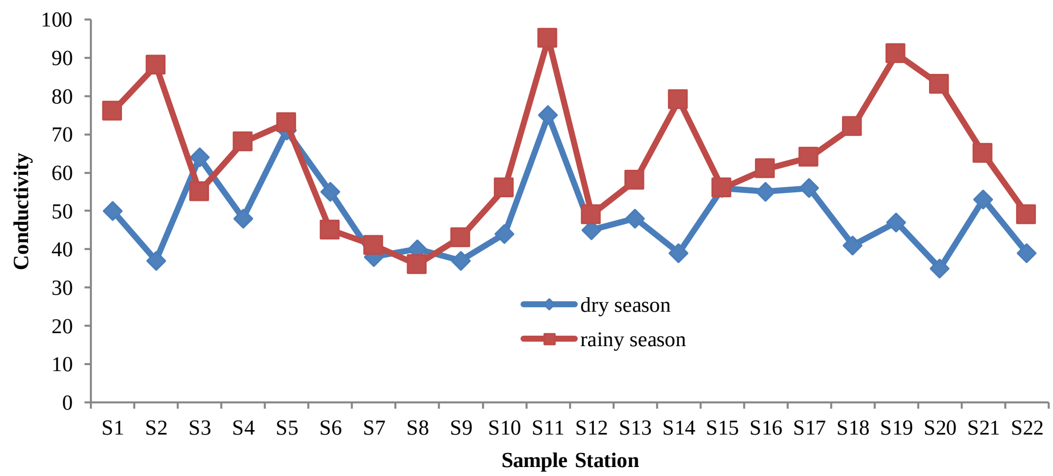

Figure 5. Conductivity Variation between Dry and Rainy Seasons

Total Dissolved Solids (TDS): TDS concentrations ranged from 20.7–44.7 mg/L in RS and 18.7–48.7 mg/L in DS (Figure 6). All values were far below the WHO recommended limit of 1000 mg/L, classifying the water as excellent (Class I) for drinking purposes. No significant differences were detected among stations (p > 0.05). Slightly higher TDS during the dry season likely reflects evaporation and reduced recharge, while lower values during the rainy season may be due to dilution.

