Water Distribution Networks and Analysis of Pipe Material Using Water Gems

Jay Kishor Mhatre[1], Om Hitendra Pandya[1], Pravin Shankar Pawar[1], Ulkesh Ulhas Shama[1*], Hemant Kumar Thakur[2], Yash Suresh Shet[2]

[1] B.E. Student, Department of Civil Engineering, G. M. Vedak Institute of Technology, Tala Raigad

[2]Assistant Professor, Department of Civil Engineering, G. M. Vedak Institute of Technology, Tala Raigad

DOI: https://doi.org/10.51244/IJRSI.2026.1304000114

Received: 08 April 2026; Accepted: 13 April 2026; Published: 04 May 2026

ABSTRACT

Efficient design and management of water distribution networks are essential for ensuring reliable and sustainable water supply in rural areas. This study presents the hydraulic modeling and analysis of a water distribution system for **Mhasoli village in Maharashtra**, using **WaterGEMS simulation software**. Population forecasting was performed using arithmetic increase, geometric increase, and incremental increase methods to estimate the future demand for a selected design period. Based on the projected population of **2431 persons**, the total daily water demand was calculated as **328,185 liters per day** considering the standard per capita water requirement. A hydraulic network model was developed using field survey data, including pipeline layout, junction elevations, and nodal demand. The model was simulated to evaluate important hydraulic parameters such as **pipe diameter, flow velocity, hydraulic gradient, and pressure distribution** throughout the network. The results show that pipe velocities vary between **0.02 m/s and 1.69 m/s**, which are within acceptable design limits for water distribution systems. The analysis also confirms that adequate pressure is maintained at all junction nodes. The study demonstrates that **WaterGEMS provides an effective tool for hydraulic analysis, design optimization, and performance evaluation of rural water distribution networks**, supporting efficient planning and sustainable water supply management.

Key words: Water Distribution, Water Gems, Population forecasting, pipe, Liters Per Capita Per Day (LPCD)

INTRODUCTION

Water distribution systems (WDSs) are one of the major infrastructure assets of the society, with new systems being continually developed reflecting the population growth, and existing systems being upgraded and extended due to raising water demands. Designing economically effective WDSs is a complex task, which involves solving a large number of simultaneous nonlinear network equations, and at the same time, optimizing sizes, locations, and operational statuses of network components such as pipes, pumps, tanks and valves. This task becomes even more complex when the optimization problem involves a larger number of requirements for the designed system to comply with (e.g., water quality), includes additional objectives beside a least-cost economic measure (e.g., potential fire damage) and incorporates more real-life aspects (e.g., uncertainty, staging of construction) (Todini & Pilati, 1988; Lansey & Mays, 1989; Alperovits & Shamir, 1977). WATERGEMS is such a computer-based program that plays out an all-encompassing period re-enactment of water powered and water quality conduct inside pressurized pipe systems (Bentley Systems, 2014; Rossman, 1993). Open Flows Water GEMS provides you with a comprehensive yet easy-to-use decision-support tool for water distribution networks. The software helps improve your knowledge of how infrastructure behaves as a system, how it reacts to operational strategies, and how it should grow as population and demands increase (Rai & Dohare, 2019; Ormsbee, 2006).

Need of Water Supply

Water quality may be assessed upon several occasions: to determine if the available water is suitable for a particular purpose, to determine if there has been a significant change in water quality or to determine if

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IV April 2026

adverse health effects that are occurring may be attributable to water contamination (World Health Organization, 2017). Numerous commercial, governmental and academic laboratories offer water quality analytical services. The assessment of the analytical results from such laboratories requires some sort of standards against which to compare the results. National, state or provincial, or local governments may regulate water quality and water quality standards may be established by any or all of those governmental bodies (BIS, 2012; WHO, 2017). The quality of drinking water intended for consumption by humans is almost always more extensively regulated than for any other water use (Garg, 2010).

