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ORGINAL ARTICLE

Physicochemical and Microbial Quality of Drinking Water and its Health Implications in Debre Tabor Town, Ethiopia

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ABSTRACT

Getting clean and adequate drinking water is a problem in speedily increasing populations. This study was designed to evaluate the water quality of drinking water sources Debre Tabor, Ethiopia. The data was collected from 44 water samples from wells, reservoirs, taps, and household containers taking samples in two seasons. The Results showed that there is a significant contamination of the water from source to point-of-use. E. coli was detected in 78% of samples, with household containers exhibiting the highest levels of 13.3 CFU/100 mL; p<0.001, confirming severe post-source contamination. A strong positive correlation (R2 of 0.82, p<0.01) was found between E. coli concentrations and a 42% increase in waterborne disease. Multivariate analysis identified inadequate latrine coverage (31%), infrequent handwashing with soap (65% of households), and unhygienic water storage as key risk factors. The findings revealed that conventional source-focused monitoring grossly underestimates public health risk. An urgent, multi-barrier intervention strategy encompassing water safety planning at the utility level, water treatment, and community-led hygiene education to mitigate the escalating burden of waterborne disease, chlorination, and smart monitoring technologies to enhance water security is crucial. The study promotes achieving United Nations Sustainable Development Goal 6 on clean water access.

Keywords: Drinking water quality; Escherichia Coli; Post-source Contamination; Waterborne diseases

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1. Introduction

The provision of safely managed drinking water is a fundamental human right (Guinness *et al*., 2020). Although, recent reports estimate that around 2.2 billion people globally lack access to safe drinking water with the burden disproportionately affecting populations in sub-Saharan Africa (Mulat *et al*., 2022). The public health implications are severe; contaminated water is a primary source for transmitting diarrheal diseases, which remain a leading cause of mortality and morbidity, especially in children under five in low-income settings (Adugna *et al.,* 2024).The theoretical basis for ensuring the quality of drinking water has shifted from a classic source-oriented approach to acomprehensive one, which is reflected in Water Safety Plans (WSPs) (Ayaliew, 2015).This framework recognizes that protecting water at the source, while necessary, is insufficient if contamination occurs during distribution, storage, and handling a phenomenon widely documented as "post-source contamination" (Beshir *et al*., 2024a). In intermittent supply systems common in many urban areas of the Global South, negative pressure in pipes can siphon pathogens from contaminated groundwater via leaks, introducing contamination into the distribution network itself (Assegide *et al*., 2022a; Kassegne & Leta, 2020a, 2020b). Furthermore, the practice of household water storage, often in insanitary containers and with unhygienic handling practices, introduces a critical final point of contamination before consumption (Zhang *et al.,* 2022a).

In Ethiopia, the situation is particularly critical. National statistical data suggest that only 48% of the population has access to basic water services, and poor Water, Sanitation, and Hygiene (WASH) conditions are attributed to 60% of the communicable disease burden (Daba *et al.,* 2025a) . While numerous studies in Ethiopia have assessed source water quality(Lewoyehu, 2021; Lewoyehu *et al*., 2023), a systematic review by (Gadiso *et al.,* 2020a; Guzmán & Stoler, 2018a, 2018b) highlighted a pronounced scarcity of integrated "source-to-consumption" studies that track water quality along the entire chain and directly correlate it with epidemiological data. This gap leads to a systematic underestimation of health risks and results in interventions that may protect water at the source but fail to safeguard it at the point of use. Recent work in other Ethiopian towns, such as Bahir Dar (Gadiso *et al*., 2020) and the Wondo Genet area (Daba *et al.,* 2025a) has confirmed significant deterioration of water quality at the household level, suggesting a systemic national challenge. The population growth process is putting enormous stress on groundwater-dependent supply that is likely to be vulnerable to the contamination.

According to (Husein *et al.,* 2023).There are several households that used multiple water sources because of the inconsistency of supply, piped water was their preferred option but was rarely unavailable, and the suggested intervention was to improve infrastructure and focus on vulnerable groups to ensure access to water that is both equitable and reliable.

The study aimed to fill the critical knowledge gap by conducting a comprehensive, assessment of drinking water quality and linking it to public health. The objectives of this study were: (i) to assess the level of fecal indicator bacteria (E. coli, Total Coliforms), and key physicochemical parameters across different components of the water supply chain, identify seasonal variations and critical points of quality deterioration; (ii) analyze the relationship between the magnitude of microbial contamination.

2. Materials and methods

2.1 Description of the study area

The population data for Debre Tabor was obtained from the Central Statistical Agency of Ethiopia (CSA) and the Debre Tabor Town Municipality Planning Office. According to the CSA 2007 census projection and updated municipal records, the estimated population of Debre Tabor (the year of our field survey) was approximately 92,000 residents. According to the Central Statistical Agency of Ethiopia (CSA, 2007 census projection), the average household size in Debre Tabor town is approximately 4.5 persons per household.

Debre Tabor town is found in the South Gondar Zone of the Amhara National Regional State of Ethiopia, about 100 kilometers from the regional town (Bahir Dar). The town is found between 11º 47’ 00” and 11º 54’ 30” N latitude, and 37 º 57’ 00” to 38 º 05’ 00” E longitude at a mean elevation of 2706 m.a.s.l. The mean annual rainfall of the study area is about 1553.7 mm, and the main rainy season is from June to September, with a maximum occurring in July or August. The average annual temperature of the town is *15ºC*. Based on the 2007 national census conducted by the Central Statistical Agency (*CSA*), the projected population figure for the year 2012 is 68,318, of whom 33,969 are males and 34,349 are females.

The source of water supply for the town is mostly from groundwater sources, and the potable water supply coverage of the town is about 60 percent. The town gets water from ten wells of Kanat (#1, #2, #3, and #4), Ajibar, Melo, Shihana, Gafat, Sebaradildiy, and Eslambet. There are also five new storage reservoirs having a capacity of storing 960 m^3 of water (*Figure 1*).