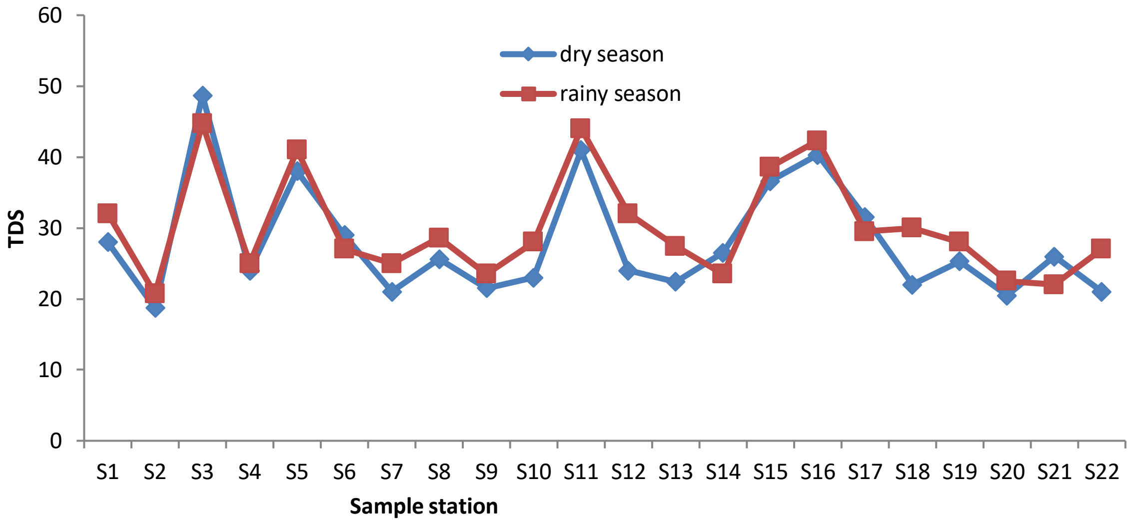

Figure 6. Total dissolved solids Variation between Dry and Rainy Seasons

Turbidity: Turbidity exhibited strong seasonal variability. During RS, values ranged from 2.9–95.5 NTU, with the highest value recorded at Station 11 (Figure 7). During DS, turbidity ranged from 0–9 NTU, with most stations showing values below 5 NTU. High turbidity during the rainy season exceeded WHO guideline values (<5 NTU) and is attributed to surface runoff, soil erosion, livestock activity, and infiltration of suspended sediments, particularly in open hand-dug wells. Although turbidity differences among stations were not statistically significant (p > 0.05), elevated turbidity poses challenges for effective disinfection and is often associated with increased microbial contamination.

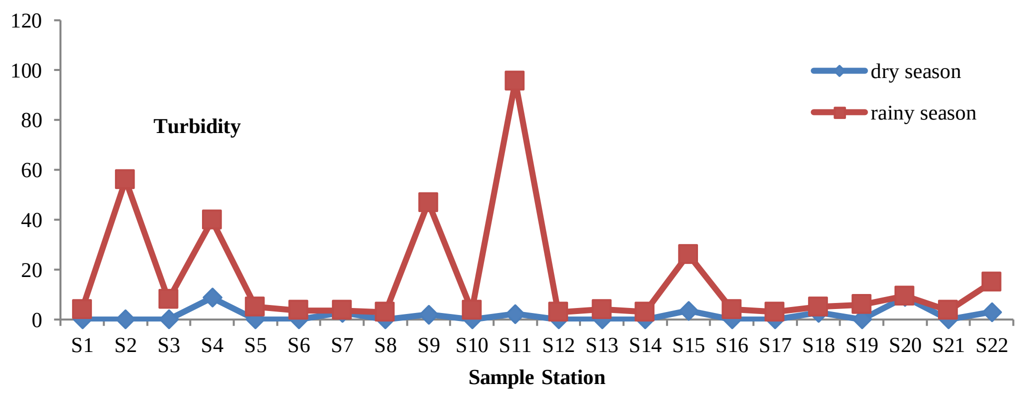

Figure 7. Turbidity Variation between Dry and Rainy Seasons

3.2 Chemical Water Quality Parameters

Fluoride: Fluoride concentrations ranged from 0.02–1.40 mg/L in RS and 0–1.09 mg/L in DS (Figure 8). All samples complied with the WHO health-based guideline value of 1.5 mg/L. Despite user complaints of dental fluorosis in three locations, laboratory results indicate fluoride concentrations were within acceptable limits. This suggests that total fluoride intake from multiple sources, including food and beverages, may contribute to observed dental effects rather than drinking water alone.

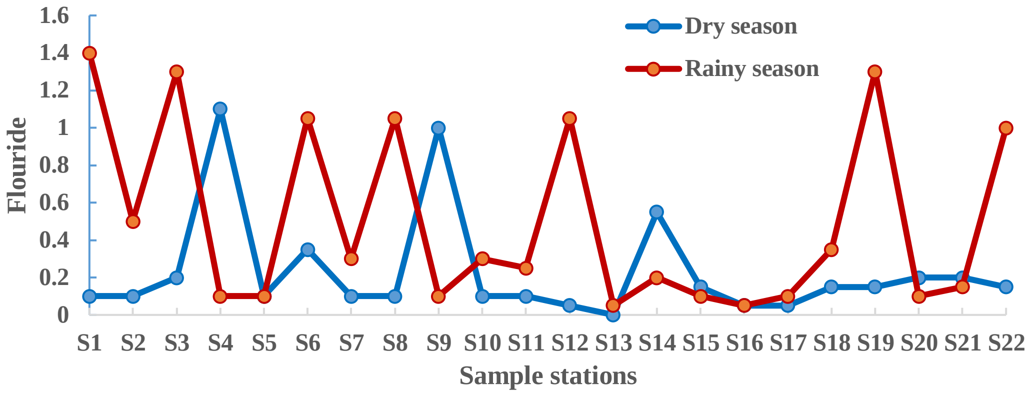

Figure 8. Fluoride Variation between Dry and Rainy Seasons

Chloride: Chloride concentrations varied between 35–177 mg/L in RS and 22–185 mg/L in DS (Figure 9). All values were below the WHO guideline limit of 250 mg/L, indicating no salinity-related concerns. Higher chloride levels during the dry season may be linked to evaporation and prolonged water–rock interaction.

