*Larhyss Journal, ISSN 1112-3680, n°57, Mars 2024, pp. 81-100*


# ANALYSIS OF WATER DISTRIBUTION NETWORK USING EPANET: A CASE STUDY OF VARIAV HEADWORK SURAT-INDIA

***MEHTA D.[1*], PRAJAPATI K.[2], VERMA S.[3], KUMAR V.[4]***

[1] Civil Engineering Department Dr. S. & S. S. Ghandhy Government Engineering College, Surat, Gujarat, India
[2] Civil Designer, LEA Consulting Ltd., Canada
[3] Civil Engineering Department, National Institute of Technology Raipur, Raipur, Chhattisgarh, India
[4] Department of Civil Engineering, Dr. Vishwanath Karad MIT World Peace University, Pune 411038, India

*(*) ap_darshan_mehta@gtu.edu.in*

Research Article – Available at http://larhyss.net/ojs/index.php/larhyss/index
Received October 20, 2023, Received in revised form February 25, 2024, Accepted February 28, 2024

## ABSTRACT

Water distribution is a critical system that involves engineered hydrologic and hydraulic components to provide water supply to a continuously growing population. Ensuring a sufficient and uniform water supply through a well-designed network is essential to meet the increasing water demand. The present study focuses on analyzing the water demand of the public water supply to facilitate effective planning, development, and operation of water supply and distribution networks. The main objective of the study is to analyze the existing water distribution network at Variyav Headwork using the **Environmental Protection Agency Network Evaluation Tool (**EPANET**)**. To conduct this analysis, various data points are needed, such as the population of the area, water demand, distribution network layout, and water tank information. Additionally, details regarding the length, nodes, and diameter of the pipes are essential for the analysis. These data are input into the EPANET software to perform analyses related to pressure, head loss, and elevation. The results of the analysis provide valuable information on pressure and elevation at different nodes and head loss along various pipes in the network. By comparing the results obtained from the EPANET with actual data, the study aims to achieve an improved water distribution network at Variyav Headwork. Therefore, in the overall conclusion, the modeled result outperforms the actual data in terms of flow and velocity, where the coefficient of determination ($R^2$) is 0.924 and 0.986, and the correlation coefficient (CC) is 0.855 and 0.973, respectively. In contrast, the modeled head loss is significantly different with respect to the actual data output; $R^2$ is 0.219, and CC is 0.048. Therefore, we can say that the model satisfactorily simulated the flow and velocity and significantly reduced the head loss to 66.46 %. Hence, the insights gained from the analysis will aid in making informed decisions for enhancing the efficiency and reliability of the water supply system.

**Keywords:** Water Distribution, EPANET, Water Demand Analysis, Distribution Network, Variav Headwork.

## INTRODUCTION

Water is an indispensable element for all living organisms, serving various purposes, such as drinking, food preparation, irrigation, and manufacturing (Hountondji et al., 2020; Verma et al., 2023a). Despite water covering over 70 % of the Earth's surface, less than 1% of it is available as fresh water, and its distribution is uneven worldwide (Peslier et al., 2017). Consequently, more than one billion people, primarily in developing nations, lack access to safe drinking water. Ensuring a secure, sufficient, and reliable water supply faces numerous challenges globally (WHO/UNICEF, 2005; Moe and Rheingans, 2006; Verma et al., 2023b).

Urban areas with water treatment plants utilize a network of pipes and reservoirs to deliver treated water to consumers. Service reservoirs, often constructed with concrete, act as backup supplies and maintain steady water distribution to meet fluctuating demands (National Research Council, 2007; Verma et al., 2023c). Water towers may replace service reservoirs in flat areas, providing pressure for gravity-based distributions (Yao et al., 2022). From the service reservoirs, distribution mainly distributes water through an underground network of pipes to houses and establishments (Aroua, 2022). In urban areas, public water points are common sources of water access (Rouissat and Smail, 2022; Verma et al., 2023d; National Research Council, 2007). However, water distribution systems are susceptible to pipe failure, leading to supply disruptions and water wastage (Shamir and Howard, 1968). India, like many other regions, faces significant water challenges due to depleting groundwater tables, deteriorating water quality, and rising pollution (Singh and Singh, 2002). Access to safe drinking water remains a critical issue, affecting more than half of the population (WHO, 2023). The urban water supply further suffers from disparities in per capita supply, inadequate water quality monitoring, and dependence on distant sources for water transport (Bandari and Sadhukhan, 2021).

Furthermore, improper sewage discharge and a lack of maintenance in water supply and sanitation systems contribute to the contamination of groundwater and surface water (Edokpayi et al., 2017; Abaidia and Remini, 2020). The absence of sewage treatment facilities in many cities exacerbates this problem (Wear et al., 2021).

Several studies have been conducted to assess the performance and reliability of existing water distribution systems, as well as to design and optimize new systems. Parmar (2019) analyzed an existing network using EPANET software to assess its reliability. Mehta et al. (2016) used EPANET to analyze fluid flow in a hydraulic network, aiming to improve the water supply scheme in the Limbayat zone. Bucur et al. (2017) modeled a cooling water system for a hydropower plant using EPANET, and the results matched existing recordings for normal and critical operating scenarios. Awe et al. (2020) used EPANET and LINGO software to optimize a water distribution network layout, resulting in a 38% reduction in the total cost of installation, operation, and maintenance.

Kumar et al. (2015) designed a water supply system for an area in Himachal Pradesh using EPANET software based on per capita water consumption. Shital et al. (2016) analyzed the hydraulic behavior of the Punagam area's water distribution network using EPANET, ensuring an adequate water supply to the study area. Anisha et al. (2016) analyzed the reliability of Chirala municipality's water supply system using EPANET. Dave et al. (2015) analyzed the continuous water distribution system in Surat city using EPANET software. Mehta et al. (2015a) simulated the Punagam area's water distribution network using EPANET to identify deficiencies and make necessary recommendations. Yunarni Widiarti et al. (2020) created a design to analyze a drinking water distribution network using EPANET software, and calibration resulted in highly correlated simulated results with field conditions.