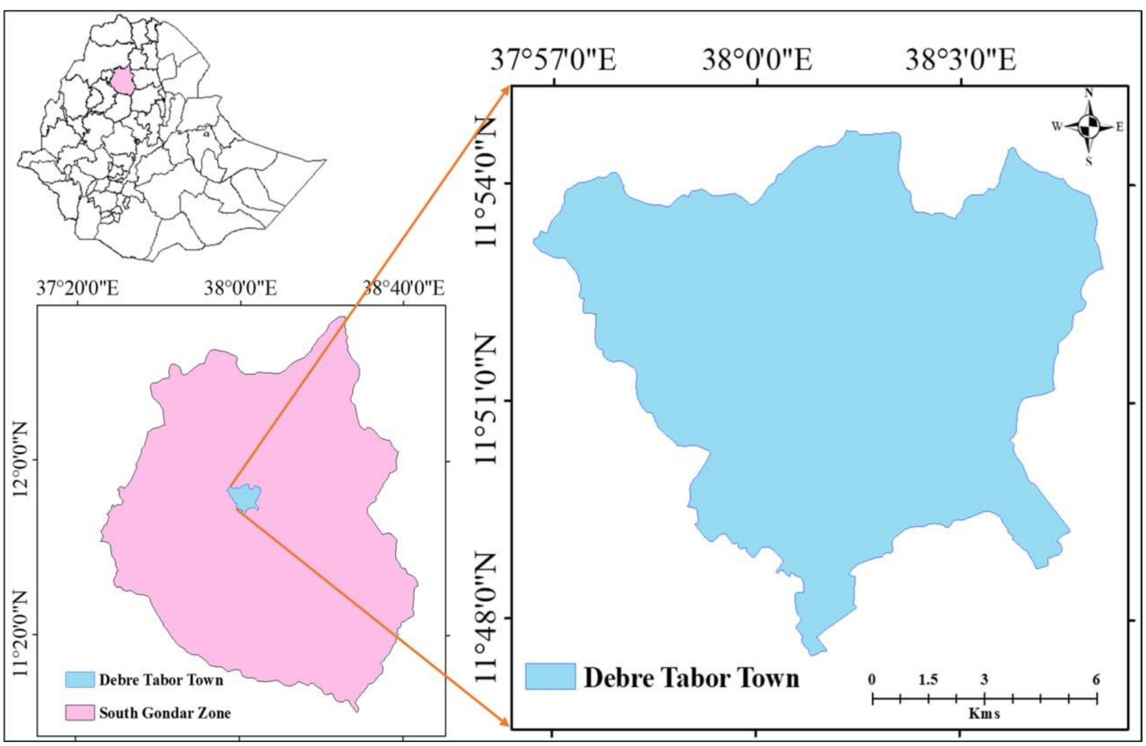

Figure 1. Study area: DebreTabor Town

2.2 Data collection and sampling procedures

This study utilized a repeated cross-sectional environmental monitoring design paired with a retrospective epidemiological analysis to evaluate drinking water safety from source to point-of-use (POU). The environmental assessment comprised targeted water quality sampling repeated across two distinct hydrologic seasons: the rainy season (July 2017) and the dry season (January 2018). This cross-sectional tracking was augmented by a 10-year retrospective analysis of health surveillance records (2015–2025) obtained from Debre Tabor municipal health centers. To ensure absolute methodological clarity, water sampled at the final consumer tier is uniformly referred to as point-of-use (POU) water throughout this text, avoiding interchangeable or ambiguous terminology.

All sampling protocols strictly followed standard methods for the examination of water and wastewater samples collection (Berhe, 2020a, 2020b; Husein *et al.,* 2023) . Samples were collected in sterile, pre-labeled containers. Samples for microbial analysis were placed in an icebox with cold accumulators and transported to the Amhara Water Works Design and Supervision Enterprise laboratory within 6 to 9 hours of collection. Microbiological analyses were initiated within 24 hours (WHO *et al.,* 2022).

The water quality sample size ($n = 44$ unique nodes per season, resulting in a total pool of $n = 88$samples) was determined using a non-probabilistic, system-wide census approach combined with representative physical node clustering. Because the municipal infrastructure comprises a finite number of active production elements, sampling all operational municipal wells ($n = 7$) and storage reservoirs ($n = 7$) constituted a total baseline universe census. The pairing of 15 network distribution taps with 15 statistically independent household POU storage containers provided a confidence level capable of identifying significant water quality deterioration down the supply chain while operating within the logistical, transport, and strict cold-chain laboratory processing time constraints (6 to 9 hours) required for accurate microbial analysis

2.2.1 Microbiological parameters

E. coli and Total Coliforms were analyzed as definitive indicators of fecal contamination. The Membrane Filtration (*MF*) method (Beshir *et al*., 2024b) was the primary method used, with samples filtered through 0.45 µm membranes and incubated on Selective *MI* Agar at 35°C for 24 hours. For highly turbid samples Multi-Tube Fermentation Most Probable Number (*MPN*) method was employed as a validated alternative. The use of both methods ensured analytical accuracy across a wide range of water qualities. Results were reported in Colony Forming Units (*CFU* 100 mL^{-1}) or *MPN* mL^{-}, respectively (Assegide *et al*., 2022d; Gundry *et al*., 2004; Guzmán & Stoler, 2018; Zhang *et al.,* 2022).

2.2.2 Physicochemical parameters

Systematic, sampling technique was used across the municipal water distribution network to ensure spatial and hydraulic representativeness in Debre Tabor’s six administrative (kebeles). purposive sampling was applied to all functional municipal water sources ($n = 7$) and primary distribution reservoirs ($n = 7$). stratified systematic approach was used to select the 15 network distribution taps ($n = 15$) and their 15 corresponding household point-of-use (POU) endpoints ($n = 15$). Taps were selected proportionally based on the population density of each *kebele* and were spatially distributed across distinct hydraulic pressure zones (upper, middle, and lower gravitational zones) to capture water age, pressure fluctuations, and potential localized pathogen ingress caused by negative pipe pressure during intermittent supply cycles.

