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Research Paper

Overall performance evaluation of an urban water supply system: a case study of Debre Tabor Town in Ethiopia

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ABSTRACT

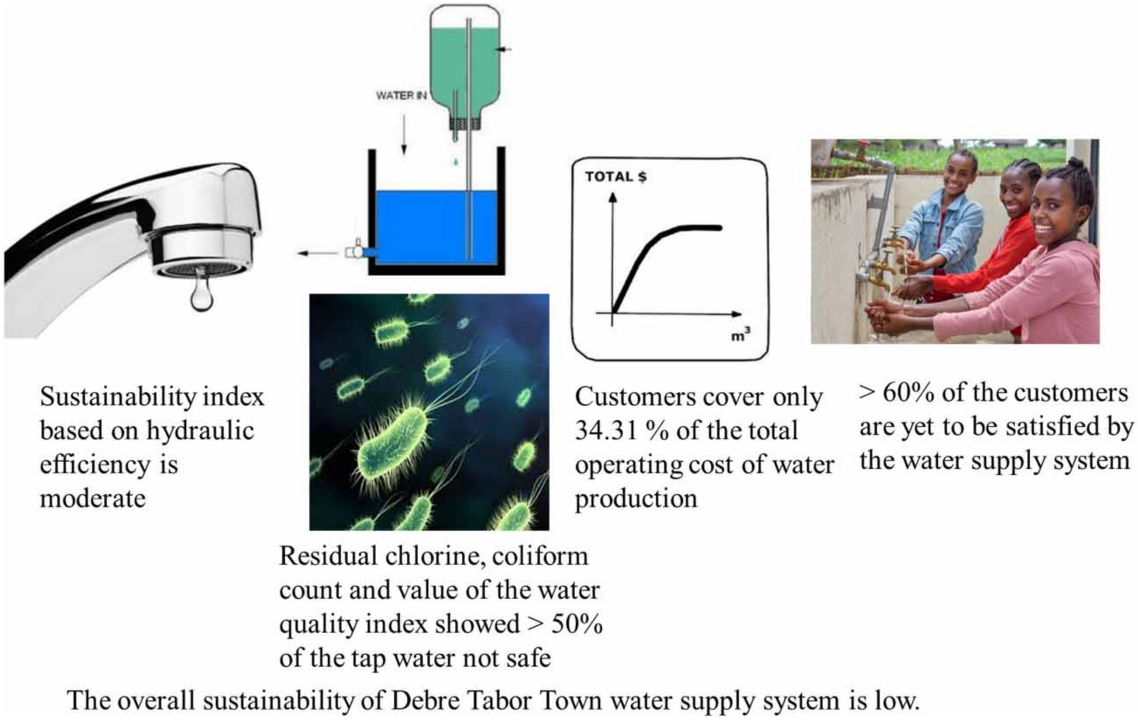
Urban water utilities in Ethiopia, including Debre Tabor Town, commonly suffer from an intermittent water supply, water quality issues, poor service delivery, and other problems. Thus, the main focus of this study was to evaluate the actual performance level of the water supply system of the town based on hydraulic efficiency, quality, cost recovery and customer satisfaction. The water distribution system status was measured by using reliability, resilience, and vulnerability as performance indicators. Weightage Arithmetic Water Quality Index (WAWQI) and household-based questionnaires were used to evaluate the water quality and customer satisfaction, respectively. Pressure and velocity-based sustainability index of 0.614 and 0.132 showed acceptable and unacceptable water supply status, respectively, and overall moderate sustainability. Results of the WAWQI revealed that more than half of the sampled tap waters were either poor or unfit for drinking purposes. The comparison of income collected from customers and the water production costs of the utility showed that only 34.31% of production cost is covered by customers. Generally, 62.6% of the society confirmed that they are unsatisfied with the existing water supply system. Thus, to improve the performance, it is recommended to address all the major social, economic, environmental and technical problems.

Key words: customer satisfaction, distribution system, intermittent, performance, water quality

HIGHLIGHTS

- In this study, Debre Tabor Town's water supply performance level was assessed.
- The system hydraulic performance and water quality are not to the required standard.
- Customer satisfaction with the existing system and utility cost recovery are considerably low.
- To upgrade the utility performance, attention is needed to pump operation, supply equitability, and loss management, among others.

GRAPHICAL ABSTRACT



INTRODUCTION

Population growth, urbanization, economic development, and lifestyle changes in the urban sectors have pressed the demand for water high in terms of both quantity and quality (Domene & Sauri 2006). Climate change and environmental pollution put additional pressure by affecting the accessibility of water resources to meet the growing demand (Danilenko *et al.* 2010). Thus, available water sources in any part of the world are becoming depleted and/or degraded (He *et al.* 2021). Water shortage, poor drinking water quality, and frequent interruption of supply in urban areas of developing countries are especially common (Kumpel & Nelson 2016; Salehi 2022). The main reasons for these are a lack of resources, low GDP, polluting industries, an insufficient response from institutions, and unsatisfactory planning and management (Talat 2021). Generally, scarcity of traditional water sources, along with poor service delivery, is increasingly threatening the security of water needs in urban centers of developing countries.

Thus, proper management of the available source, the introduction of alternative sources and surveillance of water quality, and then upgrading the performance level of the water supply system are needed. Performance assessment is a tool that can help decision- and policy-makers adopt what actions they should and should not take in an attempt to make an optimal contribution to sustainable development (Waas *et al.* 2014). The aims of sustainable development in the urban water sector are to have access to safe, adequate, and clean water to satisfy potable and non-potable needs of consumers at all times, to achieve a reasonable and lasting balance between water supply and demand, to reduce adverse impacts caused by the system to prevent permanent environmental damage, to optimize the allocation of financial resources to make water services profitable and strengthen household affordability (Motevallian *et al.* 2011).