Kaltenbacher et al. (2017) presented a dynamic model using EPANET to modify the rigid water column theory, allowing dynamic changes in nodal consumption. Saminu & Sagir (2013) carried out a hydraulic analysis of a distribution network in the study area using EPANET, ensuring an adequate water supply. Mehta et al. (2016) developed a water distribution system using EPANET software to assess the hydraulic behavior of hydraulic parameters. Sivakumar & Prasad (2014) used GIS and EPANET to estimate water demand and design transmission lines for a distribution network. Previous studies indicate that EPANET software is a valuable tool for analyzing and optimizing water distribution networks. It allows for efficient planning, design, and assessment of network performance. The use of EPANET has resulted in improved water supply and distribution systems, fulfilling the requirements of water demand and pressure for various study areas. The software has proven to be a time-saving and effective solution for water supply engineers.

In this study, Variav village in Surat city is selected as the focus area, where an analysis of the existing water distribution network will be conducted using EPANET software. The objective is to improve the water quantity distribution to consumers, and the scope involves collecting pipe and junction reports, analyzing the data using EPANET software, and comparing the results with actual data.

## STUDY AREA AND DATA COLLECTION

### Study Area

Surat, located in the state of Gujarat, India, is a dynamic city experiencing rapid growth due to migration from different parts of Gujarat and other states. It is situated at the tail end of the 750 km long River Tapi, which has been the primary water source for centuries. The city's piped water supply system started in 1894 with the first water works set up at Varachha, where water is collected from the Tapi River source. Variav village, a part of Surat city, is located on the right bank of the Tapti River and was recently incorporated into the Surat Municipal Corporation as a suburb of Greater Surat (see Fig. 1).

The water distribution network in Variav village faces challenges such as pipe damage, leakages, and failures, leading to water-related problems (see Fig. 2). To address these issues, it is essential to analyze the existing water network using the EPANET software and compare the computed results with the actual data obtained from the Surat Municipal Corporation. The water supply department in Variav has a main headwork that transports water to different village headworks, including Ambheta, Dihen Pariya, Saras, and Takarma villages. The water distribution system at Variav Headwork, known as WDS-E1, consists of ESR-E1 network systems. The analysis for this project utilizes data from WDS-E1-ESR-E1, specifically the pipe report and junction report.


**Figure 1: Map of Variav Headwork, Surat City. Source: (Google Earth)**

**Figure 2: Site Visit at Variav Headwork, Surat City**

**Data Collection**

For the present study, pipe data and junction data from the Gujarat Water Supply and Sewerage Board (GWSSB) Surat were collected. Pressure, flow, velocity, and head loss gradient were collected for analysis purposes. Tables 1 and 2 summarize the collected pipe data and junction data.

**Table 1: Summary of collected pipe data**

| Pipe No. | Scaled length (m) | Hazen Williams (C) | Flow (L/s) | Velocity (m/s) | Head loss Gradient (m/km) |
|---|---|---|---|---|---|
| P-1 | 8665 | 120 | 419.488 | 0.87 | 4.49 |
| P-2 | 430 | 120 | 42.814 | 0.66 | 3.81 |
| P-3 | 1781 | 120 | 376.674 | 0.92 | 3 |
| P-4 | 6705 | 120 | 106.626 | 0.56 | 2.09 |
| P-5 | 290 | 120 | 270.048 | 0.25 | 1.62 |
| P-6 | 4539 | 120 | 100.157 | 0.54 | 5.42 |
| P-7 | 1566 | 120 | 93.212 | 0.31 | 3.12 |
| P-8 | 958 | 120 | 6.944 | 0.24 | 1.59 |
| P-9 | 8631 | 120 | 169.891 | 0.51 | 4.46 |

**Table 2: Summary of collected junction data**

| Junctions | Elevation (m) | Demand (L/s) | Pressure (m) |
|---|---|---|---|
| J-2 | 10.467 | 0 | 27.3 |
| J-3 | 9.286 | 35.68 | 26.84 |
| J-4 | 10.573 | 0 | 22.85 |
| J-5 | 13.413 | 86.86 | 11.3 |
| J-6 | 10.512 | 0 | 22.45 |
| J-7 | 6.255 | 0 | 21.6 |
| J-8 | 6.144 | 77.68 | 21.18 |
| J-9 | 6.254 | 5.79 | 20.59 |
| J-10 | 8.977 | 141.58 | 18.53 |

## METHODOLOGY

EPANET is a computer program developed by the U.S. Environmental Protection Agency's Water Supply and Water Resources Division, designed for extended-period simulation of hydraulic and water quality behavior in pressurized pipe networks. It operates under Windows and allows the analysis of networks composed of pipes, nodes, pumps, valves, and storage tanks. The software tracks water flow, pressure, tank levels, and chemical concentrations during multiple time steps, facilitating research on drinking water constituents' movement and fate within distribution systems.

EPANET serves as a research tool for enhancing understanding and assessing alternative management strategies to improve water quality. It can analyze various scenarios, such as altering source utilization, modifying pumping and tank schedules, implementing satellite treatments, and targeted pipe cleaning or replacement. The software offers an integrated environment for editing network input data, running hydraulic and water quality simulations, and visualizing results through color-coded network maps, data tables, time series graphs, and contour plots. Among its advantages, EPANET uses linear methods for flow rate computation, employs Darcy-Weisbach or Manning's formulas for head-loss calculations, considers minor losses from bends and fittings, handles varying demands over time and accommodates different demand patterns at each node. However, EPANET has some limitations, including an outdated GUI interface, lack of automatic calibration ability, inability to process or import GIS spatial data, and incapability to couple with SCADA systems.

