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Water Supply-Demand Forecasting Using the WEAP Model for Kalyan Dombivili City

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Abstract: This study aims to make a quantitative prediction of the water supply and demand gap for the Indian city of Kalyan-Dombivili up to the year 2051. The study uses a decision-support tool called the Water Evaluation and Planning (WEAP) Model to consider the existing reservoir and different alterations to the current water supply system. Outcomes from this modeling study of the water resources system of the Kalyan Dombivili city indicate that with an increase in the reliability of water supply with the recycling of rainwater, the future demand-supply gap has a reliability of 47%. Secondly, with the increased reservoir capacity, water availability will be increased by 51.2%. However, with the existing reservoir alone, water availability will be increased by 49.4%, and effluent use will be up to 99% with the proposed new reservoir and Sewage Treatment Plant (STP).

Key words: Kalyan-Dombivili, WEAP, roof top runoff, recycle and reuse, water resilience.

Introduction

A sustainable water management system has always been key to sustainable urban living. The rapid growth of urban societies along the banks of large rivers is evidence of the value of water. The urban regions suffer several water demand challenges due to the high population density. Depending on climatic, geographic, geological, sociological, and topographical factors, every metropolitan has water quantity challenges. The global rainfall pattern is projected to shift due to rapid climate change and global warming. According to modelling research, the distribution of freshwater worldwide is predicted to change dramatically by 2051 (Alcamo et al., 2007). Global resource groundwater and surface water depletion has been brought on by the excessive exploitation of this water to satisfy the rising demand. Current issues in Mexican cities include saltwater intrusion and land subsidence (Lundqvist et al., 2005), Bangkok (Shinichi et al., 2008), Dhaka (Zahid & Ahmed, 2006), Beijing (Xu et al., 2008), Kolkata (Chatterjee et al., 2006), Chennai (Rajaveni et al., 2016) due to uncontrolled abstraction of groundwater. Studies have been conducted to improve world water resilience through a thorough assessment of the potential resource utilisation (UN, 1979). The sixth Sustainable Development Goal of the United Nations Development Program lists access to clean water as one of the essential conditions for achieving sustainable development (Sustainable Development Goals, 2016). River basins of the Mekong and Nile have implemented integrated water resource management and evolved into more sustainable entities (MRC, 2011–2015). A strong water management plan must take into account a wide range of current elements, including ecological flow, signs of climate change, the rights of indigenous people to clean water, and many more (Richter et al., 2003).

Due to the increasing intricacy of decision-making processes, new tools such as Decision Support Systems (DSS) and Water Evaluation and Planning (WEAP)

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have evolved. In several river basins, WEAP has been successfully utilized to forecast the future pattern of water availability (Arranz & McCartney, 2007; Danner, 2006; Haddad et al., 2007; Hoff et al., 2007; Hollermann et al., 2010; Mounir et al., 2011; Sivan et al., 2007). Kalyan Dombivili, the seventh largest city in the Maharashtra state of India, is facing a shortage in fulfilling the city's growing demand for water. The United Nations Development Programme (UNDP) has already conducted numerous studies on availability and quality (UNDP, 1987), seawater intrusion, and change. This study aims to quantitatively forecast the results of potential enhancement measures to increase water supply by tracking its impact on the demand that is not being met. In order to get results, various scenarios have been tested in the WEAP model. The primary data sources are the Kalyan-Dombivili water supply department and the India Meteorological Department (IMD). Figure 1 is the Google image with land use of the city and city ward boundaries.

