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Performance evaluation of water supply distribution system: a case study of Muke Turi town, Oromia region, Ethiopia

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ABSTRACT

Adequate and sustainable supply of potable water in urban areas of developing countries is often a challenge. This study assessed the performance of the water supply system in Muke Turi town, Oromia, Ethiopia. The Water Geospatial Engineering Modeling System (WaterGEMS) model was used for hydraulic analysis of the distribution network. The water losses were determined by different indicators including non-revenue water (NRW), losses per pipe connection (LPC), losses per main pipe length (LMPL), unavoidable annual real losses (UARL), and infrastructure leakage index (ILI). The water supply coverage of the town was found as 43.34%, which is considerably low. From the hydraulic analysis, the velocity of flow in 54.2% of the pipe and pressure at 60% of the nodes were found within the recommended ranges. The NRW was estimated at 37.61%, which is above the acceptable limit. Of which, the real losses are the major ones with 37.14%. Moreover, the LPC and LMPL were found to be 298 l/d and 29,709 l/km/d, respectively, which are again above the recommended limits. Based on ILI, the annual real losses were estimated to be 4.31 times the UARL. Finally, it was concluded that access to water in the town is inadequate which is exacerbated by high losses.

Key words: Muke Turi, performance, WaterGEMS, water losses, water supply

HIGHLIGHTS

- The level of performance of Muke Turi Town water supply system was assessed.
- WaterGEMS hydraulic model was employed to simulate the water distribution network.
- The water supply coverage and hydraulic performance of the system were found low.
- The supply–demand gap and the water losses are high.
- To improve the performance of the system, equitable distribution, service management, and control of losses need utmost attention.

1. INTRODUCTION

Adequate and sustainable supply of water are global problems. An estimated two billion people around the world, especially in developing countries, lack access to safely managed drinking water services (WHO 2022). This issue will even become more important in the future, as the water demand is growing significantly, while water availability is shrinking (Heryanto *et al.* 2021). Urban areas are particularly challenged as demand continues to increase due to population growth, urbanization, and improving living standards (Toma & Dananto 2022; Tekile & Legesse 2023). As a result, there is enormous pressure on existing water supply systems.

Poor service delivery along with water supply shortages is an additional problem that is threatening the security of water needs in urban areas of many developing countries (Waas *et al.* 2014). Urban water supply system demands control of losses, infrastructure renewal, and infrastructure replacement. Water losses may not be completely avoidable in distribution systems, but they can be managed to remain within economic limits (Heryanto *et al.* 2021). The infrastructure consists of several components from the source to the consumers' taps such as pumps and distribution pipes. Over long use, the pipes get old and the pump efficiency declines, which will have an impact on the performance of the system (Mishra *et al.* 2022). Thus, to sustainably guarantee good

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service levels, proper management of the available source and upgrading the performance of the existing water supply system are needed (Muranho *et al.* 2014; Waas *et al.* 2014).

A well-performing urban water supply system should provide water for domestic, industrial, and other uses in terms of coverage, quantity, reliability, and acceptable quality taking the existing and future demands of the town into consideration (Fikadu 2018). The first and most obvious factor used to improve the performance of a water distribution system is a hydraulic analysis, which is driven by the need to provide a specific set of demand points with appropriate flow velocity and pressure while avoiding significant variations in the parameters (Jalal 2008). Sufficient quantity and quality of water can be maintained by adequate pressure and velocity. Proper management of pressure in the water distribution network generally ensures a reliable operation and reduces the risk of external contamination (Dai & Li 2016; Pandya *et al.* 2019).

Developing countries such as Ethiopia have made great strides in increasing the water supply coverage of many towns but, unfortunately, the focus on expanding service provision has often been at the expense of adequate operation and maintenance of the existing infrastructure (Workneh *et al.* 2023). As a result, the level of water supply services in many towns in Ethiopia in terms of coverage, quantity, and reliability remains very low. There are frequent interruptions of water supply, and consumers usually take disproportionate amounts of water. This is not only a consequence of the gap between supply and demand but also the result of unidentified leakage and illegal connections to the system (Gebrehiyot 2015). Due to such problems in the water services, there is a growing interest by many researchers to check the performance of the water supply systems of different towns in the country so as to identify major challenges and give solutions for their improvement of services. However many previous studies have relied on questionnaire surveys to identify problems related to water services. Only a few have attempted to calculate the water coverage and losses and made a hydraulic performance check of the water supply system. Among the most recent works, Kefyalew (2018) evaluated the performance of the water supply system in Alem Gena town. The system was found to have frequent water supply interruptions and water loss of more than 37%. In another study, Tufa & Abate (2022) investigated the accessibility and hydraulic performance of the water distribution system in Ejere town. They found that access to potable water in the town was inadequate and that the hydraulic functionality of the distribution system was below the minimum required limit. Furthermore, Tekile & Legesse (2023) evaluated the performance of the water supply system in Debre Tabor town. More than 62.6% of customers affirmed that they are not satisfied with the existing water supply system.

In this study, the water supply network of Muke Turi town is considered to assess its performance in terms of water supply coverage, water loss, and hydraulic functions. Muke Turi is a town in the North Shewa Zone, Oromia Regional State, Ethiopia. A preliminary assessment of the town's water services revealed that there are severe water shortages, frequent interruptions of water supplies for days to weeks, high rates of water loss in the distribution system, inadequate storage facilities, and lack of adequate maintenance of the system. This assessment prompted the researchers for a detailed investigation of the water supply services to better understand the existing performance levels and then make an informed decision to improve the system. The study has mainly focused on the technical issues with the assumption that these issues are the major ones in the area and the source of other related problems. Thus, social issues such as customer satisfaction with the system and environmental issues such as the water quality aspects are not addressed.