The software's hydraulic modeling capabilities are comprehensive, featuring an analysis engine that places no limit on network size, computes friction head loss using various formulas, models constant or variable speed pumps, considers multiple demand categories at nodes with different time variations, and enables system operation through simple tank level and timer controls or complex rule-based controls. EPANET's user-friendly Windows interface simplifies the process of building piping network models and editing their properties. It offers data reporting and visualization tools, allowing the study of various water quality phenomena, including blending water from different sources, monitoring water age throughout the system, tracking chlorine residual losses, analyzing disinfection byproduct growth, and tracing contaminant propagation events.

**Model Input Parameters**

The choice of model input parameters has a significant impact on the effectiveness and performance of any machine learning or data-driven system. It is crucial to give thoughtful attention to aspects such as feature choice, data preprocessing, and hyperparameter tuning to achieve the desired outcomes. Optimal parameter choices can enhance accuracy, generalization, and model robustness, while incorrect selections may lead to subpar results or overfitting. Therefore, a deep understanding of the problem, data characteristics, and task requirements is vital in determining the best input parameters for successful model implementation.

**Junction Report**

These are points in the network where links join together and where water enters or leaves the network. The basic input data needed for junctions are:

1. Elevation above some reference (usually mean sea level)
2. Water demand (rate of withdrawal from the network)
3. Initial water quality
4. The output results computed for junctions at all time periods of a simulation are:
5. Hydraulic head (internal energy per unit weight of fluid)

6. Pressure
7. Water quality

Junctions can also:

- Have their demand vary with time
- Have multiple categories of demands assigned to them
- Have negative demands indicating that water is entering the network
- Water quality sources where constituents enter the network
- Contain emitters (or sprinklers) that make the outflow rate depend on the pressure (Shital et al., 2016)

**Pipe Report**

Pipes are links that convey water from one point in the network to another. EPANET assumes that all pipes are full at all times. The flow direction is from the end at the higher hydraulic head (internal energy per weight of water) to that at the lower head. The principal hydraulic input parameters for pipes are:

1. Start and end nodes
2. Diameter
3. Length
4. Roughness coefficient (for determining head-loss)
5. Status (open, closed, or contains a check valve)
6. The computed outputs for pipes include:
7. Flow rate
8. Velocity
9. Head loss
10. Darcy-Weisbach friction factor
11. Average reaction rate (over the pipe length)
12. Average water quality (over the pipe length) (Shital et al., 2016)

The hydraulic head lost by water flowing in a pipe due to friction with the pipe walls can be computed using one of three different formulas:

Hazen-William's formula (2) Darcy-Weisbach formula and (3) Chazy-Manning formula.

The Hazen-Williams formula is the most commonly used head-loss formula in the United States (US). It cannot be used for liquids other than water and was originally developed for turbulent flow only. The Darcy-Weisbach formula is the most theoretically correct. It applies over all flow regimes and to all liquids. The Chazy-Manning formula (refer to Eq. 1) is more commonly used for open channel flow. Each formula uses the following equation to compute head loss between the start and end nodes of the pipe:

$$h_L = Aq^B \quad (1)$$

where $h_L$= head-loss (length), q = flow rate (volume/time), A = resistance coefficient, and B = flow exponent. Table 3 lists expressions for the resistance coefficient and values for the flow exponent for each of the formulas. Each formula uses a different pipe roughness coefficient (refer to Table 4) that must be determined empirically (Shital et al., 2016).

**Table 3: Pipe head-loss formula for full flow**

| Formula | Resistance coefficient (a) | Flow exponent (b) |
|---|---|---|
| Hazen-Williams | 4.727 c-1.852 d-4.781 L | 1.852 |
| Darcy-Weisbach | $0.0252f (\varepsilon, d, q)\ d^{-5}\ L$ | 2 |
| Chezy-Manning | $4.66n^2\ d^{-5.33}\ L$ | 2 |

From Table 3, c = Hazen-William's roughness coefficient, ε = Darcy-Weisbach roughness coefficient (ft.), f = friction factor (dependent on ε, d, and q), n = Manning roughness coefficient, d = pipe diameter (ft.), L = pipe length (ft.), and q = flow rate (cfs).

**Table 4: Roughness coefficient for new pipe**

| Materials | Hazen Williams (C) | Darcy-Weisbach | Manning's |
|---|---|---|---|
| Cast Iron | 130-140 | 0.85 | 0.012-0.015 |
| Concrete or Lined Concrete | 120-140 | 1.0 | 0.012-0.017 |
| Galvanized Iron | 120 | 0.5 | 0.015-0.017 |
| Plastic | 140-150 | 0.005 | 0.011-0.015 |
| Steel | 140-150 | 0.15 | 0.015-0.017 |
| Vitrified Clay | 110 | - | 0.013-0.015 |

Pipes can be set open or closed at preset times or when specific conditions exist, such as when tank levels fall below or above certain set points or when nodal pressures fall below or above certain values.

**Steps Involves in EPANET Software**

**Step 1:** Draw a network representation of the distribution system or import a basic description of the network placed in a text file (see Fig. 3).