Water Resources of Kalyan Dombivili City

Description of the Research Area

The city of Kalyan Dombivili and its environs, which make up the study area, are situated within the latitudes of 19°4' - 19°14' North and Longitudes 72°9' - 73°17' East. The city as a developing megacity is included in the MMR region due to its proximity to Mumbai, having a significant scope to accommodate the population due to land availability. It is the central industrial hub in western India and one of India's top 100 Smart Cities. Since 1951, its population has doubled approximately every decade till 1991 and increased from 67006 to 18 million at present. Figure 3 shows the expected growth of the population from 2001 to 2051 to be considered for the water supply-demand gap. Population growth is a significant factor to be considered for water resilience achievement. The standard of living in Kalyan Dombivili city is increasing day by day, which is leading to an increase in the demand for water in the city. The planned new areas with green spaces in the city are also contributing to this increase in demand. According to KDMC records, the water demand in the city has increased from 210 mld to 360 mld between 2011 and 2022. As a result, the gap between water supply and demand is widening, and the city is facing a shortage of water. The city gets water supply from the Ulhas River Basin and the Kalu River Basin. The catchment area for the Ulhas River Basin is 4733 square kilometers (Das, 2018). The Ulhas River is located between latitudes of 18° 44' to 19° 42' in the north and

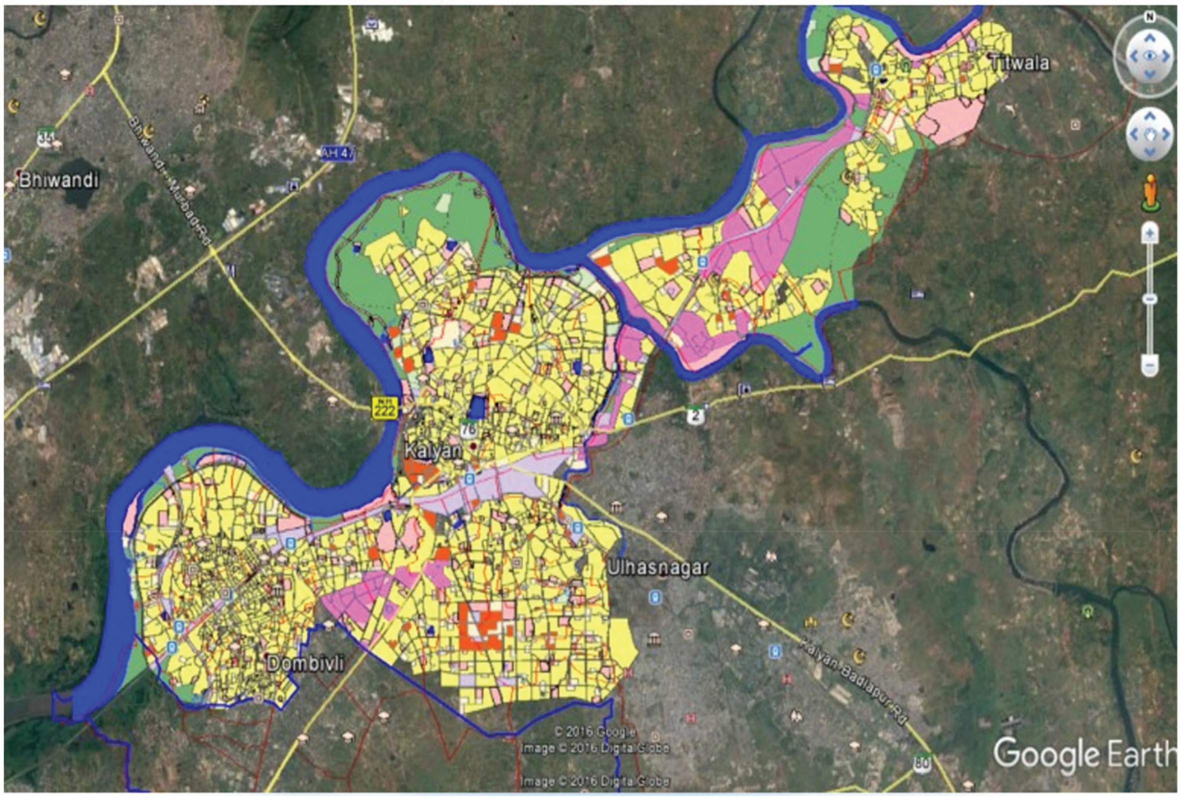


Figure 1: Kalyan Dombivili City.

