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Analyzing and Evaluating Future Water Demand Using WaterGEMS and Population Forecasting Methods for Narangi Village, Maharashtra, India

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Abstract

The analysis of the water distribution network [WDN] is essential for a sufficient water supply. In the present study, the water distribution network [WDN] of the Narangi village in Virar was analysed using WaterGEMS software. The obtained results from the analysis were used to evaluate the impact of the growing population on the water distribution system in the coming decades, i.e., from 2020 to 2050. For population forecasting, the arithmetical increase and geometrical increase methods were adopted which were later used as "Low Population Growth Scenario" [LGS] and "High Population Growth Scenario" [HGS] respectively. The results obtained show that the maximum flow is observed in pipe 1, and the maximum demand is seen at junction 67. In 2020, the flow rate in Pipe 1 was 1036 litres per minute, but by 2050, it had risen to 1655 litres per minute. Demand at junction 67 was 54 litres per minute in 2020, and it had escalated to 86 litres per minute by 2050. This shows an increasing trend in pipe flow and demand at junctions due to the growing population over the decades. The future water demand is estimated under two population growth scenarios i.e., LGS and HGS. The comparison shows that unmet water demand estimated using the HGS, i.e., 0.223 and 0.601 million m3, is more than the LGS, i.e., 0.035 and 0.174 million m3 for the years 2040 and 2050, respectively. This signifies that unmet water demand in HGS and LGS will result in water scarcity in the study area. As a result, new water sources and the construction of new storage tanks should be planned and implemented as measures to reduce future unmet water demand.

Keywords: *Water distribution network, WaterGEMS, Population forecasting, Future water demand.*

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I. INTRODUCTION

A. General

Water is one of the most basic needs of all living things [1]. Water has generally been considered as a fundamental good and a vital natural resource. Water usage for man - made activities grows as the standard of living rises [2].Water delivery systems are among the most significant public amenities since a reliable supply of drinkable water is a basic human requirement in any region [3]. In 2010, almost 85 percent of the global population [or 6.74 billion people] had direct access to water because of household piped networks [4]. Only 63% of the population has exposure to tap water, despite the fact that 82% of the populace has access to safe water [5]. Water is unequally distributed over the globe, and its availability fluctuates considerably depending on time and size. Fresh water makes up around 2.8% of the volume of water on the planet, with groundwater accounting for 0.6%. The rest is found in the seas and oceans, with just a little quantity in soil moisture. Ice sheets and glaciers are responsible for 2.15 percent of the 2.2 percent, with surface runoff accounting for the balance 0.05 percent only [6].

B. Water Distribution System

In India, population distribution is influenced by water availability. It is important to deliver the appropriate amount of water through the effective design of the pipe network to satisfy the rising water demand due to the growing urban population [7]. The term "water distribution system" refers to a system that "provides reasonable quality, enough quantities, and adequate pressure to users in order to satisfy system requirements" [8]. A water distribution system is a hydraulic structure that includes pipelines, tanks, reservoirs, pumps, and valves, among several other things. As a community's population grows, so does the demand for water, putting excessive demand on the current water distribution system [9]. It is vital to deliver drinking or potable water to end users; hence, while constructing a new WDN or enlarging an existing one, an effective water supply is necessary [10]. The complexities involved in water distribution systems [WDS] are classified into three categories: [i] establishing a new network, [ii] modifying or enlarging an existing network, and [iii] managing an existing system. [11].

