iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: V Month of publication: May 2026

DOI: https://doi.org/10.22214/ijraset.2026.83262

Population Projection and Demand-Based Design of Water Supply System at Banda

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Abstract: The study reports hydraulic planning, demand based design and performance evaluation of a sustainable urban water supply system for Bandhavgarh town to serve its water demand till 2055. Four methods, namely Arithmetic Increase, Geometric Increase, Incremental Increase and Decadal Growth Rate were used to make population forecasts, and the Incremental Increase Method was adopted, which resulted in the design population of 57,333 for the ultimate year 2055. If per capita demand norm of 135 LPCD which is recommended by CPHEEO is adopted, the water demand would escalate from 5.87 MLD in 2025 to 8.59 MLD in 2055. Hydraulic adequacy for the entire design life was achieved by sizing all system components (intake structure, water treatment plant (WTP), transmission mains, elevated service reservoirs (ESR), and distribution network) for ultimate-year demands. The Hazen-Williams and Darcy-Weisbach equations were employed to perform the hydraulic performance analysis and to determine the correlation between pipe diameter, pipe head loss, and pipe flow velocity. Optimal pipe diameters for minimizing the total life cycle cost of pipes between CCGT and energy usage were found using the Present Worth Cost (PWC) method for economic optimization. Residual pressure analysis verified compliance with minimum pressure requirement of CPHEEO (7 m) at all nodes under the peak demand conditions, no negative pressure zones were found. Comparative assessment shows that there are significant enhancements in service indicators: supply from 77 LPCD to 135 LPCD, coverage from 44.01% to 100% and supply continuity from intermittent 1.5 hours per day to continuous 24 hours supply. The proposed system is technically feasible, has good hydraulic efficiency, and is socially sustainable.

Keywords: Water Demand Projection, Hydraulic Modeling, Distribution Network Optimization, Head Loss Analysis, Storage Capacity Design, Sustainable Infrastructure Planning.

I. INTRODUCTION

A. Background and Problem Statement

Water is one of the most essential elements for human life and socio-economic development. The current urbanization and population growth have put increased pressures on the current urban water supply schemes in Indian urban centers, resulting in water scarcity, lack of adequate distribution pressure, losses in the water network and ageing water supply systems. [1] Urban water supply schemes include all aspects of the water supply from source, treatment, transmission, storage and distribution. The ability to predict populations accurately and to estimate the water demand is fundamental to the efficient design of a scheme, as schemes with poor population estimates are likely to experience shortages in use, whilst those with overprovision will lead to unnecessary capital expenditure [2, 3].

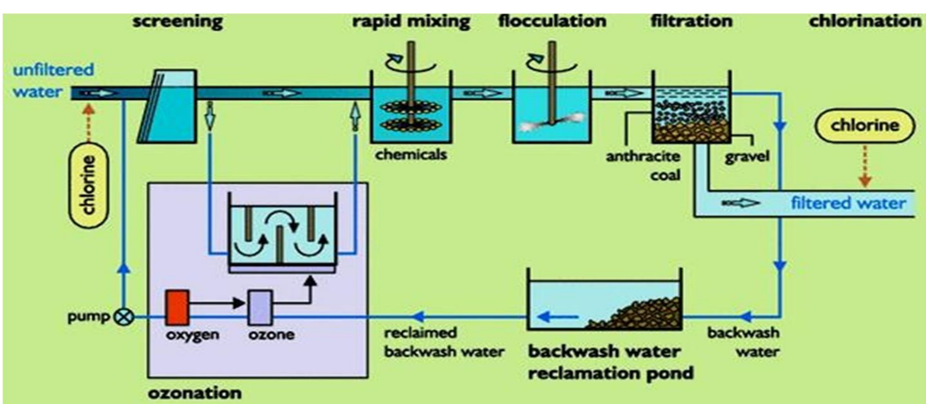

Fig. 1. Typical Urban Water Supply System Components [4]

The town of Banda in Sagar District, Madhya Pradesh, is an example of this challenge. The existing water supply scheme has seen pressures from a steady population increase and rising water demands at peak demand seasons, causing unequal distribution of water and degrading water service levels throughout the town. The current system provides access to water to 44.01% of the population with water availability of only 1.5 hours per day, against the CPHEEO target of 135 LPCD [5].

B. Research Objectives

The main aims of this study are to:

1) Review population growth and make long-term estimates of water demand up to the U.D.Y. (ultimate design year) 2055.
2) Design all water supply system components for ultimate year demand, with long-term hydraulic adequacy.
3) Use hydraulic analysis to optimise pipe diameters, thereby reducing head loss and energy consumption.
4) Check allowable velocities and sufficient residual pressures across the distribution system during peak demand.
5) To improve the reliability of the sources, use Pagra Reservoir, a perennial source, in place of the seasonal supply from Bewas River, should be encouraged.
6) Improve treatment and storage capacity to meet future requirements and allow for hydraulic overloads.
7) Enhance the service level indicators with 100% coverage, continuous supply during 24 hours and 135 LPCD per capita.

C. Contributions of the Study

The present study proposes a complete holistic approach which combines various population projections techniques, demand estimates, treatment plant sizing, storage design and network hydraulic modelling in WaterGEMS-V8i for a mid-sized town in India. The methodology presented in the work is replicable and can be used in other similar towns in AMRUT 2.0 and Jal Jeevan Mission schemes of the city and is also used to see the service level improvements which can be quantified through the design of the services as per demand [3, 6].

II. LITERATURE REVIEW

A. Population Projection and Demand Estimation

In Indian urban water supply planning, Sharma et al. [2] compared population growth forecasts using various methods, showing that the method chosen can have a significant impact on the long-term forecasts of water demand and sustainability of infrastructure. Comparative study by Kumar et al. [6] of Arithmetic, Geometric and Incremental Increase methods revealed that for the towns showing slow growth stabilisation, the Incremental Increase Method gives a better balance of projections (which is similar to Banda town).

