Research Article
Volume 15:1, 2025

Journal of Civil and Environmental Engineering

ISSN: 2165-784X Open Access

Existing Water Distribution Network Analysis for Endagebrial Subsystem, Mekelle City, Ethiopia

Tsigabu Hailu*

Department of Water Supply and Sanitation, Africa Center of Excellence for Water Management, Addis Ababa, Ethiopia

Abstract

The efficient management of water distribution networks is crucial for ensuring reliable water supply in urban areas. This study focuses on the analysis of the existing water distribution network for the Endagebrial subsystem in Mekelle city, Ethiopia. The primary objective is to evaluate the current performance of the network and identify areas for improvement to meet the growing water demand. Using EPANET 2.0, widely used hydraulic simulation software, the study models the water distribution network to assess its hydraulic performance. Key parameters such as pressure, flow rate, and velocity are analyzed under various demand scenarios. The network's ability to maintain adequate pressure and flow during peak demand periods is a critical aspect of the analysis.

The results indicate that certain sections of the network experience low pressure, particularly during peak hours, which can lead to insufficient water supply to end-users. Additionally, the study identifies areas with high head loss, suggesting the need for pipe replacement or resizing to enhance the network's efficiency. The analysis also highlights the impact of aging infrastructure on the network's performance, emphasizing the importance of regular maintenance and upgrades.

Recommendations for improving the water distribution network include the installation of pressure-regulating valves, upgrading undersized pipes, and implementing a more robust maintenance schedule. These measures are expected to enhance the overall reliability and efficiency of the water supply system, ensuring that it can meet the future demands of Mekelle city's growing population.

This study provides valuable insights into the current state of the Endagebrial subsystem's water distribution network and offers practical solutions for its improvement. The findings can serve as a reference for urban planners and water utility managers in Mekelle city and other similar urban settings, contributing to the sustainable management of water resources.

Keywords: Endagebrial • Water Distribution System (WDS) • Mekelle city • GIS software • Hydraulic pressures

Introduction

The fundamental goal of a Water Distribution System (WDS) is to convey water from water sources to designated endpoints while meeting specified water quantity, quality, and pressure standards [1]. This water is frequently provided via complicated distribution systems that include miles of pipe and several pumps, regulating valves, and storage reservoirs. Elements of water distribution network are a major problem to poor performance; the breakdown of the pumps, increase in power consumption, and problems in the water pipeline are often collected at the plants for investigation [2]. Hydraulic modeling is a multi-stage procedure that involves verifying all aspects of the water supply network. Today's IT systems allow databases and computational programs to be integrated, allowing for real-time model construction and simulation [3]. Due to its numerous components, non-linear hydraulics, and complex demand patterns, water distribution systems are challenging to study. As a result, computer network models are necessary to calculate distribution system flows and pressures [4]. Due to population expansion and increased water demand, the water demand allocation plan requires additional attention [5]. Hydraulic modeling software can allocate water consumption to the nearest pipe or node. In a GIS or hydraulic model, Thiessien polygons can be built around strategic nodes in a polygon's water consumption. Water consumption from these meters can be allocated to the closest pipe.

***Address for Correspondence:** *Tsigabu Hailu, Department of Water Supply and Sanitation, Africa Center of Excellence for Water Management, Addis Ababa, Ethiopia; E-mail: tsigabu2693@gmail.com*

Received: 08 December, 2023, Manuscript No. JCDE-23-122374; **Editor assigned:** 12 December, 2023, PreQC No. JCDE-23-122374 (PQ); **Reviewed:** 26 December, 2023, QC No. JCDE-23-122374; **Revised:** 21 January, 2025, Manuscript No. JCDE-23-122374 (R); **Published:** 28 January, 2025, DOI: 10.37421/2165-784X.2025.15.582

Data was collected from population density, point-wise consumption data, and consumption data as area [6]. According to the water demand projection was based on population furcated and per capital demand [7,8]. For the demand were identified the branches within the DMAs and manually calculated the consumption using the available billing dataset [9]. The nodal demands are obtained from the consumer usage information, *i.e.*, from billing data. The generalized diurnal demand pattern for the entire distribution network is created based on an hourly flow recorded by the flow meter installed on the outlet pipe of the Ramnagar GSR [10].