C. Literature based on WaterGEMS

WaterGEMS is a flexible hydraulic modelling software package that includes improvements in network optimization, interoperability, asset management tools and model development. WaterGEMS is a highly efficient and dynamic modelling software that offers a broad range of analyses and solutions for fire-flow analysis, water quality modelling, energy management, and capital cost management [12]. WaterGEMS is a hydraulic simulation tool for WDS with GIS model generation, optimization, an advanced interface, and asset management [13]. In past many researches have been carried out using WaterGEMS. The study utilised two software platforms, Loop v4.0 and Bentley WaterGEMS CONNECT Edition, to design and analyse the water distribution network of the Sardar Vallabhbhai National Institute of Technology-Surat [SVNIT-Surat]. After 2030, the population is expected to be around 12,000 people, including students, faculty, and other personnel. The water distribution network is designed for existing and proposed facilities, the details of which were received from SVNIT-Estate Surat's department [14]. For the design and analysis of significant WDN in this study, the WaterGEMS software was found to be the most efficient, user-friendly, and accurate. As per the area's experienced authority for water delivery provisions, Mangalnath Zone has a high demand for water [15]. Reference [16] examines the existing water distribution system and generates a model using Bentley WaterGEMS. It contributed in the overall network system analysis as well as the visualisation of specific component and variable effects. Reference [17] developed a model using WaterGEMS that gives cost-effective WDN in Wukro. The data discovered that the most economical options reliably matched the required demand and pressure at the node. The major result of this research is the water industry's action plan, which specifies a number of phases for linking and refining the maintained water distribution system [18].

In the study area, limited work has been conducted on water distribution network. As a result, in this study area, population forecasting methods are used as a significant tool for evaluating future demand of water. In light of these considerations, the village of Narangi in Maharashtra, India, has been selected for the purpose of a comprehensive study using WaterGEMS and Population Forecasting Methods for analyzing and evaluating future water demand. The present study has been conducted to achieve the following objectives:

- to analyse the water distribution network in the Narangi village of Virar using WaterGEMS software.
- population Forecasting using the Arithmetical Increase Method and the Geometrical Increase Method.
- to evaluate the flow in pipe and demand at node for the years 2020, 2030, 2040, and 2050.
- to determine the impact of a growing population on water flow in pipes and demand at junctions.to estimate and compare the unmet water demand under two different population scenarios i.e., HGS and LPS for the years 2020 to 2050.

II. STUDY AREA

Narangi is a village in the Thane district of Maharashtra, India, which can be seen in Fig. 1. The coordinates for Narangi village are 19.470 N and 72.80 E. Narangi village has a warm climate. The village is over 11 metres above sea level on average. The climate is generally dry in the winter and rather damp in the summer. Every year, from June to September, the monsoon season brings severe rains to the Narangi village. As a newly created municipality, Narangi comes under the purview of the Vasai-Virar Municipal Corporation [VVMC].