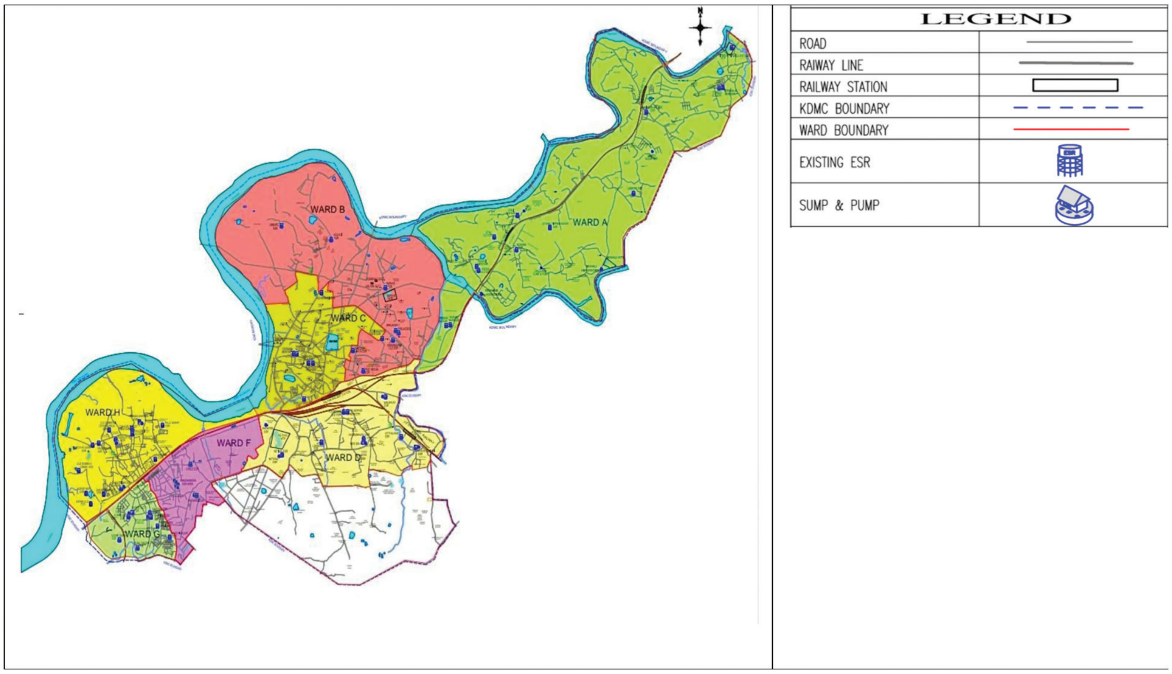


Figure 2: Key plan showing KDMCs existing ESR and WDN.

72° 45’ to 73° 48’ in the East (Doke, A). The Kalu River basin is located between 19°4’ and 19°24’N and 73°1’ and 73°24’E with an area of 710 sq. km. (www.mpcb.gov.in). The Ulhas and Kalu River, wells, and bore wells all contribute roughly 90%, 2%, and 8% of the city’s water supply. STP effluents, rooftop runoff, and extra water from Barave Dam will likely satisfy future water needs. (CDP KDMC, 2007). Figure 2 represents the ESR and sump pump locations along with the city’s present distribution network.