Temperature, *pH*, Electrical Conductivity (*EC*), and Total Dissolved Solids (*TDS*) were measured on-site using calibrated multi-parameter meters (Hanna Instruments, HI98194). Turbidity was measured using a portable turbidimeter (Hach 2100P). Major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, NO_3^{-}, F^{-}) were analyzed using Ion Chromatography and Flame Atomic Absorption Spectrometry (Leggesse *et al.,* 2024; Zhang *et al.,* 2022a). All analytical procedures were conducted by trained personnel, and quality control measures, including calibration with standards and reagent blanks, were implemented(WHO *et al.,* 2022).

A cross-sectional study design, augmented by longitudinal water sampling across two seasons (rainy: July 2017; dry: January 2018) and analysis of ten-year retrospective health data (2015–2025), was employed. A stratified multi-stage sampling strategy was implemented to ensure representativeness across the municipal water supply chain. The sampling was conducted as the entire municipal water supply system, from source to point-of-use (*Figure 2*). The figure shows the location of sampling points at groundwater sources (wells), Distribution systems, storage reservoirs, Household water containers, and public tap sampling points around Debre Tabor Town.

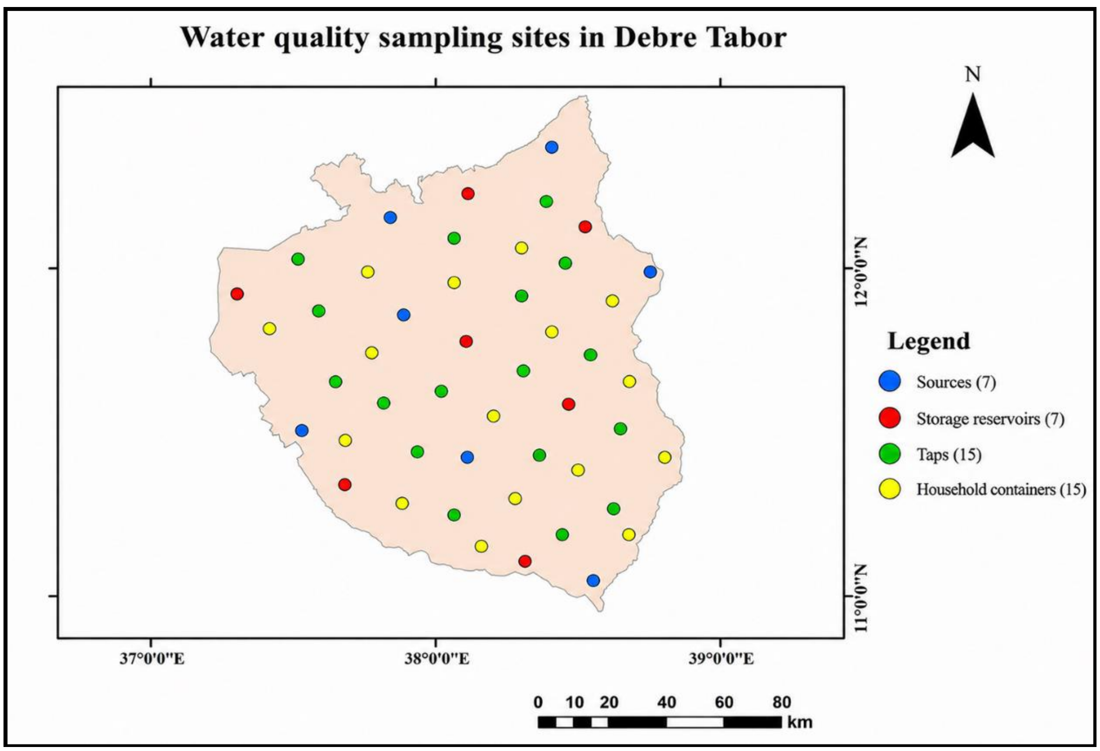

Figure 2. Water quality sampling sites: Debre Tabor Town and near

2.2.3 Household survey and health risk data

A pre-tested, structured questionnaire was administered to the heads of 165randomly selected households (separate from the 15 households in the water quality sampling) to assess socio-behavioral risk factors. Demographics (household size, education, occupation), Water collection, storage practices, and container hygiene (type, covering, cleaning frequency), sanitation (latrine type, availability, and condition), and hygiene behaviors (handwashing practices with soap after defecation and before handling food/water).The sample size was calculated using the single population proportion formula with a 95% confidence level ($Z = 1.96$), a margin of error ($d = 0.08$), a presumed prevalence ($P = 0.5$) for maximum variability, and a 10% non-response contingency, resulting in 165 households. The sample size was determined using the population proportion formula (S. Muhammad et al., 2011):

$$n = \frac{(Z\alpha/2)^2 * P(1-P)}{d^2} \dots\dots\dots\dots\dots\dots\dots\dots eq.1$$

Applying these parameters yielded a required sample size of **165 households**, which ensures that the survey results are representative of socio-behavioral and infrastructural risk factors in Debre Tabor town. Importantly, these 165 households were statistically independent from the 15 households sampled for point-of-use (POU) water quality, thereby minimizing observer bias and avoiding overlap between behavioral survey data and microbial water quality testing.

10% non-respondent rate was added during calculation. Respondents were drawn from all six sub-divisions (kebeles) of Debre Tabor town, ensuring a proportionate representation from each kebele based on population size. Purposive sampling was used to select representative households, with one adult member (aged 18 years or older) from each selected household participating in the interview. The questionnaire covered socio-demographic data, drinking water supply sources, water storage methods, existence and usage of latrines, waste and animal management practices, perceived health problems related to water consumption, and awareness levels regarding water hygiene.