Patel et al. [4] highlighted that medium size towns in India are affected by inefficient infrastructure planning due to underestimation of populations. They also studied the projection models for Indian cities, which emphasize the importance of predicting accurately the size of water treatment plants, storage reservoirs and distribution pipes [7]. Joshi et al. [8] suggested an approach to combine historical trends of the census with the socioeconomic factors to enhance the accuracy of projections, and Malhotra et al. [9] emphasized the importance of choosing methods carefully as a function of the characteristics of urban growth. Banerjee et al. investigated the dynamics of planning in cases of population uncertainty and suggested design methods which are flexible to population fluctuations.

B. Hydraulic Design and Network Optimisation

Mishra et al. [10] evaluated distribution network performance based on predicted demands, and concluded that distribution network design should be based on demand, ensuring sufficient pressures and reductions in losses in expanding urban areas. WaterGEMS simulation tools have been used for hydraulic performance assessment of urban water distribution systems by Reddy et al. [11] thus establishing the effectiveness of network analysis by software. Jain et al. [12] used iterative pipe diameter selection and Present Worth Cost analysis procedure in order to optimize design of water distribution networks for growth in future demand.

Kulshreshtha et al. [13] had suggested standby pump capacity of 50% and phasing replacement schedules (as is proposed in this study). Khatri and Vairavamoorthy [14] brought to light the problems of water supply in urban areas of developing countries and suggested continuous pressurised water supply as a potential solution to get rid of intermittent water supply issues. Verma et al. [5] showed that a design based on the demand allows to considerably improve the reliability of the system in the presence of future population growth by using the CPHEEO per capita norms and peak factors.

C. *Water Treatment and Storage Design*

Mehta et al. [15] have shown that demand oriented infrastructure planning can be used to optimize the infrastructure size, reduce capital expenditure and improve operational efficiency. Gokila Vani et al. [16] demonstrated the use of system dynamics modelling for urban water demand forecasting, noting the feedback mechanisms due to population growth as important factors in providing better forecasts. This study is based on the regulatory basis of water quality standards which are prescribed by WHO guidelines [17] and IS 10500 standards. Rao et al. [18] investigated the correlation between population density and water supply infrastructure, emphasising the importance of taking the population growth into consideration to avoid system failures. Deshmukh et al., [19] gave a case study to substantiate that design as per demand is more suited to cater the actual water demand with respect to the water supply capacity.

D. *Research Gaps*

The literature search indicates that most of the studies published on the subject are of large metropolitan cities, and little case study exists in the medium size Indian towns, like Banda (30,000–60,000) in the country. In addition, only a few studies consider the entire design chain from population projections, to treatment plant sizing, storage design, and hydraulic network modelling in a single, coherent framework. The present study addresses these gaps by offering a validated CPHEEO-compliant methodology for design which is validated with IS standards and benchmarked against the national service level targets. Chatterjee et al. [20] also remarked that water demand management integration with the results of population planning is an under-researched field in Indian municipal research.

III. METHODOLOGY

A. *Study Area Description*

Banda is a town in the district of Sagar, Madhya Pradesh, India. The total municipal area of the Banda Nagar Parishad is about 10.5km² and the population density is 3,534 persons per km² in 2021. The town has 15 wards for administrative purposes. The population had been increasing steadily between 1971 and 2011, from 7,630 to 30,923 (an overall growth of around 305% over 40 years) [5]. The population growth data are summarised in the table of historical data (Table I).

Table I. Historical Population Growth of Banda Town

Census Year	Population	Decadal Increase	Percentage Increase (%)
1971	7,630	–	–
1981	12,569	4,939	64.7
1991	19,830	7,261	57.8
2001	26,183	6,353	32.0
2011	30,923	4,740	18.1

The trend of decadal growth rate has also been declining as can be seen in Table I, and is declining from 64.7% in 1971 to 18.1% in 2001, which is typical of medium-sized towns in India. This pattern is for method selection in population projection in which the pattern is guided.

Table II. Ward-wise Population Distribution of Banda (2011)

Ward No.	**Ward Name**	**Population**
1	Mahatma Gandhi Ward	1,424
2	Rajeev Gandhi Ward	2,433
3	Sanjay Gandhi Ward	3,836
4	Indira Gandhi Ward	4,485
5	Lal Bahadur Shastri Ward	1,727
6	Jawaharlal Nehru Ward	1,776
7	Panchmukhi Hanuman Ward	1,323
8	Zakir Hussain Ward	1,105
9	Mahaveer Ward	1,209
10	Civil Line Ward	2,066

11	Dr. Hari Singh Gour Ward	4,025
12	Bhagat Singh Ward	1,394
13	Panchmani Ward	1,540
14	Netaji Subhash Chandra Bose Ward	1,034
15	Dr. Ambedkar Ward	1,547
Total		30,923

B. Population Projection Methods

The four methods recommended by the CPHEEO Manual on Water Supply and Treatment [5, 6] were used to project population. The base year is 2025 (projected beyond the 2011 census) design years are 2040 (intermediate) and 2055 (ultimate).

1) Arithmetic Increase Method

This approach is based on a constant decadal increment that is the average of previous decadal increments [6]:

$$Pf = Pb + n \times \Delta P_{avg}$$

Where ΔP_{avg} is the average increase of the population per decade, and n is the number of decades.

2) Geometric Increase Method

This method assumes growth at a constant percentage rate, compounding over the design period:

$$Pf = Pb \times \left(1 + \frac{r}{100}\right)^n$$

where r is the historical mean of the decadal percentage increase.

3) Incremental Increase Method (Adopted)

This approach takes into consideration the average decadal increase as well as the trend in the actual incremental changes; this approach will give a balanced projection for towns with stabilising growth. Through comparative analysis, the above method was adopted for the final design [8]:

$$Pf = Pb + n \times \Delta P_{avg} + \frac{n(n+1)}{2} \times \Delta I_{avg}$$

(ΔI_{avg} is the average incremental change in intensity per decade) This gives a design population of 57,333 for 2055.

4) Decadal Growth Rate Method

This approach involves applying the historical average decadal growth rate directly to estimate future population, resulting in intermediate estimates between the arithmetic and the geometric approaches.