2. MATERIALS AND METHODS

2.1. Description of the study area

The study was conducted at Muke Turi town located in the North Shewa Zone, Wuchale district, Oromia Regional State, Ethiopia. It is situated about 35 km south of Fiche town, the capital of the zone, and 89 km north of Addis Ababa. The town is geographically located between 9°32′22″ and 9° 33′50″N latitude and between 38°51′57″ and 38°52′32″ E longitude (Figure 1).

The topography of the town ranges from 2,300 to 3,300 m above the sea level. The area receives a mean annual precipitation of 1,150 mm and has a mean daily temperature of 12.87 °C. According to the projection made based on the 2015 population and housing census result, the total population of Muke Turi town is 46,109. The town serves as a major marketing centre with thousands of people flocking to the town from the surrounding rural areas. The major economic activities in the town are trading, hotel services, and small-scale industries.

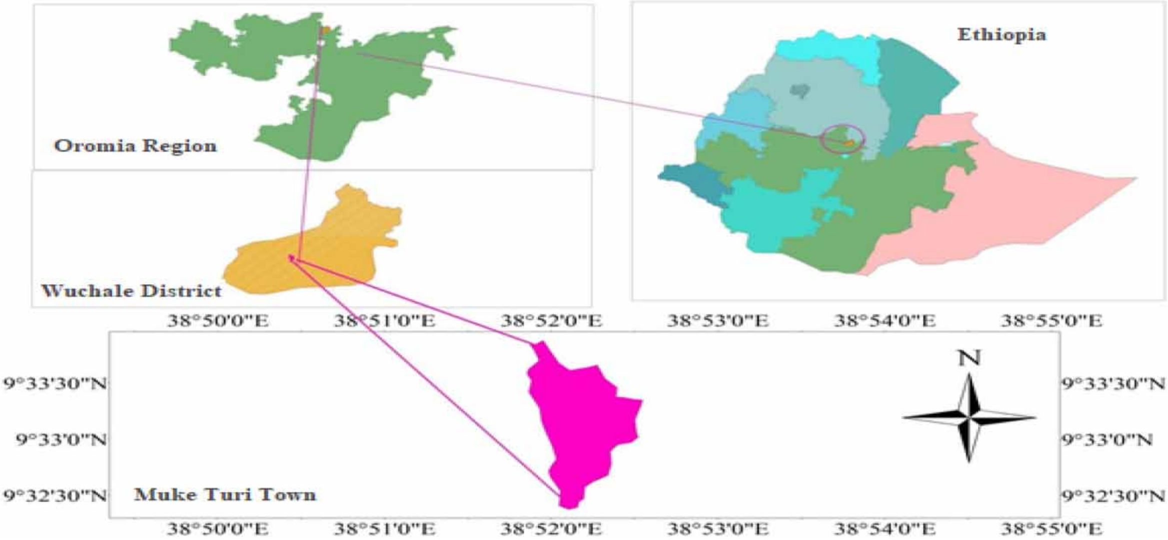

Figure 1 | Location map of the study area.

2.2. Layout and description of existing water supply distribution system

The Muke Turi town water supply system consists of two boreholes, a pipe distribution network, and two surface reservoirs. The water supply is extracted from two boreholes (BH_1 and BH_2). The submersible pumps, which are installed in the two boreholes, lift water at discharges of 5 l/s and 8.5 l/s and supply it to the surface reservoirs 1 and 2, respectively. The total length of the main supply and distribution pipelines is 19.74 km. All the pipes are galvanized steel (GS) pipes of different sizes. The layout of the system is shown in Figure 2.

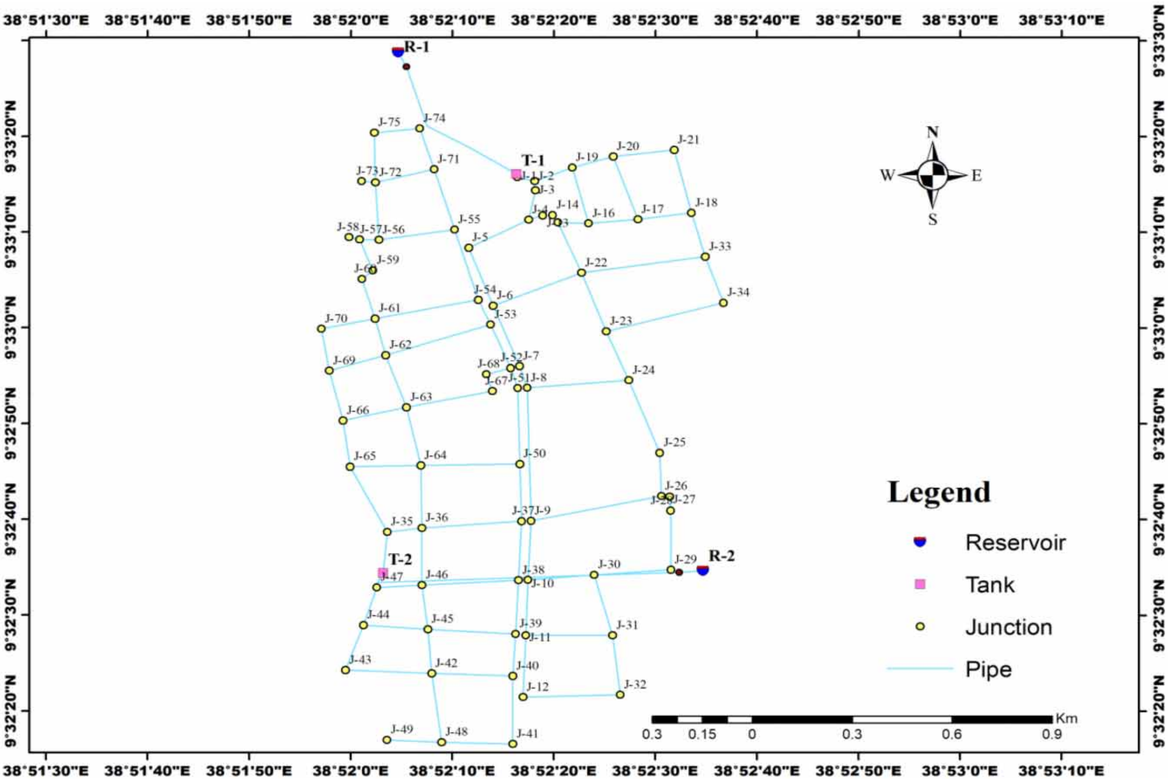

Figure 2 | Water supply distribution network of Muke Turi town.