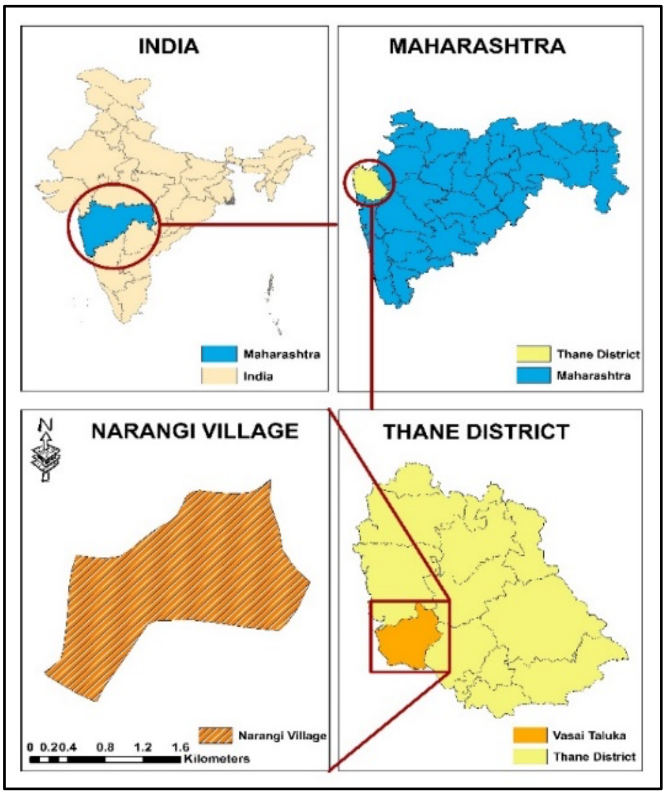

Fig. 1. Location Map of Study Area

III. MATERIALS AND METHODOLOGY

The most important source of water in the study area is surface water. The source of water supply is the Papadkhind Reservoir. The reservoir has a capacity of 0.73 million m^3/year and serves the people of Narangi village. The water from the reservoir is stored in the village's overhead water tank, which is centrally located. The circular overhead water tank has a storage capacity greater than that of the reservoir. The per capita demand for 2020 is 135 litre per day, and it is expected to rise by 2050. The current water distribution system is gravity flow with a dead-end network. The water distribution network is 10.906 kilometres long and covers the entire village. The pipe network is made up of 101 pipes of various diameters. Ductile iron pipes are employed in the network. Table I shows the length and diameter of the various pipes. In total, the network contains 101 junctions. Fig. 2. illustrates the current water distribution network of the Narangi village.

TABLE I. PIPE DETAILS USED IN THE DISTRIBUTION NETWORK

Sr.no	Pipe diameter [mm]	No. of Pipe	Total Pipe length [m]
1	150	82	8356
2	200	4	350
3	250	2	547
4	300	5	442
5	450	4	525
6	500	2	187
7	600	2	499

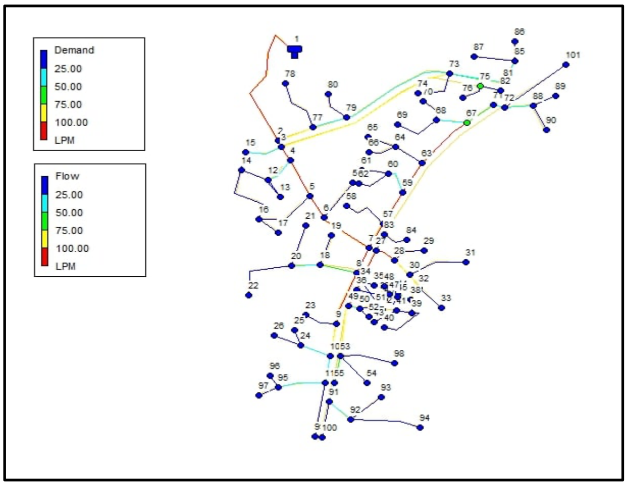

Fig. 2. Water distribution network of Narangi Village

For analysing the water distribution network using WaterGEMS, the following steps were taken:

1) Population Forecasting: VASAI VIRAR CITY MUNICIPAL CORPORATION [VVCMC] provided the population data. The population was 7085 in the year 2010, and it was 9902 in the year 2020. The population for 2030, 2040, and 2050 was calculated using the Geometrical Increase Method and the Arithmetical Increase Method. Table II shows the population forecasted using the two approaches described above.

TABLE II. POPULATION FORECASTING

Year	Arithmetic Increase Method	Geometrical Increase Method
2030	**12719**	**13839**
2040	**15536**	**19341**
2050	**18353**	**27032**

2) Encoding the input data: Almost all the hydraulic simulating tools has analogous data entry requirements. The two types of data are pipe data and nodal data. The diameter [mm], pipe number, C-value, and length are all included in the pipe data [m]. Nodal data has been allocated a node number, elevation [m], and demand [lps].

3) Hydraulic Network Simulation: WaterGEMS will complete this phase if all of the input data is valid. The software's hydraulic run may continue. Each node's head loss, head loss rate, flow velocities, and pressure are calculated by the programme.

4) Result Validation: Validation of the results obtained by WaterGEMS from the input data before comparing and analysing scenarios of a water distribution system is necessary. A computer simulation usually reveals all available hydraulic parameters.

5) Selecting the network configuration: Simulations are run until a suitable network configuration is found.

6) Result and analysis: The software provides table and graph formats for the results.

