# Smart Choices for Water Distribution Networks: Evaluating Pipe Materials & Distribution Efficiency with Water Gems

Humera A. Khandeshi[1], Fauwaz A.M. Parkar[2]
[1] *Research Graduate,Civil Engg. Dept.,Anjuman-i-Islam's Kalsekar Technical Campus, Panvel, Maharashtra, India*
[2] *Associate Professor,Civil Engg. Dept.,Anjuman-i-Islam's Kalsekar Technical Campus, Panvel, Maharashtra, India*

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**ABSTRACT**

***Access to potable water remains a global concern, despite 71% of the Earth's surface being covered by water. In India, the increasing population has placed growing stress on rural water infrastructure. While prior methods for water supply relied heavily on manual design and implementation, recent advancements in modeling tools offer improved accuracy and efficiency. This study focuses on the planning and analysis of a rural water distribution network in Mhasoli village, Maharashtra. Key design inputs included projected population, daily water demand, and optimal pipe sizing using cost-effective materials. The layout was prepared using AutoCAD, and hydraulic simulation was conducted using Water-GEMS. The performance of the network was evaluated based on pressure distribution, head loss, and flow efficiency. An evaluation was conducted for two pipe material classes to study their economic viability and hydraulic performance. Diameters of 63 mm, 110 mm, and 200 mm were selected according to pressure-head requirements. The study provides a practical framework for designing sustainable rural water systems, contributing to improved resource allocation, reduced design time, and informed policy-making.***

***Keywords: - Rural Water Supply, Water Distribution Network, Hydraulic Modeling, AutoCAD, Water-GEMS, Pipe Material Selection, Pressure-Head Analysis, Head Loss, Cost-Effective Design, Sustainable Infrastructure.***

## 1. INTRODUCTION

Many rural regions in India continue to face challenges in accessing an adequate and reliable water supply, despite the availability of natural water sources. This disparity often stems from inefficient water distribution systems, out dated infrastructure, and a lack of proper planning based on demographic needs. In response to these challenges, the present study utilizes hydraulic modeling tools to design a water distribution network (WDN) tailored to the population and geographic layout of Mhasoli village shown in figure-1. The objective is to ensure equitable water delivery across all areas of the village, based on projected population growth over the next 25 years. This study is use water-GEMS software to analyze and distribute a pipeline network. Pipe diameters and materials are selected based on performance indicators such as velocity, pressure head and head loss. Two pipe materials—High-Density Polyethylene (HDPE) and Ductile Iron —are evaluated to determine the most economic and hydraulically efficient option. Comparative analysis includes both hydraulic behavior and material costs to identify the optimal solution for long-term sustainability. The network is designed to deliver water efficiently to each junction point, accounting for future demand and operational reliability.

**Fig.- 1**: Study area-Mhasoli village

Geographically, Mhasoli is located at approximately 17°10'47.3" N latitude and 74°02'42.4" E longitude. Area of this rural area is 1215 Hectars. According to recent census data, Mhasoli has an estimated population of around 2,000 residents. Based on standard per capita water consumption rates, the village's daily water demand is estimated to be between 30,000 to 35,000 liters.