2.3. Data collection

Both primary and secondary data were used to achieve the objective of the study. The primary data including the location of water sources, services reservoirs, and nodal pressures were collected through field observations and measurements. Secondary data were collected from Muke Turi Water Utility Office and the Town Administration. These data include the water supply distribution map, water supply production, and consumption and population data.

2.4. Method of data analysis

The study employed different materials and tools to analyse the collected data. Microsoft Excel was used to screen, organize, and process the data. Global Mapper and Arc GIS were used to locate and map the water distribution system. The Water Geospatial Engineering Modeling System (WaterGEMS) model was used for the hydraulic performance analysis of the distribution system. The parameters considered in the analysis were nodal pressure and velocity. Water audit software was used to analyse water loss components by the top-down water balance method. The input data used for the water audit were water volume, billed meter and unmetered consumption, number of service connections, average operating pressure, and length of main and service pipes.

2.4.1. Population projection

The population of the town for the year 2022 was projected based on CSA (2015). The exponential increase method was used for forecasting as it is a recommended method for population forecasting for towns in developing countries. It is also the most preferred method as its percentage error of prediction is the lowest value of the other methods (Mekonnen 2018). The method is expressed as follows:

$$P_n = P_o \times e^{rn} \tag{1}$$

where P_n is the forecasted population; n is the number of years; P_o is the base population; and r is the growth rate of the population.

2.4.2. Water supply–demand gap analysis

The water supply–demand gap in the town was supposed to increase due to the population growth, climate change, the living standard of populations, and the development of industrialization and urbanization. The water supply–demand gap was evaluated by taking the difference between the maximum daily demand of the town and the current average daily production of the town. The maximum daily demand was taken as the forecasted water demand, and the daily production was considered as the daily water supply of the town.

2.4.3. Water supply coverage analysis

Water supply coverage is usually evaluated based on the quantity, quality, paying capacity of the people, and distance (Muluken 2015). However, the intention of this study was not to evaluate all of these but those related to water loss. Thus, the water supply coverage was evaluated in terms of annual water production and demand; per capita water consumption; and level of connection per family.

Based on annual water production and annual water demand, water supply coverage was determined using the following formula (Belachew *et al.* 2021):

$$WSC = \frac{AP}{AD} \times 100 \tag{2}$$

where WSC is the water supply coverage in %; AP is the annual production m^3; and AD is the annual demand in m^3.

Average per capita water consumption was used to assess the domestic water supply coverage of the town. It was derived from the town's annual consumption, which was aggregated from individual water meters and public taps. Thus, the annual water consumption data were converted to average daily per capita consumption using the population data of the town. Equation (3) is used for the determination of per capita water consumption.

$$ACC = \frac{1000 \times AWC}{365P} \times 100 \tag{3}$$

where ACC is the average per capita consumption in lit/capita/day; AWC is annual water consumption in m^3, and P is the total population of the town.

Further, the level of connection per family was used to evaluate the level of water supply coverage, which was determined by

$$CF = \frac{TC}{P/NF} \times 100 \tag{4}$$

where CF is the connection per family; TC is the total number of connections in the town; P is the total population in the town; and NF is the average family size. The total number of water meters connected in the town is about 1,968, and according to CSA (2015), the average family size in urban areas of the Oromia Region is 5. These values were used for determining the number of connections per family.

2.4.4. Hydraulic performance analysis of the distribution system

2.4.4.1. Building water distribution network. The water distribution network was created by applying the model builder in WaterGEMS to connect the hydraulic model to the geo-database. The hydraulic network along with its attribute data was imported from the master geo-database, which was developed in AutoCAD.

2.4.4.2. Demand allocation. Demand allocation is the task performed in a water distribution network modelling for assigning the water demand of the study area. Allocation of calculated base demands to the nodes in the network through GIS consists of methods including point load data, area load data, and population or land use data. In this study, load estimation by population methods was used as population information stored in ArcGIS is available in terms of the area of a given land use. The influenced area for each junction that was created within the Thiessen polygon on Water GEMS and the population shape file that was created on ArcGIS were used for the demand allocation for each junction. Assigning the population of the town in a given area, exporting the prepared population shape file from ArcGIS to Water GEMS, and finally assigning base water demand in each node were the three steps that were followed to allocate the base demand for the node in the water distribution network.

2.4.5. Hydraulic performance analysis

Both steady-state and extended-period simulations were run in the hydraulic analysis to check the performance of the system. In the steady-state simulation, the performance was checked by keeping the demands constant at each junction within 24 h of the system supply. The amount of water that is consumed in the morning when everyone is getting ready for work is different from that at midnight. The extended period simulation was run at 2-h time steps to check the performance of the system at peak and minimum consumption times.

2.4.6. Model calibration and validation

Model calibration involves finding a unique set of model parameters that provide a good description of the system's behaviour and can be achieved by comparing model predictions with actual measurements performed on the system. The parameters relied on to achieve high accuracy during calibration were pipe roughness and pressure at junction points. A trial-and-error process has been implemented for calibration (Abdulsamad & Abdulrazzaq 2022). The Hazen–William coefficients were determined through the calibration process ranging between 100 and 120 for all pipes in the system due to the age of the network being approximately 35 years, and then, greater than 85% of pipe roughness was taken. Darwin calibration was used for generating the new roughness coefficients for the pipes.