A sustainability index (SI) is used to indicate the performance of a water supply system concerning predetermined thresholds of a satisfactory state. Thus, sustainability criteria and their indicators are used to quantify the different aspects of utility services and to assess the trend of sustainable development. Generally, performance indicators of urban water supply systems can be grouped as water resources, physical, operational, quality of service, and economic performances. Water resource availability is the main water resource performance indicator. The capacity of storage, quality of the transmission and distribution lines, and the density of the metered customers are taken as physical performance; whereas, loss management, operation, and maintenance, as well as the quality of water supplied, are indicators of operational performance.

Water supply pressure adequacy, continuity, water quality and other complaints, and population coverage are quality of service performance indicators (Hashimoto *et al.* 1982; Kanakoudis *et al.* 2011; Motevallian *et al.* 2011; Sandoval-Solis *et al.* 2011; Rathnayaka *et al.* 2016).

Hydraulic performance is about the ability to provide a reliable water supply at an acceptable level of service; that is meeting all demands placed upon the system with provisions for adequate pressure and reliability of uninterrupted supply. The index related to hydraulic performance can be described as separate or weighted combinations of reliability, resilience, and vulnerability measures of various economic, environmental, technical, ecological, and social criteria (Loucks 1997). The relative sustainability of the system concerning each of these criteria is higher the greater the reliability and resilience, and the smaller the vulnerability. Numerous investigators have applied these performance indices differently. Hashimoto *et al.* (1982) analyzed the three measures to evaluate the possible performance of water resource systems. On the other hand, Tabesh & Saber (2011) proposed a model using hydraulic (pressure and velocity performances, and reliability indices), physical, and empirical indices for the rehabilitation of water distribution networks.

Similarly, the water quality index (WQI) is used to evaluate the overall water quality of the system. The physical performance of the water supply system is the ability of the distribution system to act as a physical barrier that prevents external contamination from affecting the water quality. Water quality itself is also an indicator to be used for performance assessment of urban water supply systems, in reference to a set of standards against which compliance can be assessed. On the other hand, producing water and ensuring it gets to consumers require an input of expertise, labor, energy, and chemicals, all of which cost money. Thus, the water supply system should aim to recover this expenditure and gather funds for maintenance, building up of financial reserves, and expansion of the system when the need arises. Full cost recovery ensures the sustainability of the water scheme. Thus, the cost recovery performance of the system should also be assessed. Moreover, for a complete evaluation, it would be ideal to consider customers with their preferences, expectations, and requirements and then explore the ways of meeting their expectations considering the basic water supply service parameters (WHO 2011).

The Ethiopian urban water supply sector operates under several challenges, like geographical location difficulty, rapid population growth and urbanization, and lack of resources for building new water supply facilities. These affect the attempt to provide adequate water of good quality for urban residents in the country. The challenges mainly result in intermittent piped water supply systems in almost all urban centers of the country, and thus Debre Tabor Town is not different (Abel 2020). The utility delivers water to the town once per week and sometimes once per fortnight which lasts for 5–7 h (Abel 2020). This supply system in turn creates a risk to public health due to possible water contamination.

Hence, the preliminary assessment triggered the researchers for a detailed investigation into the extent of the accessibility of sufficient and safe drinking water in the area. In another talk, the present study tried to assess the performance level of the town's water supply system. For this, the hydraulic efficiency of the water supply system was assessed to check if it guarantees the basic requirement. The water quality was also evaluated if it meets the minimum standard. Besides, the cost recovery rate of the utility was assessed as it contributes to the sustainability of the existing schemes and their future expansion. Finally, the consumer satisfaction level was investigated. The results of the study are helpful to understand existing performance levels and then making an informed decision to upgrade the system.

MATERIALS AND METHODS

Description of the study area and its water supply system

The study was conducted in Debre Tabor Town, the capital city of the South Gondar zone of the Amhara region. The town is located in the northwest part of Ethiopia, at 666 km road distance from Addis Ababa, at latitude and longitude of 11°51′N and 38°01′E, respectively, and an average elevation of 2,706 m above mean sea level (Figure 1). The average temperature and average annual rainfall of the town are 14.8 °C and 1,497 mm, respectively. The town has cold weather conditions because it is nearby the 4,231 m high Mount Guna. The topography of the town is a ragged surface, with raised ridges and ridge foot shoulders showing variable slopes. The town has a population of 103,176 or households of 20,635.

As a result of the 5-year capacity-building project of WaterAid Ethiopia, Debre Tabor Town's domestic connection increased the number of customers from 3,871 to 11,067. Thus, the water supply coverage is raised from 18.75 to 53.6%; the change is impressive. However, only about half of the population is served (WaterAid 2020). This shows that, in addition to the intermittent supply, the supply coverage is limited.