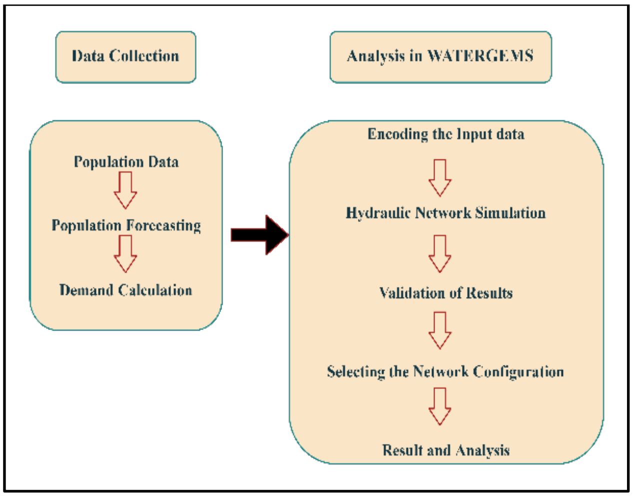

Fig. 3. Flow chart of Methodology

IV. RESULTS AND DISCUSSION

A. Analysis of Water Distribution Network

WaterGEMS was used to simulate the WDN in this study. The research period were taken for the years 2020, 2030, 2040, and 2050. According to the findings, the flow in the pipe and demand at the junction would increase as the population expands from 2020 to 2050. The forecasted population using the Arithmetical Increase Method, which is referred to as a "Low Population Growth Scenario" [LGS], was 9902 in 2020, and it is expected to grow to 18353 by 2050. Similarly, using the Geometrical Increase Method, which is referred to as the "High Population Growth Scenario" [HGS], the population was 9902 in 2020, and it is expected to grow to 27032 by 2050. Due to an increasing population, the flow in the pipe and the demand at the junction have to be increased to meet the needs of the populace [19]. The maximum flow is observed in pipe 1, and the maximum demand is seen at junction 67. In 2020, the flow rate in Pipe 1 was 1036 litres per minute, but by 2050, it had risen to 1655 litres per minute. Demand at junction 67 was 54 litres per minute in 2020, and it had escalated to 86 litres per minute by 2050. Table III shows the increase in flow in pipe 1 and demand at junction 67.

TABLE III. INCREASE IN FLOW IN PIPE 1 AND DEMAND AT JUNCTION 67 FROM 2020-2050.

Year	Flow in pipe 1 [l/min]	Demand at junction 67 [l/min]
2020	**1036**	**54**
2030	**1145**	**59**
2040	**1400**	**72**
2050	**1655**	**86**

B. The impact of a growing population on flow in pipes

Fig. 4. depicts the trends in the flow of water in pipes [L/min] for the years 2020, 2030, 2040, and 2050. In 2020, a maximum flow of 1036 L/min was detected in pipe 1, and a minimum flow of 2 L/min was detected in pipe 31 when the population of the village was 9902. As per the forecasted population, the population grew to 12719 [low growth scenario] and 13839 [high growth scenario] in 2030, the maximum flow in pipe 1 surged to 1145 L/min and the minimum flow to 3 L/min in pipe 31. When the population grew to 15536 [LGS] and 19341 [HGS] in 2040, the maximum flow in pipe 1 and the minimum flow in pipe 31 both increased to 1400 L/min and 3 L/min, respectively. Moreover, as the population grows to 18353 [LGS] and 27032 [HGS] in 2050, the maximum flow in pipe 1 and the minimum flow in pipe 31 rise to 1655 L/min and 4 L/min, respectively. Fig. 4. illustrates that flow in pipes has risen substantially throughout the decades, owing to the growing population.