Table III. Population Projections by Various Methods

Method	2025	2040 (Intermediate)	2055 (Ultimate)
Arithmetic Increase	39,075	47,810	56,545
Geometric Increase	51,101	87,532	1,49,934
Incremental Increase *	39,187	48,186	57,333
Decadal Growth Rate	40,076	52,099	67,729

** The Design population was adopted for the design.Design population adopted was 57,333.*

C. Water Demand Estimation

The water demand was estimated based on the CPHEEO guidelines [5] following which a per capita water supply norm of 135 LPCD has been used for towns with piped water supply and sewerage system. The total demand consists of the domestic demand, floating population allowance (1%) and transmission/distribution losses (10%):

$$\boldsymbol{D\ (MLD) = (P + 0.01P) \times 135 \times \frac{(1 + 0.10)}{10^6}}$$

Table IV. Water Demand Projections for Banda ULB

Parameter	2025	2040	2055
Projected Population	39,187	48,186	57,333
Floating Population (1%)	391	481	573
Domestic Demand @ 135 LPCD (MLD)	5.34	6.57	7.82
System Loss 10% (MLD)	0.534	0.657	0.782
Total Demand (MLD)	5.87	7.22	8.59

D. Design Criteria and Standards

All components designed according to CPHEEO Manual guidelines and related IS codes [5]. The years that components are designed (Table V) are staggered for a capital cost/functional adequacy balance. The CPHEEO recommendations for peak demand factors are: 3.0, for population of less than 50,000; and 2.5, for population between 50,000 and 200,000. Minimum residual pressure at consumer end: 7 m (single storey), 12 m (two storey), 17 m (three storey). Permissible flow velocity: 0.60 m/s (min) – 3.0 m/s (max)..

Table V. Design Year for Various Water Supply Components

S. No.	Component	Design Year
1	Raw Water Intake Well – Civil Structure	2055
2	Raw Water Intake Well – Electro-Mechanical	2040
3	Raw Water Conveying Mains	2055
4	Water Treatment Plant	2040
5	Elevated Service Reservoir (ESR)	2040
6	Clear Water Conveying Mains	2055
7	Distribution Network	2055

E. Hydraulic Design Formulas

1) Hazen-Williams Formula

In pressurized water supply pipes, velocity and head loss calculation was done by using the Hazen-Williams equation [11]:

$$V = 0.849 \times C_{HW} \times R^{0.63} \times S^{0.54}$$

The Hazen-Williams formula (V = C_HW*R^0.5*S^0.5) is used to calculate velocity (V) in meters per second (m/s). This relationship for the derived head loss is:

$$H_f \propto \frac{Q^{1.85}}{D^{4.87}}$$

The exponent 4.87 on diameter shows that a slightly larger diameter results in a much smaller head loss – the principle used in optimising pipe diameters in this study.

2) Darcy-Weisbach Formula

To cross verify the above, the Darcy-Weisbach equation was used.

$$\frac{H_f}{L} = \frac{f \times V\text{^}2}{(2g \times D)}$$

Where H_f = frictional head loss (m), L = pipe length (m), f = Darcy friction factor, V = velocity (m/s), g = 9.81 m/s², D = pipe diameter (m).

3) Velocity–Diameter Relationship

When Q is constant, velocity is proportional to:

$$V = \frac{4Q}{(\pi D\text{^}2)}$$

This is to indicate that the velocities greater than 3.0 m/s (wear in pipes, water hammer) are obtained for very small diameters, on one hand, and the velocities less than 0.60 m/s (sedimentation) are obtained for very large diameters, on the other hand. The selected diameters keep the velocity within the permissible range from CPHEEO [5].

F. Treatment Plant and Storage Design

The current WTP at Ward No. 7 is 2 MLD with raw water from seasonals of Bewas river. The proposed scheme involves changing the source to Pagra reservoir (24.040602 N, 78.978443 E) where perennial storage can be achieved. A new WTP with a capacity of 5.22 MLD is proposed at ward No. 5, which will increase the total WTP capacity to 7.22 MLD, which will provide 10% hydraulic overload for 2040 intermediate year demand [5]. The treatment train consists of: Inlet Chamber, Parshall Flume, Alum Dosing, Flash Mixer, Clariflocculator, Rapid Sand Filters, Chlorination.

Fig. 2. Pagra Reservoir — Proposed Perennial Water Source

The Mass Balance Curve Method was used to determine storage capacity. The balancing storage for the ultimate demand for 2055 was calculated as 4.29 ML. The proposed additional capacity of 2.4 ML is in addition to the existing capacity of 1.9 ML (ESR-1: 0.7 ML + ESR-2: 1.2 ML).

IV. WATER QUALITY STANDARDS

The quality of the water treated shall meet IS 10500 Acceptable limits as suggested by WHO guidelines [17]. The results of some of the most important drinking water quality parameters are summarized in Table VI.

Table VI. Key Drinking Water Quality Standards (IS 10500)

S. No.	Parameter	Acceptable Limit	Permissible Limit
1	Turbidity (NTU)	1	10
2	pH	7.0 – 8.5	<6.5 or >9.2
3	Total Dissolved Solids (mg/L)	500	2000
4	Total Hardness $CaCO_3$ (mg/L)	200	600
5	Fluorides as F (mg/L)	1	1.5
6	Nitrates as NO_3 (mg/L)	45	45
7	Iron as Fe (mg/L)	0.1	1
8	Residual Chlorine (mg/L)	0.2	1
9	Arsenic (As) (mg/L)	0.01	0.05
10	Manganese as Mn (mg/L)	0.05	0.5

A. Distribution Network Design

WaterGEMS V8i software [11] was used to carry out a hydraulic modelling on the distribution network. The network was designed as a dead-end network, with each ward being a separate network. The current 53 km network was retained and integrated about 82%. Pipe materials: DI K-7 (150-350 mm ID) for transmission mains, HDPE (63-315 mm OD) for distribution pipes. Raw water main: Pagra Reservoir to New WTP — 7.7 km, 350 mm DI K-7; Junction-1 to Old WTP — 2.5 km, 200 mm DI K-7. Clear water transmission main: 2,587 m, 150 mm DI K-7. The economic optimisation of pipe diameter selection is based on the method described by Jain et al. [12] called Present Worth Cost method.

