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Assessing Efficiency and Resilience in the Dewathang Thromde Water Distribution System

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Abstract

Dewathang Thromde, a subdivision of Samdrup Jongkhar Thromde, faces a significant challenge in its drinking water supply. The region relies on a gravitational water supply system from Lemtshorong and Zalakhe. This study aims to assess the current system and determine its adequacy for the future population. The study employs manual methods, such as bucket and stopwatch techniques, to determine discharge at the water source, complemented by field observations for pipe size measurements. Utilizing EPANET software and a Demand Driven Analysis (DDA) approach, distribution network's pressure and velocity requirements are analyzed. Elevation data from the My Elevation mobile app, validated by Google Earth images, contribute to a comprehensive evaluation. During peak season, a discharge of 35.92 l/s is documented, contrasting with 9 l/s during the lean season. The population, recorded at 2644 in 2005, surged to 3881 in 2017, with a forecast anticipating 7170 people by 2035 using the Incremental Increase Method. Average water consumption per person is approximately 113.35 lpcd, exceeding the WHO standard, influenced by climatic conditions. With a population of approximately 4389 in 2021, the current water demand in Dewathang Thromde is 13.72 l/s, surpassing the discharge capacity of 9 l/s during the lean season. By 2035, the projected water demand is expected to reach 22.41 l/s, exceeding the current source discharge by over 100%. Simulation results for the upstream and downstream networks of the Break Pressure Tank (BPT) reveal pressure-related challenges, with over 20 percent of nodes experiencing excessive pressure along HDPE pipes. Bursting incidents and negative pressure at more than 10 percent of nodes emphasize the need for network improvements, especially during reduced source discharge. The final segment of the pipe network surpasses the prescribed maximum flow velocity due to the direct proportionality between velocity and pipe diameter. Smaller pipe sizes, while limiting velocity, paradoxically contribute to actual velocities exceeding specified limits. Addressing these challenges is crucial for ensuring a sustainable and reliable water supply system in Dewathang Thromde.

Keywords— Dewathang Thromde, population forecast, EPANET, water distribution network, per capita demand

1 Introduction

Water stands as a crucial element for all living organisms, constituting the most vital resource on earth. Bhutan, as outlined in the 2018 National Water Resources Inventory report by the National Environment Commission [1], boasts abundant water resources, with an impressive per capita water availability of 94500 cubic meters. However, the uneven spatial and temporal distribution poses challenges, resulting in shortages in specific localities. According to the UNDP's report on water and climate change [2], only 63 percent of the population enjoys 24-hour access to drinking water. The primary contributors to these shortages are the depletion of water sources and irregularities in the distribution network. In alignment with the UNDP report, the Royal Audit Authority (RAA) report also highlights that 34 percent of water is lost within the network due to issues such as faulty connections, illegal tapping, and bypassing water meters [3]. Dewathang Thromde, a subdivision under Samdrup Jongkhar Thromde, is currently facing a significant challenge related to drinking water [4]. This water crisis has persisted over an extended period and remains unresolved to this day. According to Thromde, there was an expectation that the scarcity of drinking water in Samdrup Jongkhar Thromde would be resolved by 2018 through the construction of a new water distribution system [5]. However, during the recent Thromde election in 2021, both aspiring candidates emphasized resolving the water issue as their primary focus [6]. In alignment with the 12th five-year plan, the Thromde has proposed a budget of Nu. 80 million for water projects under the water flagship programme, funded through the Asian Development Bank. These projects aim to establish a water treatment plant and distribution network in Dewathang. The report indicates that, as of June 2018, the Thromde has already spent Nu. 125 million, surpassing the allocated budget of Nu. 123.58 million, specifically for ensuring safe drinking water [7]. Supplying safe drinking water remains Thromde's top priority, as outlined in their Annual Performance Agreement (APA). While residents acknowledge considerable progress, including the establishment of a water treatment plant and a few water projects, water-related challenges persist [8]. For over a decade, the community has been struggling with water shortages, primarily attributed to the inadequacies of the existing water distribution channel. The aging and leaky water distribution pipes exacerbate the problem. According to the Thrompon, a solution is on the horizon as they are in the process of constructing a new water distribution network [9]. According to the Population Housing Census of Bhutan 2017 [10], the population of Samdrup Jongkhar Thromde alone is recorded at 9,325. The census reveals that 6,613 individuals have migrated to Samdrup Jongkhar Thromde, while 3,027 have out-migrated, resulting in a net gain of 3,586 persons compared to the 2005 census data, signifying an almost 40 percent increase in population. As per the World Health Organization (WHO), an average of 50 to 100 liters of water per person per day is necessary to meet basic needs and address health concerns [11]. The global average is estimated to be around 60 liters per person per day [12]. The minimum water requirement for the Thromde population alone would be more than 1 million liters per day (MLD). However, considering the hot and humid climate conditions of the area, the demand would likely be significantly higher, as reflected in the Thromde report indicating an increase in demand from 1.6 MLD to 1.9 MLD [7]. Presently, Dewathang Thromde relies on the gravitational water supply system sourced from Lemtshorong and Zalakhe. The residents of Dewathang have been utilizing this water source for an extended period. This study seeks to ascertain the water discharge and assess its adequacy for both the existing population and future needs. Additionally, the efficiency and resilience of the water distribution network will be evaluated. The area of interest is shown in Figure 1.