Reports of results of water quality analyses often include water quality standard ranges against which to assess the reported results. They may include graphical comparisons of the results to the water quality standards, making identification of parameters that fall outside of the standard limits easily identifiable. Such reports often use water quality standards intended for human drinking water. Assessment of the results of water quality analyses must be done using standards that are applicable for the intended use of the water and which are in force for the venue at which the water is to be used (Maharashtra Jeevan Pradhikaram, 2012). The suitability of water intended for use as drinking water by animals is better assessed using drinking water standards for animals instead of standards for humans. Otherwise, animal owners may take unnecessary and costly actions to mitigate what are erroneously believed to be unacceptably high risk of some sort of adverse health effect.

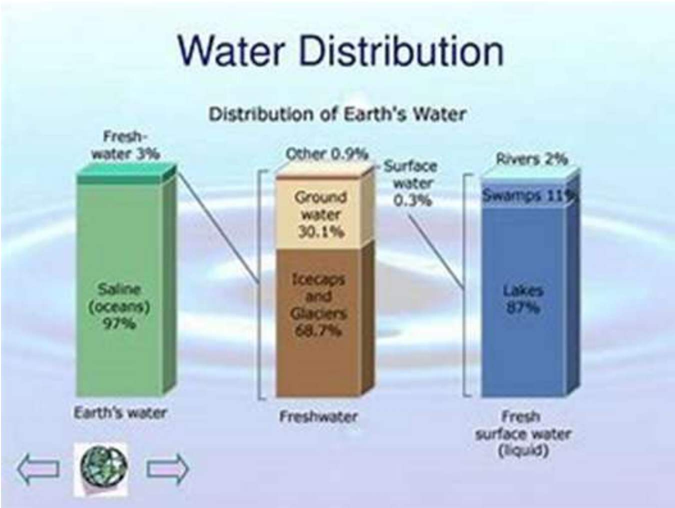

Figure 1. water distribution

Pipe Materials:

HDPE (high-density polyethylene) pipes are flexible, durable, and corrosion resistant pipes widely used in various industries for fluid and gas transfer (Pillai, 2020).

Figure 2. HDPE Pipe

HDPE pipe is made from thermoplastic highdensity polyethylene, known for its strong molecular structure, wh ich allows it to withstand high pressures and resist environmental factors (Pillai,2020).

It is commonly used for applications such as:

Water and sewer systems: HDPE pipes are ideal for municipal water supply and wastewater management due to their leak-free joints and resistance to corrosion.

Gas distribution: They are also used in natural gas pipelines, providing a safe and reliable option for gas trans port.

Irrigation and drainage: HDPE pipes are effective for agricultural irrigation systems and stormwater drainag e due to their flexibility and durability.

Figure 3. HDPE Pipe Joints

Some investigators have attempted to analyzed the pipeline distribution of this city but not any detailed investigation is considering analysis and design method with respect to Indian Standards. A brief review of these investigations, analysis and design parameters, theories have been reported in these chapter and also the objectives of this investigation.

LITERATURE SURVEY

The design and analysis of water distribution systems have been extensively studied using both conventional approaches and modern simulation tools. With the advancement of computational techniques, software such as EPANET and WaterGEMS has significantly improved the accuracy and efficiency of hydraulic modeling.

Van Blaricum and Hock investigated the application of multi-parameter water quality and corrosion sensors in water systems, demonstrating their effectiveness in monitoring system performance and optimizing chemical treatment processes. Their work highlights the importance of integrating monitoring technologies into water distribution networks to ensure long-term sustainability and reliability (Van Blaricum and Hock).

Sharma and Khatiwada explored the design of micro water supply systems using solar energy, emphasizing the importance of sustainable and cost-effective solutions in rural water supply. Their study demonstrated that renewable energy-based systems can reduce operational costs; however, it lacked detailed hydraulic modeling and network optimization, which are essential for system design (Sharma and Khatiwada).

Fundamental concepts of fluid mechanics and hydraulic design, including population forecasting and water demand estimation, have been well established in standard textbooks such as those by Bansal. These principles form the theoretical foundation for water distribution system design and are widely used in engineering practice (Bansal).

Yang et al. addressed several technological challenges in water treatment and distribution, including pH regulation, sterilization, and pipe material selection. Their research demonstrated that advanced treatment methods can significantly improve water quality and system efficiency, though their work focused more on treatment processes than on network design (Yang et al.).