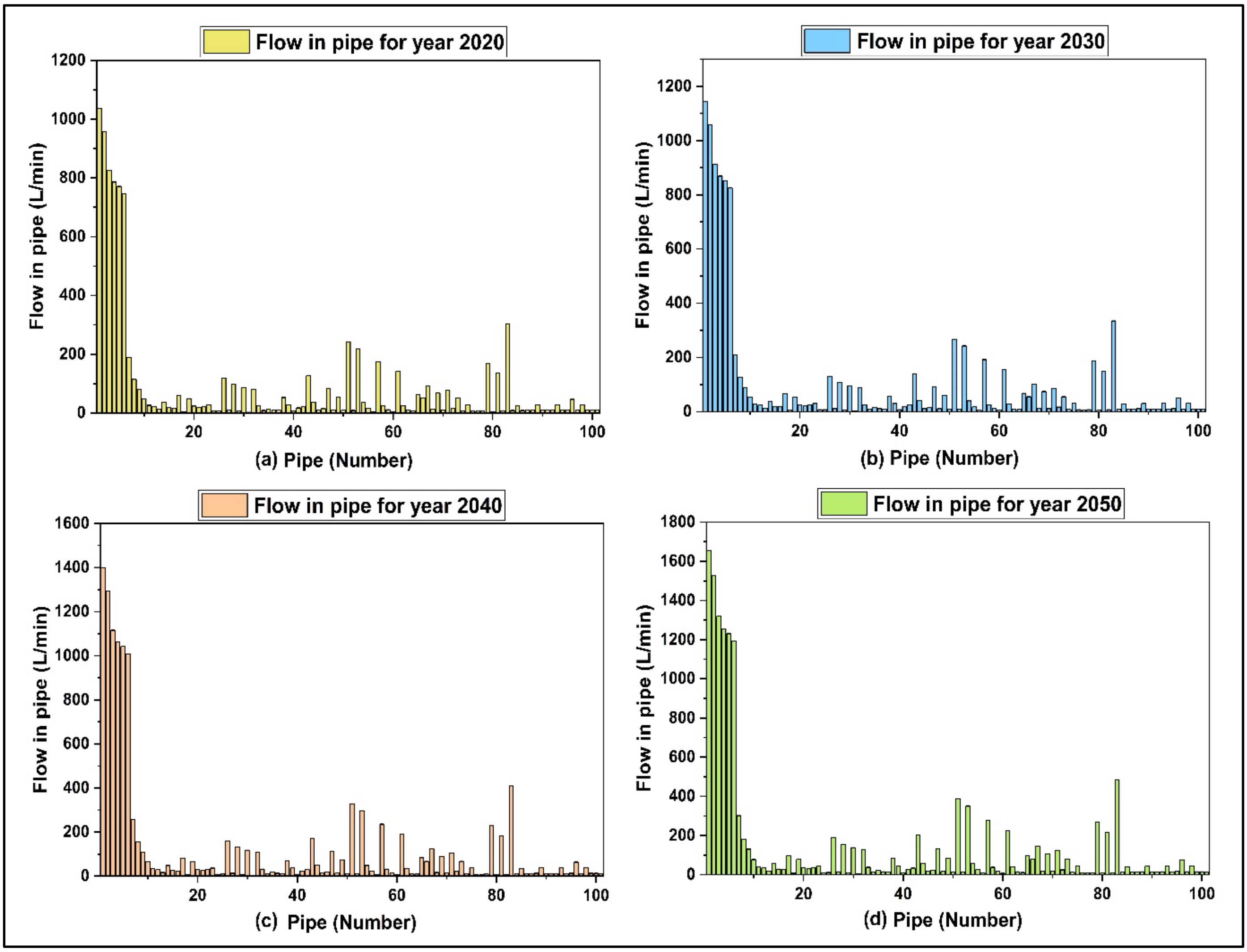

Fig. 4. Flow [L/min] in each pipe: [a]For the year 2020 [b]For the year 2030 [c] For the year 2040 [d]For the year 2050.