2 Methodology

The following sequence of methods shown in Figure 2 was implemented for the achievement of the aim and objectives set for this research. The study used the data collected from the existing

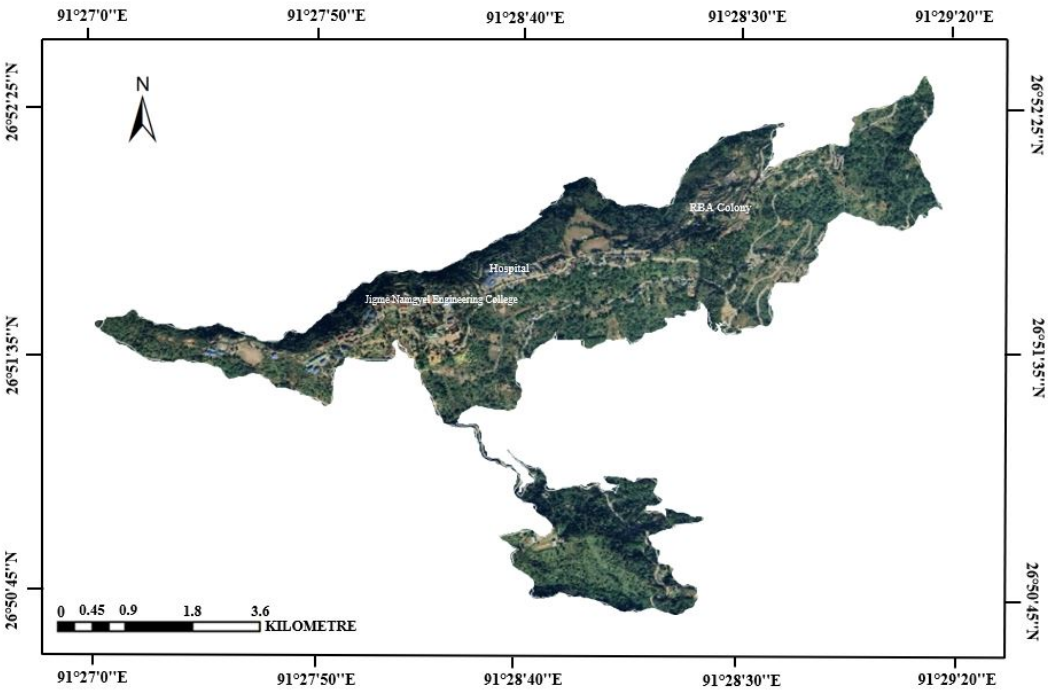

Figure 1: Area of interest

water distribution system. The discharge of the water is determined based on the flow of the water at the source. The size of the pipes was measured from the actual observation in the field. The existing water distribution system is analyzed using EPANET software. A free mobile app called My Elevation was used for collecting the elevation of pipe networks and tanks. The Google Earth image of the water distribution system was used to validate the data obtained from the Mobile App. Then the Google Earth image of the water distribution system was cooperated in EPANET software and its elevation of nodes, tanks, and length of pipe were recorded. Then it's analyzed for pressure and elevation at various nodes and head loss at various pipes.