Kumar et al. applied EPANET software for designing a water distribution system and highlighted the importance of providing adequate and uniform water supply to meet increasing population demands. Their study demonstrated the effectiveness of simulation tools in hydraulic design; however, it primarily focused on urban areas and did not consider rural-specific challenges (Kumar et al.).

Similarly, Ramana et al. conducted a network analysis of rural water distribution systems using EPANET and emphasized the importance of maintaining sufficient pressure at all nodes. Their study confirmed that hydraulic modeling is essential for ensuring system reliability, though it lacked integration with population forecasting methods and long-term demand analysis (Ramana et al.).

The application of WaterGEMS for water distribution system design has also been explored in previous studies. These studies indicate that WaterGEMS provides advanced capabilities for simulation, optimization, and decision support. However, many of these works remain theoretical and do not provide comprehensive methodologies for practical implementation in real-world rural scenarios.

Guidelines provided by Maharashtra Jeevan Pradhikaram (MJP) emphasize the importance of optimizing both cost and reliability in water distribution networks. The use of multi-objective approaches, such as genetic algorithms, has been suggested for achieving optimal design solutions. However, such approaches are often complex and require detailed computational analysis (MJP).

Despite these contributions, there is limited research integrating population forecasting, hydraulic modeling, and validation against standard guidelines in rural Indian contexts. This study aims to address these gaps.

METHODOLOGY & MATERIALS

In this chapter, methods used to achieve the desired results are explained. After a thorough study of literature, the appropriate methodology is fragmented and observations use in software and calculations were done (Kumar et al., 2015; Ramana et al., 2015).

Work process:

1. First data preparation for study area including information like Google and Satellite Image,
2. Road network map and Land use or cover area then data collection for field survey includes population, source and water tank, Pipe and nodal these all data collected to department of rural water supply and construction, the next step is setting up the network based on the observation.
3. This network can be drawn using AUTOCAD software.
4. After finalizing the network diagram, it is then materialized in this software.
5. The other important details are necessarily provided for such a network in hydraulic software (WATERGEMS).
6. This important detail is categorized into link/pipe input and node/junction input. Link/pipe details include length, roughness and diameter of pipe and Node/junction detail include elevation of ground and demand of water at that node.
7. This is fair enough to run water gems software with the provided details. After running the network with given detail, the output is analyzed.
8. This analyzed report would then tend to give the answer to a simple but effective question that whether it is satisfactory or not.
9. If the analyzed result tends to unsatisfactory result, then the details provided are returned and again the output is analyzed. If the analyzed result is satisfactory then the output is extracted in the form of graphs and tables. Figure 3.1 shows the flowchart of the methodology used.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IV April 2026