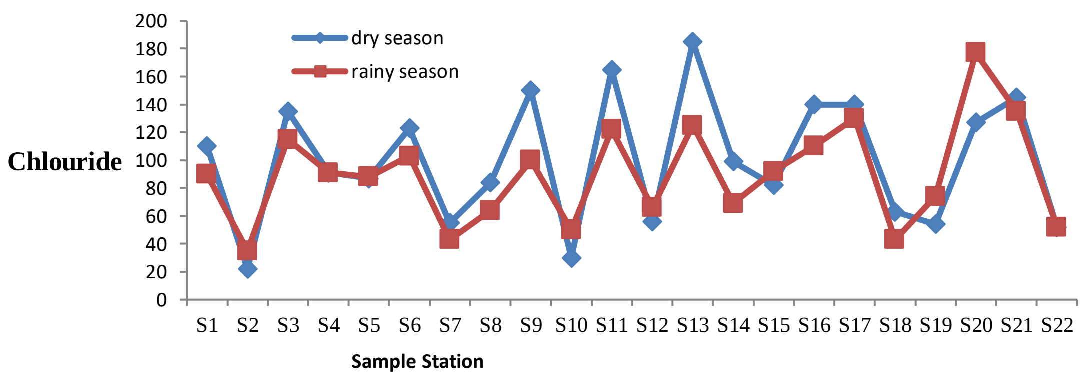

Figure 9. Chloride Variation between Dry and Rainy Seasons

Ammonia: Ammonia concentrations ranged from 0–3.0 mg/L in RS and 0–0.73 mg/L in DS (Figure 10). Elevated ammonia levels during RS likely reflect organic matter decomposition, agricultural runoff, and livestock waste infiltration. Lower concentrations during DS indicate reduced surface input and dilution effects.

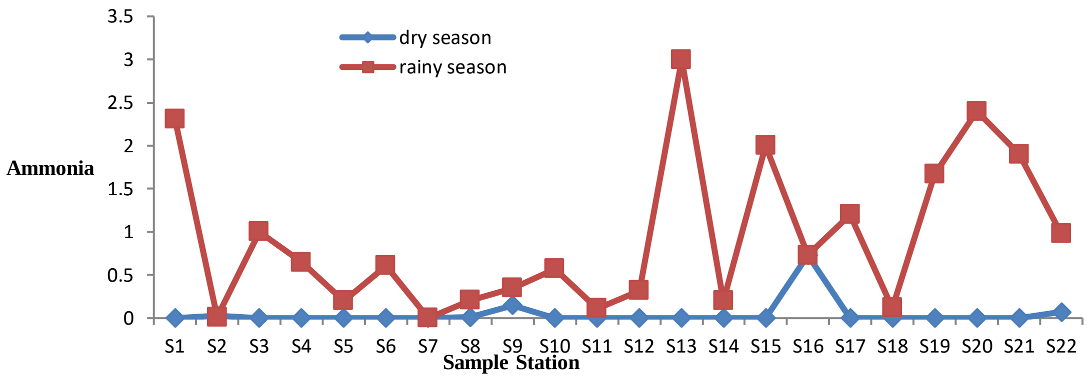

Figure 10. Ammonia Variation between Dry and Rainy Seasons

Iron: Iron concentrations varied from 0.003–11 mg/L in RS and 0–0.3 mg/L in DS (Figure 11). Rainy-season concentrations at several stations exceeded the WHO aesthetic limit of 0.3 mg/L, likely due to leaching from iron-rich soils and increased runoff. High iron levels may affect water taste, color, and user acceptance, particularly in hand-dug wells.