2.2.4 Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs)

The Key informants were, local water utility staff, health officers, community leaders, and local administration representatives. The interview was made aiming to gather expert opinions on water management challenges, public health issues, and existing sanitation infrastructure.

2.2. 5 Field Observations

Research teams were conducting field observation, field visit and repeatedly checking the hygienic status and overall water quality assessment in the water sources, water supply points, households survey and distribution systems for the sake of cross checking the result with the laboratory test.

2.3 Data analysis

SPSS (v.28.0) and R (v.4.2.1) were used for data analysis. Descriptive statistics (mean, standard deviation, min, max) were computed for all parameters. One-way Variance (*ANOVA*) with post-hoc Tukey *HSD* tests was used to compare mean water quality results (Source, Reservoir, Tap, Household). A paired t-test was used to assess seasonal differences (dry vs. rainy) for each parameter. Pearson's correlation analysis was performed to examine the relationship between the mean annual *E. coli* counts (averaged across all sampling points per year) and the annual incidence of waterborne diseases. Statistical significance was set at $p < 0.05$.

3. Results

3.1 Water quality Detection

The water quality result of this study showed that microbial quality was detected and it highly affected the community health (*Table1),* indicating that the potential risk of water quality to the community. On the other hand ,the groundwater sources meet acceptable physicochemical standards; however, several wells show signs of quality deterioration. Elevated turbidity, iron, and hardness levels in some sources suggest inadequate source protection and possible influence of local geology or surface runoff around the wells. The detection of *E. coli* and total coliforms in certain wells confirms intermittent fecal contamination, likely due to poor sanitary conditions around wellheads or seepage from nearby latrines. The results revealed that although the sources are chemically suitable for drinking, microbial contamination and excess iron levels pose a risk, emphasizing the need for better well protection, regular disinfection, and monitoring at the source level.

Table 1. Mean physico-chemical and microbial water quality of water sources (*n=7*)

Parameter	Unit	W1	W2	W3	W4	W5	W6	W7
Temperature	°C	10.9	21.6	20.6	9.0	14.1	11.9	10
Turbidity	NTU	1.3	12.3	10.5	3.3	5.33	10	10
pH	-	6.5	7.5	6.5	6.7	6.7	8.5	6.7
EC	µS/cm	153	157.6	156	143	151	153.	153.7
TDS	mg L^{-1}	994	984	994	794	994	994	974.5
Total Hardness	mg L^{-1}	250	250	250	600	250	356	256
E. coli	CFU100 mL^{-1}	1	0	0	5	4	0	0
Total Coliform	CFU100 mL^{-1}	6	0	0	4	12	8	11
Calcium (Ca)	mg L^{-1}	200	300	201	200	100	200	216.5
Magnesium (Mg)	mg L^{-1}	3.5	2.5	3.90	3.5	5.0	3.50	1.5
Sodium (Na)	mg L^{-1}	8.85	7.85	8.05	7.85	3.85	8.8	6.8
Potassium (K)	mg L^{-1}	3.5	5.5	3.5	3.5	3.5	3.5	3.3
Sulfate (SO_4)	mg L^{-1}	5.8	10	9	5	5.8	7	5.8
Fluoride (F)	mg L^{-1}	0.6	0.7	0.1	0.3	0.6	0.7	0.6
Chloride (Cl)	mg L^{-1}	14.5	20	14.5	10.5	14.5	14.5	14.5
Phosphate (PO_4)	mg L^{-1}	0.5	0.5	0.1	0.1	0.1	0.1	0.1
Nitrate (NO_3)	mg L^{-1}	0.1	0.1	1.3	4.3	1.4	5	4.2
Iron (Fe)	mg L^{-1}	6.3	6.3	0	2	2	10	10
Parameters exceeding limits	-	4	3	2	4	5	5	5

Table 2 showed that the reservoir water quality was generally good, with most physicochemical parameters within acceptable limits and adequate residual chlorine maintained, indicating effective treatment at the storage level. However, the occasional detection of *E. coli* and total coliforms in some reservoirs reveals minor microbial contamination, possibly from inadequate reservoir sealing, poor maintenance, or contamination during water transfer. The slight turbidity variations and a few parameters exceeding standards suggest localized management issues. The reservoirs act as a relatively well-controlled point in the system but still require improved sanitary protection and regular cleaning to prevent recontamination before distribution.

Table 2. Mean physico-chemical and microbial water quality at reservoirs (*n=7*)

Parameter	Unit	R1	R2	R3	R4	R5	R6	R7
Temperature	°C	14	21.5	15	14.9	19	14.8	12
Turbidity	NTU	1 2	2.7	3.5	2	2.5	3.0	7
pH	-	7.9	7.1	6.9	7.50	-	7.4	6.7
FCR	mg L^{-1}	0.7	0.7	0.7	0.6	0.6	0.5	0.7
E. coli	CFU 100 mL^{-1}	1	0	0	1	1	2	1
Total Coliform	CFU 100 mL^{-1}	0	1	0	1	1	0	7
Parameters exceeding limits	-	1	1	0	2	3	1	3

In the study area, the tap water quality met acceptable physicochemical standards, but microbial contamination and inconsistent disinfection (Table 3). There was low free chlorine residual and detectable E. coli and total coliform counts suggest a pathogen distribution system, likely through pipeline leaks or backflow during intermittent supply. Elevated *TDS* levels in some samples also point to possible mineral intrusion or aging infrastructure. The results imply that the water distribution network itself contributes to contamination, highlighting the need for continuous chlorination monitoring and maintenance of the supply system to ensure safe drinking water at the tap.