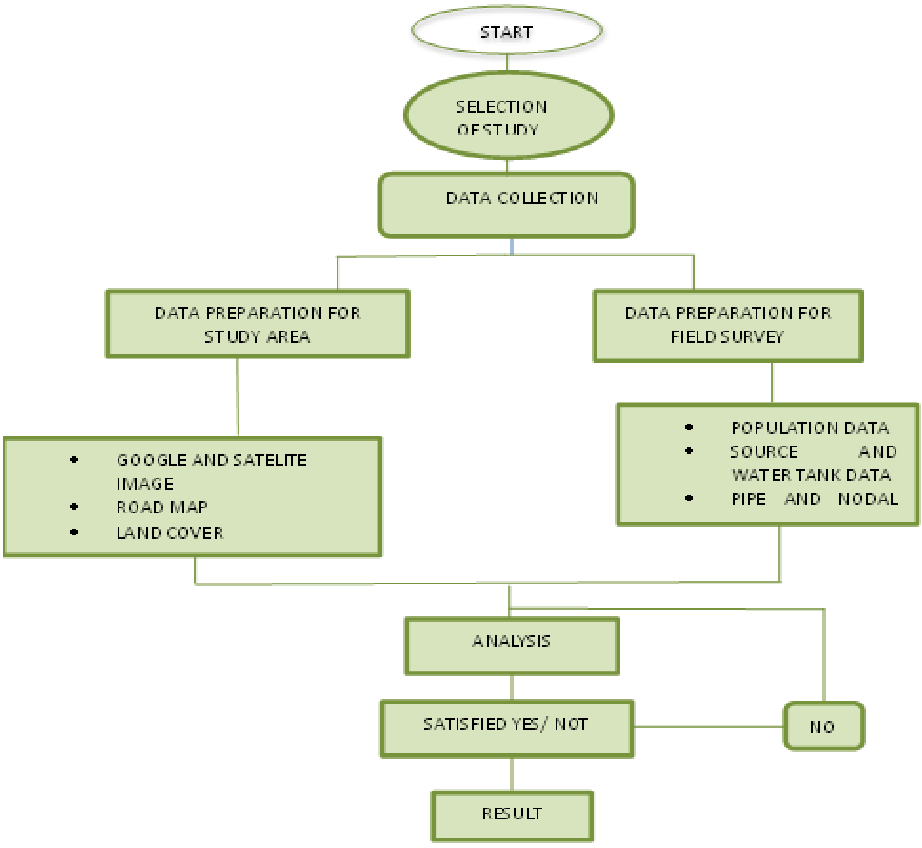

Figure 4. flowchart of the methodology

Figure 5. Pipeline distribution through A-CAD

Analysia And Result for Population Determination in Mhasoli Village

In this section emphasis on discussion of date collection out of field survey and following points has been given:

Population Determination Method:

To find out the population is a standout amongst the most significant factors in arranging, if the undertaking needs to serve the network for a specific plan period. Regularly, a design period of 20 to 40 years is chosen.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IV April 2026

What will be the population toward the finish of the plan period is the fundamental inquiry? This can be accomplished by utilizing different strategies for the population determination shown in the following Equation 5.1, 5.2 and 5.3 (Arjun Kumar 2015).

1.Arithmetical Increase Method

- Population increases at constant rate (dp/dt = const.)

$$P_n = (P_0 + n * X) \quad \text{… (Equation5.1)}$$

2.Geometrical Increase Method

- Rate of growth is progressively increasing or decreasing

$$P_n = p_0 \, [1 + \frac{r}{100}]^n \quad \text{… (Equation 5.2)}$$

3. Incremental Increase Method

- Percentage growth rate (r) is assumed to be constant
- The increase is compounded for the existing population, every decade

$$p_n = p_0 + n * x + \{n\left(\frac{n+1}{2}\right)\} \quad \text{... (Equation 5.3)}$$

Where,

p_n = Forecasted Population after n decades

p_0 = Population at present

n = No. of decades between now & future

r = Growth rate

X = Arithmetic Mean

Y = Av, of incremental increase

The following table shows previous year population and increasing decades of Mhasoli village

Tabel 1. Population and decades of Mhasoli village

YEAR	POPULATION	INCREASE DECADE	r%
1999	1577	-	-
2001	1774	197	12.49
2011	1892	118	6.651
2021	1985	93	4.91

Population forecasting for Mhasoli:

2051=?

Here, p_0=1985,

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IV April 2026

$$n=\frac{2051-2021}{10},$$

$$n=3$$

1. Geometric Increase Method:

$$r=\frac{12.49+6.651+4.91}{3}$$

r= 8.017

where, r= per decade%,

$$P_{2051}=p_0\,[1+\frac{r}{100}]^n$$

$$P_{2051}=1985[1+\frac{8.017}{100}]^3$$

$$\mathbf{P_{2051}=2501}$$

2. Arithmetical Increase Method:

$$X=\frac{197+118+93}{3},$$

X=136

$$P_n=(P_0+n*X)$$

$$P_{2051}=(1985+3*136)$$

$$\mathbf{P_{2051}=2393}$$

3. Incremental Increase Method:

$$p_n=p_0+n*x+\{n\left(\frac{n+1}{2}\right)\}$$

$$p_{2051}=1985+3*136+\{3\left(\frac{3+1}{2}\right)\}$$

$$\mathbf{p_{2051}=2399}$$

$$\text{Average Population}=\frac{2501+2393+2393}{3}$$

Average Population=2431

Water Demand for Mhasoli:

The estimation of water demand is a fundamental aspect of water distribution system design. The per capita water requirement varies depending on the type of settlement, climatic conditions, living standards, and level of urbanization. According to the Central Public Health and Environmental Engineering Organisation (CPHEEO), the recommended domestic water supply for urban areas in India is 135 liters per capita per day

(LPCD) (CPHEEO). In contrast, rural water supply schemes typically adopt lower values ranging between 55 to 100 LPCD, depending on infrastructure availability and socio-economic conditions (Ministry of Jal Shakti).