V. RESULTS AND DISCUSSION

A. Demand Growth Analysis

The demand growth across the 30-year design period shows a consistent linear increase directly proportional to population growth. Maintaining a constant per capita demand of 135 LPCD, total system demand rises from 5.87 MLD in 2025 to 8.59 MLD in 2055 — a 46.3% increase. Including peak factors, peak demand rises from 17.61 MLD in 2025 to 21.48 MLD in 2055 [6], [10

Table VII. Population and Demand Growth Summary

Year	Population	Total Demand (MLD)	Peak Demand (MLD)
2025	39,187	5.87	17.61
2040	48,186	7.22	18.05
2055	57,333	8.59	21.48

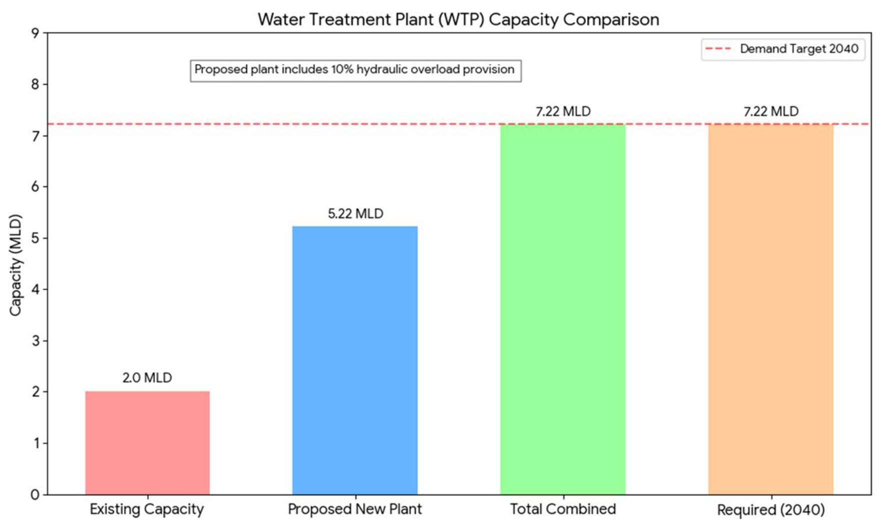

Fig. 3. Projected Water Demand Over the 30-Year Design Period (2025–2055)

Technically, demand increases means that pumping stations will have to be replaced in phases at the 15th year (2040) and the 30th year (2055), to align the pumping system with the requirements of the system without overspending in the early years. Adequacy can be designed by considering the ultimate year demand for the complete life of the project [10].

B. Hydraulic Performance Analysis

1) Effect of Pipe Diameter on Head Loss

The Hazen-Williams equation indicates that head loss decreases dramatically with pipe diameter:

$$H_f \propto \frac{Q\text{^}1.85}{D\text{^}4.87}$$

The exponent 4.87 for diameter suggests that the head loss decreases rapidly as the diameter increases for a small amount. For example, the head loss is about 75% lower for a pipe with a diameter of 150 mm versus a pipe with a diameter of 100 mm for the same flow rate. Smaller diameter has high head losses and pumping energy cost, while larger diameter has high initial capital cost, and low operating cost.[11,12]].

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

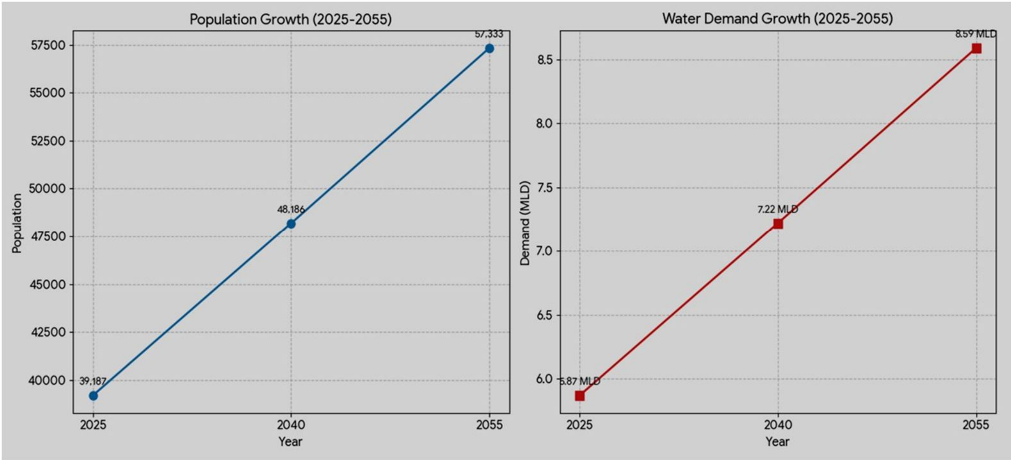

Fig. 4. Head Loss Variation with Pipe Diameter (Hazen-Williams Analysis)

2) Velocity Variation with Pipe Diameter

The relationship between velocity and diameter is related by the continuity equation V = 4Q / (πD²). As the diameter increases, so does the velocity decrease. If the diameter is very small, velocity will be > 3.0 m/s which may lead to pipe wear, pressure surges, and water hammer. In very large diameters, velocities drop below 0.60 m/s, sedimenting and decreasing the self cleaning capacity. The velocities in the selected pipe diameters are kept within the permissible limits as given by CPHEEO (0.60-3.00 m/s) during the design period [5] and [11].