## 2. LITERATURE REVIEW

Kumar *et al.* (2015) designed a water supply scheme for Kathgarh using EPANET to ensure consistent distribution through a structured pipeline system [1]. Ramana *et al.* (2015) used EPANET to simulate head losses and flows in complex pipe networks based on elevation and demand inputs [2]. Singh *et al.* (2017) developed a water supply plan focused on minimizing losses and optimizing pump design based on hydraulic principles [3]. Mehta *et al.* (2017) assessed pressure, leakage, and GIS-based monitoring for Surat's Pungam area using WaterGEMS[4]. Angolo(2017) analyzed a water distribution system's detailing treatment processes, modular plant design, and gravity-challenged pumping logistics [5]. Hooda *et al.* (2017) proposed a cost-efficient linear programming model for rural pipe networks via JalTantra, outperforming traditional tools [6]. Chang *et al.* (2019) enhanced Pressure-Driven Analysis (PDA) with accurate Head-Outflow Relations for emergency WDN scenarios [7]. Sharma *et al.* (2019) advocated solar-powered pumping as a cost-effective alternative in WDN infrastructure design [8]. Wéber *et al.* (2020) developed a vulnerability metric combining hydraulic and topological data to assess pipe burst impact in WDNs [9]. Navin *et al.* (2020) compared WaterGEMS and EPANET, favoring WaterGEMS for efficient urban WDN design with GIS integration [10]. Huzsvár *et al.* (2021) used pressure sensitivity and genetic algorithms to pinpoint critical nodes and optimize pipeline additions [11]. Bashar *et al.* (2022) applied hybrid AI models to predict rural water demand; subscriber count had the highest influence [12]. Tornyeviadzi *et al*. (2022) introduced a dynamic segment criticality model combining PDA and multilayer analysis for WDN maintenance [13]. Munsamy *et al.* (2022) proposed a Fourth Industrial Revolution (4IR)-based energy–water–carbon dioxide ($CO_2$) nexus model leveraging Variable Speed Drives (VSDs) and the Internet of Things (IoT) in WDNs [14]. Darunte *et al.* (2022): Designed Saigaon's water network using WaterGEMS with CAD and GIS data to meet projected demands [15]. Adhav *et al.* (2022) optimized a continuous supply system using WaterGEMS to enhance flow and pressure over 30-year forecasts [16]. Shelar *et al.* (2022) designed a gravity-fed and pump-assisted water system for Kharwal village using WaterGEMS and field surveys [17]. Desta *et al.* (2022): Used WaterGEMS and genetic algorithms to enhance Adama city's network pressure and water quality [18]. Shahhosseini *et al*. (2023) employed GA and NLP in Tehran's WDN to reduce leakage and optimize pipe sizing using real pressure data [19]. Kapoor *et al.* (2023) focused on designing cost-effective, high-quality water supply systems to meet rising urban and rural demands [20]. Chavhan (2023) demonstrated how WaterGEMS aids clean water access by optimizing system design and scenario analysis in Waddhamna [21]. Rashid & Kumari (2024) used ANFIS to create a cost-efficient, high-reliability WDN design through neural-fuzzy optimization [22]. Bideris-Davos & Vovos (2024) designed an energy recovery system via micro-turbines in WDNs, optimizing PRV losses economically [23]. Brahmamiah *et al.* (2024): Modeled hydraulic performance using regression and found WaterGEMS superior to EPANET for usability [24]. Yennawar (2024) redesigned WDN using Darwin Designer in WaterGEMS resolving most pressure inadequacies efficiently [25]. Brás *et al.* (2025) reviewed optimization models for pump scheduling, favoring duty-cycle and VSPs for energy-efficient water supply [26].

## 3. AIM & OBJECTIVES

The primary aim of this study is to formulate a Water Distribution Network & evaluate Pipe Materials & Distribution Efficiency with Water-Gems in rural area.
To achieve this aim following objectives are set:

- To collect existing topographical, water resources and population data through open data sources and government agencies.
- To formulate smart model of water distribution network in AutoCAD software and deep analysis in WATER-GEMS.
- To analyses different pipe materials for pipeline distribution based on velocity & head loss.