The World Health Organization also suggests that a minimum of 50–100 LPCD is required to ensure basic health and hygiene, while higher consumption levels are observed in urbanized regions due to increased domestic and commercial usage (World Health Organization). Similarly, the Bureau of Indian Standards provides guidelines for drinking water supply, emphasizing that urban water demand should consider future growth and service level requirements (Bureau of Indian Standards).

In addition, Garg highlights that water demand in developed and densely populated areas may reach up to 150–180 LPCD, particularly when accounting for peak demand conditions and system losses (Garg). However, for design purposes, CPHEEO standards are widely accepted in engineering practice.

Although Mhasoli is classified as a village, it exhibits characteristics of a semi-urban or developing area, including increasing population and infrastructure growth. Therefore, adopting 135 LPCD is considered appropriate for ensuring adequate water supply over the design period.

$$\text{Total Water Demand} = \text{Average Population} \times \text{LPCD}$$
$$\text{Total Demand} = 2431 \times 135 = \mathbf{328,185\ liters/day}$$

RESULT & DISCUSSION

1. The average population of Mhasoli village is **2431**,

2. The total demand of water is **328,185lpcd.**

Results of Pipe Data:

Below table we discussed about velocity, diameter of pipes, the material of pipe and hydraulic gradient.

Tabel 2. Result for pipe data

ID	LABEL	L	S-N1	S-N2	DIA.	M	C	V	H
30	P1	15.14	J-1	J-2	63	HDPE	145	0.83	12.218
33	P2	17.46	J-3	J-4	140	HDPE	145	0.77	4.143
36	P3	18.75	J-5	J-6	63	HDPE	145	0.2	0.881
39	P4	18.75	J-6	J-7	63	HDPE	145	0.07	0.115
41	P5	19.40	J-8	J-9	63	HDPE	145	0.02	0.012
44	P6	20.84	J-10	J-11	63	HDPE	145	1.69	45.16
47	P7	23.90	J-2	J-12	63	HDPE	145	0.04	0.04
49	P8	25.73	J-8	J-13	63	HDPE	145	0.04	0.04
51	P9	26.73	J-14	J-15	63	HDPE	145	0.91	14.307
54	P10	33.81	J-16	J-17	63	HDPE	145	0.05	0.064
57	P11	28.91	J-18	J-19	63	HDPE	145	0.3	1.814

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IV April 2026

60	P12	29.21	J-20	J-21	110	HDPE	145	1.45	17.774
63	P13	31.32	J-22	J-23	63	HDPE	145	0.4	3.186
66	P14	31.71	J-24	J-25	63	HDPE	145	0.11	0.268
69	P15	31.71	J-26	J-24	63	HDPE	145	0.26	1.406
71	P16	31.88	J-27	J-3	110	HDPE	145	1.3	14.429
73	P17	36.51	J-21	J-28	110	HDPE	145	0.44	1.91
75	P18	32.59	J-2	J-16	63	HDPE	145	0.77	10.425
76	P19	32.66	J-29	J-20	110	HDPE	145	1.49	18.57
78	P20	32.34	J-30	J-31	63	HDPE	145	0.11	0.268
81	P21	33.78	J-32	J-33	63	HDPE	145	0.09	0.185
84	P22	37.53	J-26	J-34	63	HDPE	145	0.07	0.116
86	P23	44.03	J-19	J-35	63	HDPE	145	0.1	0.225
88	P24	37.21	J-22	J-1	63	HDPE	145	0.83	12.158
89	P25	38.92	J-36	J-16	63	HDPE	145	0.05	0.069
91	P26	39.91	J-37	J-38	63	HDPE	145	0.13	0.362
94	P27	40.84	J-39	J-36	63	HDPE	145	0.22	1.075
96	P28	43.04	J-15	J-5	63	HDPE	145	0.65	7.644
97	P29	45.83	J-39	J-40	63	HDPE	145	0.06	0.088
99	P30	51.28	J-24	J-41	63	HDPE	145	0.09	0.184
101	P31	49.20	J-42	J-26	63	HDPE	145	0.38	2.913
103	P32	64.91	J-4	J-43	63	HDPE	145	0.08	0.148
105	P33	52.57	J-16	J-42	63	HDPE	145	0.71	9.101
106	P34	54.10	J-36	J-44	63	HDPE	145	0.05	0.062
108	P35	53.27	J-11	J-14	63	HDPE	145	0.62	7.104
109	P36	61.79	J-6	J-45	63	HDPE	145	0.1	0.224
111	P37	60.80	J-32	J-27	63	HDPE	145	0.96	15.884
112	P38	60.30	J-42	J-8	63	HDPE	145	0.1	0.223
113	P39	62.54	J-5	J-39	63	HDPE	145	0.4	3.096