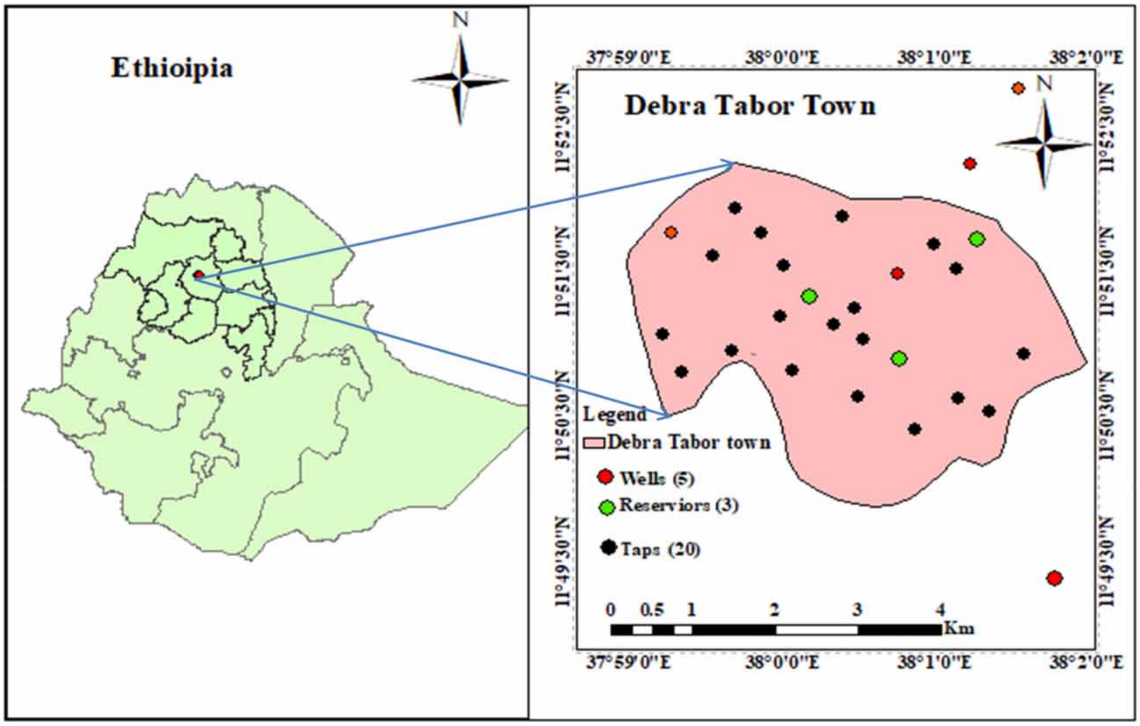


Figure 1 | Location map of the study area along with the sampling points of the sources, service reservoirs and private taps for water quality analysis.

The main source of Debre Tabor Town's piped water supply system is groundwater. There are 12 boreholes, out of which only eight are functional. According to the data from the water supply office of the town, the designed gross water production capacity of the boreholes is 78 L/s; however, currently, only around 48.02 L/s of water is produced from the boreholes with an average pump working hour of 9 per day. The raw water from each functioning borehole in the town is pumped to the existing three main ground service reservoirs. A 70-m^3 circular masonry reservoir, a 300-m^3 rectangular concrete reservoir, and a 50-m^3 circular masonry reservoir are located in the town. Water is distributed to consumers by both pressurized and gravity systems. The total length of the main and the secondary distribution lines is 128 km (Figure 2). In this study, exhaustive inspections of the installation were undertaken to comprehend the status of the water distribution system and to identify the challenges in operation and maintenance.

Data collection and sampling techniques

Primary data were collected from sample households using a questionnaire-based assessment of water supply, face-to-face interviews, field measurement and simulation for the distribution system and based on representative samples for water quality analysis. The questionnaire-based data were obtained from households and technical staff of the utility; whereas key informant interviews were conducted with individuals purposively selected from community members and the town water supply office. All the basic service parameters, which are water quality and quantity, accessibility (distance and time to fetch water), water availability, affordability to pay, and the level of continuity of water supply were considered for the survey (WHO 2011). The key informant interview was used in gathering information about administrative, technical, and other attempts made to address issues related to the services of the utility. For the water quality analysis, samples were collected from water sources, reservoirs, and customer taps using polyethylene sampling bottles. The bottles were washed well with boiled water to avoid contamination and labeled carefully. The pressure was measured by a pressure gauge installed at the household taps for calibration. The cost of water production covered by the customers was determined based on the current price of water and the revenue collection efficiency of the utility.

The town administration units were purposefully selected by considering spatial variation (mainly topography) and distance from the service reservoir. Random sampling was preferred to select sample households since household

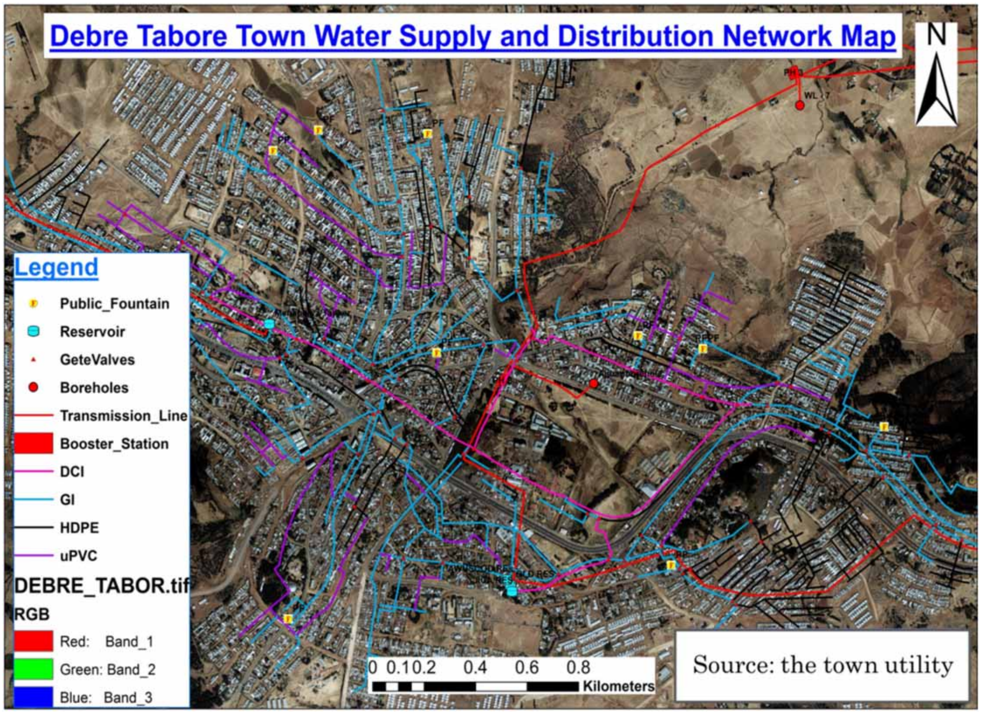


Figure 2 | Layout of the town's existing water distribution system.

representatives can give relevant information for the study from their experience. Thus, three admin units, namely, units 1, 3 and 6 were purposively selected out of six of the town. Detail of the questionnaires, existing water supply system components and the sampling points is given in the Supplementary Material.