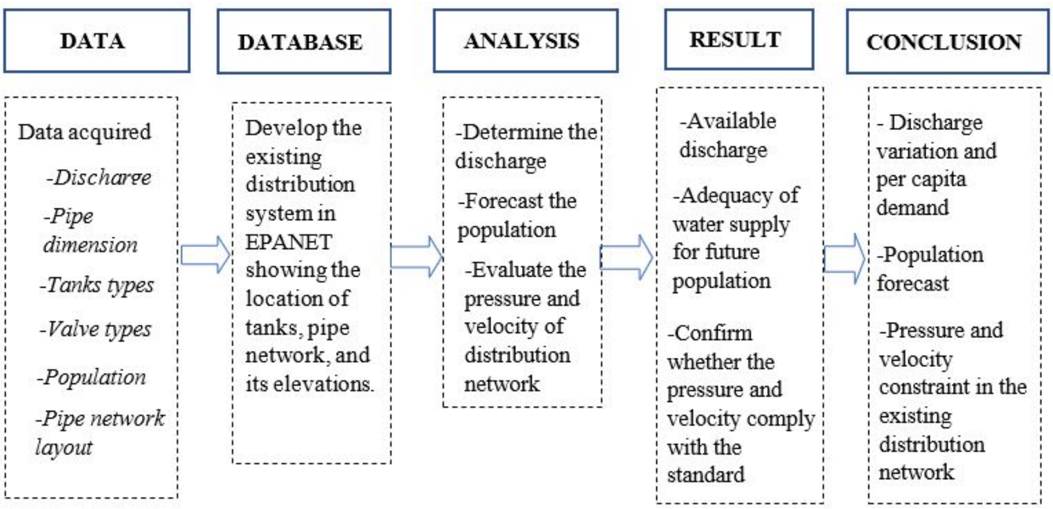

Figure 2: Methodology Chart

3 Data

3.1 Water distribution network

The pipe network is configured in a dead-end system, where a single water supply from the main pipe is distributed to sub-main pipes. The sub-main pipes then channel the water to various areas, including the town and regions of Pazor, Kesantayre, Bangtsho, and Samdrupgatshel under Dewathang Thromde. Notably, a gravity distribution system is employed, capitalizing on the available elevation to supply water without necessitating the use of a pump system.

3.2 Plumbing Data

The distribution system incorporates both Galvanized Iron (GI) pipes, known for their durability and rust-resistant properties, and High-Density Polyethylene (HDPE) pipes, renowned for their high quality, reliable fittings, and ease of loading and transportation. Table 1 provides a comprehensive overview of the pipe lengths, sizes, and recorded discharge rates for each segment of the network.

Table 1: Plumbing data

Source	Types of pipe	Pipe size (mm)	Pipe Length (m)
Lemtshorong 1	HDPE and GI pipe	90 mm and 80 mm	8391
Lemtshorong 2	HDPE and GI pipe	90 mm and 80 mm	4121
Zalakhe	HDPE pipe	90 mm	2310

Water sourced from Zalakhe is transported through a 90 mm HDPE pipe and stored in a tank situated above the army camp. Subsequently, it is distributed to the town and Samdrupgatshel area using 63 mm and 40 mm HDPE pipes respectively. To ensure smooth water flow and prevent backflow, break pressure tank (BPT) measuring 1.9m in width and 1.1m in height are strategically placed along the route.

Similarly, water from Lemtshorong is initially stored in a 20 cumec reservoir tank. It is then conveyed through an 80 mm GI pipe and 90 mm HDPE pipe and stored in a 3.9m diameter BPT situated below Choki Gyatsho Institute. The water is further distributed to Pazor, Kesantayre, and Bangtsho areas using 63 mm and 40 mm HDPE pipes. Along this route, BPT with dimensions of 1.9m in diameter and 1.1m in height are installed to regulate water flow and prevent any backflow issues.

3.3 Discharge data

The discharges from the three sources were manually determined utilizing the bucket and stopwatch method. In this method, the time required for water to fill a bucket with a known volume, specifically 17.5 liters in this case, was measured and recorded. This process was repeated for five sets, and the discharges were then calculated. The resulting calculated discharges are detailed in Table 2.