Similarly, the pressure was measured in the field at sampling points at different consumption times throughout the day to compare with the result of the distribution model. The critical times, low and high demands, were selected when measuring pressure with a pressure gauge. But it was difficult to take measurements at a direct connection to the water main nodes, due to the size of the pressure gauge used. Therefore, the measurements were taken at a location other than the point of direct connection to the water mains, near the supply main nodes at the home's faucet and water point. The Darwin calibrator tool was used to calibrate and adjust the hydraulic model in Water GEMS until it was in good agreement with the field data. The model was then validated using datasets at eight junction points from field observations and eight datasets from simulated findings. The eight sample junction points were decided based on the recommendation that 2–10% of the total junction points can be used as representatives for validation. Since the total number of junction points in the network is 75, eight junction points were used (EPA 2005; Tufa & Abate 2022).

2.4.7. Water loss analysis

One of the major challenges for water utilities is the high volume of water loss in the distribution networks. If a large quantity of supplied water is lost, it will be difficult to meet the demands and consequently difficult to keep the water tariffs in the system at a reasonable level. In this study, the water loss in the town water supply distribution system was evaluated using the top-down water balance method. Detailed analysis of the water loss components including the non-revenue water (NRW) and the apparent and real losses has been done using the water audit software. In addition, the water loss as per the number of service connections and the water loss as per the main pipe length were also estimated (Legese 2020).

2.4.7.1. Non-revenue water. NRW includes water losses in the water distribution system due to leakage, illegal connections, and improper metering and recording. It is expressed as a percentage of the volume of water supplied into the system. NRW was determined by the following formula:

$$NRW = \frac{TWP - TWB}{TWP} \times 100 \tag{5}$$

where NRW is the NRW losses or total water losses in %; TWP is the total water produced in m^3; and TWB is the total water billed.

2.4.7.2. Apparent and real losses. Apparent losses consist of unauthorized consumptions (illegal connections, unauthorized use of fire hydrants, meter bypassing, and poor billing collection system), data handling errors in the meter reading and billing system (billing system entry error, account adjustment, invalid meter consumption reading, poor accounting, and others), and metering inaccuracies (Frauendorfer & Liemberger 2010). On the other hand, real losses include the amount of water lost due to all types of leaks, bursts and overflows on the main, service reservoir, and service connection, up to the point of customer metering. Real losses were calculated as the volume of NRW minus the sum volume of apparent losses and unbilled authorized consumption.

2.4.8. Performance indicators

The performance indicators are used to characterize real losses from distribution systems. These performance indicators are unavoidable annual real losses (UARL) and infrastructure leakage index (ILI).

The UARL represent the allowable volume of real losses from the system, which estimated a volume of leaks that are undetectable or would be uneconomical to repair during the years. This can help to evaluate the feasibility of real loss minimization (provides a better understanding of the real loss component). UARL in the system was computed according to Farley *et al.* (2008).

$$UARL = P(18L_m + 0.80N_c + 25L_P) \tag{6}$$

where UARL is unavoidable annual real losses (L/d); L_m is mains length (km); N_c is the number of service connections; L_p is the total length of pipe to customer meter (km); and P is the average pressure (m).

The ILI is the measure of how well a distribution network was managed, maintained, repaired, and rehabilitated for the control of real loss, at the current operating pressure (EPA 2005). ILI was calculated as follows:

$$ILI = \frac{CAVRL}{UARL} \tag{7}$$

where CAVRL is the current annual volume of real losses, which is derived from NRW.

3. RESULTS AND DISCUSSION

3.1. Water supply–demand gap

The maximum daily water demand and the current daily water production of the town are 2,168.84 and 1,166.4 m^3/d, respectively. So, the supply and demand gap between production and demand consumption of the town was found to be 1,002.44 m^3/d (11.6 l/s). This shows that the water supply from the system does not fulfil the demand of the town. The possible reason for this is the reduction of borehole discharge, high water loss, and an increase in the population growth from time to time. This does agree with the findings of Kefyalew (2018).

3.2. Water supply coverage

The water supply coverage of the town was evaluated based on the average per capita consumption and the level of connection per family. It is the ratio of the annual water production and demand of the town. The water supply coverage of the town was found to be 43.34%, which is very low. In other words, it means that the annual water demand of the town is much greater than the annual production of the town. Due attention is thus required to improve the water supply services of the town.

In addition, the average per capita water consumption of the town was found to be 12.72 l/c/d. This figure is very low compared to the national target (MoWIE 2019), which is 50 l/c/d for category-4 towns or cities, wherein the study area is categorized. Therefore, further work is required by the water supply service of the town to improve the current per capita water consumption of the town.

Furthermore, as an important additional element in evaluating the level of water coverage, with the assumption of an average family size of five, the average connection per family was found to be 0.23 or about 1 connection for five families. According to MoWR (2006), the maximum level of domestic water supply connection per family is 1 or 100%, which means one connection for one family. Therefore, the average level of connection per family in Muke Turi town is very low. In agreement with the findings of Tufa & Abate (2022), there is low access to drinking water supply in the town. The result also indirectly confirms the low level of satisfaction with the existing system similar to the report by Tekile & Legesse (2023). Therefore, the number of water supply connections shall be increased to improve access and for equitable distribution of water to consumers.

3.3. Model calibration and validation

3.3.1. Model calibration

Pipe roughness is one of the most important model parameters for hydraulic networks. The material type of all pipes in the system is GS. The model assigns a C value of 120 for GS pipes. Since the actual roughness values of the pipes are less than that assigned by the software, a Darwin calibrator was used to adjust the roughness coefficient of the selected pipes (P-1 up to P-110). Based on the Darwin calibrator, the C values for GS pipes were fixed as 102. The new roughness, which was generated from the Darwin calibration, was entered into the software for model simulation. Further, the pressures measured at sampled points in the field were compared to the distribution system's results. The simulated pressure values were found within the average error of ± 0.6 m from the observed values. Hence, the model is accepted as it has satisfied the criteria for pressure calibration (average ± 1.5 m to maximum ± 5 m) (Kuma & Abate 2021).