The sample size (n) was determined using Yamane (1967), which is:

$$n = \frac{N}{(1 + Ne^2)}$$

where N is the total number of households (20,635) and e is the level of precision (5% is taken). Thus, the sample size was 393.

For the assessment of water quality, samples were taken three times from each point in different months (from March to May 2021). Five samples from water sources, three samples from storage tanks, and 20 samples from private taps were collected (Figure 1). The most important tests for water quality surveillance of small communities, namely total coliform, turbidity, residual chlorine, and pH, were used for this study (WHO 1997). Then, laboratory analysis was conducted on the stated physicochemical and microbiological water quality parameters.

Methods of the system performance analysis

In analyzing the hydraulic performance of the water distribution system, AWWA (1999) recommends minimum criteria of 3–6% of nodes for hydraulic network model calibration. There are 144 total numbers of junctions in the network. Thus, using a sample size of 5% of the total junction, seven representative measurements were taken for calibration. To calibrate the model, junctions which were accessible and available for pressure measurement were needed. However, in this case study, the pressure was measured on the faucet which was nearest to the junction as the junction is lined with asphalt and concrete and thus measuring the pressure is difficult without excavating the road. According to Walski *et al.* (2003), the calibration process was performed by adjusting sensitive parameters, such as pipe type (thus its roughness coefficient), water demand, and pattern of demand until it became within the acceptable limit of 85% of the field test measurements. It should be within 0.5 m or 5% of the maximum head loss across the system.

On the other hand, the model validation involved comparing model results with numerical data collected independently from experiments or observations. The coefficient of determination (R^2), which describes the degree of co-linearity between simulated and measured data, was used to manually validate the model. Typically, $R^2 > 0.5$ is considered acceptable. To update the system, demand from the current population must be considered; thus, this study used a number of base populations from Debre Tabor Town.

Pressure and velocity were identified as a hydraulic performance of water distribution system indicators, which were used to calculate reliability, resilience, and vulnerability. Performance indices for all these parameters were aggregated into the SI. In order to obtain the overall SI for each part of the network, sustainability indices of individual parameters were combined into an overall SI score (Aydin *et al.* 2014). To determine the performance of the system, the satisfactory state should be distinguished mathematically from the unsatisfactory state. Mathematically the satisfactory and unsatisfactory states for pressure are defined as

$$P_{j,t} = \begin{cases} \textit{unsatisfactory}\ (0)\ P_{j,t} < P_{\min} \text{ or } P_{j,t} > P_{\max} \\ \textit{Satisfactory}\ (1)\ P_{j,t} \geq P_{\min} \text{ and } P_{j,t} \leq P_{\max}. \end{cases}$$

where $P_{j,t}$ is the pressure at node j at time t; $P_{\min}$ is the minimum pressure; $P_{\max}$ is the maximum pressure.

Similarly, the satisfactory and unsatisfactory states for velocity are defined as

$$V_{j,t} = \begin{cases} \textit{unsatisfactory}\ (0)\ V_{j,t} < V_{\min} \text{ or } V_{j,t} > V_{\max} \\ \textit{Satisfactory}\ (1)\ V_{j,t} \geq V_{\min} \text{ and } V_{j,t} \leq V_{\max} \end{cases}$$

In the current study, the SI assessment using reliability, resilience and vulnerability performance criteria was applied, which are described as:

Reliability (*Re*) is the probability that the water distribution system is in a satisfactory state.

$$\text{Reliability } (Re) = \frac{\textit{number of times satisfactory occurs}}{\textit{total number of time steps}}$$

Resilience (*Rs*) represents how fast the system recovers from a failure. Park & Um (2018) indicated a system's capacity to adapt to changing resilient conditions.

$$\text{Resilience } (Rs) = \frac{\textit{number of times satisfactory follows unsatisfactory}}{\textit{toal number of times unsatisfactory occurs}}$$

Vulnerability (*Vul*) refers to the likely magnitude of a failure if one occurs. It is a statistical measure of the extent or duration of failure, should a failure (unsatisfactory value) occur (Loucks 1997)

$$\text{Vulnerability } (Vul) = \frac{\Sigma \textit{unsatisfactory values}}{\Sigma \textit{all values}}$$

Then, performance indicators for both pressure and velocity were determined by SI definition proposed by Sandoval-Solis *et al.* (2011), which is:

$$SI = \sqrt[3]{Re * RS * (1 - Vul)}$$

Table 1 shows the degree of sustainability, which ranges from 0 (lowest degree of sustainability) to 1 (highest degree of sustainability).

For water quality analysis, the weightage arithmetic water quality index (WAWQI) approach was used (Akter *et al.* 2016). WAWQI method has an advantage over the other methods as it incorporates multiple water quality parameters into a mathematical equation that rates the suitability of water for human consumption and/or also it describes the level of

Table 1 | SI evaluations (Aydin *et al.* 2014)

SI range	State
0–0.25	Unacceptable
0.25–0.5	Moderate
0.5–0.75	Acceptable
0.75–1	Ideal

contamination. It is a widely acknowledged method for calculating the WQI. The steps used to determine WQI using WAWQI method are:

Step 1: Data of various physicochemical water quality parameters are collected from lab analysis.