Table 3**.** Mean physico-chemical and microbial quality of tap water samples (*n=15*)

Parameter	Unit	Mean	Min	Max	Std Dev
Temperature	°C	12.42	8.0	19.4	3.45
Turbidity	NTU	2.52	0.3	10	2.67
pH	-	7.18	6.20	9	1.78
FCR	mg L^{-1}	0.18	0.0	0.4	0.12
E. coli	CFU 100 mL^{-1}	4.13	0.0	12	3.45
Total Coliform	CFU 100 mL^{-1}	6.27	1.0	16	4.12
EC	ms/cm	682.47	456.5	900	138.2
TDS	mg L^{-1}	1073.16	234	5345	1187.5
Parameters exceeding limits	-	3.73	2	5	0.96

Table 4 shows that the mean physico-chemical quality of household water was in the acceptable limit. however, the microbial indicator showed that there exists indication of bacterial count. This demonstrates that the main threat to drinking water safety in Debre Tabor Town arises not from the supply system itself but from post-source contamination at the household level, underscoring the urgent need for improved hygiene practices and point-of-use water treatment.

Table 4. Mean physico-chemical and microbial qualities at household containers (*n=15*)

Parameter	Unit	Mean	Min.	Max.	Std. Dev.
Temperature	°C	20.13	15.40	23.90	1.9
Turbidity	NTU	0.89	0.20	3.40	1
pH	-	7.78	6.59	8.50	0.6

FCR	mg L^{-1}	0.00	0.00	0.00	0.0
E. coli	CFU 100 mL^{-1}	13.27	1.00	24.00	6.89
EC	µs/cm	851.13	678.00	1000.00	109.5
TDS	mg L^{-1}	498.73	345.00	760.00	133.1
Parameters exceeding limits	-	3	3	3	0

Table 5 indicates that there was relationship b/n the physicochemical indicators and bacterial indicators that require attention. Strong positive correlations were observed between *EC* and *TDS* (0.88), SO_4 and *K* (0.80), and pH and Fe (0.64), indicating linked chemical behaviors in the water. Conversely, strong negative correlations included *TDS* and total hardness (-0.94), *EC* and total hardness (-0.89), E. coli and *EC* (-0.86), and Na and chloride (-0.99), suggesting that certain chemical conditions may influence microbial presence or reflect specific geochemical processes. These findings revealed the interconnected nature of physicochemical and bacteriological parameters and underscore the importance of monitoring multiple indicators to ensure safe and reliable drinking water.

Table 5. Paired samples correlations of physicochemical and bacteriological indicators

	Temp	Turb.	PH	EC	TDS	Total hardness	E. coli	Total Coliform	Ca	Mg	Na	K	SO_4	Fluoride	Chloride	PO_4	NO_3	Fe
Temp	1																	
Turb.	0.09	1.00																
PH	0.46	0.58	1.00															
EC	0.35	0.67	0.56	1.00														
TDS	0.62	0.40	0.59	0.88	1.00													
Total hardness	-0.54	-0.37	-0.35	-0.89	-0.94	1.00												
E. coli	0.03	-0.67	-0.61	-0.86	-0.70	0.64	1.00											
Total Coliform	0.39	-0.28	0.07	-0.24	0.15	-0.10	0.25	1.00										
Ca	-0.48	0.51	0.27	0.40	-0.03	-0.02	-0.57	-0.66	1.00									
Mg	0.57	-0.43	-0.13	-0.26	0.03	0.07	0.53	0.08	-0.73	1.00								
Na	-0.61	0.07	0.23	0.11	-0.09	0.21	-0.49	-0.57	0.65	-0.39	1.00							
K	0.12	0.48	0.32	0.45	0.11	-0.19	-0.26	-0.57	0.73	-0.29	0.12	1.00						
SO_4	0.15	0.75	0.44	0.75	0.42	-0.43	-0.60	-0.72	0.65	-0.17	0.24	0.80	1.00					
Fluoride	0.48	0.04	0.60	0.24	0.40	-0.33	-0.20	0.53	0.08	-0.25	-0.14	0.26	-0.06	1.00				
Chloride	-0.19	-0.54	-0.40	-0.57	-0.25	0.33	0.37	0.50	-0.72	0.34	-0.09	-0.99	-0.82	-0.34	1.00			
PO_4	0.06	-0.19	0.15	0.32	0.21	-0.29	-0.23	-0.28	0.51	-0.23	0.32	0.60	0.30	0.49	-0.62	1.00		
NO_3	-0.49	-0.01	-0.08	-0.65	-0.62	0.72	0.28	0.34	-0.10	-0.28	0.08	-0.46	-0.55	-0.10	0.51	-0.62	1.00	
Fe	-0.04	0.27	0.64	0.27	0.30	-0.19	-0.54	0.39	0.36	-0.67	0.31	0.07	-0.06	0.76	-0.16	0.26	0.27	1.00

According to Table 6, there is the existence of E. coli and Total coliforms throughout the sampling sites, surpassing WHO and Ethiopian guidelines, indicating fecal contamination throughout the whole water chain process and accounting for the 42% increment in water-borne diseases. The highest level of contamination was observed in household storage tanks (E. coli: 13.3 CFU 100 mL^{-1}), which demonstrates that post-source contamination poses a great health hazard, thus posing challenges in source-based monitoring. Source turbidity (7.4 NTU) implies that the water source lacks proper cover against runoffs and is not effectively disinfected, whereas the higher levels of iron (6.6 mgL^{-1}) indicate geological leaching or pipe corrosion.

Table 6. Comparing means of water quality between samples.