3.3.2. Model validation

The model was then validated using eight datasets from field observations and eight datasets from simulated findings. The field measured pressures were at J-12, J-18, J-25, J-43, J-54, J-60, J-65, and J-68. If the model results are close to the field results at an appropriate time, the calibrated model is considered to be validated (Muluken 2015). Based on this, the measured and simulated pressures at peak demand were compared and were found in good agreement with a coefficient of correlation (R^2) of 0.985 (Figure 3).

3.4. Hydraulic performance evaluation of water distribution network

3.4.1. Pressure distribution analysis

Water distribution systems must maintain optimal pressure to efficiently provide water to each demand category, particularly at peak hours. The peak hour consumption is the maximum amount of water consumed in 1 h on the maximum day during any month of the year. At peak consumption time, the town is affected by water interruption. This interruption was due to low pressure in the system. The pressure distribution at peak hour consumption time contains about 33.33% of nodes with pressure below 15 m and 64% within the recommended limit (15–60 m), while 2.67% above 60 m. Similarly, the pressure distribution at low consumption hours was also found to be at 9.33% of the nodes with pressure below 15 m, while 61.3% was within permissible pressures and the remaining 29.33% with pressures higher than 60 m. Such pressure distributions below and above the recommended ranges have a significant impact on the hydraulic performance of the network. This implies that all

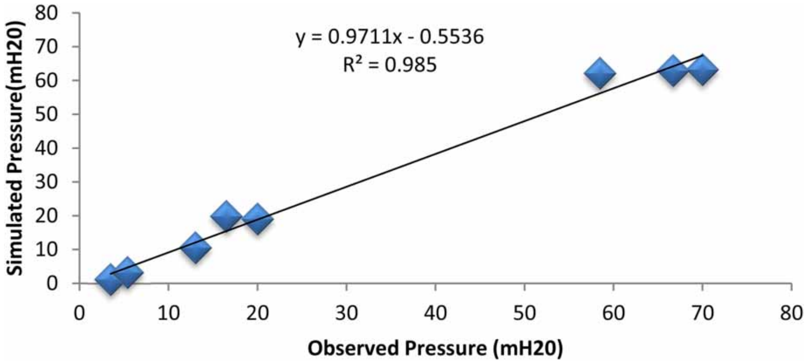

Figure 3 | Scatter plots of observed vs. simulated pressure for validation.

nodes with pressure below 15 m do not get enough quantity of water, while those above 60 m pressure get enough water but there is a high risk for pipes breakage or failure of the distribution system.

Furthermore, variation of elevation differences in the town has an impact on the rising and reduction of water pressure in the network. Fluctuations in water supply and demand are also the causes of variations in water pressure in the distribution system. Therefore, during peak demand time, most of the distribution networks have low pressures and the wide residential area of the town was not getting water. While most of the residents get and collect water at night flow during low demand. The town nodal pressure variations during peak consumption times are described by contours as shown in Figure 4.

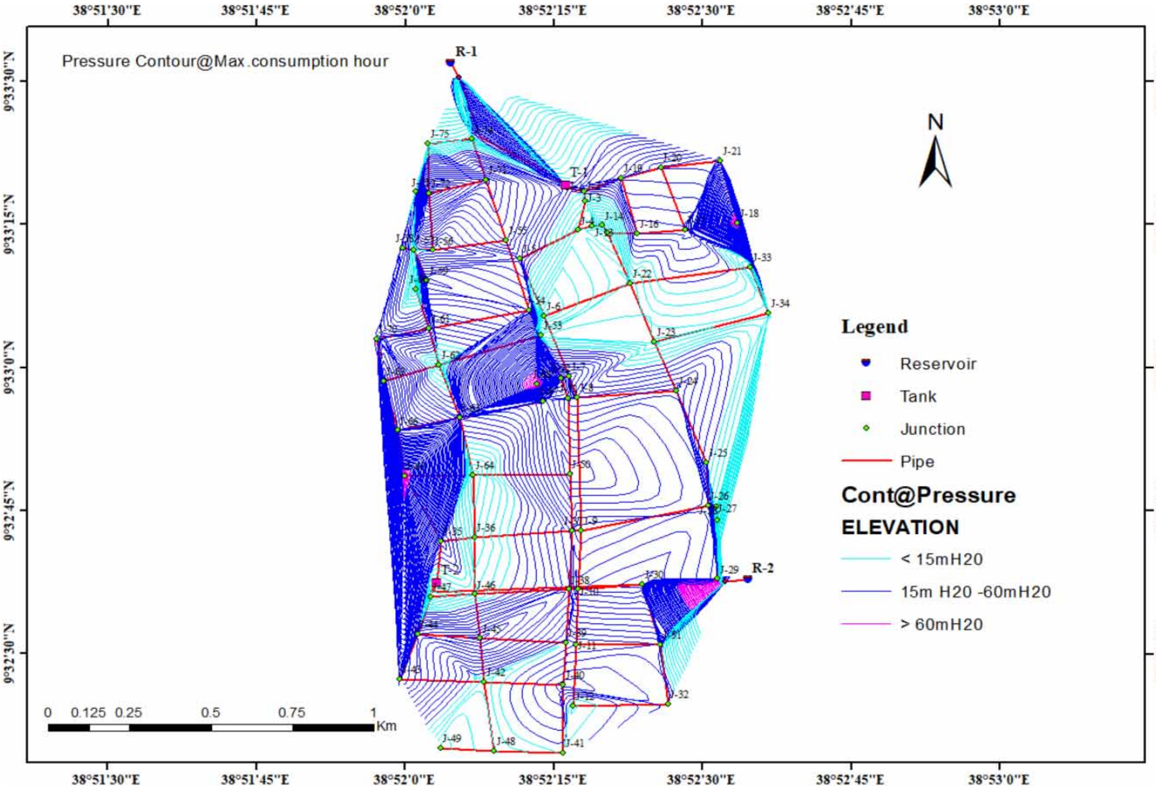

Figure 4 | Pressure variations in the town with contour descriptions.