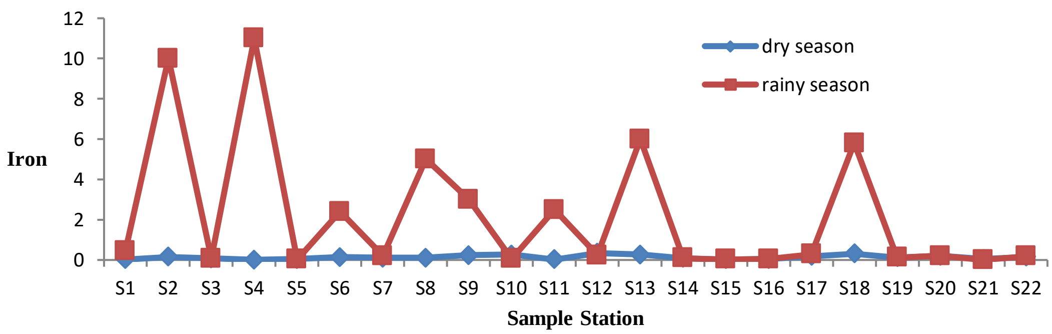

Figure 11: Iron Variation between Dry and Rainy Seasons

Manganese: Manganese-containing minerals are widespread, and manganese salts are commonly present in many natural waters. While manganese is a naturally occurring element, it can be undesirable in water used for domestic or industrial purposes. Even at very low concentrations, manganese can cause brown or dark staining of clothing and plumbing fixtures, and in industrial applications such as paper manufacturing or textile finishing, it can lead to discoloration. Manganese salts may also impart an astringent taste to drinking water and cause aesthetically undesirable brown coloration in swimming pools. In this study, manganese concentrations during the rainy season (RS) ranged from 0.003 to 1.5 mg/L, with the highest value recorded at Station 4 and the lowest at Station 19. During the dry season (DS), concentrations ranged from 0 to 0.001 mg/L, with the lowest values observed at Stations 2, 3, and 5–22, and the highest at Stations 1 and 4. These results indicate higher manganese levels during the rainy season, likely due to increased surface runoff and leaching of manganese-containing minerals into water sources. The Palintest Manganese test provides a sensitive method for measuring these concentrations, which is essential for evaluating water quality and guiding manganese removal for domestic or industrial use (Figure 12).

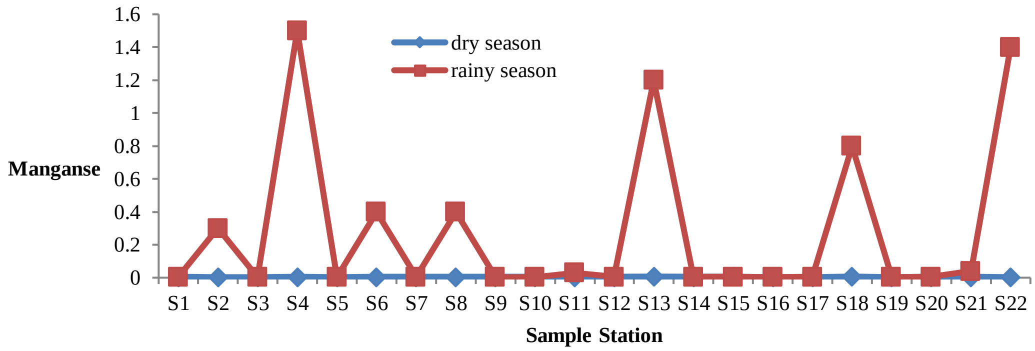

Figure 12: Manganese Variation between Dry and Rainy Seasons

3.3 Microbiological Water Quality

Total Coliforms: Total coliform counts ranged from 0–100 CFU/100 mL in RS and 0–120 CFU/100 mL in DS (Figure 13). A substantial proportion of water points exceeded the WHO guideline of 0 CFU/100 mL, indicating widespread microbial contamination. Higher counts were generally associated with open hand-dug wells, poor source protection, and proximity to human and animal activities.