Parameter	Unit	WHO Standard	Ethiopian Standard	Sources (*n*=7)	Reservoirs (*n*=7)	taps (*n*=*15*)	Containers (*n*=*15*)	*ANOVA* (p-value)
Temperature	°C	–	–	12.5 ± 4.2	16.2 ± 3.8	12.4 ± 3.5	20.1 ± 1.9	<0.001
Turbidity	NTU	≤5	≤5	7.4 ± 3.9*†	3.1 ± 2.1	2.5 ± 2.7	0.9 ± 1.0	<0.001
pH	–	6.5–8.5	6.5–8.5	7 ± 0.8	7.3 ± 0.5	7.2 ± 1.8	7.8 ± 0.6	0.312 (*NS*)
E. coli	CFU 100 mL^{-1}	0		1.4 ± 2.1*†	0.7 ± 0.8*†	4.1 ± 3.5*†	13.3 ± 6.9*†	<0.001
Total Coliforms	CFU 100 mL^{-1}	0	0	6.3 ± 4.5*†	1.4 ± 2.6*†	6.3 ± 4.1*†	15.2 ± 7.3*†	<0.001
TDS	mg L^{-1}	≤1000	≤1000	928.6 ± 85.2	–	1073.2 ± 1187.5†	498.7 ± 133.1	0.001
Iron (Fe)	mg L^{-1}	≤0.3	≤0.3	6.6 ± 3.5*†	–	–	–	–
Nitrate (NO_3^-)	mg L^{-1}	≤50	≤50	2.3 ± 2.1	–	–	–	–
Fluoride (F^-)	mg L^{-1}	≤1.5	≤3.0	0.5 ± 0.2	–			

* Above WHO recommendation; † Above Ethiopian Standard; NS: Not Significant ($p \geq 0.05$); -: Not available.

3.2 Health Risk Assessment Findings

3.2.1 Community Perceptions and Field Observations

Health risk assessment, incorporating the views of the community, field findings, and health center data, was highly correlated with the laboratory results for water quality. The household survey (n=165), which included qualitative interviews, highlighted many activities that have an impact on the water quality and public health.

3.2.2 Water Access and Storage

Although many houses have access to piped water sources, there was some apprehension about the reliability of this source as well as the cleanliness of the public taps where people can access their water from. Many households had issues with storage of water in dirty or unclean containers.

3.2.3 Sanitation and Hygiene Practices

Observations in the field revealed widespread improper sanitation behaviors in relation to sources of water and public taps, with the presence of waste materials and locations near defecation sites. A sizable number of households (figures from original Table 5 need to be included here, e.g., "X% of the people interviewed lacked adequate latrines") engaged in poor hygiene habits, which include poor management of human and animal wastes. It was clear from the qualitative findings that there is a lack of understanding of the relationship between these behaviors and disease causation via contaminated water. This is exemplified by the fact that community members attributed sicknesses to "bad water," rather than their behaviors.

3.2.4 Perceived Health Problems

Members of the community consistently indicated high prevalence rates of diarrheal diseases, gastroenteritis, and other related stomach diseases, mainly among the younger generation, as a result of poor quality of water. This was in line with the health data obtained through the survey. Just 35% of the respondents stated that they regularly washed hands with soap after defecation or before handling any food or water. About 45% of the surveyed people had wide-mouth and uncovered water containers and 31% of them cleaned their containers less than once a week. Health center data analysis indicated an average increase rate of 42% of acute cases of diarrhea and gastroenteritis from 2015 to 2025. Through Pearson correlation test, there was found to be a very high positive relationship between the annual average E. coli bacteria in the water system and the annual incidence of waterborne diseases (R2 = 0.82, $p < 0.01$). From health data analysis of Debre Tabor town health centers (2015-2025), there is a trend of increased cases of waterborne diseases.

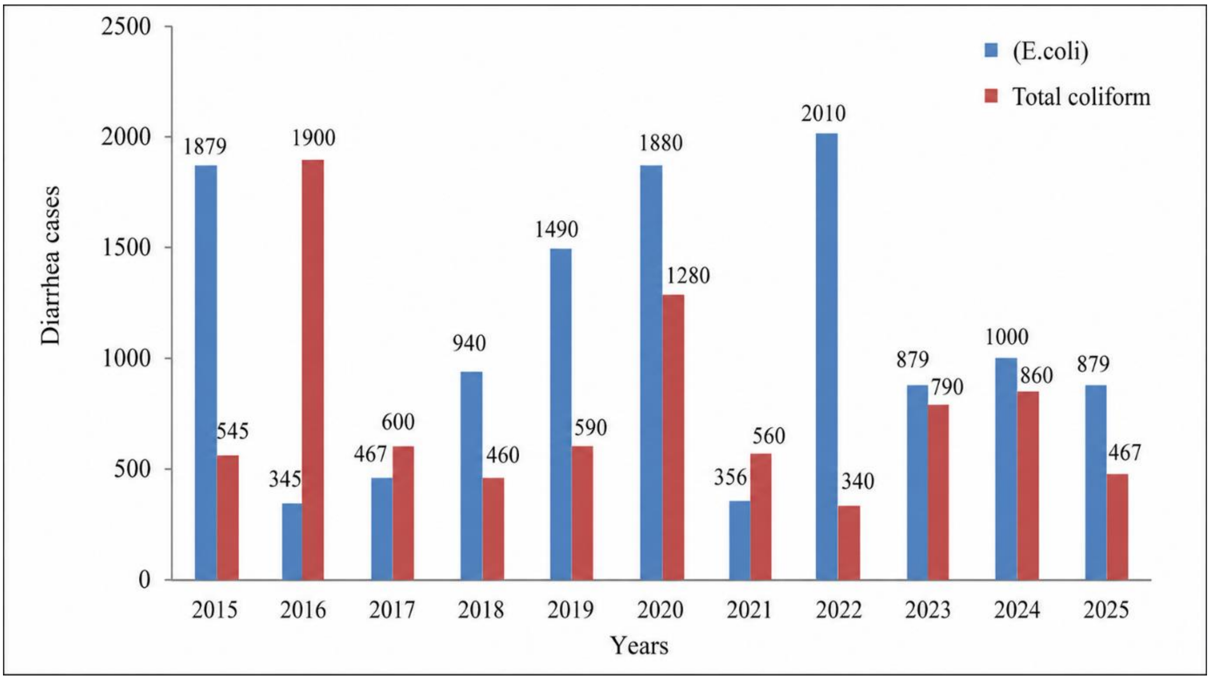

Figure 3. Annual cases of Diarrhea (2015 to 2025) in Debre Tabor Town

As seen from the data, there is a serious public health hazard resulting from microbial contamination of the water resources that is due to poor hygiene and sanitation and also due to the increasing occurrence of water-borne diseases in Debre Tabor (Fig. 3). Although most of the physicochemical parameters were well within the limit, the presence of high turbidity levels adds to the hazard.