C. The impact of a growing population on demand at junctions

Fig. 5. depicts the trends in the junction demand [L/min] for the years 2020, 2030, 2040, and 2050. In 2020, when the population of the village was 9902, a maximum demand of 54 L/min was observed at junction 67, while a minimum demand of 2 L/min was observed at junctions 2, 33, 39, and 83, respectively. The maximum demand at junction 67 increased to 59 L/min and the minimum demand at junctions 2, 39, and 83 was 2 L/min when the population grew to 12719 [low growth scenario] and 13839 [high growth scenario] in 2030. The maximum demand at junction 67 and the minimum demand at junctions 2, 33, 39, and 83 both increased to 72 L/min and 3 L/min, respectively, as the population grew to 15536 [LGS] and 19341 [HGS] in 2040. Furthermore, as the population increases to 18353 [LGS] and 27032 [HGS] in 2050, the maximum demand at junction 67 and the minimum demand at junctions 2, 39, and 83 increase to 86 L/min and 3 L/min, respectively. Fig. 5. illustrates that over the decades, demand at the junction has increased due to rising populations.

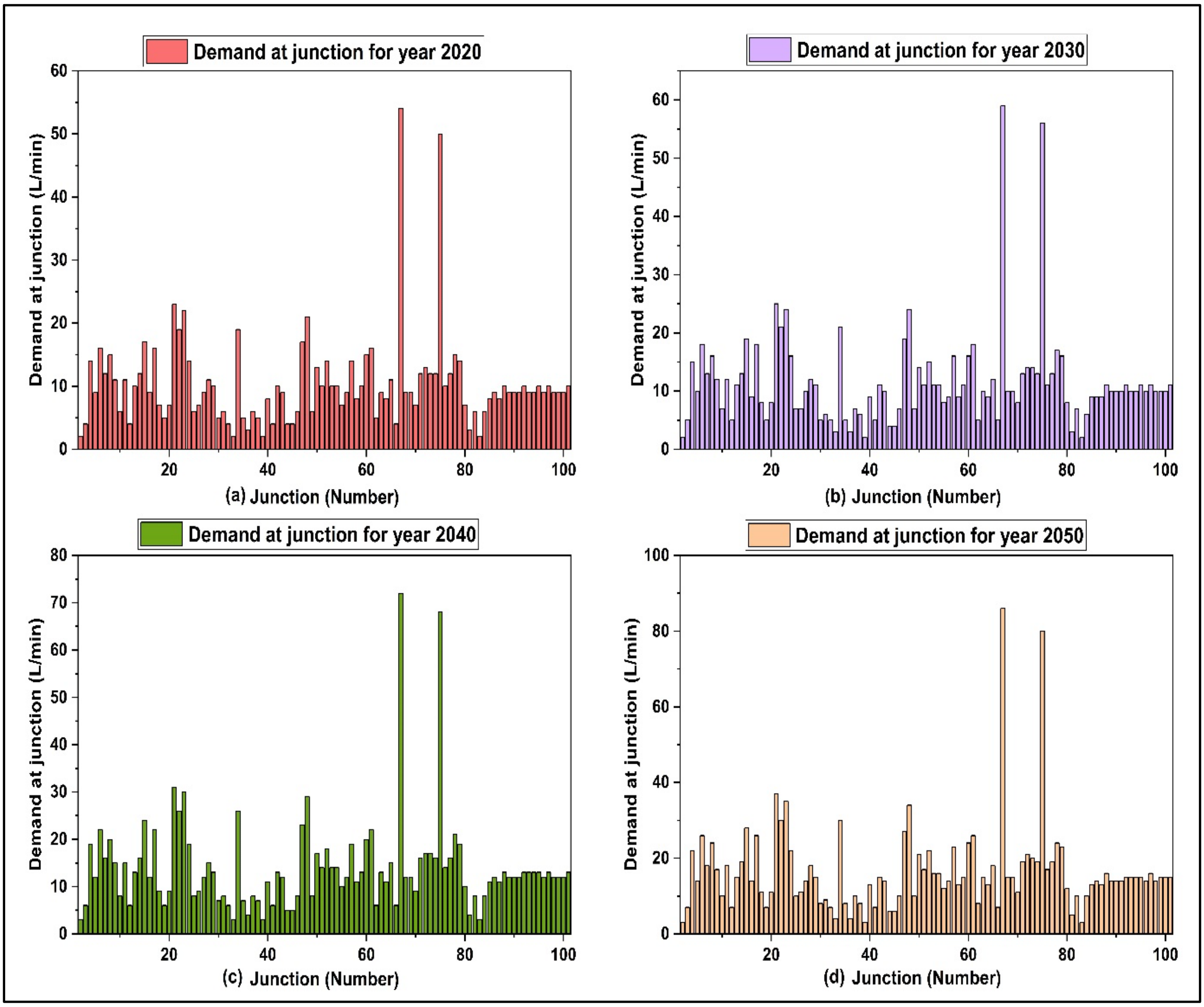

Fig. 5. Demand [L/min] at each junction: [a]For the year 2020 [b]For the year 2030 [c] For the year 2040 [d]For the year 2050.

D. Future water demand

The estimation of unmet water demand is highly dependent on future water demand. It helps in predicting whether the available water will be sufficient enough to serve the population in the coming decades. The available water is 0.73 million m^3/year, which is the capacity of the Papadkhind reservoir. For the estimation of future water demand, the population plays the most important role. In this study, two population scenarios were undertaken, namely "Low Population Growth Scenario" [LGS] and "High Population Growth Scenario" [HGS]. Table IV shows the unmet water demand under these two scenarios from the years 2020 to 2050.