C.V.S.S. Sudheer, et al. compares various methods available in demand control center of WaterGEMS software and allocation of demands to the node and concludes that, Thiessen polygon method is accurate and efficient when compared to that of unit pipe length method and equal distribution method [11]. The other type of to be considered are firefighting demand and unaccounted for water, unaccounted water was estimated by calculating the difference between the total supply from the billing records and the system's daily supply for the same period. The method for allocating baseline demands is flow distribution method illustrated in that involve distributing a lump-sum demand among a number of service polygons [12]. The WaterGEMS reveals the scenario computed about conduit pressure, flow characteristics such as discharge, velocity, and head-loss and more accurate than the others [13,14].

Demand-Driven Analysis (DDA) and Pressure-Driven Analysis (PDA) are two types of Water Distribution Network (WDN) analysis (PDA) [15]. Compared the Demand Drive Approach (DDA) and the Pressure Drive Approach (PDA) and concluded that Demand-Driven Analysis (DDA) at which engineers satisfy the demand at each node and then calculate the pressure in the design of new networks [16]. In modeling, urban water network was designed based on pressure criteria and in accordance with the existing criteria on minimum and maximum pressure in the network [17].

Darwin calibrator is a technology for calibrating water distribution networks that is both quick and accurate. It allows you to freely manage field data, choose calibration criteria, and weigh the value of accurate field data results [18]. Comparisons between a model and field data should be made in terms of HGL values that can potentially be adjusted rather than pressure values. While both are related, HGL values can be compared at a glance unless the ground is completely level; pressures cannot be compared so easily [19]. In Mekelle, Ethiopia, municipal waterworks are continually repairing and rebuilding water distribution network infrastructure, mostly in the Endagebrial subsystem (Pressure zone one). The water distribution system in the community is unbalanced, and the network is poorly planned. The goal of this study is to create a water distribution network to remedy the Endagebrial subsystem's current water distribution imbalance.

Materials and Methods

Description of the study area

The Endagebrial subsystem is based in Mekelle, Ethiopia's northernmost city. This subsystem is on the 1965 m-2220 m subsystem and is located in the southern part of Mekelle city. It covers 105.2 km^2 and is located on the 1965 m-2220 m subsystem. It lies between 39°210-39°430E and 13°240-13°300N as shown in Figure 1, with an average mean temperature of 19°C, altitudes ranging from 1965 to 2220 meters above sea level, with annual rainfall ranging from 450 to 600 millimeters. The Water Supply and Sanitation Service (MWSSS) is in responsibility of providing water to the general public, regulating water charge prices, and managing water supply. In 2021, there are 6023 households with a population density of 5 people per house.

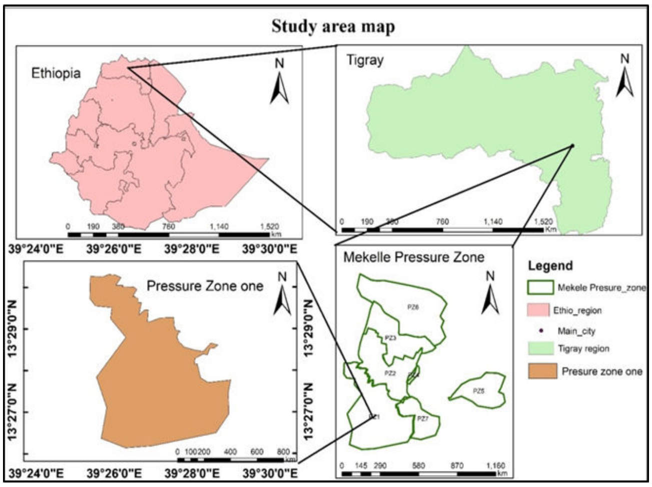

Figure 1. Map of location study area.