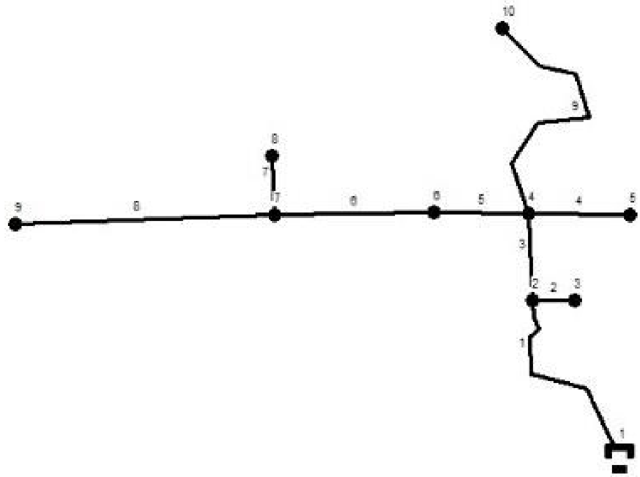

**Figure 3: Water distribution network**

**Step 2:** Edit the properties of the objects that make up the system (see Figs. 4 and 5). It includes editing the properties and entering the needed data in various objects, such as reservoirs, pipes, nodes or junctions.

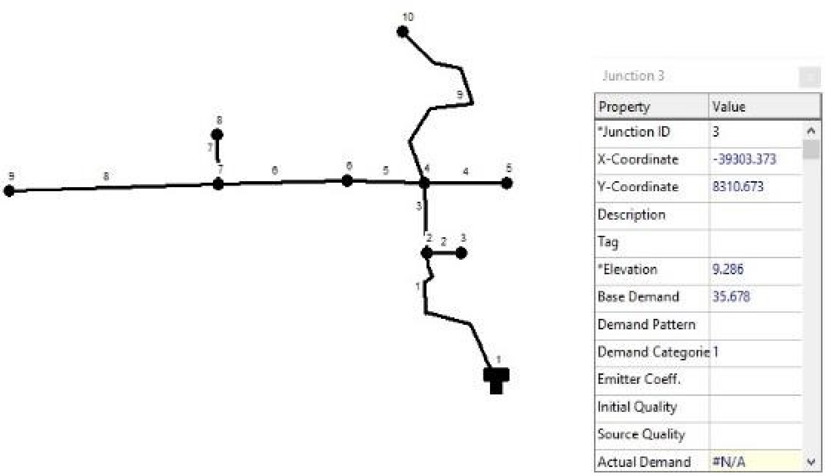


**Figure 4: Property editor for junctions**

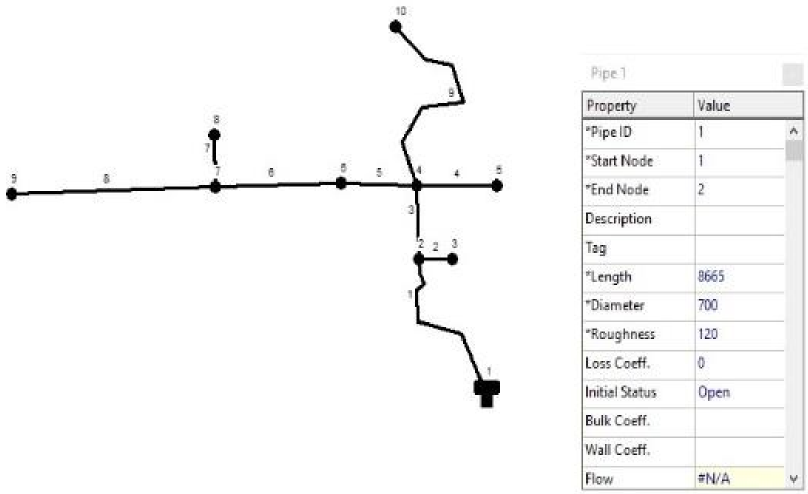


**Figure 5: Property editor for pipe**

**Step 3:** Describe how the system is operated and select a set of analysis options (see Fig. 6).

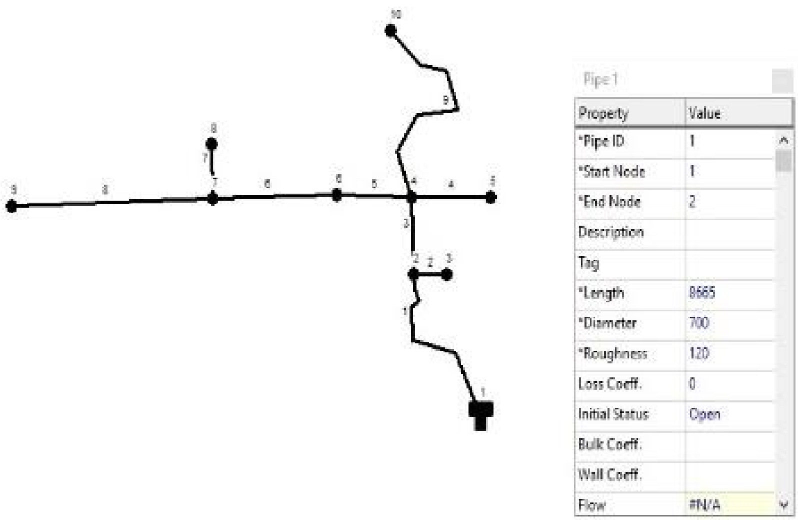


**Figure 6: Selection of types of analysis**

**Step 4:** Run a hydraulic/water quality analysis (refer to Fig. 7).

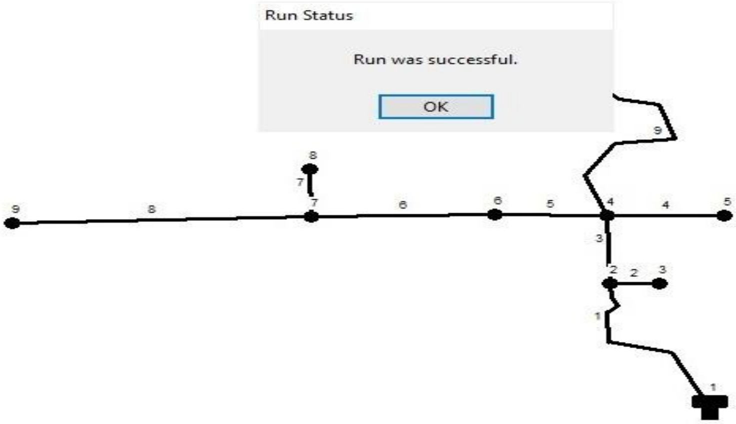


**Figure 7: Running of analysis**

**Step 5:** View the results of the analysis, which can be viewed in various forms, i.e., in the form of tables and graphs (refer to Fig. 8).