Step 2: Proportionality constant 'K' value is determined, using:

$$K = \frac{1}{\sum (1/S_i)}$$

where S_i is the standard permissible value of ith parameter.

Step 3: Quality rating scale for ith parameter (Q_i) is calculated, using:

$$Q_i = 100\left[\frac{(V_i - V_{io})}{(S_i - V_{io})}\right]$$

where V_i is the estimated value of the ith parameter of the given sampling station, V_{io} is the ideal value of this parameter in pure water, S_i is the standard permissible value of the ith parameter.

Step 4: The unit weight for each water quality parameter is determined by $W_i = (k/S_i)$.

Step 5: WQI is determined, using $WQI = \Sigma(W_i * Q_i)/\Sigma W_i$. After determining WQI values, the rating of the water quality was stated in reference to Table 2.

GPS was used to obtain the coordinates of points and WaterCAD V8i software was used to simulate the velocity and nodal pressure of the water distribution system. To assess the pressure head of water users and the water flow rate, field measurements were carried out, by using a pressure gauge and from known volume and stopwatch for the time of filling, respectively. To analyze water quality, using the APHA standard method (Baird & Laura 2017), the Debre Tabor Town water supply service lab was used. Sampling bottle, test tubes, beakers, distilled water, taste tubes, spoon, boiling water, incubation machine, turbid meter, pH meter, volumetric flask, pad, filter pad, Petri dish, forceps, microscope coliform counter, and filter membrane were used for the water quality analysis. On the other hand, the Statistical Program for Social Sciences (SPSS) was used to organize and analyze household survey questionnaire data and then to evaluate the overall performance of the urban water supply system. The findings were analyzed in descriptive statistics.

Table 2 | WQI range and the type of water (Kizar 2018)

WQI	Type of water
<50	Excellent
50–100	Good
100–200	Poor
2,000–300	Very poor
>300	Unfit for drinking

RESULTS AND DISCUSSION

Results

Water distribution network simulation

Hydraulic modeling of the water supply system of the town is comprised of 144 nodes and 195 pipes. Ethiopia's water supply distribution (WSD) system standard specifies the minimum and maximum operating pressures of 15 and 70 m, respectively (MoWR 2006). The pressure values in this study were within an average error of 2.68 m between simulated and observed values, which is below the maximum value of ± 5 m. Model validation was also achieved as the correlation coefficient was 0.91. However, at peak demand time, only 69.44% of the nodes showed pressure within the standard range. A junction was under negative pressure, another node had a value above the desirable maximum pressure, and 43 of the nodes showed pressure below the minimum requirement. The color coding in Figure 3 indicates the pressure at peak hour consumption for the nodes in the system.

Velocity in a pipe is another important parameter to evaluate hydraulic performance. The country's guideline states velocity to be above 0.6 m/s to prevent sedimentation and bacterial growth in the pipe, and it should be limited to 2 m/s (MoWR 2006). The velocity of Debre Tabor Town's WSD system during peak hour consumption is given in Table 3. The full nodal pressures and line velocities are given in the Supplementary Material.

Based on equations given under the methods section, the performance criteria of the distribution system were determined and shown in Table 4. From the values shown in the table, the sustainability indices for pressure and velocity are 0.614 and 0.132, which are acceptable and unacceptable, respectively. In this study, the overall sustainability score of the water distribution system (average of the two) is 0.373 and it indicates that the system is just moderately sustainable in terms of the variables considered.

Water quality of the system

The pH values of the samples taken from wells and reservoirs were within the Ethiopian Drinking Water and WHO guidelines of 6.5–8.5. Similarly, pH values were from 6.76 to 8.34 for tap water. The turbidity values of most of the water samples were within both standard limits of turbidity in water for domestic use, which is <5 NTU. However, a maximum value of 10.33 NTU was found in one of the wells and a value of 10.23 NTU was recorded for a sample from a tap. On the other hand, residual chlorine plays an important role in ensuring that water is safe from any microbial contamination when it comes to drinking water. The average value of residual chlorine at unit 3, Site1 (0.62 mg/l) was more than the maximum value of 0.5 and at 50% of the sampling sites the values are below the 0.2 value, set by the Ethiopian standard. Almost all the values are below the WHO recommended range of residual chlorine for domestic purposes, which is 0.5–1.5 mg/l. The average residual chlorine of the tap water is given in Figure 4.

Coliform organisms have long been recognized as a suitable microbial indicator of drinking water quality. The result showed that coliform was detected at a well; however, three of the wells had no coliform counts. From the tap water samples,

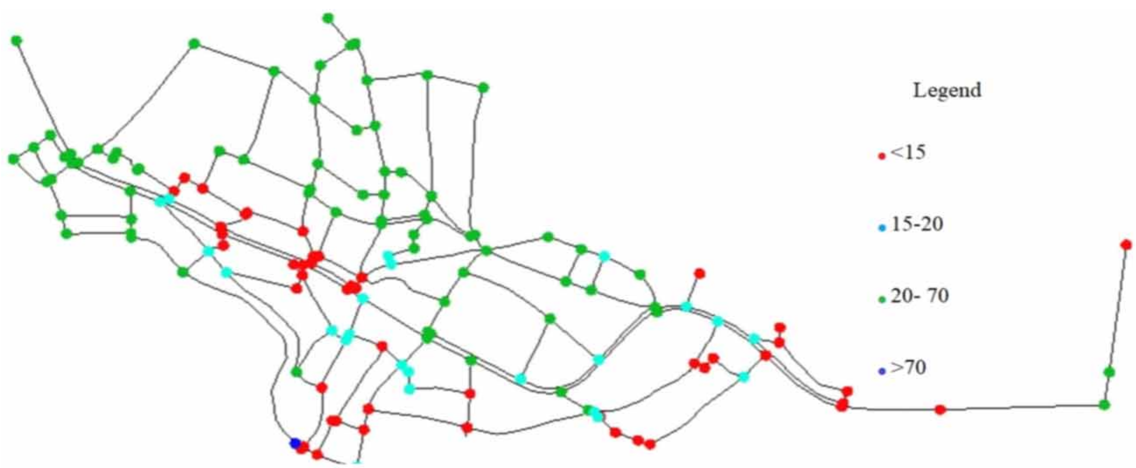


Figure 3 | Nodal pressure variation in the distribution system of the town at peak hour consumption.