The discharge from the water source is influenced by rainfall. As per information supplied by Thromde officials, the discharge during the peak season is documented at 35.92 l/s. Due to a lack of adequate equipment for measuring substantial discharge, the data provided by them is employed for assessment. Furthermore, the lean discharge data they obtained is 8.44 l/s, closely resembling the computed value of 9 l/s.

Table 2: Discharge data for the lean season

Source	Volume (l)	Time (s)	Discharge (l/s)
Lemtshorong 1	17.50	3.99	4.40
Lemtshorong 2	17.50	7.16	2.44
Zalakhe	17.50	2.16	2.16
		Total	9

3.4 Population data

The Dewathang Thromde encompasses an area of 2.39 square kilometers, with a population density of 2086.12 individuals per square kilometer, as reported in the statistics of Samdrup Jongkhar Thromde [7]. In 2005, the population was documented at 2644, according to the statistics from the Office of the Census Commissioner [13]. The Population Housing Census of Bhutan in 2017 [14] recorded the population of Samdrup Jongkhar Thromde at 9,325, including 3881 individuals from Dewathang Thromde. As of 2021, the population has risen to 10,545 based on data provided by Thromde. Notably, the total water consumption through the Thromde water meter for the year 2021 is 407,877 cubic meters. Assuming a per capita consumption of 100 liters per day, the calculated population of Thromde reaches around 11,175, surpassing the official statistics of 10,545.

4 Data Analysis

4.1 Distribution Network Analysis

An analysis of the water distribution network was carried out using EPANET (Environment Protection Agency Network Evaluation Tool). This tool is instrumental in evaluating the hydraulic performance of water-supply systems, encompassing the assessment of pressure profiles, water velocity, and network optimization. The EPANET analysis played a vital role in providing essential information for evaluating the efficiency and feasibility of the distribution network. Notably, the EPANET offers options for Demand Driven Analysis (DDA) and Pressure Demand Analysis (PDA), with this study opting for DDA. This choice is driven by the specific water demand at the consumer point, guiding the analysis of the water supply system. For the analysis, the Hazen-Williams (H-W) friction head loss formula was employed, given its widespread use in turbulent flow conditions, which aligns with our case. Considering the use of HDPE and GI pipes, roughness coefficients of 140 and 120 were selected, respectively. Additionally, a minor loss coefficient of 0.4 was applied for bends and pipe fittings, consistent for both types of pipes. The 80 mm GI pipe is utilized from the source up to node 17, and the entire pipe network is laid alongside the road surface. Moving from node 17 to the BPT at node 27, 90 mm HDPE pipes are employed due to the network traversing rugged terrain and forested areas. Beyond the BPT, the network transitions to using 63 mm HDPE pipes to supply water to the town area and its vicinity, while 40 mm HDPE pipes are employed to distribute water in the Samdrupgatshel area. The BPT's control head and system pressure bring the pressure down to 0 m relative to atmospheric pressure. The simulation was conducted separately for the upstream and downstream networks of the BPT. The flow/demand upstream of the BPT is estimated at 9 l/s, whereas the flow toward the town area is 6 l/s, and 3 l/s towards the Samdrupgatshel area. The elevation varies from 1440 m above mean sea level (msl) at the source to 700 m above msl in the Samdrupgatshel area.

4.1.1 Pressure Analysis

According to the Bureau of Indian Standards [15], the maximum permissible working pressure for PN12.5 HDPE pipe is 1.25 MPa. The corresponding water head value is 127.5 m considering 1 MPa pressure equals 101.9977 m of water head. Similarly, the maximum pressure handled by galvanized iron pipe 3.5 inches nominal pipe size is 14 MPa, which is equivalent to 1428 m of water head [16].