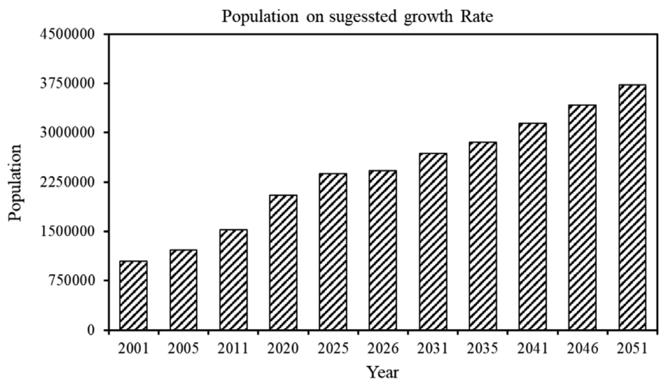
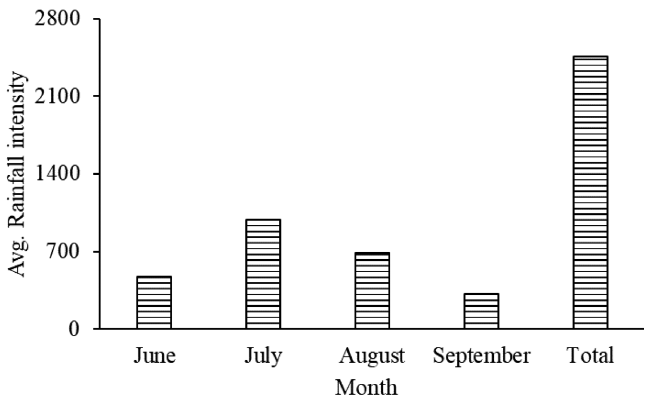


Figure 3: KDMC population projection till 2051.

The Water Supply Scenario in Kalyan Dombivili

In order to meet water needs, the residents of Kalyan Dombivili relied on wells, replenishable aquifers, and water from the ancient Kala talao till 1890 (Hile, 2012). Building a Barvi dam on the Barvi River in 1978 was the foundation of a managed water supply system for KDMC. The average yearly rainfall in Kalyan Dombivili is 2454.6 mm, as shown in Table 1. The data on rainfall of the KDMC area is collected from IMD from 1998 to 2022 and presented in Figure 4. This also shows that in 2009 the rainfall received was 0.62% of the average rainfall. The same condition was observed again in 2015. The data shows that in the last 25 years, the city received short rainfall in only 02 years. Figure 4 reveals the rainfall history compared with the average rainfall of the city.

Table 1: The average rainfall intensity of Kalyan Dombivili city



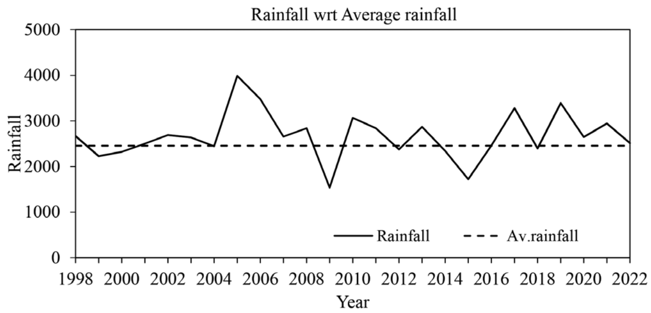


Figure 4: Rainfall presentation wrt average rainfall.

The four lifting stations (Table 6) located in the Ulhas and Kalu rivers, namely Barave, Netivili, Mohali, and Titwala, serve as the backbone for the city of Kalyan Dombivili's water supply by lifting 320 MLD of water from the Ulhas and Kalu river basins. Barvi Dam, which is 28 km from Kalyan and has been supplying water since 2011, has a capacity of roughly 320 MLD. Water from these dams is pressure-pumped to the city through a closed iron conduit for distribution after treatment at several plants (with a capacity of 360 MLD) (KDMC WSD, 2019). Since 2015, groundwater pumping for the city's water supply has decreased due to the rapid reduction in groundwater heads in the wellfields. More innovative and cutting-edge actions were taken in response to the sharp rise in water demand, including the construction of sewage treatment facilities and the introduction of rainwater collecting in urban areas. A total of 08 sewerage treatment plants have been set up to date, with 210 MLD capacities at various locations in the KDMC area, as shown in Figure 5, with capacities tabulated in Table 7 (Kulkarni, 2022). Water supply and demand in Kalyan Dombivili are complicated webs of social, economic, and political influence. Kalyan Dombivili Municipal Corporations Water Supply department (KDMCWSD) were formed in 1983 under the BPMC Act 1949. This metro city area always has a shortage of water supply from January to the rainy season every year (Nambiar, 2018).