Table 3 | Velocity for the town's WSD system during peak hour consumption

Velocity (m/s)	Number	Percentage	Comment
<0.6	169	86.7	Sedimentation likely
0.6–2	26	13.3	Acceptable level
>2	0	0	Head loss may happen
Total	195	100	

Table 4 | Values of the performance indicators of Debre Tabor Town's distribution system

	Hydraulic parameter	
Performance criteria	Pressure	Velocity
Reliability	0.63	0.15
Resilience	0.46	0.04
Vulnerability	0.20	0.62

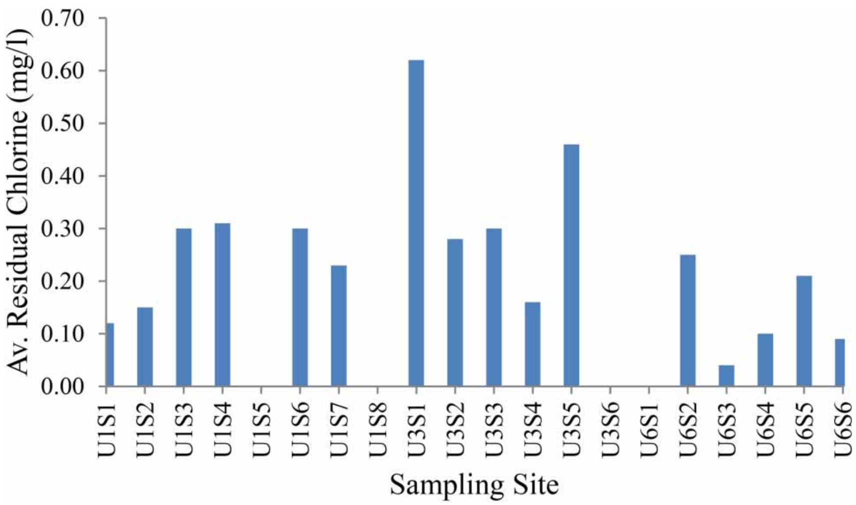


Figure 4 | Average concentration of residual chlorine in household taps (U: administration unit and S: sampling site).

maximum coliform of 31 CFU was found at U1S5. The combined effect of the various water quality measures, given by WQI values, was between 13 and 186.7 at boreholes and reservoirs. The water quality of three of the boreholes was classified as excellent water, two of the reservoirs were classified as good water and for a well and in two of the reservoirs it was under the poor water class. WQI results of the boreholes and reservoirs of WQI are shown in Table 5 and that of the tap water is shown in Figure 5. The raw water quality data and the WQI values are given in detail in the Supplementary Material.

Water production versus revenue collection

After the WaterAid Ethiopia capacity building was provided to Debre Tabor Town, the NRW is reduced from 19.5 to 13.85%, the maintenance cost is reduced to 9.3% of the total operating cost and the revenue collection efficiency reached 98.5%. Currently, the utility sells water to customers in a rising block tariff type on average at 14 birr/m^3 and the operating cost of water production is 31.68 birr/m^3 (birr is Ethiopian currency, 1 birr = 0.02 USD). Thus, considering the revenue collection efficiency and the NRW, the income collected and the total water production costs are 11.88 and 34.63 birr per m^3 of water. This shows that only 34.31% of water production cost is collected from customers.

Table 5 | WQI values of boreholes and reservoirs

Site code	QWI	Water type
R1	186.7	Poor
R2	99.0	Good
R3	142.9	Poor
W1	184.7	Poor
W2	19.0	Excellent
W3	93.0	Good
W4	14.0	Excellent
W5	13.0	Excellent

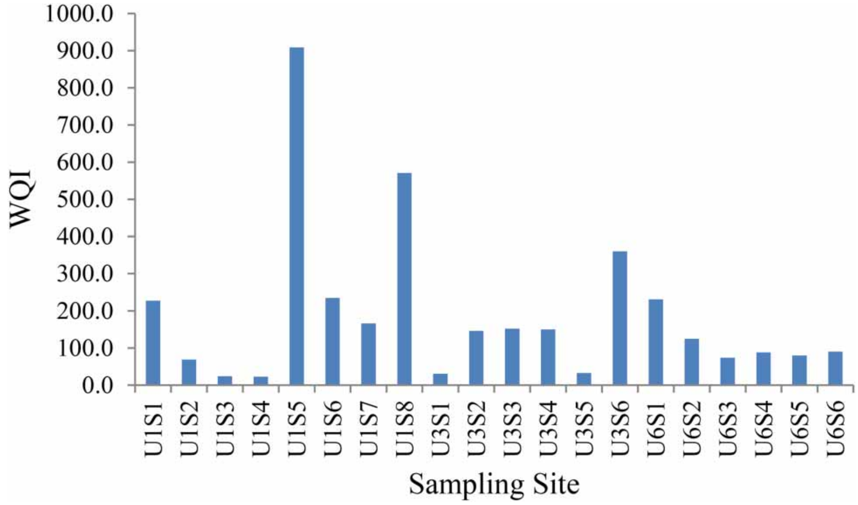


Figure 5 | WQI values of the tap water.