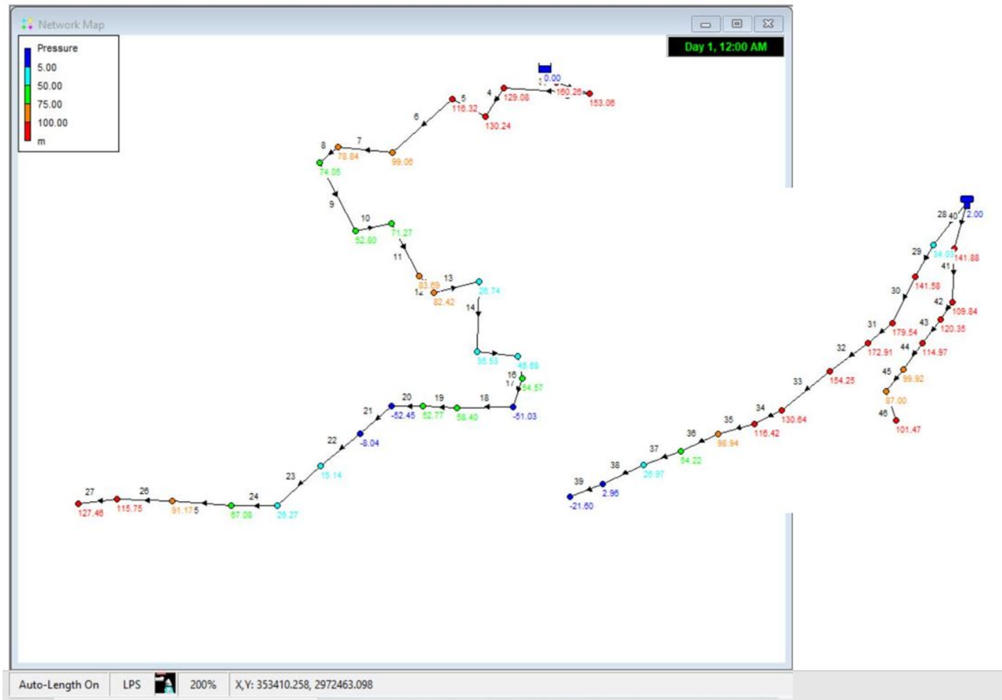

Figure 3: Simulation result of pressure head in the node along pipe network

In the GI pipe section extending up to 4.85 km from the source, the depicted Figure 4 does not display the limiting pressure head of 1428 m. This omission is notable because it surpasses the 160 m threshold experienced by GI pipes.

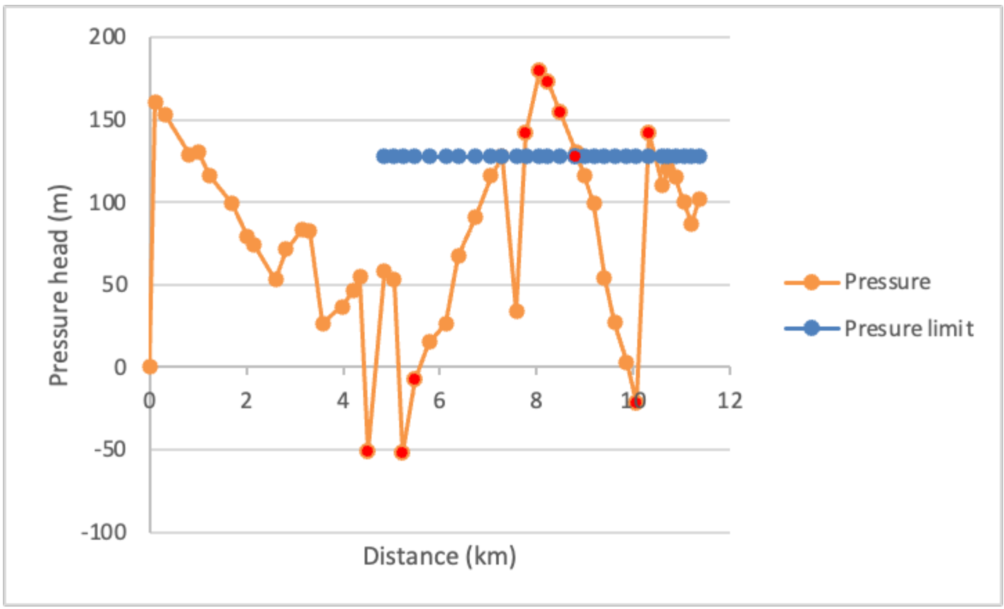

Figure 4: Limiting pressure and pressure head w.r.t distance of pipe network

Figure 3 and Figure 4 reveal a concern regarding the maximum pressure along the HDPE pipes. Over 20 percent of nodes register a pressure head exceeding 127.5 m. This issue is substantiated by the frequent bursting of HDPE pipes throughout the network. Similarly, more than 10 percent of nodes encounter problems associated with negative pressure. When there is a reduction in discharge from the source, the network experiences water shortages. This circumstance underscores the need for addressing pressure-related challenges in the network.