Endagebrial subsystem water supply system

The endagebrial subsystem's current water source provides water from 13 boreholes with a combined average water production capacity of roughly 34 l/s, while the delivered water to the consumer is 19 l/s, according to data collected by the Mekelle Water Supply and Sanitation Service (MWSS). It draws water from boreholes, which are underground wells. In the Endagebrial subsystem, there are 13 water sources and three reservoirs: Endagebrial (2000 m^3), Ashago (500 m^3), and Endagebrial (500 m^3), which serve as storage reservoirs. The WDS of the subsystem in Figure 2, was investigated using a typical branched and looped network made of a mix of DCI, HDPE, GI, and PVC pipe materials with diameters ranging from 40 mm to 400 mm, beginning at the borehole and ending at each consumer, with a total estimated length of distribution lines of about 87.2 km.

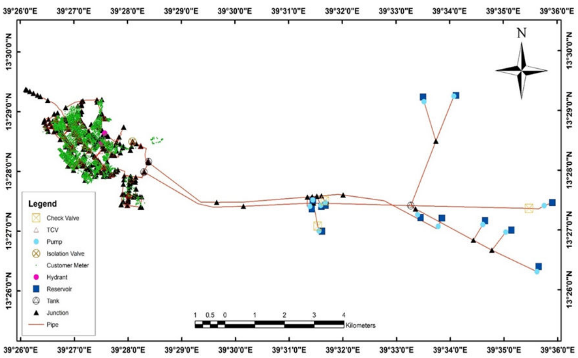

Figure 2. Layout of water distribution network system.

Data and analysis of data

The data that is used in this study consists of data on the number of households and the amount of consumption from recorded bills, study area, data on water production, scheme and technical data on pipe network, and measured pressure. However, the steps of study are as followed:

- To collect the secondary data that is technical data and the other supporting data that is used in the network. analysis.
- To calculate the amount of consumption per household and total water demand.
- To analyze the performance of the network system.
- To calibrate the model using primary data collection for pressure measurement.

Calculated water demand and allocating

The most uncertain and driving parameter in the performance of a water distribution network is demand. The water demand is utilized in this study to evaluate the performance of the water distribution network system and to calibrate the model. The actual water demand in the subsystem was calculated using data from water utility billing records and data on borehole water abstraction. The water utility supplied information on total water consumption for the years 2018-2019, based on 6023 water meter readings. The difference between total production and total consumption was used to quantify water loss, with a 15% firefighting demand estimated. For a 24 hour flow duration period, demand was computed for each supply node using demand multiplier factors and weighted base demand. According to the billing meter aggregation is the method in which it assigns the demands to all the nodes confined within the service polygon. This method involves a detailed household survey in order to find the exact number of billing meters within the service polygon.

Model calibration

Model calibration was determined based on the results of model pressure and measured pressure in the selected nodes has been used for calibration. According to, the percentage of measurement nodes satisfied the essential minimal number of measurement points (2% of all nodes) for design and operation purposes. The metrology (Figure 3) was installed for 24 hours for each junction to measure the pressure of water at five nodes (Junction-28, Junction-259, Junction-119, Junction-234, and Junction-450) from 320 nodes for maximum hour demand (9 AM) and minimum hour demand (Midnight) for five days to check the simulation results. The model performance was evaluated using the Darwin calibrator for hydraulic grade line difference and Root Mean Square Error (RMSE).

Figure 3. Pressure measurement equipment.

Results and Discussion

Water balance

The existing water balance evaluation in the study area was quantified by computing the difference between the values of water production and consumption data. The volume of water produced from the two tanks included in the study was 34 l/the total consumption information collected for 6023 customer meters was 19 l/sec. The firefighting demand accounts for approximately 15% of the water demand, which is 2.85 l/s and is distributed as 1.42 l/hydrant/sec. Water loss was estimated to be 33% of water production, which is 12 l/s (Figure 4).