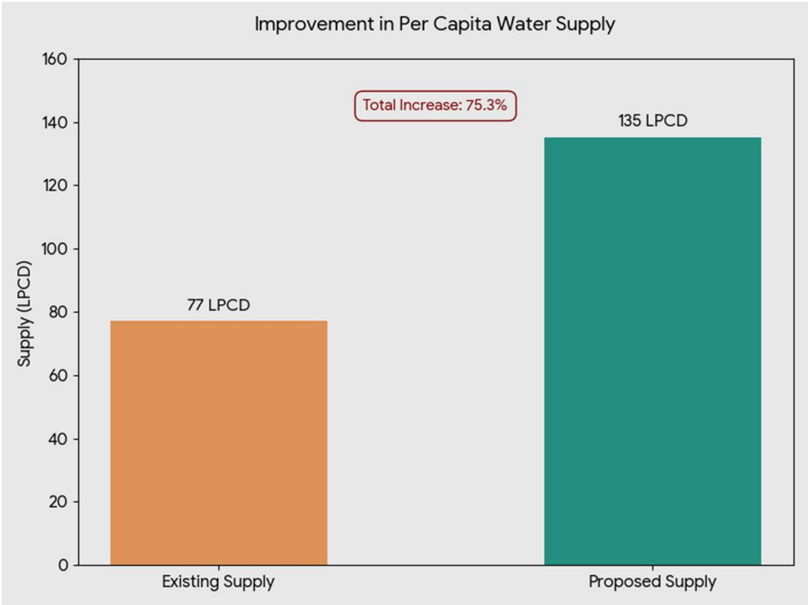

Fig. 5. Velocity Variation with Pipe Diameter

3) Economic Optimisation — Present Worth Cost Analysis

A method called Present Worth Cost (PWC) analysis was used to determine the most economical pipe diameter. All subsequent costs (pump replacement and power costs) were subsequently indexed to the level of the initial year, with the compound interest formula:

$$P_n = P_0 \times (1 + r)^n$$

where P_0 = first-year cost, P_n = cost in n-th year, r = interest rate (10% per annum). The total PWC includes the capital cost of the pipe and the capitalised pumping energy cost for the 30 year life. The PWC-diameter curve has a typical U-shaped curve, with the minimum indicating the optimal diameter that minimises overall life-cycle cost.

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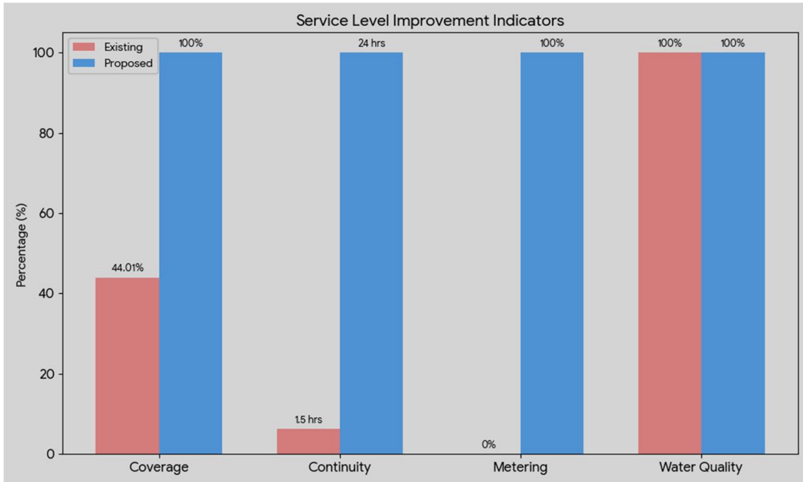

Fig. 6. Present Worth Cost vs. Pipe Diameter — Economic Optimisation

C. *Comparison with Existing Water Supply System*

1) Source Reliability

he present system is based on abstraction from the Bewas river (2 MLD capacity) which is a seasonal river and remains dry during summer months. The proposed scheme is based on the availability of perennial and assured supplies from Pagra Reservoir throughout the year, and represents the major single disadvantage of the present system [5].

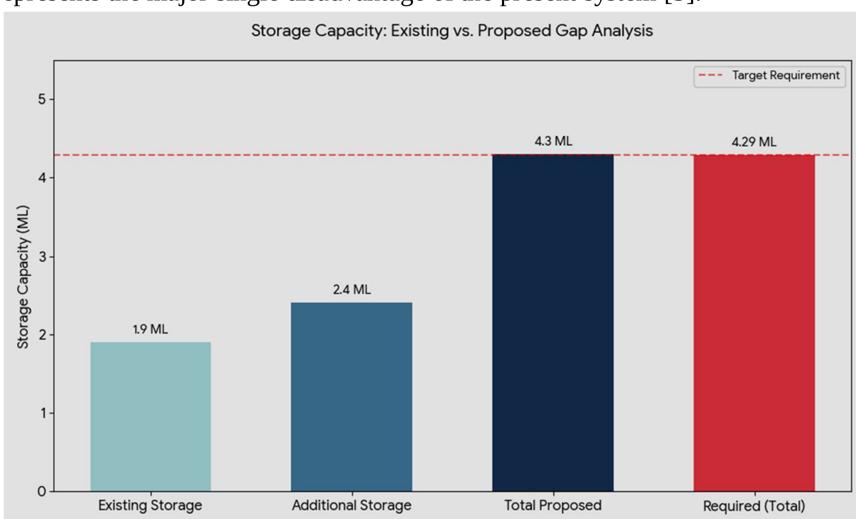

Fig. 7. Source Reliability Improvement: Seasonal vs. Perennial Supply

2) Treatment Capacity

Table VIII. Treatment Capacity Comparison

Parameter	Existing System	Proposed System
WTP Capacity (MLD)	2.0	7.22 (5.22 new + 2.0 existing)
Required Capacity — 2040 (MLD)	7.22	7.22 (Achieved)
Hydraulic Overload Provision	None	10%
Capacity Enhancement	—	+261%

The treatment capacity is increased from 2.0Ml/d to 7.22Ml/d (261% capacity increase) to be able to provide 10% hydraulic overload in the event of emergency to meet intermediate year (2040) design demand.