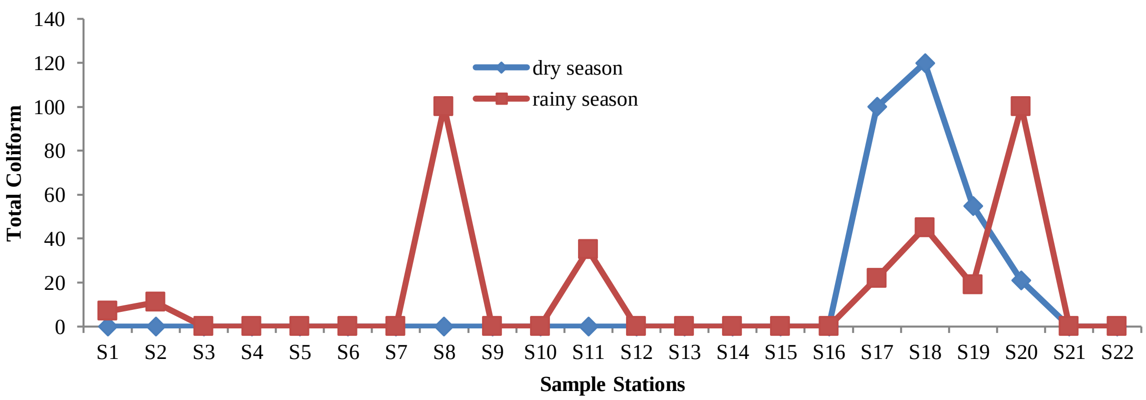

Figure 13: Total Coliform Variation between Dry and Rainy Seasons

Fecal Coliforms: Fecal coliform concentrations ranged from 0–100 CFU/100 mL in RS and 0–203 CFU/100 mL in DS (Figure 14). Significant spatial differences were observed ($p < 0.05$). Station 13 exhibited the highest contamination, likely due to nearby livestock farms and inadequate sanitation infrastructure. The presence of fecal coliforms above WHO limits confirms recent fecal contamination and represents a serious public health concern.

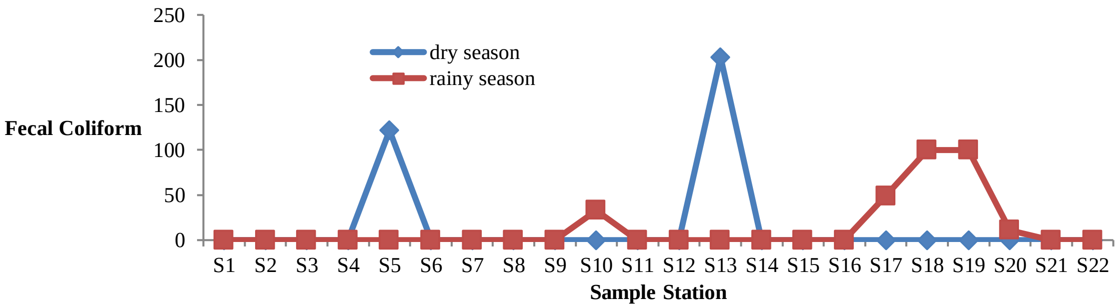

Figure 14: Fecal Coliform Variation between Dry and Rainy Seasons

3.4 Factors Influencing Water Quality

Sanitary inspections revealed that 45% of water points were affected by human activities, including washing, bathing, and livestock access. Approximately 27% lacked fencing, increasing vulnerability to contamination. More than 50% of users reported increased turbidity following heavy rainfall, indicating rapid infiltration and surface runoff effects. Although periodic chlorination was reported for some water points, inconsistent treatment, poor drainage, and lack of protective infrastructure contributed to seasonal degradation of water quality.

3.5 Implications for Water Supply Sustainability

Despite improvements in access to improved water sources under Ethiopia's Universal Access Plan, water quality and sustainability remain major challenges. Many improved sources fail to meet microbiological safety standards, underscoring the limitations of technology-based classifications without routine water quality monitoring.

Overall, physicochemical parameters generally complied with WHO guidelines, while microbiological contamination was widespread, particularly during the rainy season and in open hand-dug wells. Seasonal rainfall, source protection status, sanitation practices, and surrounding land use were the dominant factors influencing drinking water quality in Dembia District

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

This study was conducted to evaluate the physicochemical and bacteriological quality of borehole water sources in Dembia Woreda, with the overarching aim of improving public health through safer drinking water supply. The findings demonstrate that water quality in the study area exhibits clear seasonal and spatial variability, influenced by hydroclimatic conditions, source protection status, and surrounding human activities.