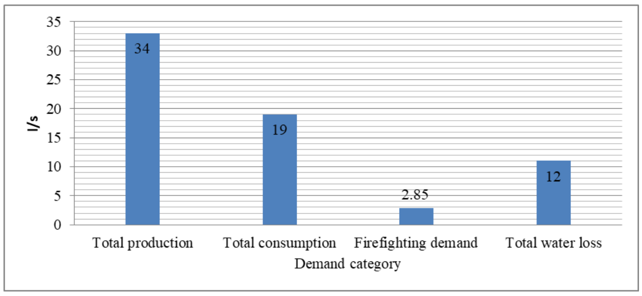

Figure 4. Water balance.

Point demand allocation

The total daily water consumption assigned to each node is the sum of consumption connected to that node with various demand patterns throughout the day. The load builder distributed requests based on geocoded meter data using GIS software's spatial analytic capabilities. Using GIS spatial analysis tools and demand allocation techniques supplied by hydraulic modeling software, water consumption from these meters may be routed to the nearest node. The result is a Thiessien polygon with a nodal location described in Figures 5 and 6.

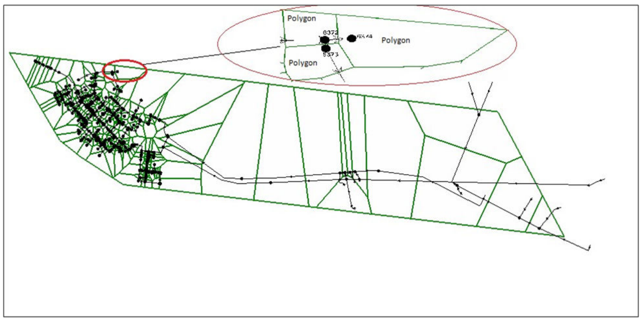

Figure 5. Partial views of Thiessen polygons for each node.

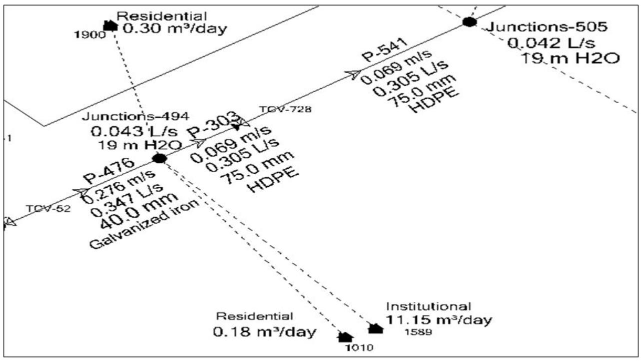

Figure 6. Customer meter and junction combination.

From Figure 6, the conservation of energy was performed using WaterGEMS software. Junctions-494 was a demand junction serving two residential (ID 1900 and ID 1010) and one institutional (ID 1589) with a calculated demand of 0.3 m^3/day, 0.18 m^3/day and 11.15 m^3/day respectively. The input and output flows for Junction 494 are 0.347 l/s and 0.305 l/s respectively. 0.042 l/s is the amount of demand needed for junction 494. Furthermore, the total flow was decreased as junction demand was available. From the study, the maximum and minimum demand calculated for each junction ranged from 0-50 m^3/day and out of 329 junctions, 70 have zero demand for the current year. The high customer meter that is assigned to a junction is 121 customer meters.

Model calibration

Figure 7 shows that the WaterGEMS model has a good capability to predict the pressure at the node, as confirmed by 7 of them, and the 3 nodes are above the acceptable hydraulic grade line. Models used for design and operations assessments would normally be subjected to the lower accuracy criterion for HGL of 1.5 m. The model calibration results showed that the WaterGEMS model is a good predictor of pressure in the study area. The Darwin calibrator module for manual calibration was used. After observed field data for the calibration study was input into this module, roughness groups with similar material and age resulted for adjustment. The defined criterion used was to minimize the sum of squares of the discrepancy between the observed data and the model simulated values.