## 4. METHODOLOGY

Fig 2 shows the systematic process adopted as methodology for the study

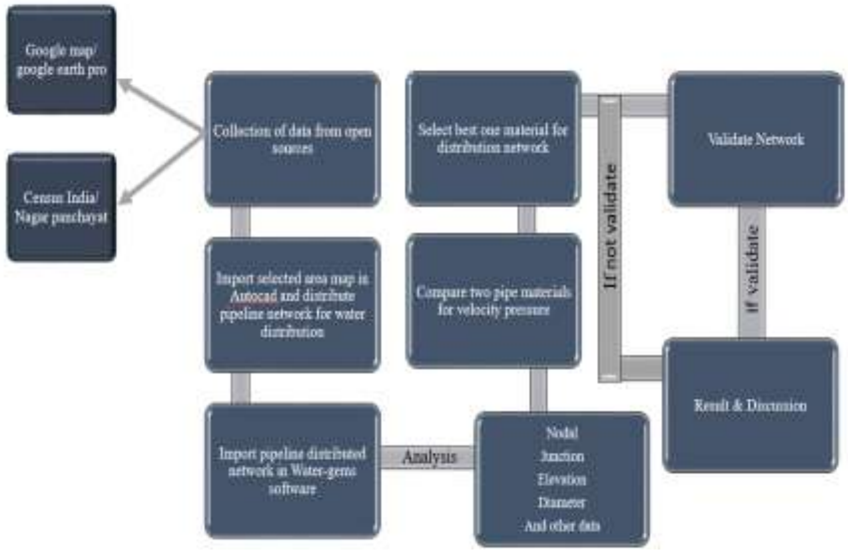


**Fig.- 2**: Methodology adopted

The methodology adopted in this study is illustrated in Fig.-2 and comprises several systematic stages aimed at designing and analyzing the rural water distribution network for Mhasoli village. Initially, spatial and demographic data were collected for the study area. This incorporates satellite images and baseline maps from Google Earth, along with the schematics of the road network and land use data. Field survey information such as population statistics, pipe routes, and nodal locations was obtained from the Department of Rural Water Supply and Construction. These datasets served as the foundation for network design. The preliminary layout of the water distribution network was developed using AutoCAD, where pipeline alignments and nodal junctions were defined according to topographical and infrastructural observations. Upon finalizing the network layout, the schematic was imported into Water-GEMS software for hydraulic analysis.

Within the Water-GEMS environment, essential input data were categorized into two primary types: link (pipe) and node (junction) parameters. Pipe-related inputs included pipe length, diameter, and roughness coefficients, while junction-related inputs involved ground elevation and estimated water demand at each node, calculated based on population projections. With the dataset fully integrated, the hydraulic model was executed to simulate flow dynamics, pressure distribution, and head loss across the network. The resulting output was critically evaluated to determine system performance and reliability. If the model output indicated suboptimal or unsatisfactory results, the input parameters were reviewed and adjusted iteratively until satisfactory hydraulic behavior was achieved. Once validated, the final results were extracted in the form of graphs and tabulated data for interpretation and reporting.

## 5. DATA COLLECTION AND ANALYSIS

In the initial design phase, the geographical map of the study area is imported into AutoCAD, where the pipeline layout is drawn to represent the spatial distribution of the water distribution network. This layout is then imported into Water-GEMS for hydraulic modeling. In Water-GEMS, junctions are created, water demand is assigned based on population and household data, and key hydraulic parameters such as pipe diameter, velocity, and head loss at each node and pipe segment are analyzed. The platform also facilitates the evaluation of different pipe materials, enhancing efficiency in design optimization. Fig-3 shows the network layout in AutoCAD software.

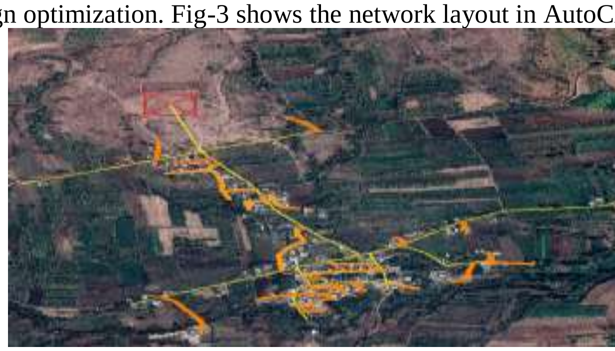

**Fig.- 3**: Water Distribution Network in AutoCAD

Fig.-4 shows the schema for Water Distribution Network Analysis done for the study in Water-GEMS

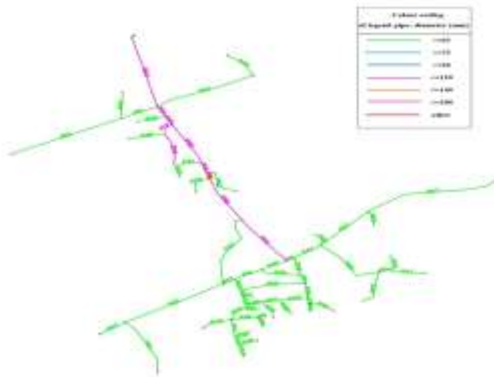

**Fig.- 4**: Water Distribution Network in Water-Gems

To ascertain the hydraulic efficiency of the system under varied operating conditions, Water-GEMS assesses key network parameters such as head loss, pipe diameter, flow velocity, water demand (derived from household and population statistics), and junction location. The study further evaluates various pipe materials to optimize for durability and energy efficiency, minimizing losses while ensuring reliable supply. Integration with AutoCAD supports accurate mapping and seamless data transfer, enhancing both the design and simulation processes. This combined approach is especially effective for large-scale urban water distribution systems where precision, adaptability, and performance are critical.