**Step 6:** Repeat the procedure for other distribution networks.

Network Table - Nodes at 0:00 Hrs

| Node ID | Base Demand LPS | Demand LPS | Head m | Pressure m |
|---|---|---|---|---|
| Junc 2 | 0 | 0.00 | 36.16 | 25.70 |
| Junc 3 | 35.678 | 35.68 | 35.17 | 25.88 |
| Junc 4 | 0 | 0.00 | 32.95 | 22.38 |
| Junc 5 | 86.855 | 86.86 | 23.47 | 10.06 |
| Junc 6 | 0 | 0.00 | 32.90 | 22.39 |
| Junc 7 | 0 | 0.00 | 27.76 | 21.51 |
| Junc 8 | 77.677 | 77.68 | 27.24 | 21.10 |
| Junc 9 | 5.787 | 5.79 | 26.84 | 20.59 |
| Junc 10 | 141.576 | 141.58 | 27.44 | 18.46 |
| Tank 1 | #N/A | -347.57 | 46.63 | 13.31 |

**Figure 8: Analysis of tables**

## RESULTS AND DISCUSSION

This section involves the results of the pipe data, which consist of flow, velocity and head loss, and the results of the junction data, which consist of pressure results. Analysis of the results was carried out, and the errors between the computed results and actual results were compared for the junction and pipe reports of the distribution network.

### Analysis of Data

#### *Junction Data*

It includes 10 junctions. The results obtained using EPANET are presented in Table 5. The error between the actual pressure and pressure computed by EPANET is also shown in Table 5. The pressure profile for WDS ESR E1 is shown in Fig. 9.

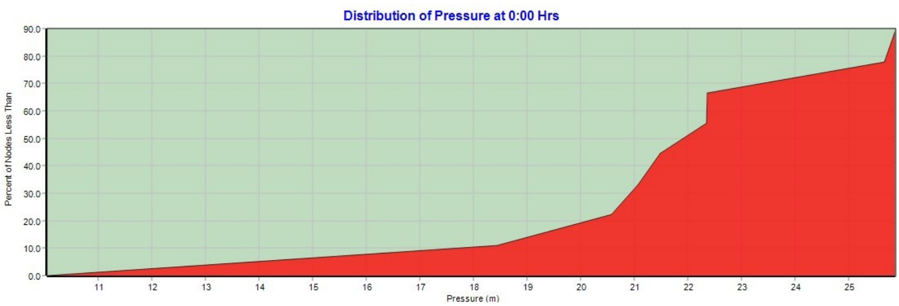


**Figure 9: Pressure profile of the water distribution network**

The assessment of pressure depends on the Hazen-Williams methodology, which enjoys widespread acceptance in the realms of engineering and fluid dynamics. This approach provides a pragmatic and effective way to compute pressure in diverse piping systems, ensuring the smooth conveyance of fluids while taking into account variables such as pipe material, diameter, and flow rate. Through the utilization of the Hazen-Williams formula, engineers can establish and uphold systems that enhance water distribution, rendering it an essential instrument in the realm of hydraulic engineering. Therefore, to summarize, the pressure values derived from EPANET, although useful for network analysis and planning purposes, often fall short of accurately representing the true flow conditions within the system. This discrepancy suggests that pipe friction, unforeseen shifts in demand, or other dynamic factors may have an impact on real-world hydraulic situations. It is imperative for engineers and water system operators to recognize this limitation when relying on EPANET results for decision-making. This underscores the importance of periodic field validation and a thoughtful interpretation of simulation results to guarantee the dependability and efficiency of water distribution networks. Therefore, the variation in pressure head within EPANET, a vital parameter in water distribution systems, calls for diligent oversight and control. Grasping these fluctuations holds immense importance in upholding system dependability and water quality. Through the utilization of adept modeling, effective control approaches, and routine upkeep, operators can alleviate pressure head fluctuations, guaranteeing the steady provision of safe and dependable water to consumers. This not only ensures public health but also enhances the overall effectiveness and sustainability of the water distribution network, underscoring the significance of EPANET as a valuable resource for optimizing water supply systems.

**Table 5: Analysis of junction data**

| Label | Pressure (m) | |
|---|---|---|
| | Actual | EPANET |
| J-2 | 27.3 | 25.7 |
| J-3 | 26.84 | 25.88 |
| J-4 | 22.85 | 22.38 |
| J-5 | 11.3 | 10.06 |
| J-6 | 22.45 | 22.39 |
| J-7 | 21.6 | 21.51 |
| J-8 | 21.18 | 21.1 |
| J-9 | 20.59 | 20.59 |
| J-10 | 18.53 | 18.46 |

***Pipe Data***

The pipe report of WDS ESR-1 includes 9 pipes. The results obtained using EPANET software for WDS ESR-SE-1 are presented in Table 6. The error between the actual flow and flow computed using EPANET software is compared. The error between the actual head loss and head loss computed by the EPANET software is also compared.