Customer satisfaction

The majority (94.5%) of the respondents use piped water supply, 2.5% use spring water, and 3% use hand-dug wells. However, the piped water flows in an on-and-off manner for a few hours that customers store water in containers to use until the water comes again. Improper storage may result in contamination (Gizachew *et al.* 2020). To overcome the existing water supply shortage, the community uses untreated alternative sources of water, such as surface water, spring, and rainwater (in the rainy season), and 76.9% of them hand-dug wells. Thus, due to the intermittent supply of piped water, people are forced to use water from unimproved sources that may be contaminated with infectious microorganisms and may be subject to waterborne diseases (Kumpel & Nelson 2016). Table 6 gives the reasons for limited access to water and equity of distribution.

The amount of water used by households is primarily a function of the distance to the water supply or the total collection time required. This broadly determines the level of service. Figure 6 gives the household responses to the distance covered to fetch water. Only 54% of the households fetch their main drinking water within 100 m of their home and 16.1% travel more than a kilometer to get water. Only 22.9% of the residents had private meter connections, 71.6% of them use yard meter connections of their own, and 5.5% depend on group meter connections/shared by neighbors. Thus, the society has limited access, which may expose them to the use of water of poor quality and a public health risk (Kumpel & Nelson 2016). On the other hand, 60.6% had to wait for more than 30 min to collect water, which is below the service level stated by WHO standards for safe drinking water. It is common to see a queue line at the water point, which leads consumers to wait for a long period.

Table 6 | Reflections of the society on access to and reasons for the unbalanced water supply

Parameters	Frequency	Percentage (%)
Reason for limiting access of water		
Unavailability from the source	166	42.2
Water is too expensive	20	5.1
Infrastructure problem	84	21.4
Sources are not accessible	123	31.3
Reasons for inequitable supply		
Scarcity of water	29	7.4
Line extension problem	135	33.4
WSD problem	66	16.8
Topography	94	23.9
Other reasons	69	17.5
Total	**393**	**100**

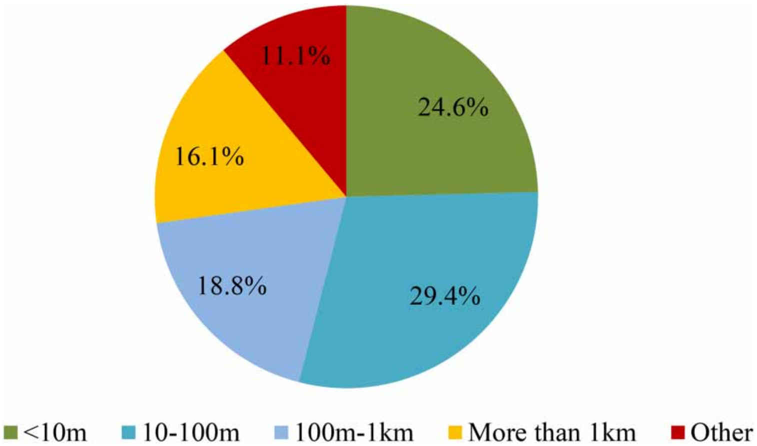


Figure 6 | Distance to collect water from the main sources.

Households were also asked about the quality of water they use for domestic purposes. The majority of the respondents had good awareness toward their water quality. More than 50% of them feel safe that the quality of water is good for domestic purposes. Some households stated, 'sometimes there will be sludge at the bottom of water holders when the water is finished'.

The affordability of water has also a significant impact on the use of water and the selection of water sources. Only 68.6% of surveyed householders replied that they pay for the piped water supply service. The payment is entirely in the form of a bill, and the majority of respondents pay between 30 and 200 birrs per month per household. The households were also asked about their judgments on the town's piped water tariff. 13.8, 34.2, 15.6, and 5% of the respondents stated the piped water supply tariff to be cheap, fair, expensive and very expensive, respectively. However, according to the interview with the utility officials of the town, the piped water supply tariff is low to cover the maintenance and operation costs. This agrees with the comparison made between water production and revenue collection. The results of the household survey showed that the overall satisfaction level of the existing water supply in the town is low, as 62.6% of them were not satisfied, and 35.9% are at intermediate satisfaction level and only 1.5% stated that they are satisfied by the town's water supply service.

DISCUSSION

In agreement with the results of this study, Ebsa *et al.* (2022) showed only 39.9% of nodes of Jaldu town of Ethiopia have a pressure range specified by the standard. As pressure lower than the specified standard can result in a reduction in the amount of water supplied to the consumer as well as the introduction of contaminants or self-deterioration of water quality within the network itself, causing harm to public health, attention should be given to the related nodes. The velocity assessment also showed that only a limited number of the pipes were within the standard, as 86.7% of the velocity is not within acceptable limits, which may affect the water quality. This service delivery can be considered a failure as it is below 50% to call it at minimum standard service.

The system needs solutions such as pump operational changes, providing pressure control valves, and/or adjustment of network components such as a booster pump installation and replacement of old pipes with new ones of proper diameter to operate within required pressure and velocity and then to upgrade the service level. By using a similar approach to this study, Ebsa *et al.* (2022) also found an overall SI of 0.399, based on the values of the technical performance indicators pressure and velocity. Moreover, the study by Adank *et al.* (2016) on water and sanitation service levels of 16 small and medium towns in four regions of Ethiopia showed that a small minority of households receive services, with characteristics such as reliability, quality, quantity, and accessibility of water meeting the standards set by the government.