Table 7: Comparison of Water Quality Parameters at Sampling Sites Against WHO and Ethiopian Standards

Parameter	Unit	WHO Guideline	Ethiopian Standard	Sources (n=7)	Reservoirs (n=7)	Taps (n=15)	Household Containers (n=15)	ANOVA (p-value)
Temperature	°C	–	–	12.5 ± 4.2	16.2 ± 3.8	12.4 ± 3.5	20.1 ± 1.9	<0.001
Turbidity	NTU	≤5	≤5	7.4 ± 3.9*†	3.1 ± 2.1	2.5 ± 2.7	0.9 ± 1.0	<0.001
pH	–	6.5–8.5	6.5–8.5	7.0 ± 0.8	7.3 ± 0.5	7.2 ± 1.8	7.8 ± 0.6	0.312 (NS)
E. coli	CFU/100mL	0	0	1.4 ± 2.1*†	0.7 ± 0.8*†	4.1 ± 3.5*†	13.3 ± 6.9*†	<0.001
Total Coliforms	CFU/100mL	0	0	6.3 ± 4.5*†	1.4 ± 2.6*†	6.3 ± 4.1*†	15.2 ± 7.3*†	<0.001
TDS	mg/L	≤1000	≤1000	928.6 ± 85.2	–	1073.2 ± 1187.5†	498.7 ± 133.1	0.001
Iron (Fe)	mg/L	≤0.3	≤0.3	6.6 ± 3.5*†	–	–	–	–
Nitrate (NO_3^-)	mg/L	≤50	≤50	2.3 ± 2.1	–	–	–	–
Fluoride (F^-)	mg/L	≤1.5	≤3.0	0.5 ± 0.2	–			

Symbols and Notes Symbols and Notes: *Excessively above WHO guideline, †Excessively above Ethiopian guideline,NS: Not significant (p ≥ 0.05), –: Not measured or no

The detection of E. coli and Total Coliforms in all sampling points (above WHO standards and Ethiopian standards) proves the contamination of the water with feces throughout the chain. This has been clearly shown through the increase of water-borne diseases by 42% in health centers. The highest concentration of contaminants was noted in the household storage (E. coli at 13.3 CFU/100mL) and this shows that post-source contamination is the cause of health risks. This defies the existing monitoring system based on source quality alone. Turbidity Excess (7.4 NTU in sources): Indicates poor protection of the source against run-off, particularly in rainy season. High turbidity makes water difficult to disinfect (challenged by chlorine). Iron Level (6.6 mg/L in sources): Above the aesthetic limit of 0.3 mg/L, indicating pipe corrosion or geological leaching.

3.3 ANOVA Test Results Summary

Table 8: ANOVA Test Results Summary

Parameter	F-value	p-value	Significance	Key Findings
Temperature (°C)	25.67	<0.001	***	Highest in household containers (20.13°C)
Turbidity (NTU)	8.92	<0.001	***	Highest in water sources (7.40 NTU)
pH	1.23	0.312	NS	No significant differences
E. coli (/100mL)	12.45	<0.001	***	Highest in household containers (13.27)
Total Coliform (/100mL)	9.87	<0.001	***	Highest at the point of consumption in household containers (15.2 ± 7.3 CFU/100mL), indicating significant post-source contamination ($p < 0.05$); tap water mean was 6.3 CFU/100mL
Parameters Exceeding Limits	6.54	0.001	**	Most in water sources & taps

***(p < 0.001) Highly significant, **(p < 0.01) Very significant, NS = Not significant

From the results from the ANOVA test (Table 8), it can be seen that there were significant differences in the counts of Total Coliforms for different sample sites ($p<0.05$). The average level at the public tap was 6.3 CFU/100mL, while the highest levels of significance were at the point of use of the water in households with levels at 15.2±7.3 CFU/100mL (Table 7).

4. Discussions

In this complete assessment, an upward trend in the degree of microbial contamination from the source to storage within households is clearly evident. Turbidity was noted as one of the important factors since some of its levels occasionally reached 7 NTU, which exceeds the 5 NTU maximum as recommended by the WHO. It was found out that most of the time the turbidity level increases due to storm conditions or particulate loading possibly brought about by catchment runoff. This has been observed before in other rural water systems.(Kassegne & Leta, 2020a).

This thorough analysis demonstrates a marked rise in microbial contamination between water sources and house storage tanks. It was established that turbidity is an important parameter for the water quality, sometimes getting up to 7 NTU and surpassing the WHO threshold value of 5 NTU. We have noted that high levels of turbidity were mostly recorded during rainfall or particulates influx, due to runoff water from the catchment area or suspension of sediments. There is evidence that similar trends have been recorded elsewhere, especially in rural areas. (Kassegne & Leta, 2020b, 2020c, 2020a).

The heterotrophic plate count was marginally high in the distal taps, corresponding to low levels of free chlorine residuals (0.1-0.2 mg/L). (Bain *et al.,* 2021). This inverse relationship between residual chlorine and bacterial growth is widely documented: chlorine decay, long water retention times, and biofilm development in pipes facilitate microbial regrowth (Andualem *et al.,* 2019; Schmidt *et al.,* 2025). Comparable observations in Ethiopian towns such as Adama, Bahir Dar, and Wondo Genet show that intermittent water supply, pipeline leakage, and inadequate residual chlorine contribute significantly to post-source contamination (Beshir *et al.,* 2024; Shferaw *et al.,* 2024a).