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue IV April 2026

114	P40	64.07	J-10	J-46	63	HDPE	145	0.96	15.707
116	P41	64.07	J-22	J-46	63	HDPE	145	0.49	4.491
117	P42	66.85	J-20	J-47	63	HDPE	145	0.07	0.116
119	P43	66.91	J-48	J-49	63	HDPE	145	0.07	0.116
122	P44	68.37	J-11	J-30	63	HDPE	145	0.97	16.189
123	P45	71.07	J-42	J-50	63	HDPE	145	0.05	0.062
125	P46	76.26	J-51	J-52	63	HDPE	145	0.04	0.041
128	P47	88.94	J-19	J-53	63	HDPE	145	0.13	0.364
130	P48	82.74	J-28	J-54	63	HDPE	145	0.12	0.313
132	P49	85.16	J-55	J-56	63	HDPE	145	0.09	0.184
135	P50	104.19	J-3	J-57	63	HDPE	145	0.05	0.062
137	P51	89.44	J-29	J-51	63	HDPE	145	0.17	0.664
138	P52	95.67	J-14	J-46	63	HDPE	145	0.41	3.274
139	P53	101.08	J-18	J-58	63	HDPE	145	0.11	0.266
141	P54	99.21	J-28	J-32	110	HDPE	145	0.37	1.406
142	P55	130.94	J-21	J-27	110	HDPE	145	1	8.974
143	P56	142.04	J-4	J-59	110	HDPE	145	1.2	12.539
145	P57	146.33	J-30	J-37	63	HDPE	145	0.32	2.04
146	P58	149.41	J-1	J-15	63	HDPE	145	0.12	0.298
147	P59	173.06	J-30	J-18	63	HDPE	145	0.45	3.926
148	P60	156.07	J-59	J-10	110	HDPE	145	0.89	7.184
149	P61	170.98	J-48	J-60	63	HDPE	145	0.08	0.148
151	P62	220.35	J-59	J-23	63	HDPE	145	0.77	10.508
152	P63	210.56	J-15	J-29	110	HDPE	145	1.61	21.438
154	P64	236.25	J-29	J-55	63	HDPE	145	0.14	0.474
155	P65	248.62	J-23	J-48	63	HDPE	145	0.22	1.045
156	P66	268.31	J-51	J-62	63	HDPE	145	0.08	0.148
158	P67	318.05	J-37	J-63	63	HDPE	145	0.12	0.313

- The minimum diameter is used for water distribution system is 63mm and the maximum diameter is 140mm.
- The minimum velocity is 0.02m/s, and the maximum velocity is 1.69m/s, for water distribution system. And the average velocity is used for the network is 0.45m/s.
- The mean hydraulic gradient is 5.16m.