4.1.2 Velocities Analysis

The velocity is the function of pipe diameter and discharge. The maximum and minimum velocity is given by

$$v_{recommended} < 0.127D^{0.4} m/s$$

$$v_{min} > 0.3 m/s$$

Where v is the maximum velocity (m/s) and D is the internal diameter of the pipe in mm.

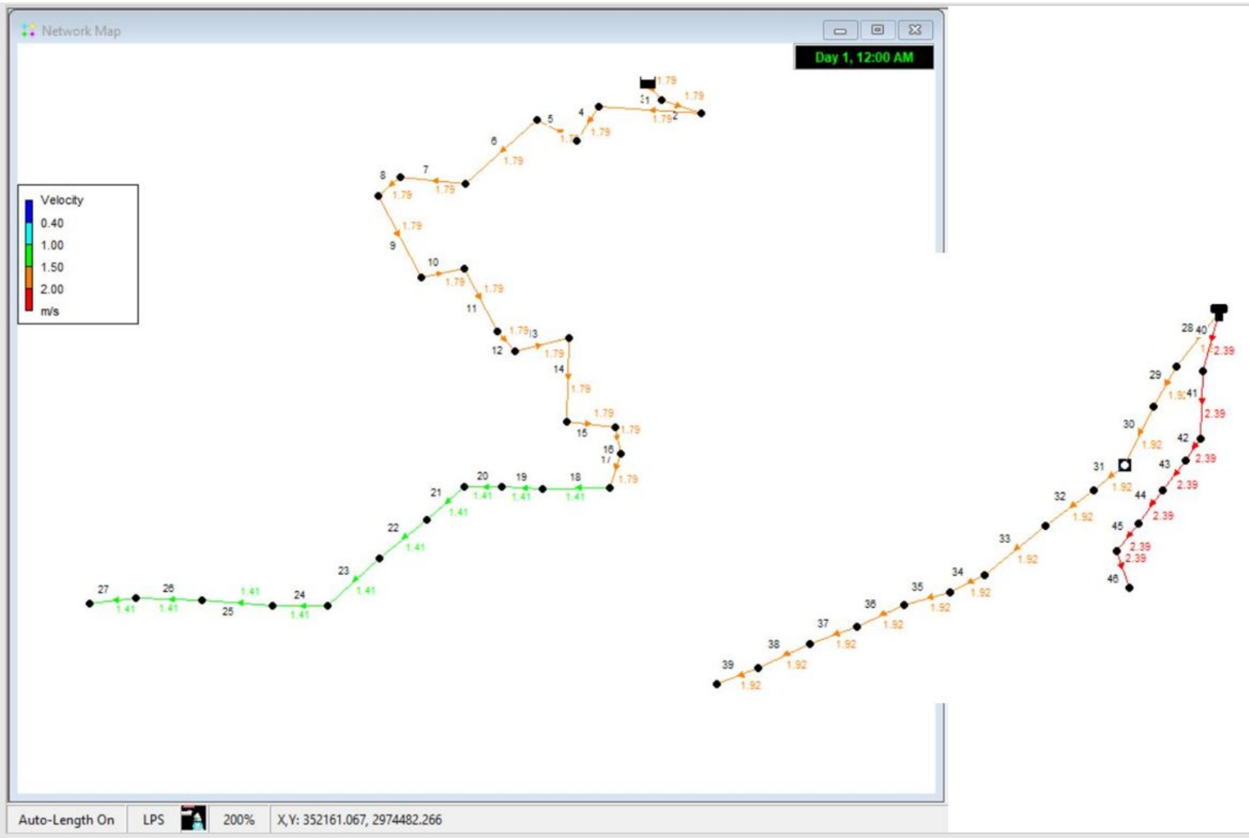

Figure 5: Simulation result of velocity along the pipe network

Figure 6 illustrates that the final segment of the pipe network exceeds the prescribed maximum flow velocity. This occurrence is attributed to the direct proportionality between velocity and pipe diameter. Smaller pipe sizes impose limitations on velocity, but this constraint often leads to the actual velocity surpassing the specified maximum limit.