The velocity results obtained from EPANET consistently surpass the observed actual velocities, suggesting a potential problem of overestimation. This notable difference, which can be as high as 50%, underscores the importance of rigorously calibrating and validating EPANET models to guarantee precise hydraulic simulations. Hence, the flow computed using EPANET consistently falls short of the actual flow, sometimes by as much as 50%. Subsequently, the calculated head loss in EPANET appears to underestimate the actual head loss in our analysis. This discrepancy implies that the model's predictions may not comprehensively account for the complexities within the system. Variables such as pipe roughness, turbulence, or real-world operational fluctuations could contribute to this disparity. It is crucial to exercise caution when interpreting EPANET results and to acknowledge the potential disparities between model estimates and real-world hydraulic conditions in water distribution systems. This will lead to more precise assessments and better-informed decision-making.

**Table 6: Analysis of pipe data**

| Label | Flow (L/s) | | Velocity (m/s) | | Head loss Gradient (m/km) | |
|---|---|---|---|---|---|---|
| | Actual | EPANET | Actual | EPANET | Actual | EPANET |
| P-1 | 419.488 | 347.57 | 0.87 | 0.9 | 4.49 | 1.21 |
| P-2 | 42.814 | 35.68 | 0.66 | 0.73 | 3.81 | 2.32 |
| P-3 | 376.674 | 311.89 | 0.92 | 1.1 | 3 | 1.81 |
| P-4 | 106.626 | 86.86 | 0.56 | 0.69 | 2.09 | 1.41 |
| P-5 | 270.048 | 83.46 | 0.25 | 0.3 | 1.62 | 0.16 |
| P-6 | 100.157 | 83.46 | 0.54 | 0.66 | 5.42 | 1.13 |
| P-7 | 93.212 | 77.68 | 0.31 | 0.4 | 3.12 | 0.33 |
| P-8 | 6.944 | 5.79 | 0.24 | 0.33 | 1.59 | 0.96 |
| P-9 | 169.891 | 141.58 | 0.51 | 0.6 | 4.46 | 0.64 |
| Mean | 176.21 | 130.44 | 0.54 | 0.63 | 3.29 | 1.11 |
| Std | 138.31 | 112.45 | 0.23 | 0.25 | 1.28 | 0.65 |
| Cv | 0.78 | 0.86 | 0.43 | 0.39 | 0.39 | 0.59 |
| CC | 0.855 | | 0.973 | | 0.048 | |
| $R^2$ | 0.924 | | 0.986 | | 0.219 | |
| % change | 25.97 | | 16.66 | | 66.46 | |

As per Table 6, we also assess the model performance (i.e., mean, standard deviation, coefficient of variation, correlation coefficient, coefficient of determination, percentage change) and compare it to the observed data in terms of flow, velocity, and head loss.

According to the findings (see Table 6), the mean of the model flow (i.e., 130.44 L/s) is slightly different from the actual flow value (176.21 L/s). Similarly, the standard deviation (Std.) and coefficient of variation (Cv) are also different from the actual flow value. In addition, the CC, $R^2$, and % change are also calculated for the modeled flow with respect to the actual flow. However, the significance results obtained were CC = 0.855, $R^2$ = 0.924, and 25.97% change.

Based on the results, there is a slight disparity between the mean of the modeled flow velocity (0.63 m/s) and the actual flow velocity value (0.54 m/s). Likewise, the standard deviation (Std.) and coefficient of variation (Cv) also deviate from the actual flow velocity. Additionally, we assessed the correlation coefficient (CC), the coefficient of determination ($R^2$), and the percentage change in relation to the modeled flow compared to the actual flow velocity. The statistical significance tests yielded the following results: CC = 0.973, $R^2$ = 0.986, and a 16.66% change (refer to Table 6).

The results indicate a significant difference between the average modeled head loss (1.11 m/km) and the actual head loss value (3.29 m/km). Furthermore, the standard deviation (Std.) and coefficient of variation (Cv) also exhibit disparities from the actual head loss. In addition, we examined the correlation coefficient (CC), coefficient of determination ($R^2$), and percentage change relative to the modeled output compared to the observed data. The statistical significance tests produced the following outcomes: CC = 0.048, $R^2$ = 0.219, and 66.46% variation (refer to Table 6). Therefore, in the overall conclusion, the modeled result outperforms the actual data in terms of flow and velocity, where $R^2$ is 0.924 and 0.986 and CC is 0.855 and 0.973, respectively. In contrast, the modeled head loss is significantly different with respect to the actual data output; $R^2$ is 0.219, and CC is 0.048. Therefore, we can say that the model satisfactorily simulated the flow and velocity and significantly reduced the head loss to 66.46%.

## CONCLUSION

In this study, the existing water distribution network was analyzed with the help of EPANET software, in which we used the number of nodes, elevation, number of pipes and demands of Variav village. The main focus of this study is to analyze the water distribution network and identify deficiencies in its suitability, implementation and usage. At the end of the analysis, it was found that the resulting pressures at all the junctions and the flows with their velocities at all pipes are enough to provide water to the study area. It was observed that the pipes connected to the tanks as distribution pipes to the other pipes had smaller diameters. A comparison of these results indicates that the simulated model seems to be better than the actual network. Discharge should be increased to achieve the base demand. This study will help water supply engineers.

This case study underscores the crucial role of periodic network analysis and simulation in addressing issues such as pressure fluctuations, concerns about water quality, and system inefficiencies. The utilization of EPANET enables water utilities to make informed decisions regarding infrastructure upgrades, maintenance schedules, and emergency response strategies. Furthermore, the case study emphasizes the vital importance of data accuracy and reliability in hydraulic modeling. Precise input data, including demand patterns, pipe characteristics, and boundary conditions, are indispensable for obtaining realistic simulation outcomes. To summarize, the examination of Variav Headwork's water distribution network through EPANET demonstrates the software's effectiveness in assisting water utilities in designing, operating, and managing their systems. Therefore, in the overall conclusion, the modeled result outperforms the actual data in terms of flow and velocity, where $R^2$ is 0.924 and 0.986 and CC is 0.855 and 0.973, respectively. In contrast, the modeled head loss is significantly different with respect to the actual data output; $R^2$ is 0.219, and CC is 0.048. Therefore, we can say that the model satisfactorily simulated the flow and velocity and significantly reduced the head loss to 66.46%. Hence, the utilization of such tools and conducting regular assessments can ensure the delivery of safe, sustainable, and efficient water services to communities, thereby contributing to overall public health and well-being.