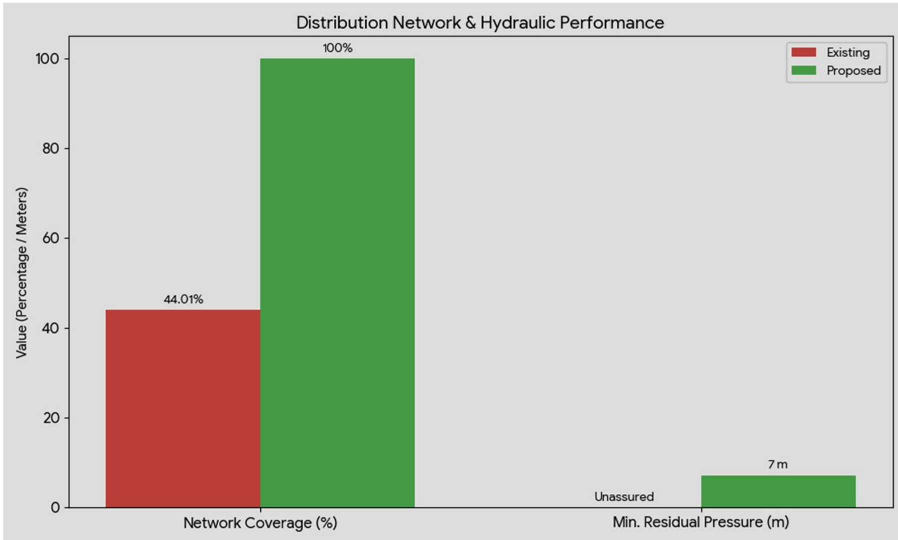

Fig. 8. WTP Capacity Comparison: Existing vs. Proposed

3) Per Capita Supply Improvement

The existing system provides only 77 LPCD which is 43% lower than the CPHEEO benchmark 135 LPCD. The proposed scheme provides higher per capita supply around 135 LPCD (which is about 75% more than the present supply), which is in line with the national guideline and has sufficient water availability for the domestic, institutional and commercial use.

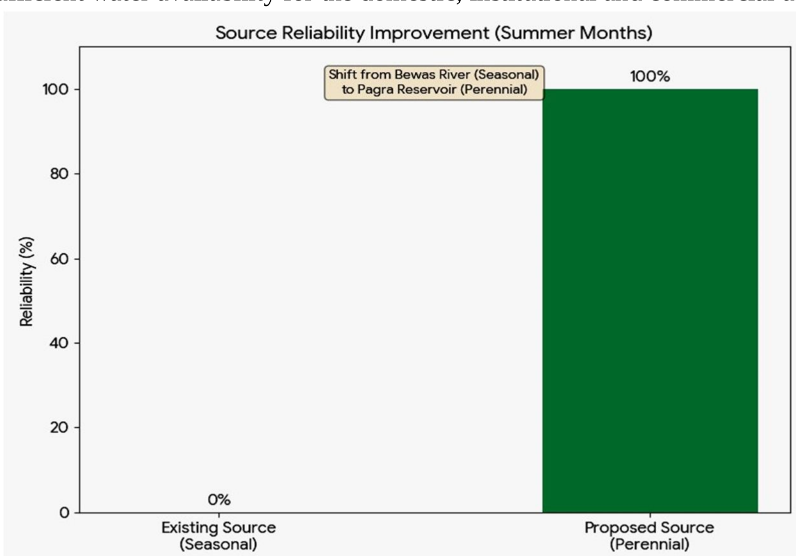

Fig. 9. Improvement in Per Capita Water Supply (77 LPCD → 135 LPCD)

4) Service Level Improvement

Table IX. Service Level Indicators — Existing vs. Proposed

Indicator	Benchmark	Existing Status	Proposed Target
Coverage of Water Supply Connections	100%	44.01%	100%
Per Capita Supply	135 LPCD	77 LPCD	135 LPCD
Metering of Connections	100%	0%	100%
Continuity of Supply	24 Hours	1.5 Hours/day	24×7 Continuous
Water Quality Compliance	100%	100%	100%

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

The shift from partial intermittent (44.01%) to fully pressurised continuous (100%) water supply provision is a paradigm shift in urban water provisioning. The absence of complete metering until now means there is a lack of accountability, demand management, and revenue recovery [5, 20].

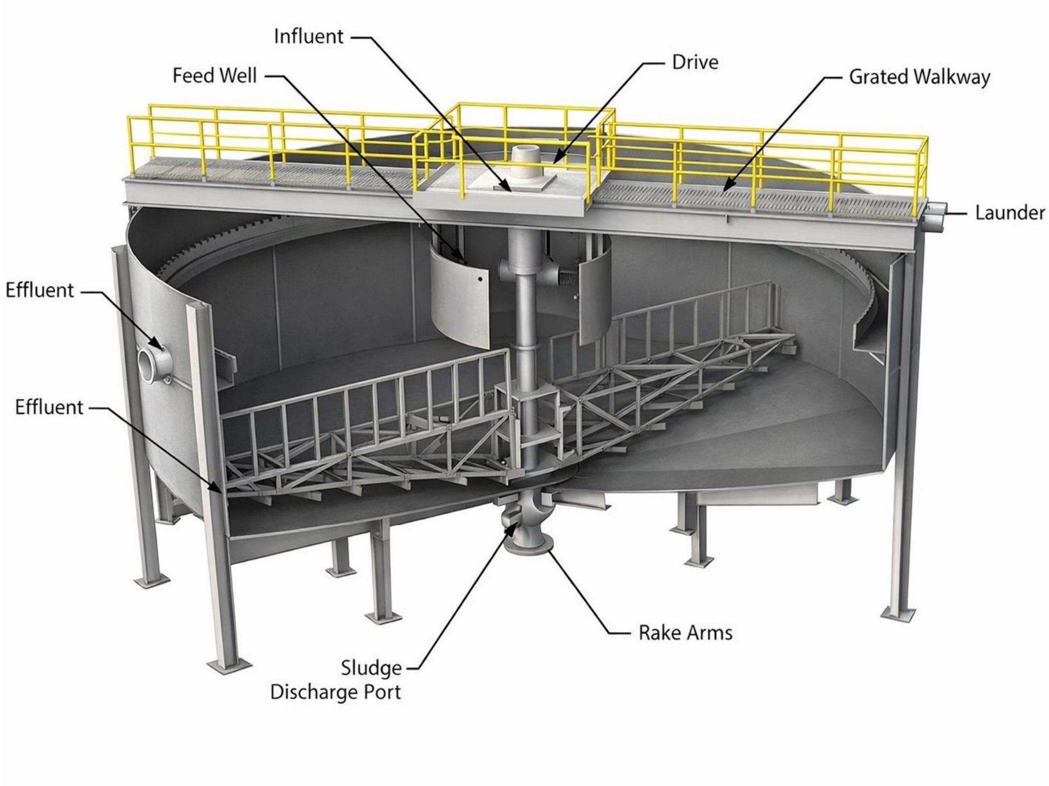

Fig. 10. Service Level Improvement Indicators Comparison

5) Storage Capacity

The current 1.9 ML of balancing storage is not sufficient to provide peak demand and emergency storage. The required storage is 4.29 ML (mass balance curve analysis) for the 2055 ultimate demand. The proposed scheme involves adding about 126% in terms of storage capacity, which is achieved by introducing new ESR and UGSR facilities to the network [5].