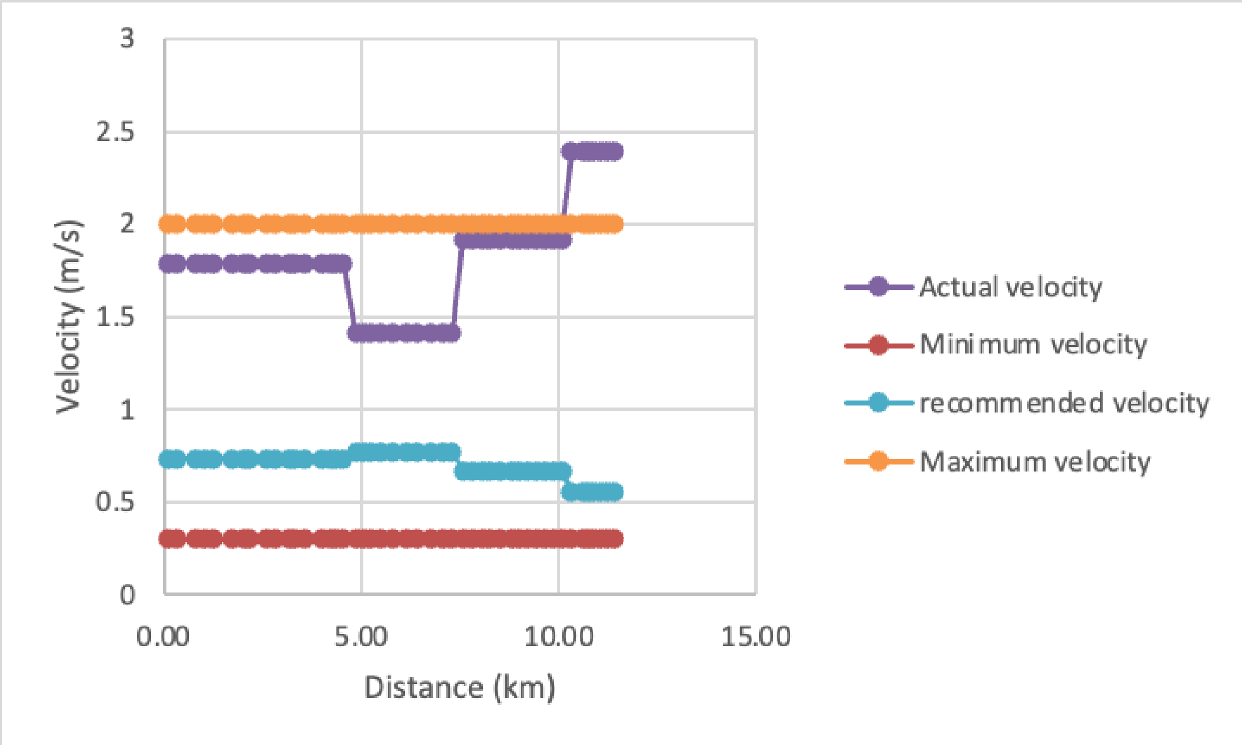

Figure 6: Velocity analysis graph

4.2 Water Demand Analysis

4.2.1 Population Forecasting

Wilson et al. [17] assess the present status of forecasting small-area populations. They refine the appropriate techniques for smaller populations, including extrapolative and comparative methods, simplified cohort-component methods, model averaging and combining, incorporating socioeconomic variables and spatial relationships, 'downscaling' and disaggregation approaches, connecting population with housing, estimating and projecting small area component input data, microsimulation, machine learning, and forecast uncertainty. According to their findings, various traditional and modern extrapolative and comparative methods effectively forecast total small-area populations, such as the Linear/Exponential model (linear for positive growth; exponential for negative growth). Due to the complexities associated with data, methodologies, and the inherent variability and randomness in small-area populations, errors tend to escalate as population size decreases. Specifically, these errors exhibit a rapid increase when the population size falls below approximately 10,000 [18]. The Incremental Increase Method is employed for population forecasting due to its appropriateness for average-sized towns in typical conditions. This method is particularly suitable when the population growth rate is not constant.

$$P_n = (P_o + n\overline{x}) + (n((n+1))/2)\overline{y}$$

Where $P_{(n)}$ = Population after n$^{\text{th}}$ number of decades
P_o = Last known population
n = Number of decades between P_n and P_o
$\overline{x}$ = mean or average of increase in population and,
$\overline{y}$ = algebraic mean of incremental increase (an increase of increase) of population.