KDMC has 07 operational sewage treatment plants and one upcoming STP plant. These STPs collectively span the whole KDMC region. The considered returned flow for WEAP is shown in Figure 6 up to December 2051. This indicates that KDMC is keen on utilising 100% STP effluent. The locations of sewage pumping stations (SPS) support to pumping off all municipal sewage to STPS. Table 7 shows that though the present capacity of treating wastewater is 210 MLD, the present treated water received by KDMC is 66 MLD. KDMC has planned to use all treated water up to 2051.

WEAP Modelling for the City of Kalyan Dombivili

Using the Stockholm Environment Institute's (SEI) Water Evaluation and Planning (WEAP) software, the future demand-supply gap for water in the Kalyan Dombivili metropolis was predicted. WEAP can model, analyse, and improve water use based on the demand-supply equilibrium concept (SEI, 2015). By addressing ecological flow limits, this software combines ecological and environmental issues and demand and supply gaps, making it a complete tool for modeling water and improving its management.WEAP is best suited for planning surface water uses in the future. WEAP's primary flaw is that it develops scenarios that are quantified before informing the process of developing scenarios. The quality of water that bridges the supply and demand gap cannot be modelled using WEAP. The WEAP has become a handy management tool due to the growing demand for biodiversity conservation and taking climate change into account for sustainable development (Smith, 2007) for creating policies for the appropriate use and management of surface and groundwater resources (Johnson et al., 1995). Throughout the lifespan of the water supply, WEAP can be used to simulate the water quality and the flow of money. Figure 7 is the schematic presentation of the study area of KDMC. It shows the WEAP study constituents such as a river, demand sites, catchments, return flow areas and others of KDMC.

Statistics and Schematics

By equating the supply and demand locations with the water year approach, the modeling method is used to consider KDMC's yearly rainfall volatility. In order to generate the grid of demands and supply nodes, which are all connected by transmission lines, modeling with WEAP requires a large amount of data of various kinds. By reading from the data file or giving data for one year for which all parameters are known and then using the water per year approach for reference scenarios, the various data have been incorporated into the WEAP analysis. Modeling the rivers in the research area using data from the UNDP (1987) report and KDMCWSD provided the information needed to model the reservoirs. Table 4 summarises the data on storage, flow, and losses collected from the KDMCWSD and used for modeling. Table 3 lists the elevation of the water level in the reservoirs that provide water to the city and the related storage volume. The water in the reservoirs was computed using the data from the last 30 years in Table

2. The Indian Meteorological Department provided the rainfall data (Open Government Data, 2014). The evaporation data for all basins have been obtained from the KDMCWSD. KDMCWSD has made information on the sewage treatment plants available online, and it is documented that the currently operating plants have been using their combined generating capacity of 210 MLD (KDMCWSD, 2020) (Table 7). The data relating to Month-wise inflow in Reservoirs in CMS are tabulated in Table 5 based on the last ten years of data collected.

The agricultural water demand for this study was considered as 0.0%. Additionally, the industrial sector has a requirement of about 60 MLD (KDMCWSD, 2020). The KDMCWSD provided the sewage treatment facility data needed for the study; a list of them is

Table 2: The volume of water in reservoirs (observed volume in MCM)