## 6. RESULTS AND DISCUSSION

In this study, the two pipe materials HDPE and Ductile Iron were evaluated for their performance in terms of water demand fulfilment, velocity, and head loss within the distribution network. Table-1 shows comparative analysis of two different pipe materials.

**Table 1**: Comparison between HDPE pipe and Ductile Iron Pipe

| Pipe | Dia. (mm) | HDPE | | Ductile Iron | | Pipe | Dia. (mm) | HDPE | | Ductile Iron | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Velocity | Head Loss | Velocity | Head Loss | | | Velocity | Head Loss | Velocity | Head Loss |
| P1 | 63 | 0.83 | 12.218 | 0.91 | 15.77 | P35 | 63 | 0.56 | 3.164 | 0.61 | 4.08 |
| P2 | 140 | 0.77 | 4.143 | 0.84 | 5.34 | P36 | 63 | 0.1 | 0.224 | 0.11 | 0.29 |
| P3 | 63 | 0.20 | 0.881 | 0.22 | 1.14 | P37 | 63 | 0.96 | 15.884 | 1.05 | 20.49 |
| P4 | 63 | 0.07 | 0.185 | 0.08 | 0.24 | P38 | 63 | 0.1 | 0.223 | 0.11 | 0.29 |
| P5 | 63 | 0.02 | 0.012 | 0.02 | 0.02 | P39 | 63 | 0.4 | 3.096 | 0.44 | 3.99 |
| P6 | 63 | 1.69 | 45.16 | 1.84 | 58.25 | P40 | 63 | 0.96 | 15.707 | 1.05 | 20.24 |
| P7 | 63 | 0.04 | 0.04 | 0.04 | 0.05 | P41 | 63 | 0.49 | 4.491 | 0.53 | 5.79 |
| P8 | 63 | 0.04 | 0.04 | 0.04 | 0.05 | P42 | 63 | 0.07 | 0.116 | 0.08 | 0.15 |
| P9 | 63 | 0.91 | 14.307 | 0.99 | 18.39 | P43 | 63 | 0.07 | 0.116 | 0.08 | 0.15 |
| P10 | 63 | 0.05 | 0.064 | 0.05 | 0.08 | P44 | 63 | 0.97 | 16.189 | 1.06 | 20.88 |
| P11 | 63 | 0.30 | 0.814 | 0.33 | 1.05 | P45 | 63 | 0.05 | 0.062 | 0.05 | 0.08 |
| P12 | 110 | 1.45 | 17.774 | 1.58 | 22.91 | P46 | 63 | 0.04 | 0.041 | 0.04 | 0.05 |
| P13 | 63 | 0.40 | 3.186 | 0.44 | 4.11 | P47 | 63 | 0.13 | 0.364 | 0.14 | 0.47 |
| P14 | 63 | 0.11 | 0.268 | 0.12 | 0.35 | P48 | 63 | 0.12 | 0.313 | 0.13 | 0.40 |
| P15 | 63 | 0.26 | 1.406 | 0.28 | 1.82 | P49 | 63 | 0.09 | 0.184 | 0.10 | 0.24 |
| P16 | 110 | 1.30 | 14.429 | 1.42 | 18.62 | P50 | 63 | 0.05 | 0.062 | 0.05 | 0.08 |
| P17 | 110 | 0.44 | 1.91 | 0.48 | 2.47 | P51 | 63 | 0.17 | 0.664 | 0.19 | 0.86 |
| P18 | 63 | 0.77 | 10.425 | 0.84 | 13.45 | P52 | 63 | 0.41 | 3.274 | 0.45 | 4.22 |
| P19 | 110 | 1.49 | 18.57 | 1.62 | 23.95 | P53 | 63 | 0.11 | 0.266 | 0.12 | 0.34 |
| P20 | 63 | 0.11 | 0.268 | 0.12 | 0.35 | P54 | 63 | 0.37 | 1.406 | 0.40 | 1.82 |
| P21 | 63 | 0.09 | 0.185 | 0.10 | 0.24 | P55 | 110 | 1.00 | 8.974 | 1.09 | 11.60 |
| P22 | 63 | 0.05 | 0.116 | 0.05 | 0.15 | P56 | 110 | 1.20 | 12.539 | 1.31 | 16.18 |
| P23 | 63 | 0.10 | 0.225 | 0.11 | 0.29 | P57 | 63 | 0.32 | 2.04 | 0.35 | 2.63 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P24 | 63 | 0.83 | 12.158 | 0.91 | 15.69 | | P58 | 63 | 0.12 | 0.298 | 0.13 | 0.38 |
| P25 | 63 | 0.05 | 0.069 | 0.05 | 0.09 | | P59 | 63 | 0.45 | 3.926 | 0.49 | 5.06 |
| P26 | 63 | 0.13 | 0.362 | 0.14 | 0.47 | | P60 | 110 | 0.89 | 7.184 | 0.97 | 9.27 |
| P27 | 63 | 0.22 | 1.075 | 0.24 | 1.39 | | P61 | 63 | 0.08 | 0.148 | 0.09 | 0.19 |
| P28 | 63 | 0.65 | 0.644 | 0.71 | 0.83 | | P62 | 63 | 1.23 | 10.508 | 1.34 | 13.56 |
| P29 | 63 | 0.06 | 0.088 | 0.07 | 0.11 | | P63 | 110 | 1.61 | 21.438 | 1.75 | 27.65 |
| P30 | 63 | 0.09 | 0.184 | 0.10 | 0.24 | | P64 | 63 | 0.14 | 0.313 | 0.15 | 0.40 |
| P31 | 63 | 0.38 | 2.913 | 0.41 | 3.75 | | P65 | 63 | 0.22 | 1.045 | 0.24 | 1.35 |
| P32 | 63 | 0.08 | 0.148 | 0.09 | 0.19 | | P66 | 63 | 0.12 | 0.313 | 0.13 | 0.40 |
| P33 | 63 | 0.71 | 9.104 | 0.77 | 11.74 | | P67 | 63 | 0.12 | 0.313 | 0.13 | 0.40 |
| P34 | 63 | 0.22 | 1.045 | 0.24 | 1.35 | | | | | | | |