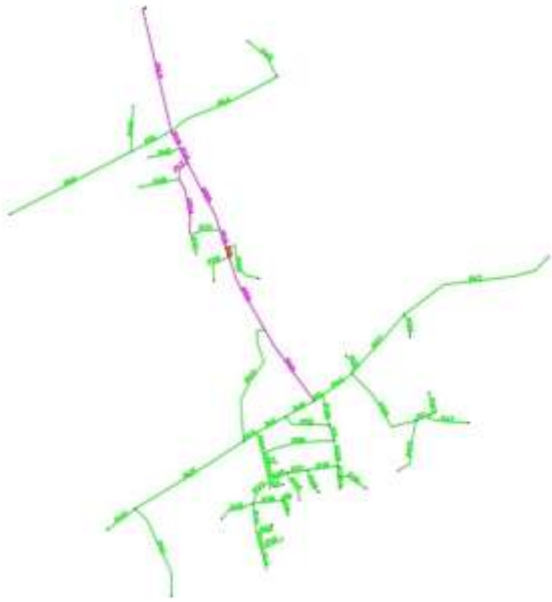

Figure 6. Network modelling through water-gems

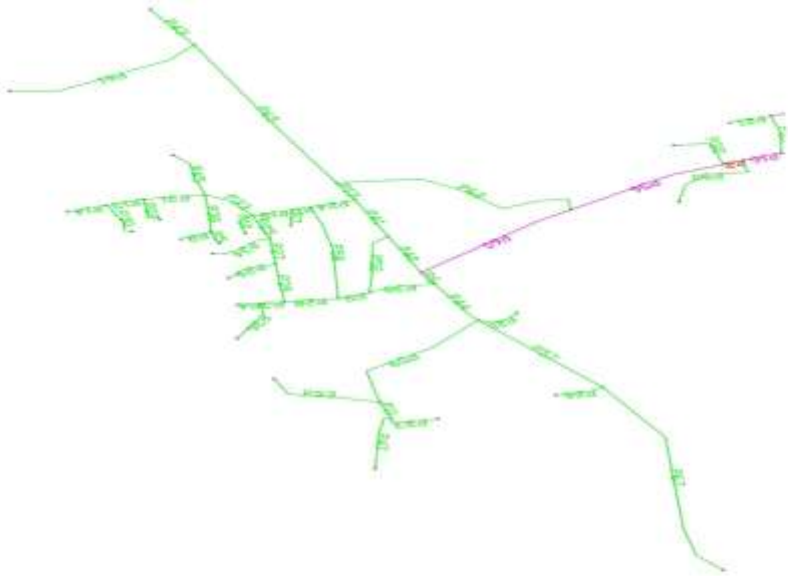

Figure 7. Network modelling through water gems zone-1

Result of Junction points:

Tabel 3. Elevation, demand and pressure at each junction point

ID	LABEL	ELEVATION	DEMAND	HYDRAULIC GRADE	PRESSURE
31	J-1	660	0.36	673	0.127

32	J-2	660	0.09	672.82	0.125
34	J-3	663	0.33	677.73	0.144
35	J-4	662	0.18	677.65	0.153
37	J-5	653	0.15	672.72	0.193
38	J-6	651	0.12	672.7	0.212
40	J-7	650	0.21	672.7	0.222
42	J-8	655	0.12	671.99	0.166
43	J-9	655	0.06	671.99	0.166
45	J-10	657	0.21	674.75	0.174
46	J-11	657	0.3	673.81	0.165
48	J-12	660	0.12	672.82	0.125
50	J-13	653	0.12	671.99	0.186
52	J-14	656	0.39	673.43	0.171
53	J-15	656	0.45	673.05	0.167
55	J-16	660	0.18	672.48	0.122
56	J-17	657	0.15	672.48	0.151
58	J-18	655	0.15	672.02	0.167
59	J-19	657	0.24	671.97	0.147
61	J-20	670	0.12	679.88	0.097
62	J-21	669	0.12	679.36	0.101
64	J-22	659	0.18	673.46	0.141
65	J-23	660	0.45	673.56	0.133
67	J-24	654	0.21	671.81	0.174
68	J-25	652	0.33	671.8	0.194
70	J-26	656	0.18	671.86	0.155
72	J-27	665	0.21	678.19	0.129
74	J-28	669	0.27	679.29	0.101
77	J-29	672	0.15	680.49	0.083
79	J-30	656	0.3	672.7	0.163