The physicochemical parameters, including temperature, pH, electrical conductivity, total dissolved solids, chloride, iron, manganese, and fluoride, were generally within the World Health Organization (WHO) guideline values for drinking water. These results indicate that, from a chemical perspective, most borehole water sources in Dembia are acceptable for domestic use. However, elevated turbidity levels during the rainy season at several stations suggest increased surface runoff, infiltration, and sediment transport, which may compromise aesthetic quality and indirectly affect microbial safety.

In contrast, bacteriological contamination remains a major concern. A substantial proportion of sampled water points showed detectable levels of total coliforms and fecal coliforms, with several stations exceeding the WHO guideline of zero coliforms per 100 mL for drinking water. The presence of these indicator organisms suggests potential fecal contamination and indicates that consumption of untreated water from some boreholes poses a public health risk. Seasonal increases in coliform counts during the rainy season further emphasize the vulnerability of groundwater sources to surface-derived contamination.

Although routine chlorination of water points was reported, its effectiveness appears to be undermined by design flaws, inadequate source protection, poor drainage, and unhygienic activities around water points, including livestock access, washing, bathing, and ineffective fencing. Complaints related to taste and odor may also negatively influence user acceptance, potentially leading to abandonment of improved water sources. Reports of dental fluorosis in a few communities were not supported by measured fluoride concentrations, suggesting that cumulative exposure from multiple sources or long-term intake may be responsible.

Overall, while the chemical quality of borehole water in Dembia Woreda is largely satisfactory, microbiological contamination constitutes the principal limitation to safe drinking water supply. Addressing this issue requires integrated interventions that combine source protection, improved sanitation, community awareness, and effective water safety management from the point of source to the point of use.

4.2 Recommendations

Based on the findings of this study, the following recommendations are proposed to improve drinking water safety and sustainability in Dembia Woreda and similar rural settings:

Strengthen source protection measures: All water points should be adequately protected through fencing, proper drainage systems, well-maintained concrete platforms, and controlled access to prevent contamination by animals and surface runoff. Latrines and waste disposal facilities must be located at safe distances from water sources to minimize fecal seepage into groundwater.

Promote household water treatment and safe storage (HWTS): Given the widespread presence of bacteriological contamination, household-level water treatment methods, such as boiling, chlorination, filtration, and solar disinfection, should be actively promoted. Awareness campaigns should emphasize the health risks of consuming untreated water and demonstrate correct treatment and storage practices.

Improve water handling and storage practices: Since jerry cans are widely used for water collection and storage, households should be educated on proper cleaning and maintenance of containers. Where possible, safer storage containers with narrow necks and covers should be introduced to reduce post-collection contamination. Targeting women, who are primarily responsible for water collection, in hygiene education programs is particularly critical.

Institutionalize regular water quality monitoring: Routine physicochemical and bacteriological monitoring should be established for rural water supply systems to ensure compliance with national and WHO standards. Simple field-based testing tools and sanitary inspections can serve as effective early warning mechanisms for contamination risks.

Enhance capacity of Water User Associations (WUAs): Strengthening the technical and managerial capacity of WUAs through training in operation, maintenance, source protection, and environmental sanitation is essential for sustaining water supply systems. Empowered local management structures are critical for timely repairs and long-term functionality.

Integrate sanitation and hygiene interventions: Improvements in water supply must be accompanied by enhanced sanitation and hygiene practices. Expansion and proper use of latrines, effective waste management, protection of livestock areas away from water sources, and consistent hand washing promotion are vital to reducing fecal contamination pathways.

Support evidence-based planning and reporting: Accurate reporting of water access coverage and functionality should be prioritized to guide investments and avoid overestimation of service delivery. Continuous follow-up of existing schemes is necessary to ensure sustainability and maximize health benefits.

Future research directions: Future studies should incorporate epidemiological assessments to examine spatial correlations between waterborne disease incidence and fecal indicator bacteria levels. Such integrated analyses would strengthen understanding of health impacts and support targeted public health interventions.

In conclusion, achieving safe and sustainable drinking water supply in rural Ethiopia requires a holistic approach that combines infrastructure development with water quality monitoring, sanitation improvement, community engagement, and institutional strengthening. Only through such integrated efforts can progress toward the Sustainable Development Goals be effectively realized.

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