TABLE IV. COMPARISONS OF UNMET WATER DEMAND IN TWO DIFFERENT SCENARIOS

Scenario	Unmet Water Demand [million m3/year]			
	2020	2030	2040	2050
LGS	-	-	**0.035**	**0.174**
HGS	-	-	**0.223**	**0.601**

Future water demand under the low population growth scenario [LGS]

The forecasted population using the Arithmetical Increase Method is referred to as the "Low Population Growth Scenario". With a 28.45% population growth rate, the predicted population of Narangi village is going to be 12719 by 2030. Similarly, with a 22.148% and 18.132% population growth rate, the population is going to be 15536 and 18353 by the years 2040 and 2050, respectively According to this scenario, total demand will increase from 0.487 million m^3 in 2020 to 0.904 million m^3 in 2050. The most important assumption is that per capita consumption will stay at 135 litres per day. In this situation, the results show an increase in demand as the population rises. Water availability would lead to inadequate water supply in the case of a low population growth scenario. Unmet water demand is calculated with the help of total demand and available water in the study area. The water demand in the years 2020 and 2030 is less than the available water. However, the demand for water in 2040 and 2050 is expected to be higher. As a result, the unmet demand in 2040 and 2050 is estimated to be around 0.035 and 0.174 million m^3 respectively. Fig. 6 shows the unmet water demand variation from 2020 to 2050 under LGS.

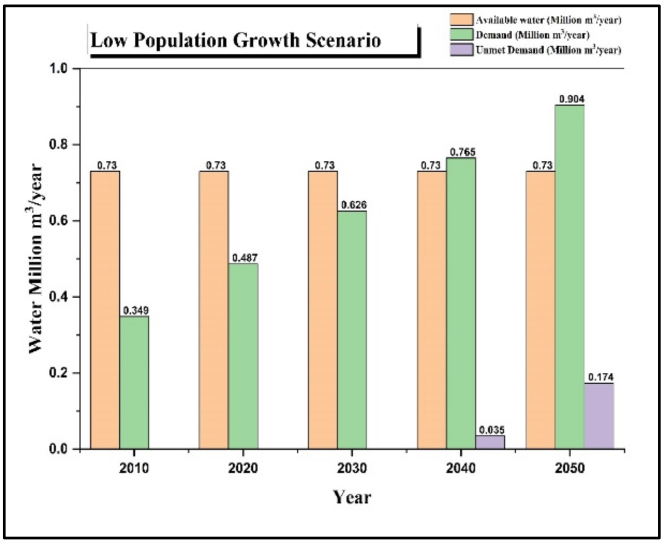

Fig. 6. Unmet demand adopting LGS

Future water demand under the high population growth scenario [HGS]