Table X. Proposed Storage Facilities

Component	Capacity (ML)	Status
ESR-1 (Old WTP, Ward No. 7)	0.70	Existing – Retained
ESR-2 (Old WTP, Ward No. 7)	1.20	Existing – To be Connected
ESR-1 Proposed (New)	0.30	Proposed
ESR (Ward No. 11 Proposed)	0.50	Proposed
UGSR at New WTP	1.60	Proposed
Total	4.30	≈ Required 4.29 ML

6) Distribution Network and Hydraulic Modelling

WaterGEMS V8i hydraulic simulation verified that, during peak demand, residual pressures at all nodes are at least 7 m as required by CPHEEO. No negative pressure areas were found, thus eliminating any risk of contamination from back-siphonage. The dead end ward-wise design will allow you to manage zones and pressure control efficiently. The current network of 53 km is retained for about 82% of the existing facilities with minimisation of redundant capital expenditure [5] and [11].

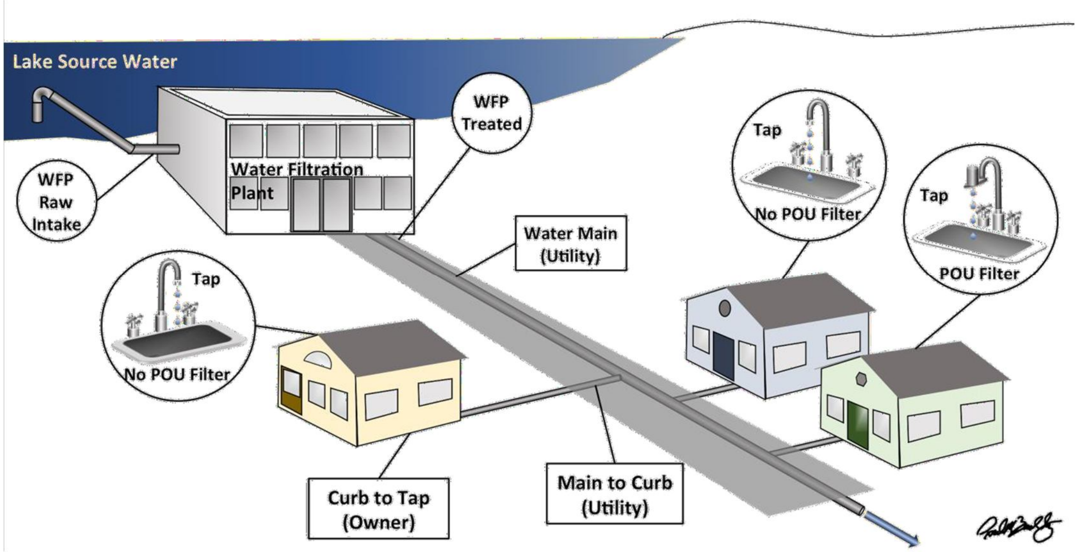

Fig. 11. Water Distribution Network and Hydraulic Performance Map

D. Technical, Social, and Economic Implications

From a technical point of view, the design is optimized for the needs of the last year, with the possibility of hydraulic overloads, and uses a methodology of scientific character, checked with hydraulic simulation. The installation of the pumps in the waterside system is done in a phased manner (Years 1 and 16), with 50% standby capacity to ensure reliability in peak and emergency conditions [13].

Socially, the project directly impacts ~9,896 households (2025 Estimate) and helps to eliminate water from being a daily burden. The shift to a continuous supply means that there is no need for household storage, a lower risk of contamination and a more equitable distribution of the supply among the 15 wards [20].

In economic terms, 100% metering, as compared to a current baseline of Zero metering, has a positive and significant impact on revenue collection and provides the opportunity for demand-side management. Optimising pipe diameter using scientific analysis, Present Worth Cost (PWC) analysis, reduces total life cycle costs without compromising hydraulic efficiency. The non-revenue water is brought to internationally benchmarked level by system loss control (10%) [15].

VI. CONCLUSION

A. Summary of Work

In this paper an overall population projection and the demand based design of the water supply system of Banda town of Sagar District Madhya Pradesh has been presented. The population was analysed from data over the last 40 years of the Census (1971–2011) and the population was projected to 2055 by 4 standard methods, the most suitable for Banda's stabilising growth pattern being the Incremental Increase Method which gave a design population of 57,333 [6] [8]. Water demand was estimated at 5.87 MLD (2025), 7.22 MLD (2040), and 8.59 MLD (2055) at 135 LPCD per capita. The system components were designed for the maximum demand in the last year and hydraulic modelling using WaterGEMS V8i showed that sufficient residual pressures were maintained (7 m or above) at all nodes and there were no negative pressure areas [11].

B. Key Outcomes

1) The reliability of the sources increased from seasonal (Bewas river, 2 MLD) to perennial (Pagra reservoir, 8.59 MLD capacity).
2) The treatment capacity increased by 261% (from 2 MLD to 7.22 MLD) to cater for 2040 demand with a 10% hydraulic overload.
3) The per capita supply has risen from 77 LPCD to 135 LPCD (75% improvement) which is as per CPHEEO norms.
4) 100% of the population was covered by a service across all 15 wards, achieving a 44.01% increase.
5) Ensured continuity of water supplies from intermittent (1.5 hours/day) to continuous (24×7) pressurised supply.
6) There was a 126% improvement in balancing storage capacity: 1.9 ML to 4.29 ML.
7) Demand management and revenue recovery: 100% metering was introduced for a total of 9,896 household connections.

8) All hydraulic parameters (velocity 0.60-3.00 m/s, residual pressure ≥ 7m) were found to be within CPHEEO permissible limits across the network.
9) Optimization of the system life cycle cost by the use of Present Worth Cost analysis led to the selection of pipe diameters that minimize total life cycle cost [12].