## LIMITATIONS OF THE PRESENT STUDY

The present study analyzing a water distribution network using EPANET, specifically focusing on the Variav Headwork, has several limitations that should be considered when interpreting its findings. First, the accuracy of the results heavily depends on the quality and completeness of the input data. Any inaccuracies or omissions in the network data, such as pipe characteristics, demand patterns, or hydraulic properties, can lead to unreliable simulation outcomes. Second, the study assumes a static model, neglecting dynamic factors such as water quality variations, transient flow conditions, and changes in demand over time. These dynamics can significantly impact the network's behavior and were not considered in the analysis. Third, EPANET models typically simplify complex hydraulic processes, potentially leading to a lack of precision in predicting real-world system behavior. The accuracy of EPANET's hydraulic equations can diminish when dealing with extreme scenarios or nonstandard conditions. Additionally, the study might not account for future changes or expansions in the water distribution system, limiting its applicability for long-term planning and management. Last, the findings of this case study may not be directly transferable to other water distribution networks due to variations in network structure, operational parameters, and geographical factors. In summary, while the analysis of the Variav Headwork using EPANET provides valuable insights, its limitations related to data accuracy, simplifications in modeling, neglect of dynamics, and generalizability should be acknowledged to ensure responsible interpretation and application of the results.

## FUTURE SCOPE OF THE STUDY

Examining water distribution networks through the lens of EPANET, particularly when applied to the Variav Headwork case study, provides valuable insights into the existing water infrastructure. Furthermore, it opens up numerous promising avenues for future research and development. Here are some potential directions for future studies in this field:

- One promising avenue for future development is the optimization of water distribution networks. Researchers have the potential to fine-tune the EPANET model, allowing for the identification of opportunities to improve network performance. This could result in a more efficient water supply system and a reduction in energy usage.
- In light of escalating environmental apprehensions, upcoming research endeavors could delve into amalgamating sustainable and resilient strategies within the water distribution system. Such efforts may encompass the integration of renewable energy sources, bolstering the supervision of water quality, and evaluating the system's capacity to endure natural calamities and the consequences of climate change.
- The emerging field of smart technology integration in water distribution systems offers promising avenues for future research. One area of investigation could involve examining the integration of EPANET with real-time data from IoT

sensors and advanced analytics, with the aim of enhancing the intelligence and responsiveness of water distribution networks.

- Integrating EPANET with geographic information systems (GIS) offers a holistic view of the spatial layout of the network and aids in enhancing resource allocation efficiency, particularly in rapidly expanding urban regions.
- Examining the relationship between water distribution systems and energy consumption is crucial. Researchers can evaluate the network's energy efficiency and investigate methods for lowering energy consumption by conducting simulations using EPANET.
- To effectively put the research findings into action, we can create capacity-building programs and training modules aimed at instructing water utility staff, engineers, and policymakers about the utilization of EPANET and its potential for enhancing water distribution networks.

In summary, the assessment of the Variav Headwork through EPANET acts as a starting point for numerous forthcoming research and development prospects. Attending to these aspects can pave the way for more sustainable, efficient, and robust water distribution systems, guaranteeing access to clean and safe water for communities in the midst of ever-changing challenges.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**REFERENCES**

ABAIDIA S., REMINI B. (2020). Ghrib and Boukourdane (Algeria): when the water discharged from the dams feed the alluvial aquifer, Larhyss Journal, No 44, pp. 133-159.

ANISHA G., KUMAR A., KUMAR J., RAJU P. (2016). Analysis and Design of Water Distribution Network Using EPANET for Chirala Municipality in Prakasam District of Andhra Pradesh, International Journal of Engineering and Applied Sciences, Vol. 3, Issue 4, pp. 53-60.

AROUA N. (2022). Long term city development versus water strategy in al-Maghreb, Larhyss Journal, No 50, pp. 173-197.

AWE O.M., OKOLIE S.T.A., FAYOMI O.S.I. (2020). Analysis and optimization of water distribution systems: A case study of Kurudu post service housing estate, Abuja, Nigeria, Results in Engineering, Vol. 5 Issue January, Paper 100100.

BUCUR D.M., COSOIU C.I., IOVANEL R.G., NICOLAE A.A., GEORGESCU S.C. (2017). Assessing the Operation of the Cooling Water System of a Hydro-Power Plant Using EPANET, Energy Procedia, Vol. 112, Issue October, pp. 51–57.

BANDARI A., SADHUKHAN S. (2021). Determinants of per capita water supply in Indian cities with low surface water availability, Cleaner Environmental Systems, Vol. 3, Issue December, Paper 100062.

DAVE B.H., RAJPARA G., PATEL A., KALUBARME M.H. (2015). Analysis of Continuous Water Distribution System in Gandhinagar City Using EPANET Software : A Case Study of Sector-8, National Conference on ‘ Transportation and Water Resource Engineering, Vol. i, Issue April, pp. 1–6.

EDOKPAYI J.N., ODIYO J.O., DUROWOJU O.S. (2017). Impact of wastewater on surface water quality in developing countries: a case study of South Africa, Water quality, Vol. 10, Paper 66561.