3.4.2. Velocity distribution analysis

According to MoWR (2006), the velocity of flow in a pipe is desired to be between 0.6 and 2 m/s. The velocity in the water distribution system was observed to change as the demand pattern changed. As shown in Figure 5, during peak hour demand, 40% of the length of pipes were found to have a flow below optimum minimum

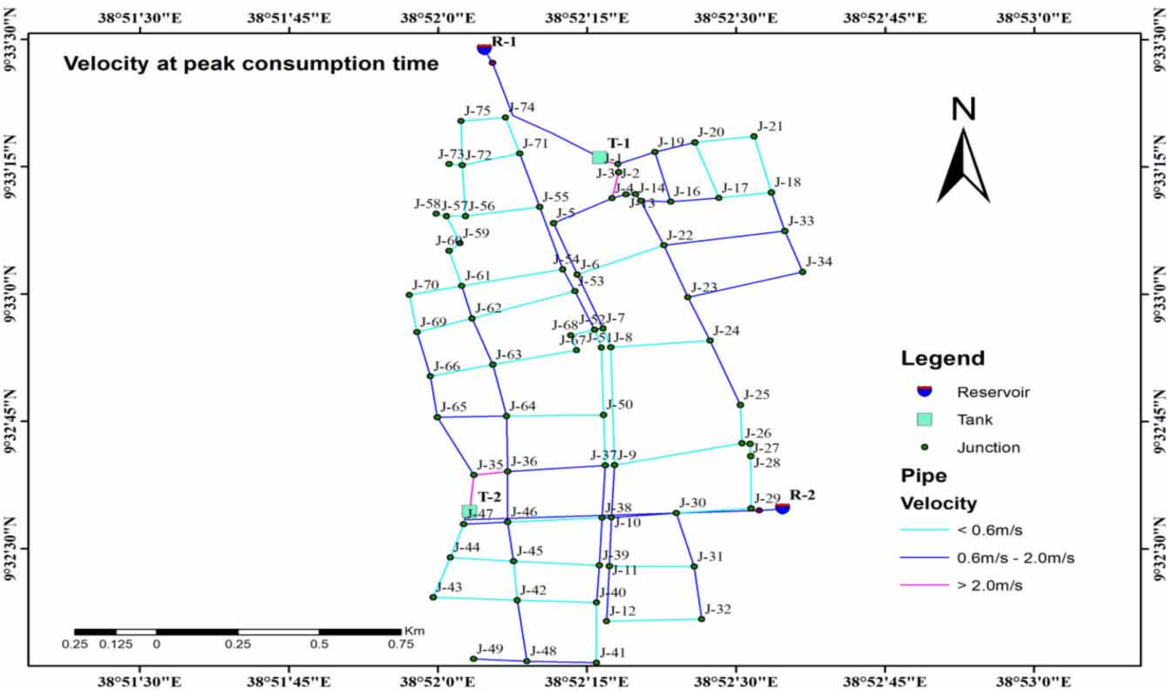

Figure 5 | Velocity at peak consumption time.

velocity (less than 0.6 m/s), while 54.52% were within the recommended velocity (0.6–2 m/s). In the remaining 5.45% of the pipes, the water was found to flow above the maximum velocity (2.0 m/s).

Similarly, during low consumption times, 19.09% of the pipes were found between the permissible velocity ranges and 80.91% were below the minimum permissible velocity limit (0.6 m/s). This is similar to the findings by Tufa & Abate (2022). Considerable lengths of pipes are operating below the recommended limits. These can be fixed by re-running the hydraulic model and adjusting the pipe sizes for optimum operation.

3.5. Water loss analysis

3.5.1. Water audit

From the water balance analysis (Table 1), the annual NRW in 2021 was found to be 129,040 m^3, which was 37.61% of total water production. The loss excluding unbilled authorized consumption was 37.45%, and thus, only 62.55% of produced water reached the consumers. According to Deme (2021), the system efficiency is

Table 1 | Water balance showing NRW components (m^3) for the year 2021

System input volume 343,140 m^3 (100%)	Authorized consumption 214,635.25 m^3 (62.55%)	Billed authorized consumption 214,100 m^3 (62.4%)	Billed metered consumption (including water exported) 214,100 m^3 (62.4%)	Revenue water 214,100 m^3 (62.4%)
			Billed unmetered consumption	
		Unbilled authorized consumption 535.250 m^3 (0.16%)	Unbilled metered consumption	NRW 129,040 m^3 (37.61%)
	Water loss 128,504.75 m^3 (37.45%)		Unbilled unmetered consumption 457.75 m^3 (0.16%)	
		Apparent losses 1,070.5 m^3 (0.312%)	Unauthorized consumption 457.75 m^3 (0.16%)	
			Customer metering inaccuracies	
		Real losses 127,434.25 m^3 (37.14%)	Leakage on transmission and/or distribution mains	
			Leakage and overflows at utility storage tanks	
			Leakage on service connections up to the point of customer metering	

acceptable if above 75% of the water produced reaches the consumer. Based on this recommendation, the efficiency of Muke Turi town water supply system is not acceptable, implying that a reduction of water losses in the town is inevitable. Figure 6 depicts the town's water production, consumption, and NRW for the last 6 years, showing that the loss has an increasing trend. The town water service administration shall therefore have, if not at once, a gradual rehabilitation plan to reduce water losses.