Table 3: Population data

Year	Year	Population	Projected Population	Increase in population	Incremental increase	$\overline{x}$	$\overline{y}$
2005		2644					
	2015		3675	1031			
2017		3881				1126.5	191
2021		4389					
	2025		4897	1222	191		

$$P_{2035} = (P_{2005} + 3 * 1126.5) + (3 * ((3 + 1))/2)191 = 7170$$

To calculate for the decade, population data for the years 2015 and 2025 were selected. Given the absence of data for certain years, interpolation and extrapolation were conducted based on the available data. Using Incremental Increase Method, the population of Dewathang Thromde in year 2035 is forecasted as 7170 people.

4.2.2 Water Demand Projection

The per capita water consumption by Dewathang Thromde residents, as illustrated in Table 4, was determined through a survey conducted via questionnaires.

Table 4: Per capita water consumption per day

Sl No	Use of water	litre per capita demand(lpcd)
1	Drinking	2.35
2	Bathing	35.00
3	Washing of face, hand, Leg, etc (Freshen up)	7.25
4	Cooking	15.5
5	Washing of clothes	17.20
6	Washing or cleaning of hostel room	7.75
7	Flushing of water closets, etc	28.30
	Total	113.35

According to the survey findings, the average water consumption for domestic purposes per person is approximate 113.35 lpcd, surpassing the World Health Organization's (WHO) standard [11]. The per capita demand is influenced by the climatic conditions of the area. Following the Indian standard code [15], they typically consider a range of 150 to 200 lpcd. According to this code, the total water demand is calculated by multiplying 270 lpcd by the population of the locality to account for losses and peak values. As of 2021, with approximately 4389 residents in Dewathang Thromde, there is a need for 1,185,030 liters of water per day, equivalent to 13.72 liters per second (l/s). It is noteworthy that the water demand exceeds the discharge capacity (9 l/s) during the lean season. In 2035, the water demand is projected to reach 22.41 l/s, surpassing the current source discharge by over 100%.

5 Conclusion

In summary, the analysis of the water supply system in Dewathang Thromde reveals several key findings and challenges. The discharge varies significantly between peak and lean seasons, with a recorded peak of 35.92 l/s and a lean season discharge of 9 l/s. This discrepancy poses challenges for meeting water demand during periods of lower supply. The population has seen a notable increase from 2644 in 2005 to 3881 in 2017. Using the Incremental Increase Method, a projected population of 7170 people is anticipated by the year 2035. This population growth significantly influences water demand. The average water consumption per person for domestic purposes is approximately 113.35 liters per capita per day (lpcd), exceeding the World Health Organization's (WHO) standard of 50 to 100 lpcd. Climatic conditions in the area influence per capita demand. According to the Indian standard code, the current water demand in Dewathang Thromde (2021) is 1,185,030 liters per day, equivalent to 13.72 l/s. Notably, the water demand surpasses the discharge capacity of 9 l/s during the lean season. In 2035, the projected water demand is expected to reach 22.41 l/s, exceeding the current source discharge by over 100%. The simulation highlights various challenges in the water distribution network, including pressure issues in both GI and HDPE pipes. Notably, bursts in HDPE pipes and negative pressure at certain nodes pose concerns, leading to water shortages during reduced source discharge. The prescribed velocity for the water flow is recommended to be around $0.127D^{0.4}m/s$, but the final segment of the pipe network exceeds this limit. The direct proportionality between velocity and pipe diameter, coupled with smaller pipe sizes, results in actual velocities surpassing specified maximum limits. Addressing these challenges is crucial for ensuring a sustainable and reliable water supply system in Dewathang Thromde, especially considering the anticipated population growth and changing water demand patterns.

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