The household behaviour in Debre Tabor in the use of wider mouthed receptacles and less frequent washing of these further aggravates the risks associated with the presence of microbes, an observation that has been seen before in Ghana and India. Taken together, these findings clearly show that managing water quality should not be limited to the treatment plant.(Shferaw *et al.,* 2024a). E. coli detection at some public taps, despite adequate chlorination at reservoirs, suggests pathogen ingress due to aging pipelines, intermittent supply, and network leaks. Intermittent flows can generate negative pressures, drawing contaminated water into the system, while biofilms in pipes protect microbes from disinfection (Bain *et al.,* 2021; Y. Zhang *et al.,* 2019). Studies in Ankober and Adama similarly report that leakage, irregular chlorination, and hydraulic disruptions are major contributors to microbial contamination in distribution networks(Andualem *et al*., 2019; Beshir *et al*., 2024) *(Assegide et al., 2022c; Shferaw et al.*, 2024a). These findings underscore that the distribution network is often the weakest link in water safety, particularly in low and middle-income countries, where energy shortages and maintenance delays are common (Daba *et al*., 2025b).

Chemical variables for the Debre Tabor town water supply system have been measured within the acceptable range. The pH value of ~7.2 is favorable for chlorine treatment and protects against corrosion and formation of disinfectant by-products. Nitrate concentrations of 5–10 mg/L are far below the WHO recommended value and suggest that there is no effect of agriculture on water quality. Iron and manganese concentrations of less than 0.1 mg/L are due to natural groundwater and pipe leaching. (Adugna *et al.,* 2024b).

A strong correlation between E. coli levels and reported waterborne disease incidence *(R^2 = 0.82, p < 0.01)* indicates that contamination along the supply chain translates directly into health risks. National analyses suggest that over half of diarrheal cases in Ethiopia result from unsafe household water (Tamiru *et al.,* 2022). The observed 42% increase in diarrheal and gastroenteritis cases in Debre Tabor between 2015 and 2025 reflects the combined influence of environmental and behavioural factors. According to (Gadiso *et al.,* 2020b), microbial-risk guidelines, the measured bacterial concentrations correspond to a high probability of infection from common enteric pathogens, highlighting the urgency of multi-barrier risk management extending beyond water treatment to household-level hygiene interventions.

Comparisons with regional and global studies further contextualize these findings. Research in Kenya (Wambui *et al.,* 2025) Ghana (Schmidt *et al.,* 2025) and Ethiopia (Adugna *et al.,* 2024c) demonstrates that improvements at the source or treatment stage alone are insufficient to guarantee safe drinking water. (Shiferaw *et al.,* 2024b) reported that monitoring programs focused only on water sources can underestimate microbial risk by up to 70%. By integrating field measurements with ten years of health data, this study provides a temporally grounded perspective that adds significant value to the existing Ethiopian literature. Iron concentrations above 6 mg/L can accelerate pipe corrosion, which encourages microbial colonization—a mechanism observed in Lake Tana catchments (Tekile & Legesse, 2023). This demonstrates that both natural and anthropogenic factors interact to influence water safety, highlighting the need for holistic management approaches.

Debre Tabor had a 42% increase in cases of diarrhea, which could be attributed to environmental and household activities. This shows that improving the source is not enough and that there is a need for multibarrier approach that will involve treatment, delivery and hygiene education. Household practices like point-of-use chlorination, solar disinfection and filtration are other ways of reducing contamination. (Wambui *et al*., 2025).

5. Conclusions

Water quality of the town of Debre tabor is greatly influenced by the presence of contaminants in the sources of water to household level. The finding of E. coli in public tap water and household water storage signifies the ongoing presence of fecal contamination posing a serious health risk to the population.

While most physiochemical measurements fell within acceptable ranges, the elevated turbidity values in some samples, especially during the rainy season, may be an indication of the presence of suspended particles and inefficiency in the process of disinfection. Laboratory results of microbial presence in the water are strongly corroborated by the community perception of water-borne diseases and the increased number of diseases like stomach flu and diarrhea that have been reported in local clinics.

The research further discovered that unsanitary behavior like open defecation and poor waste disposal, along with inadequate community campaigns and limited capacity within institutions, are critical factors contributing to water pollution and occurrence of waterborne diseases. It has been conclusively proven from the research results that the community of Debre Tabor is highly vulnerable to waterborne diseases due to poor water quality.

In summary, this comprehensive assessment highlights the existence of a serious public health challenge for Debre Tabor owing to high levels of contamination of its drinking water sources by various pathogens as a result of insufficient infrastructure and lack of hygiene among the community members. The link between the two variables clearly supports the existence of a health challenge.

6. Recommendations

- There should be immediate and urgent need to take measures on how to protect water sources from contamination (entry of fecal and surface runoff).
- Regulatory work on inspections and repairs of the existing water distribution system is crucial to identify and seal leakages, prevent cross-contamination, and ensure pipe integrity.
- Water quality test should be conducted regular and treatment measures has to be timely added to reduce bacterial contamination of water. testing for both microbial (E. coli, Total Coliforms) and key physicochemical parameters (e.g., turbidity, residual chlorine) at all points of the supply chain, with timely reporting and corrective action mechanisms.
- Public health movements to increase community awareness on the importance of safe water handling, storage, and household water treatment.
- Increase collaboration between water authorities, health bureaus, and education sectors to implement integrated WASH programs that address water supply, sanitation, and hygiene parallelly.
- Conduct follow-up studies to identify specific pathogenic microorganisms present in contaminated water, perform evaluate the long-term impact of implemented strategies on water quality and public health.

Authors' contributions

Mulatu Kassa Gedamu: Conceptualization, Methodology, Investigation, Formal Analysis, writing – Original Draft, Project Administration, **Tesfa Gebrie Andualem**: Investigation, Formal Analysis, Data Curation, writing – Original Draft, Visualization. **Girum Getachew Demeke**: Investigation, Resources, Visualization, Writing – Review & Editing. **Dessale Wassie Gebrie**: Formal Analysis, Validation, Data Curation, Writing – Original Draft. **Mengesha Tesfaw Abay:** Supervision, Validation, Methodology, Writing – Review & Editing.

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Availability of data and materials: The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

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***Informed consent statement*:** Informed consent was obtained from all participants involved in the study.

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