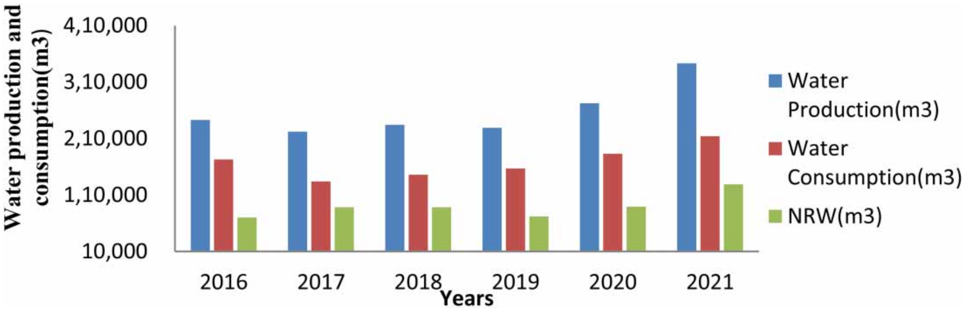

Figure 6 | Water production and consumption of the Muke Turi town.

As summarized in Table 1, the apparent losses are only 0.312%, whereas the real losses are 37.12%, implying that the total water loss in the system is attributed to physical problems in the system including leakage, bursts and overflows on the main, and service reservoir and service connection problems as affirmed during the field observations.

3.5.2. Water loss as per the number of service connections

One of the appropriate indicators of water loss in the distribution system is describing it as per the number of service connections (l/c/day), and it gives a more precise figure than NRW as a percentage of the input volume. Based on the obtained data; the total number of service connections in Muke Turi town was 1,968, and taking this, the volume of water loss as per service connection was analysed from the total unbilled volume and was found to be 298.06 l/d.

According to Sardinha *et al.* (2017), the distribution system is said to be in good condition if the loss is less than 250 l/connection/day, in average condition if it is 250–450 l/connection/day, and in bad condition if it is greater than 450 l/connection/day. Based on the aforementioned guide, the system at Muke Turi town is in average condition, showing that the system requires improvement to reduce the existing losses.

3.5.3. Water loss as per main pipe length

The other good indicator of water loss in the distribution network is determining loss as per pipe length (litres per kilometre of pipeline per day (l/km/d)). According to the town water utility, the total length of the water distribution line including both the riser and main line was 19.74 km. Therefore, using this, the estimated amount of water loss per kilometre of the pipe length of the town was found to be 29,709.04 l/km/d.

According to Sardinha *et al.* (2017), the distribution system is said to be in good condition if the loss is less than 10,000 l/km/day, in average condition if it is 10,000–18,000 l/km/day, and in bad condition if it is greater than 18,000 l/km/day. Accordingly, the Muke Turi water supply distribution system is in bad condition in terms of water loss per pipe length, indicating that the system needs improvement.

3.5.4. Physical performance indicators

Based on the analysis, the UARL and ILI of the town were found to be 82.1 m^3/d and 4.31, respectively. According to Farley *et al.* (2008), the performance indicator of the physical loss target matrix for developing countries was categorized as good, when ILI values are between 1 and 4, which could be a further loss reduction. Therefore, further loss reduction and improvement of the network are needed using economically effective options such as active leakage control and pressure management. The value of ILI indicates that the current annual real losses were 4.31 times as high as UARL for the system.

4. CONCLUSIONS

The study was conducted in Muke Turi town, North Shewa District, Oromia Regional State, Ethiopia, with the objective of performance evaluation of the water supply distribution system, which included water supply coverage, water losses, and hydraulics performance of the town's water distribution system. From the annual water consumption of the town, the current average per capita consumption was found to be 12.72 l/c/d. Based on the water balance analysis, the existing water supply and demand gap was found to be 11.6 l/s, and the water supply coverage of the entire town was 43.34%. According to the hydraulic performance analysis, 33.33% of the pipe nodes in the distribution system have a pressure below 15 m and 64% within the recommended limit (15–60 m), while the remaining 2.67% is above 60 m during peak consumption hours. Similarly, the nodal pressures at low consumption were computed. However, it was found that the pressures at low consumption hours were greater than those found at maximum consumption because there was a minimum flow at low consumption time (in the middle of the night). In terms of velocity during peak hour demand, the flows were below optimum minimum velocity (less than 0.6 m/s) in 40% of the pipes, while the flows were at the recommended velocity ranges (0.6–2 m/s) in 54.52% of the pipes. The study also found that the real loss was large, and it covered 37.14% of the total volume of water losses in the system, while the apparent loss and unbilled authorized consumption contributed 0.31 and 0.16% of total NRW, respectively. The losses per number of connections and main pipe length were also estimated and were found as 298 l/connection/d and 29,709 l/km/d, respectively. Both these values of losses showed that the system requires improvement to reduce the existing losses. Based on the performance indicators for the losses, the UARL and ILI values were found to be 82.1 m^3/d and 4.31, respectively. Finally, the result of the analysis revealed that the overall technical performance of the existing water distribution of the town is poor, which is reflected by low water production and consumption, high level of NRW, and low water supply coverage, and the velocity and pressure in significant portions of the pipeline and pipe nodes are not in the permissible range. The town water supply administration shall, therefore, focus on resolving the problems of shortage of water supply by finding alternative water sources and controlling water losses through detection of leakages based on the pressure distribution and fixing them as an immediate remedy, but in the long run, it is important to regularly monitor the system and strengthen the town water supply service management.

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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.

REFERENCES

Abdulsamad, A. A. & Abdulrazzaq, K. A. 2022 Calibration and analysis of the potable water network in the Al-Yarmouk region employing water GEMS and GIS. *Journal of the Mechanical Behavior of Materials* **31**(1), 298–305.

Belachew, S., Shiferaw, T., Temam, D. & Diriba, H. 2021 Evaluating hydraulic performance of water supply distribution network: a case of Asella Town, Ethiopia. *International Journal of Advances in Engineering and Management* **3**(10), 1418–1433.

CSA 2015 *Central Statistical Agency of Ethiopia, Annual Report*. Available from: http://www.csa.gov.et/index.php/2013-02-20-13-43-35/national-statistics-abstract/141-population.

Dai, P. D. & Li, P. 2016 Optimal pressure regulation in water distribution systems based on an extended model for pressure reducing valves. *Water Resources Management* **30**(3), 1239–1254.