The forecasted population using the Geometrical Increase Method is referred to as the "High Population Growth Scenario." With a 39.76% population growth rate, the predicted population of Narangi village is going to be 27032 by 2050. According to this scenario, total demand will increase from 0.487 million m^3 in 2020 to 1.331 million m^3 in 2050. The most crucial assumption is that daily consumption per person will remain constant at 135 litres. In this situation, the outcome shows an increase in demand as the population rises. Water availability would lead to inadequate water supply in the case of a high population growth scenario. Unmet water demand is calculated with the help of total demand and available water in the study area. The water demand in the years 2020 and 2030 is less than the available water. However, the demand for water in 2040 and 2050 is expected to be higher. As a result, the unmet demand in 2040 and 2050 is estimated to be around 0.223 and 0.601 million m^3 respectively. Fig. 7 shows the unmet water demand variation from 2020 to 2050 based on HGS.

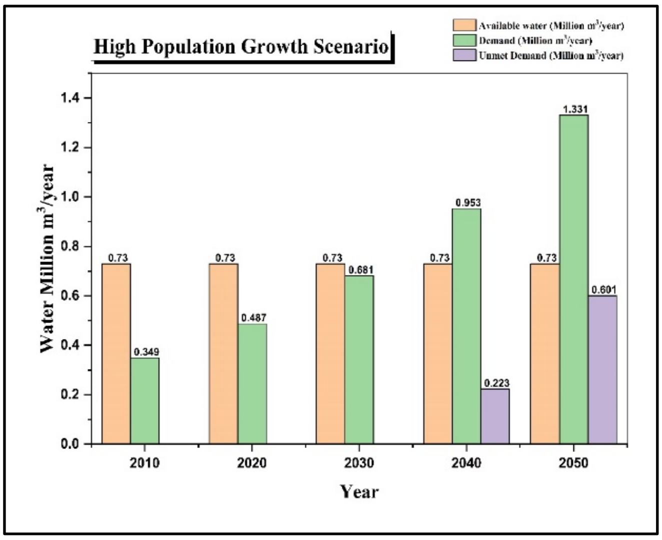

Fig. 7. Unmet demand adopting HGS

Due to a lack of past population data for the village, population forecasting was done using two methods: the Arithmetical Increase Method and the Geometrical Increase Method. If adequate present and past population data is available, various methods, such as the incremental increase method, the graphical method, the master plan method, and the curve method, can be used. The present study focuses solely on the impact of growing population on the WDN. Researchers can, however, consider the impact of climate change on the water network in future work.

V. CONCLUSION

In the present study, the WDN in the Narangi village of Virar was analysed using WaterGEMS software. During the simulation, the WaterGEMS programme analyses the demand at each junction as well as the flow of water in each pipe. The results obtained are used to evaluate the effects of the population increase on the water distribution system for the years 2020, 2030, 2040, and 2050. The increase in population is determined by adopting two population forecasting methods, namely, arithmetical increase and a geometrical increase. The forecasted population using the Arithmetical Increase Method was 9902 in 2020, and it is expected to grow to 18353 by 2050. Similarly, using the Geometrical Increase Method, the population was 9902 in 2020, and it is expected to grow to 27032 by 2050. This increasing population has an effect on the flow in the pipe and demand at the junction. Fig. 4. and Fig. 5. clearly show an increasing trend in the flow in the pipe and junction demand because of the increase in the population over the decades. Table IV shows the comparison of the obtained unmet demand [million m^3/year] under these two scenarios. The comparison shows that unmet demand estimated using the HGS, i.e., 0.223 and 0.601 million m^3, is more than the LGS, i.e., 0.035 and 0.174 million m^3 for the years 2040 and 2050, respectively. According to the results, there will be a water shortage in the near future, and it is likely to grow enormously if timely measures are not taken to develop new sources as well as the construction of new storage tanks. Due to the scarcity of water in the near future, most of the population will have to depend on tanker-fed water supply. To solve this issue, it is, therefore, imperative to focus on ensuring the long-term sustainability of water sources.

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