On the other hand, the water quality-related finding indicated that most of the town's domestic tap waters did not have proper chlorination systems. This result agrees with the general national drinking water quality (CSA 2017). Thus, the drinking water may develop waterborne diseases such as amoeba and giardia, which are a matter of public concern. The study suggests the addition of adequate chlorine, say by setting new re-chlorination points on the distribution system, to kill pathogens and ensure public health. The majority of the water samples had high counts of total coliforms. Similar to these results, the drinking water supply of Kobo town, which is from a borehole through pipes, showed coliform counts not meeting the national and WHO standards (Sitotaw & Nigus 2021). The zero or low value of the residual chlorine effect, the age of the pipes, and the intermittent water supply system are possible causes of the contamination (Kumpel & Nelson 2016; CSA 2017). According to verbal information gathered from the health center of the town, the top three diseases in the area are water-related and waterborne. Gizachew *et al.* (2020) showed in their water quality study of the Wolaita zone (Ethiopia) that 44% of water source samples and 91% of household water samples were positive for coliform. The water sources had fecal coliform means, and noncompliance with the WHO water quality guideline and they recommended capacity building for the protection and management of water sources and safe water handling practices at the end of use.

Out of the 20 tap water sampled, more than 50% are either poor or totally unfit for drinking purposes. Generally, the results of the WQI indicated that the water quality gets deteriorated from the source to the reservoir and then to the tap, signifying the entry of pollutants on the way. The finding agrees with a similar study conducted in Bangladesh, in which the majority (67%) had poor-drinking water quality (WQI value $>$ 100) and the quality of the drinking water was found to be unsuitable for drinking (Akter *et al.* 2016). Similarly, Addisie (2022) studied the water quality of the Sidama district, which is close to the current study area, and found WQI values for both improved and unimproved sources in the rank of unsuitable for drinking purposes.

Coming to the financial issues, the 34.31% cost recovery of the utility agrees with ADB (2020), which concluded financial viability to be the weakest performance indicator in the region. If a water supply service could not recover its costs, this would restrict chances to develop and extend networks; particularly affecting the poor. For domestic users, the price is decided considering affordability, which varies depending on the local situation, but for water to be affordable; its price should not exceed 5% of the income of households. In small towns in developing countries, water has to be made accessible and affordable for them at the cost of the utilities not covering expenses. That is, water resource management policy requires social tariffs to be set up for poor communities, based on the recovery of operation and maintenance costs only. The principle behind such a policy is that each person should have the right to access a minimum level of water supply (MoWE 2013).

There are many reasons for tariffs to fail or at least, tariffs not to provide an adequate level of financial sustainability for a utility's operations. Among them is 'the imperative to suit local needs'. Short- and long-term recommendations to overcome this challenge are to decide how the structure should meet local needs and to evolve the structure proportionately to socioeconomic development (Yates *et al.* 2020). Besides, for the economic feasibility of the system, in addition to lowering maintenance costs by both preventive and corrective actions and increasing revenue collection efficiency, the strategic business plan needs to be in place by utilities of developing countries. This plays a significant role to overcome the challenge of the limited willingness and capacity of consumers to cover the basic costs. For instance, Ambo town of Ethiopia has built a multi-story building, the ground floor of which is rented to a bank, and playing a huge role in making the municipal water supply sustainable (WaterAID 2020).

The household survey's result confirmed water scarcity in the area. Water is unequally distributed due to line extension issues, and the town's topography occasionally causes WSD failure, based on responses to both questionnaires and interview surveys. Steady and rapid spatial expansion of the built-up area crossing the existing municipal boundary of the town further impacted the pipeline extension management, which in turn influenced meter-connection. The most dominant factor affecting the water consumption of inhabitants of the town is the quantity of water as confirmed by both interview and questionnaires results. The actual production of piped water is significantly lower than the demand due to under-capacity production and frequent interruptions in well operation. Besides, the limited number of boreholes and a high percentage of water loss have further reduced the actual amount of water made available. The majority of the households depend on 5–20 L/capita/day, which is in the basic access service level. Even though distributing water through a house connection use is obviously the most convenient system of water supply for households, the related installation is costly, which most of the households in the community, especially the poorest of the poor, could not afford. Most parts of the peripheral built-up areas of the town are currently beyond the reach of pipelines; thus, those living in these areas suffer greatly from the complete lack of water supply around their homes. This confirms the limitation in equitable access to a potable water supply.

Generally, it is assumed that the potential for long-term performance improvement in urban water supply systems can be established through the application of all the indicators studied. Water quantity and quality should be together studied and managed to attain a better water supply service for urban areas. It should also be emphasized that cost recovery and financial capability and fairness and effectiveness (affordability) in drinking water supply need to be balanced in developing countries (Debel *et al.* 2020). Simply, trade-offs are expected.

CONCLUSIONS

The present study assessed the performance level of Debre Tabor Town's water supply system, based on the hydraulic efficiency of the distribution system, water quality, comparison of water production cost and revenue collection and customer satisfaction. The SI of the distribution system was on average 0.37 that the system is moderate and needs pump operational changes and additional network components to upgrade its hydraulic performance. The WQI results showed that most of the tap water was below standards for drinking purposes set by both WHO and Ethiopia. The intermittent water supply systems may contribute to poor tap water quality. Debre Tabor Town's per capita water consumption was also lower than the regional and country-level standards set by the country's ministry of water resources and WHO domestic water standards. On the other hand, only 34.31% of water production cost is covered by revenue collected from customers, showing that the system is currently far from being economically viable. Generally, the overall performance of the system is weak and improvement of the coverage, quality and thus satisfaction of the community needs due attention. Using additional alternative sources of clean water, reducing water loss, and expanding distribution networks in areas where it is not available are required to upgrade the system's performance. Developing an applicable business plan is also recommended to achieve economic capability. Debre Tabor Town is a fast-growing town and the distribution network expansion service needs to be widely available. The utility should also provide customer awareness programs to limit illegal connections and other sources of non-revenue water. Generally, system-based improved water management approaches in which the factors are considered in combination, are required to realize sound performance in the long-term.

DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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