Deme, A. 2021 *Evaluating Hydraulic Performance of Water Supply System in the Case of Gerba Guracha Town, Ethiopia*. Unpublished MSc Thesis, Bahir Dar University, Bahir Dar, Ethiopia.

EPA 2005 *Water Distribution System Analysis: Field Studies, Modeling and Management – A Reference Guide for Utilities*. United States Environmental Protection Agency, Cincinnati, Ohio.

Farley, M., Wyeth, G., Ghazali, Z., Istandar, A. & Singh, S. 2008 *The Manager's Non-Revenue Water Handbook: A Guide to Understanding Water Losses*. United States Agency for International Development (USAID), pp. 1–110.

Fikadu, R. 2018 *Urban Water Supply System Performance Assessment: The Case of Holeta Town, Ethiopia*. Unpublished MSc Thesis, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia.

Frauendorfer, R. & Liemberger, R. 2010 *The Issues and Challenges of Reducing Non-Revenue Water*. Available from: http://hdl.handle.net/11540/1003.

Gebrehiyot, T. 2015 *Assessing Water Supply Coverage and Water Losses in Distribution System: A Case Study of Debre Birhan Town, Ethiopia. Unpublished MSc Thesis*, Arba Minch University, Addis Ababa, Ethiopia.

Heryanto, T., Sharma, S. K., Daniel, D. & Kennedy, M. 2021 Estimating the economic level of water losses (ELWL) in the water distribution system of the city of Malang, Indonesia. *Sustainability* **13**(6604), 1–15. doi.org/10.3390/su13126604.

Jalal, M. M. 2008 *2008 Performance Measurement of Water Distribution Systems (WDS). A Critical and Constructive Appraisal of the State-of-the-Art*. Master of Applied Science Thesis, University of Toronto, Toronto, ON. Available from: https://hdl.handle.net/1807/17207.

Kefyalew, L. 2018 *Urban Water Supply System Performance Assessment: The Case of Alem Gena Town*. Unpublished MSc Thesis, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia.

Kuma, T. & Abate, B. 2021 Evaluation of hydraulic performance of water distribution system for sustainable management. *Water Resources Management* **35**(15), 5259–5273.

Legese, L. 2020 *Hydraulic Performance of Gimbi Town Water Distribution Network*. Unpublished MSc Thesis, Addis Ababa Institute of Technology, Addis Ababa University, Addis Ababa, Ethiopia.

Mekonnen, Y. A. 2018 Population forecasting for design of water supply system in Injibara Town, Amhara Region, Ethiopia. *Civil and Environmental Research* **10**(10), 54–65.

Mishra, A. K., Sudarsan, J. S. & Suribabu, C. R. 2022 Performance evaluation of existing water supply system: a case study. *International Journal of Energy and Water Res*. doi:10.1007/s42108-022-00195-z.

MoWIE 2019 Second Growth and Transformation National Plan for the Water Supply and Sanitation Sub-Sector (2015/16–2019/20) Ministry of Water, Irrigation and Energy, Addis Ababa, Ethiopia.

MoWR 2006 *Urban Water Supply Design Criteria*. Water Resources Administration Urban Water Supply and Sanitation Department, Ministry of Water, Irrigation and Energy, Addis Ababa, Ethiopia. pp. 1–60.

Muluken, S. 2015 *Hydraulic Modeling and Improvement of Addis Ababa Water Supply System: The Case of Bole Bulbula*. Unpublished MSc Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Muranho, J., Ferreira, A., Sousa, J., Gomes, A. & Sá Marques A. 2014 Technical performance evaluation of water distribution networks based on EPANET. In: *12th International Conference on Computing and Control for the Water Industry*, Vol. 70. Procedia Engineering, pp. 1201–1210.

Pandya, N. C., Popawala, R. & Yadav, S. M. 2019 Performance evaluation of water distribution parameter. *International Journal of Research and Analytical Reviews* **6**(2), 289–295.

Sardinha, J., Serranito, F., Donnelly, A., Marmelo, V., Saraiva, P., Dias, N., Guimaraes, R., Morais, D. & Rocha V. 2017 *Active Water Loss Control*, 2nd edn. EPAL Technical Editions. Available from: https://www.epal.pt/EPAL/docs/default-source/epal/technical-editions/active-water-loss-control.pdf?sfvrsn=6 (accessed 10 September 2023).

Tekile, A. & Legesse, Y. Z. 2023 Overall performance evaluation of an urban water supply system: a case study of Debre Tabor Town in Ethiopia. *Journal of Water, Sanitation and Hygiene for Development* **13**(4), 250–264.

Toma, Z. T. & Dananto, M. 2022 Evaluating the hydraulic performance of existing water supply distribution system: the case of Teblela Town of Wolaita Zone, Southern Ethiopia. *International Journal of Advanced Multidisciplinary* **1**(3), 181–198.

Tufa, G. & Abate, B. 2022 Assessment of accessibility and hydraulic performance of the water distribution system of Ejere Town. *AQUA-Water Infrastructure, Ecosystems and Society* **71**(4), 577.

Waas, T., Huge, J., Block, T., Wright, T., Benitez-capistros, F. & Verbruggen, A. 2014 Sustainability assessment and indicators: tools in a decision-making strategy for sustainable development. *Sustainability* **6**(9), 5512–5534.

WHO 2022 *Guidelines for Drinking-Water Quality*, 4th edn. World Health Organisation, Geneva. Available from: https://www.who.int/publications/i/item/9789240045064 (accessed 8 September 2023).

Workneh, Z. G., Gebremedhin, E. K., Beyene, N. A. & Nigatu, N. M. 2023 Hydraulic performance evaluation of Yeka Abado supply zone of Addis Ababa's water distribution network. *AQUA – Water Infrastructure, Ecosystems and Society*. doi:10.2166/aqua.2023.025.

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