HOUNTONDJI B., CODO F.P., AYELABOLA K. M. L. A. (2020). Supply of drinking water from a photovoltaic pumping system in the commune of Kandi in Benin, Larhyss Journal, No 41, pp. 71-89. (In French)

KALTENBACHER S., STEFFELBAUER D.B., CATTANI M., HORN M., FUCHS-, D. (2017). A Dynamic Model for Smart Water Distribution Networks, Conference : CCWI - At : Sheffield, September.

KUMAR A., KUMAR K.B.B., MATIAL N., DEY E., SINGH M., THAKUR V., SHARMA S., MALHOTRA N. (2015). Design of Water Distribution System Using Epanet, International Journal of Advanced Research, Vol. 3, Issue 1, pp. 789–812.

MEHTA D., LAKHANI K., PATEL D., PATEL G. (2016). Study of Water Distribution Network Using EPANET, International Journal of Advanced Research in Engineering, Science, Management, pp. 1–11.

MEHTA D., WAIKHOM S., YADAV V., LAKHANI K. (2015a). Simulation of Hydraulic Parameters in Water Distribution Network using EPANET : A Case Study of Surat City, 20th International Conference on Hydraulics, Water Resources and River Engineering, Issue December, pp. 17–19.

MEHTA D., YADAV V., PRAJAPATI K., WAIKHOM S. (2017). Design of optimal water distribution systems using WaterGEMS: a case study of Surat city, E-Proceedings of the 37th IAHR World Congress, Issue December, pp. 1–8.

MOE C.L., RHEINGANS R.D., (2006). Global challenges in water, sanitation and health, Journal of water and health, Vol. 4, Issue S1, pp.41-57.

NATIONAL RESEARCH COUNCIL. (2007). Drinking water distribution systems: Assessing and reducing risks. National Academies Press.

PARMAR P.A. (2019). Water Distribution Network using EPANET : A Case Study of Olpad Village, Emerging Research and Innovations in Civil Engineering, Vol. 6, Issue February, pp. 25–30.

PESLIER A.H., SCHÖNBÄCHLER M., BUSEMANN H. KARATO S.I. (2017). Water in the Earth’s interior: distribution and origin. Space Science Reviews, Vol. 212, Issue 1-2, pp.743-810.

ROUISSAT B., SMAIL N. (2022). Contribution of water resource systems analysis for the dynamics of territorial rebalancing, case of Tafna system, Algeria, Larhyss Journal, No 50, pp. 69-94.

SAMINU A., SAGIR L. (2013). Design of NDA Water Distribution Network Using EPANET, Internation Journal of Emerging Science and Engineering, Vol. 1, Issue 9, pp. 5–9.

SHITAL K., KRUNALI M., MEHTA D., YADAV V., STUDENT U.G. (2016). Simulation of Existing Water Distribution Network by using EPANET : A Case Study of Surat City, Recent Advances in Civil Engineering for Global Sustainability|, Vol. 34, Issue March, pp. 184–192.

SIVAKUMAR P., PRASAD R.K. (2014). Simulation of Water Distribution Network under Pressure-Deficient Condition, Water Resources Management, Vol. 28, Issue 10, pp. 3271–3290.

SHAMIR U.Y., HOWARD C.D. (1968). Water distribution systems analysis, Journal of the Hydraulics Division, Vol. 94, Issue 1, pp.219-234.

SINGH D.K., SINGH A.K. (2002). Groundwater situation in India: Problems and perspective, International Journal of Water Resources Development, Vol. 18, Issue 4, pp.563-580.

VERMA S., SAHU R., PRASAD A., VERMA M. (2023a). Reservoir operation optimization using ant colony optimization a case study of Mahanadi reservoir project complex Chhattisgarh-India, Larhyss Journal, No 53, pp.73-93.

VERMA S., VERMA M.K., PRASAD A.D., MEHTA D.J., ISLAM M.N. (2023b). Modeling of uncertainty in the estimation of hydrograph components in conjunction with the SUFI-2 optimization algorithm by using multiple objective functions, Modeling Earth Systems and Environment, Vol. 9, Issue 2, pp.1-19.

VERMA S., KUMAR K., VERMA M.K., PRASAD A.D., MEHTA D., RATHNAYAKE U. (2023c). Comparative analysis of CMIP5 and CMIP6 in conjunction with the hydrological processes of reservoir catchment, Chhattisgarh, India. Journal of Hydrology: Regional Studies, Vol. 50, Issue 1, pp.101533.

VERMA S., SAHU I., PRASAD A.D., VERMA M.K. (2023d). Modified Particle Swarm Optimization for the Optimum Use of Multi-Reservoir Systems: MRP Complex, Chhattisgarh, Journal of Environmental Informatics Letters, Vol. 11, Issue 1.

YUNARNI WIDIARTI W., WAHYUNI S., UTAMI AGUNG WIYONO R., HIDAYAH E., HALIK G., SISINGGIH D. (2020). Evaluation of pipe network distribution system using EPANET 2.0 (a case study of the city of Jember). IOP Conference Series: Earth and Environmental Science, Vol. 437, Issue 1, pp. 0–9.

WHO/UNICEF, (2005). Joint Water Supply and Sanitation Monitoring Programme. Water for life: making it happen. World health organization.

WHO/UNICEF., (2023). Unfpa. Geneva: WHO, p.2.

WEAR S.L., ACUÑA V., MCDONALD R., FONT C. (2021). Sewage pollution, declining ecosystem health, and cross-sector collaboration, Biological Conservation, Vol. 255, Paper 109010.

YAO T., BOLCH T., CHEN D., GAO J., IMMERZEEL W., PIAO S., SU F., THOMPSON L., WADA Y., WANG L., WANG T., (2022). The imbalance of the Asian water tower, Nature Reviews Earth & Environment, Vol. 3, Issue 10, pp.618-632.