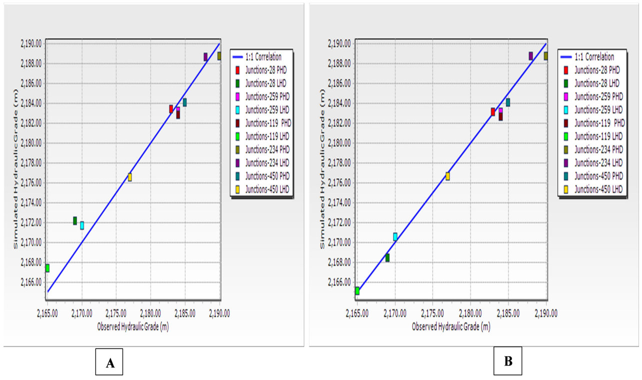

Figure 7. Correlation for observed and simulated hydraulic grade (m). (A): Correlation hydraulic grade for existing WD; (B): Correlation hydraulic grade for pipe roughness adjusted WDS.

The performance evaluation results revealed that the WaterGEMS has a promising approach to simulating the water pressure at nodes in the WDS for maximum and minimum hour demands. Figures 7A and 7B present the RSME and the correlation between observed and simulated hydraulic grade of the existing WDS and pipe roughness adjusted WDS respectively. The improved WDS was based on pipe roughness adjustment for optimization run and the RMSE pressure was 1.288 m, adjusted to 0.724 m according to. The lower the RMSE, the more accurate the estimation is the therefore, these results RSME pressures indicate that the WaterGEMS model has very good performance in the study area. Model verification was carried out using different data sets from those used during the calibration process.

Hydraulic model results

The hydraulic analysis of the existing WDS has been carried out to evaluate the hydraulic behaviors by considering the pressure and velocity in existing WDS. The study WDS includes 520 pipes of different materials, 320 junctions, 13 pumps, 13 water source reservoir, and 3 tanks (Figure 8).

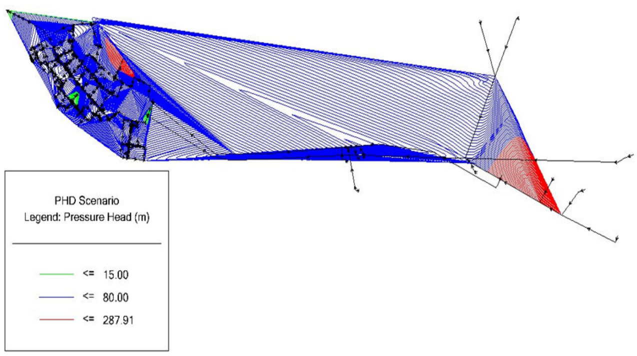

Figure 8. Map of pressure existing distribution system at PHD.

The hydraulic model result for pressure at the PHD in the existing WDS is illustrated in Table 1 and Figure 8, which compares the minimum, allowable and maximum pressures in the nodes.

Pressure grade	Number of junctions	Percentage	Calculated demand	Percentage
P<=15	15	4.6	1.38	3.08
15<P<80	309	93.9	43.424	96.83
P>=80	5	1.5	0.041	0.09

Table 1. Hydraulic results of pressures.

It has been observed that the 309 nodes (93.9%) in the existing WDS satisfied the recommended pressure of 15 m to 80 m of water as per Ethiopian standard. Some nodes were below the recommended values, which included 15 nodes (4.6%); whereas a very few nodes were above the recommended values, which held 5 nodes (1.5%). Therefore, the whole parts of the study area, particularly the minimum pressure nodes, may not get sufficient water at Peak Hour Demand (PHD) time (9:00 AM) at the reservoir area, the green color of the town. On the other hand, the maximum pressure at nodes may also cause very high-water leakage. Furthermore, pipes cause breakage of the red color at source flow to the tank. The hydraulic model result for velocity at the PHD in the existing WDS is presented in Table 2, which compares the allowable, minimum, and maximum velocities in the pipes.