80	J-31	656	0.33	672.69	0.163
82	J-32	663	0.24	679.15	0.158
83	J-33	661	0.27	679.14	0.178
85	J-34	655	0.21	671.85	0.165
87	J-35	659	0.3	671.96	0.127
90	J-36	658	0.39	672.48	0.142
92	J-37	660	0.24	672.4	0.121
93	J-38	660	0.39	672.39	0.121
95	J-39	655	0.36	672.53	0.172
98	J-40	652	0.18	672.52	0.201
100	J-41	652	0.27	671.8	0.194
102	J-42	660	0.57	672	0.117
104	J-43	662	0.24	677.64	0.153
107	J-44	653	0.15	672.48	0.191
110	J-45	647	0.3	672.69	0.251
115	J-46	658	0.18	673.74	0.154
118	J-47	670	0.21	679.87	0.097
120	J-48	662	0.24	673.3	0.111
121	J-49	665	0.21	673.29	0.081
124	J-50	659	0.15	672	0.127
126	J-51	671	0.18	680.43	0.092
127	J-52	679	0.12	680.42	0.014
129	J-53	655	0.39	671.94	0.166
131	J-54	668	0.36	679.26	0.11
133	J-55	671	0.18	680.37	0.092
134	J-56	672	0.27	680.36	0.082
136	J-57	666	0.15	677.72	0.115
140	J-58	647	0.33	672	0.245
144	J-59	659	0.57	675.87	0.165

150	J-60	659	0.24	673.27	0.14
157	J-62	673	0.24	680.39	0.072
159	J-63	659	0.36	672.3	0.13
187	J-71	0	(N/A)	(N/A)	(N/A)

The minimum demand is 0.06 m^3/s and the maximum demand is for the water distribution network is 0.57 m^3/s.

CONCLUSION

This study presented the **hydraulic modeling and analysis of a rural water distribution network for Mhasoli village using WaterGEMS software**. Population forecasting methods were applied to estimate future demand, and the **projected population of 2431** was used to determine the **total daily water demand of approximately 328,185 liters**. A hydraulic model of the distribution network was developed to evaluate critical parameters including **pipe diameter, velocity, pressure distribution, and hydraulic gradient**. The simulation results indicate that the **designed network satisfies standard hydraulic design criteria**, with **pipe velocities ranging from 0.02 m/s to 1.69 m/s** and **adequate pressure maintained at all junction nodes**. The use of **HDPE pipes** provides advantages such as **corrosion resistance, durability, and reduced leakage**, making them suitable for rural water supply systems. Overall, the results demonstrate that **WaterGEMS is an effective decision-support tool for hydraulic modeling and optimization of water distribution networks**. The proposed approach can support **efficient planning, design, and sustainable management of rural water supply infrastructure** in similar developing regions.

REFERENCES

1. Alperovits, E., & Shamir, U. (1977). Design of optimal water distribution systems. Water Resources Research, 13(6), 885–900.
2. Bansal, R. K. (2018). Fluid mechanics and hydraulic machines. Laxmi Publications.
3. Bentley Systems. (2014). WaterGEMS user guide.
4. Bureau of Indian Standards. (2012). Drinking water specifications (IS 10500:2012).
5. Garg, S. K. (2010). Water supply engineering. Khanna Publishers.
6. Kumar, A., et al. (2015). Design of water distribution system using EPANET. International Journal of Advanced Research.
7. Lansey, K. E., & Mays, L. W. (1989). Optimization model for water distribution system design. Journal of Hydraulic Engineering, 115(10), 1401–1418.
8. Maharashtra Jeevan Pradhikaram. (2012). Basic of water supply system.
9. Ormsbee, L. E. (2006). History of water distribution system analysis.
10. Pillai, L. (2020). Design of pipeline distribution network. Maharashtra Water Resources Department.
11. Rai, R., & Dohare, D. (2019). Application of WaterGEMS in hydraulic modeling. Global Journal of Engineering Science.
12. Ramana, G. V., et al. (2015). Network analysis of water distribution systems using EPANET.
13. Rossman, L. A. (1993). EPANET user manual. U.S. Environmental Protection Agency.
14. Todini, E., & Pilati, S. (1988). A gradient algorithm for pipe network analysis. Computer Applications in Water Supply.
15. Van Blaricum, V. L., & Hock, V. F. (2007). Water quality sensor validation study.
16. World Health Organization. (2017). Guidelines for drinking-water quality.
17. Yang, C., et al. (2006). Water treatment and pipe system optimization. Journal of Environmental Engineering.