As seen in Table 1, the key performance differences between HDPE and Ductile Iron pipes, based on material characteristics & hydraulic behaviour, are highlighted while HDPE pipes are known for their considerable flexibility, portability, low leakage rates, and affordability, they are thought to be less suitable for high-pressure applications than ductile iron pipes, which offer better strength and resistance to pressure. The ductile iron ranges velocity from 0.02m/s to 1.84m/s although the HDPE pipe ranges velocity values from 0.02m/s to 1.69m/s, but in case of head loss the maximum head loss at ductile iron is reached up to 58.2m but in case of HDPE pipe it is reached up to 45.16m, it means ductile iron pipes provide better flow characteristics with higher velocity and slightly higher head loss in relation to the cost; this makes them suitable for enhanced hydraulic performance. On the other hand, HDPE pipes have lower head loss and are more energy-efficient and cost effective, which makes them the best option for the studied village's water distribution network. Thus from the above analysis, it is evident that, HDPE pipes are best suited as WDN material for the rural area under study.

## 7. CONCLUSION

In this study, a hydrological parametric analysis of the water distribution network was conducted using computer-based hydraulic simulation software. The software utilized Water-GEMS is a robust and efficient tool widely adopted for the design and evaluation of water supply systems. The network was modeled and analyzed in accordance with relevant guidelines and standards prescribed by the Government of India. The use of this software significantly reduces the time required for system analysis and design compared to traditional manual methods.

Two pipe materials Ductile Iron and HDPE were selected for comparative evaluation based on parameters such as flow velocity, head loss, and material cost. Improved velocity performance within the optimal range of 0.6 to 2.0 m/s was demonstrated by ductile iron pipes, which reduced operational risks and increased flow stability. However, their higher cost makes them less economically viable for rural applications. In contrast, HDPE pipes exhibited lower head loss values, indicating better hydraulic efficiency. They are also easier to install and cost effective, making them a better choice for Mhasoli village's water distribution system.

The hydraulic model was developed to accommodate population growth over a 25-year planning horizon. Based on projected demographics, the estimated average daily water demand for Mhasoli village is approximately 328,187 liters.

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