Velocity grade	Number pipe	Percentage	Length	Percentage
Velocity<=0.5	400	77.1	43119	49.5
0.5<Velocity<1.5	79	15.2	15123	17.3
Velocity>=1.5	40	7.7	28923	33.2

Table 2. Hydraulic results of velocity.

The model results displayed that 15.2% (79 pipes) and 17.3% (15.1 km length) of the existing WDS met the required design velocity of the Ethiopian standard (0.5-1.5 m/s) [20]. However, 77.1% (400 pipes) were found below the minimum velocity standards and thus may cause low water quality due to an increase in the age of water in the pipes. Practically, the water supply system is intermittent and most end users face corrosion and poor water quality (Figure 9).

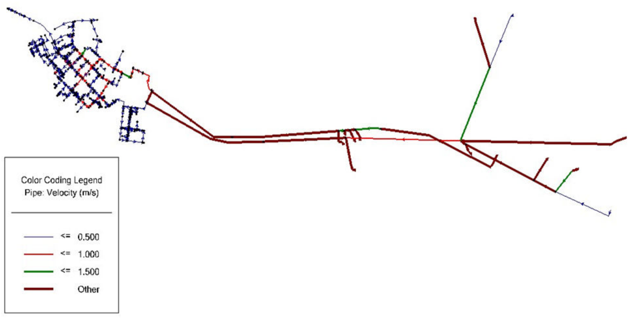

Figure 9. Map of velocity existing distribution system at PHD.

The WaterGEMS results revealed that the designed pressure and velocity did not meet the whole network of the existing WDS in the study area (Figure 9). As a result of this, the consumption of water for the study area was low and 77.1%faced below standard velocity. The flow in the pipe has experienced inadequacy of flow and siltation problems throughout the link depend on low velocity. Such a problem could increase due to decreasing consumption of water in the study area.

Conclusion

The study was addressed by assessing the water distribution network for the existing water demand with Bentley WaterGEMS software. The most uncertain variable in water distribution network modeling is demand junction. The first objective of this study was to have a reliable and acceptable result for the analysis of water distribution network systems. The objective hydraulic model analysis was based on pressure and velocity for peak hour demand and resulted in the pressure allowable for peak hour demand being 93.9%, under allowable pressure was 4.6% and above allowable pressure was 1.5%. For velocity during peak hour time, only 17.3% is with limited allowable velocity. This means, there is a shortage or insufficient supply of water for the Endagebrial subsystem. The model result had good performance with an acceptable calibration level. The findings of this study can be concluded that the WaterGEMS modeling approach is based on Thiessen polygon method and demand drive approach for assessing water distribution systems, as they confirmed for the Mekelle water distribution case study, the Endagebrial subsystem was considered in terms of hydraulic pressure and velocity efficiency.

Recommendations

Based on the study, the following recommendations have been drawn:

- An alternative source of water supply in addition to the existing system should be considered for fulfilling the self-cleaning of pipes.
- Assessment of water distribution network using a model is a solution to this problem, but the microbial treatment of supplied water is a prerequisite for the provision of safe water with regard to quality and quantity.
- In the assessment of water distribution networks in urban centers of Ethiopia and other countries, the application of WaterGEMS models can be used as an effective tool for demand allocating and further research should be done regarding the optimization of water distribution systems.

References

1. Paluszczyszyn, Daniel. "Advanced modelling and simulation of water distribution systems with discontinuous control elements." *Ph.D. Thesis, de Montroft University Licester* (2015).

2. Shibnauth, V. D., and B. Y. R. Surnam. "Issues Affecting Water Distribution Systems." *Conference on Computer Science, Data Mining and Mechanical Engg, Bangkok, Thailand* (2015).