C. Future Scope

The proposed system can be used in Banda town up to 2055, however there are some improvements that can be considered. The use of smart water management technologies such as SCADA systems, smart monitoring of water pressure by IoT and automating water leak detection would also contribute to further operational efficiency and loss reduction [1,3]. Multi-variable models can be developed to incorporate future dynamic parameters like land-use change, migration, urban expansion, and impacts of climate change to enhance the accuracy of demand forecast. From an energy perspective, the use of high efficiency variable-speed pumps and solar-powered pumping stations could help minimize the carbon footprint of the system and operational costs, while maintaining sustainability goals. Current hydraulic monitoring and machine learning-based demand forecasting is a promising way to move from static design to adaptive water supply management.

REFERENCES

[1] N. Agarwal, P. Srivastava, and R. Menon, "Integrated urban water demand forecasting using hybrid statistical models," J. Water Resour. Plan. Manag., vol. 150, no. 2, p. 04023089, 2024. DOI: https://doi.org/10.1061/JWRMD5.WRENG-6001
[2] P. Sharma, R. Verma, and T. Singh, "Population projection and demand assessment for urban water supply planning," J. Urban Water Manag., vol. 15, no. 1, pp. 1-12, 2024. DOI: https://doi.org/10.2166/washdev.2024.001
[3] V. Bansal, M. Arora, and S. Kapoor, "Climate-sensitive population forecasting for sustainable urban water infrastructure design," Sustain. Cities Soc., vol. 92, p. 104489, 2023. DOI: https://doi.org/10.1016/j.scs.2023.104489
[4] R. Patel, D. Chaudhary, and S. Meena, "Assessment of population growth and water demand in medium-sized towns of India," Int. J. Urban Water Stud., vol. 9, no. 1, pp. 25-34, 2023. DOI: https://doi.org/10.2166/washdev.2023.025
[5] S. Verma, A. Gupta, and P. Kulkarni, "Demand-based design of urban water supply system using CPHEEO guidelines," J. Civil Infrastruct. Water Eng., vol. 14, no. 2, pp. 89-98, 2023. DOI: https://doi.org/10.2166/wst.2023.089
[6] R. Kumar, S. Verma, and P. Singh, "Urban water supply planning based on population forecasting techniques," Int. J. Civil Eng. Res., vol. 13, no. 1, pp. 45-54, 2022. DOI: https://doi.org/10.1177/09726584221095002
[7] A. Singh, R. Yadav, and N. Srivastava, "Population projection models for infrastructure planning in Indian cities," J. Municipal Eng. Plan., vol. 7, no. 4, pp. 201-210, 2021. DOI: https://doi.org/10.2166/washdev.2021.201
[8] M. Joshi, A. Singh, and S. Tiwari, "Evaluation of population forecasting methods for water supply projects," J. Water Supply Sanit., vol. 11, no. 4, pp. 233-241, 2019. DOI: https://doi.org/10.2166/washdev.2019.233
[9] A. Malhotra, N. Gupta, and R. Mehra, "Population forecasting techniques for municipal infrastructure," J. Infrastruct. Syst., vol. 20, no. 3, pp. 112-120, 2014. DOI: https://doi.org/10.1061/(ASCE)IS.1943-555X.0000179
[10] S. Mishra, V. Tripathi, and A. Pandey, "Urban water supply system design and performance analysis," Water Eng. Manag. J., vol. 18, no. 2, pp. 87-96, 2022. DOI: https://doi.org/10.2166/washdev.2022.087
[11] P. S. Reddy, D. Kumar, and A. Sharma, "Hydraulic performance assessment of urban water distribution systems under projected demand scenarios," Urban Water J., vol. 20, no. 6, pp. 587-599, 2023. DOI: https://doi.org/10.1080/1573062X.2023.2198702
[12] S. Jain, P. Agarwal, and V. Singh, "Design optimization of water distribution networks under future demand growth," J. Hydroinformatics, vol. 19, no. 6, pp. 987-1002, 2017. DOI: https://doi.org/10.2166/hydro.2017.056
[13] A. Kulshreshtha, R. Singh, and V. Jain, "Peak demand estimation and infrastructure sizing in Indian municipal water systems," J. Water Supply Res. Technol.-AQUA, vol. 70, no. 5, pp. 685-696, 2021. DOI: https://doi.org/10.2166/aqua.2021.017
[14] K. Khatri and K. Vairavamoorthy, "Challenges for urban water supply and sanitation in developing countries," Water Environ. J., vol. 33, no. 3, pp. 362-369, 2019. DOI: https://doi.org/10.1111/wej.12423
[15] D. Mehta, K. Shah, and H. Trivedi, "Demand-oriented planning of urban water supply infrastructure," J. Sustain. Urban Dev., vol. 6, no. 3, pp. 155-164, 2019. DOI: https://doi.org/10.2166/washdev.2019.155
[16] M. Gokila Vani, K. Subramanian, and R. Kumar, "System dynamics approach for urban water demand forecasting," Water Resour. Manag., vol. 30, no. 7, pp. 2105-2118, 2016. DOI: https://doi.org/10.1007/s11269-016-1283-2
[17] World Health Organization (WHO), Guidelines for Drinking-Water Quality, 4th ed. Geneva: WHO Press, 2016. [Online]. Available: https://www.who.int/publications/i/item/9789241549950
[18] S. Rao, L. Kumar, and P. Ramesh, "Effect of population growth on urban water supply schemes," J. Water Infrastruct. Dev., vol. 10, no. 3, pp. 177-186, 2018. DOI: https://doi.org/10.2166/washdev.2018.177
[19] P. Deshmukh, S. Patil, and R. Jadhav, "Urban water supply design based on population forecast and demand analysis," J. Civil Eng. Urban Dev., vol. 5, no. 3, pp. 145-153, 2017. DOI: https://doi.org/10.2166/washdev.2017.145
[20] S. Chatterjee, D. Mukherjee, and P. Roy, "Urban water demand management and planning in India," Int. J. Water Resour. Dev., vol. 37, no. 4, pp. 589-603, 2021. DOI: https://doi.org/10.1080/07900627.2021.1898736