3. Zimoch, Izabela, and Ewelina Bartkiewicz. "Process of hydraulic models calibration." *E3S Web of Conferences* 59 (2018): 00007.

4. Van Zyl, J. E. "Introduction to operation and maintenance of water distribution systems EDITION 1." *Water Research Commission* (2014).

5. Haque, Md Mahmudul, Ataur Rahman, Dharma Hagare, and Rezaul Kabir Chowdhury. "A comparative assessment of variable selection methods in urban water demand forecasting." *Water* 10 (2018): 419.

6. Momenzadeh, R, R. Azarm, and R. Aghamajidi. "Demand allocation pattern for consumption points in domestic water distribution networks: A case study of Ilam Campus." *J Biochem Tech* 2 (2018): 67-72.

7. Bisri, Mohammad Dian Sisinggih, and Wahyu Dwi Putra. "Development of clean water distribution network capacity by using watercad." *Int J Civ Eng Technol* 9 (2018): 466-473.

8. Izinyon, Osadolor C, and B.U. Anyata. "Water distribution network modelling of a small community using watercad simulator." *Global J Eng Res* 10 (2011): 35-47.

9. Alves, Z., J. Muranho, T. Albuquerque, and A. Ferreira. "Water distribution network's modeling and calibration. A case study based on scarce inventory data." *Proc Eng* 70 (2014): 31-40.

10. Jadhao, Ramrao D., and Rajesh Gupta. "Calibration of water distribution network of the Ramnagar zone in Nagpur City using online pressure and flow data." *Appl Water Sci* 8 (2018): 1-10.

11. Sudheer, Chekka V.S.S., Maddamsetty Ramesh, and Gedela Venkata Ramana. "Feasible study for allocation of nodal demands through WaterGEMS." *Adv Geotech Transport Eng* (2020): 339-352.

12. Elsheikh, Mahmoud A., Hazem I. Saleh, Ibrahim M. Rashwan, and Mohammed M. El-Samadoni. "Hydraulic modelling of water supply distribution for improving its quantity and quality." *Sustain Environ Res* 23 (2013): 403-411.

13. Paneria, Dilip Babubhai, and B. V. Bhatt. "Analyzing the existing water distribution system of Surat using Bentley Water GEMS." *J Emerg Technol Innov Res* 4 (2017): 19-23.

14. Paneria, Dipali Babubhai, and Bhasker Vijaykumar Bhatt. "Modernization in water distribution system." *Proceedings of New Horizons in Civil Engineering (NHCE-2017)* (2017): 1-6.

15. Hamed, Mohammed Magdy, Wael Hamdy Khadr, Sameh Youssef Mahfouz, and Mohamed Ashraf Elsayad. "Different methods of water distribution network analysis." *2nd International Conference of Chemical, Energy and Environmental Engineering* (2019): 1-12.

16. Riis, Thomas Sjømoen. "Modeling water distribution systems-integration between SCADA systems and hydraulic network simulation models." *Master's Thesis, NTNU* (2016).

17. Tavosi, Mohammad Ghareb, and Maaroof Siosemarde. "Hydraulic analysis of urban water-supply networks in Marivan." *Ind Eng Manag Syst* 15 (2016): 396-402.

18. Apaydın, Oncu. "Automated calibration of water distribution networks." *Master's Thesis, Middle East Technical University* (2013).

19. Walski, Thomas. "Procedure for hydraulic model calibration." *J Am Water Work Assoc* 109 (2017): 55-61.

20. MoWR. "Urban water supply design criteria." *Water Resources Administration Urban Water Supply and Sanitation Department* (2006): 1-60.

How to cite this article: Hailu, Tsigabu. "Existing Water Distribution Network Analysis for Endagebrial Subsystem, Mekelle City, Ethiopia." J Civil Environ Eng 15 (2025): 582.