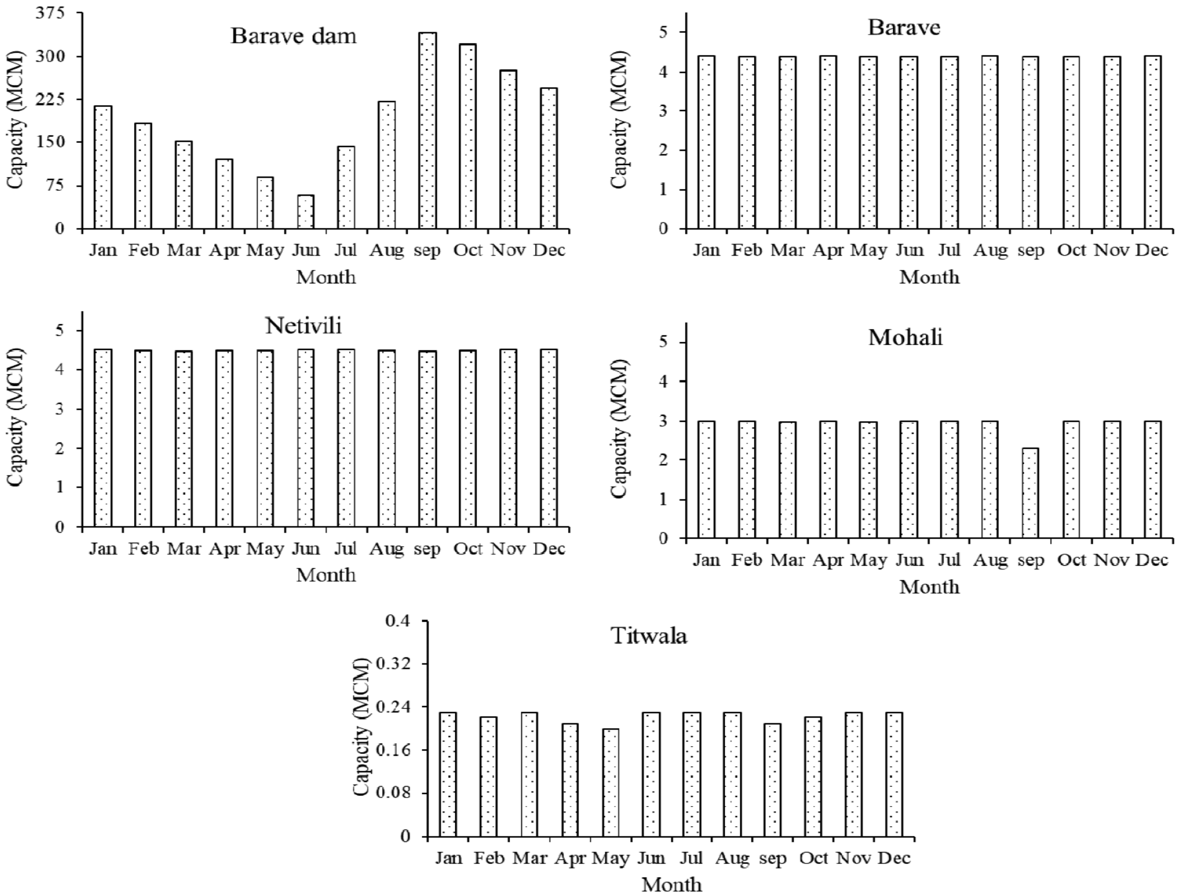


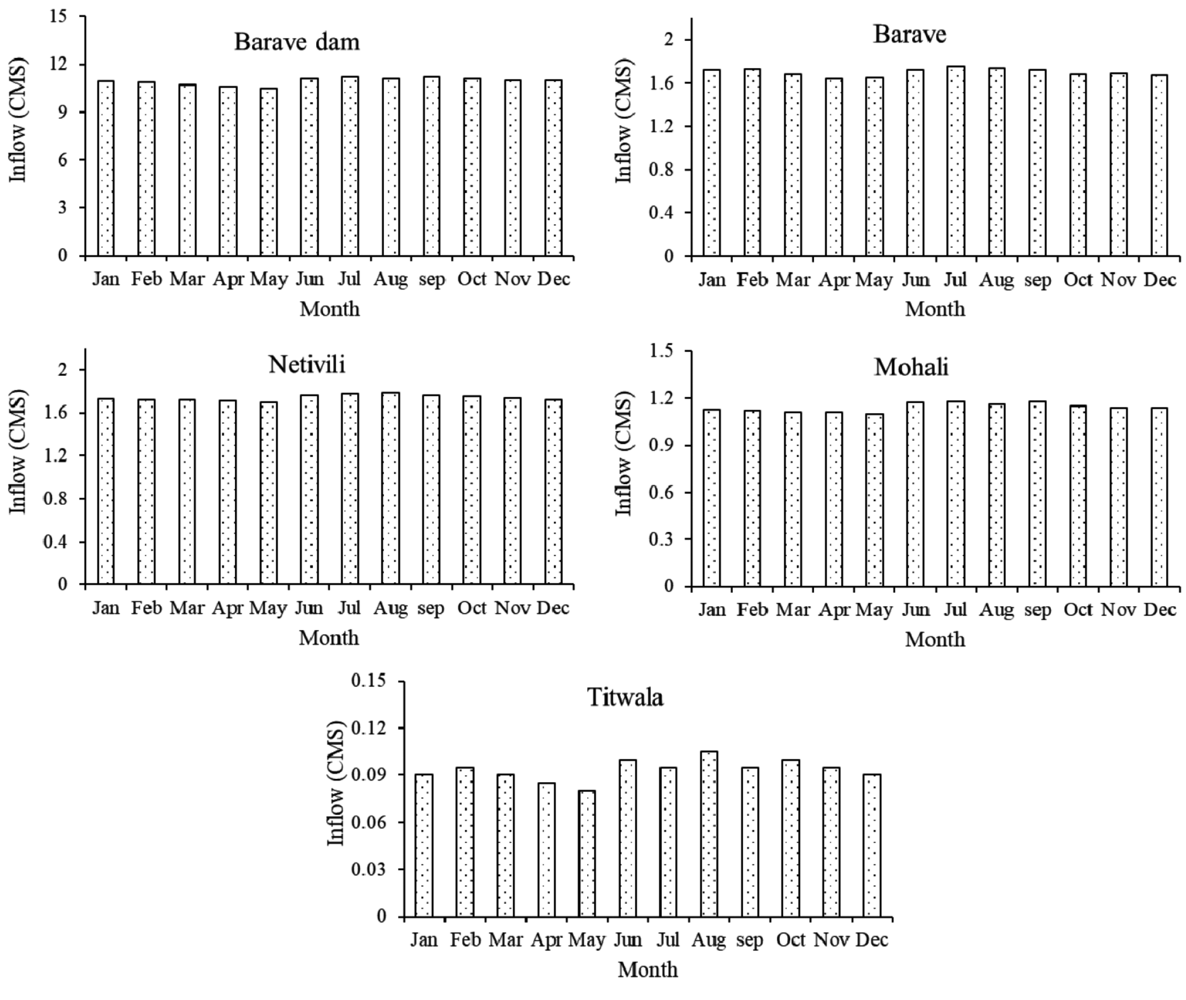
Table 3: An elevation of water level and volume of water storage at reservoirs

Reservoirs Name			
Barave dam	Volume (CM)	234.71	340.48
	Elevation (M)	68.6	72.6
Barave	Volume (CM)	0.14	0.18
	Elevation (M)	4	5
Netivali	Volume (CM)	0.14	0.2
	Elevation (M)	5	7
Mohali	Volume (CM)	0.07	0.12
	Elevation (M)	2	3.5
Titwala	Volume (CM)	0.01	0.02
	Elevation (M)	2	4

Table 4: Storages, losses and flows in reservoirs

		Flow (CMS)		*Losses*	
Reservoir	*Total storage in(MCM)*	*Inflow*	*Outflow*	*Evaporation*	*Ground Water*
Barave dam	340.48	10.94	10.8	3630	142
Barave	4.41	1.7	1.69	10	0.22
Netivali	4.5	1.74	1.73	15	0.23
Mohili	3	1.14	1.14	8	0.15
Titwala	0.23	0.09	0.08	13	0.01

Table 5: Month-wise inflow in reservoirs in CMS



provided in Table 7. Figure 8 represents the increasing water demand of the study area with an increase in population. The demand for the study area is increasing for the period 1951 to 2051 from 9.04 MLD to 503.61 MLD.

Calibration and Validation of the Model

Starting in 1991, WEAP was used to calculate the gap between water supply and demand. From 1991 to 2011, the model was calibrated. Calibration is necessary since WEAP is a semi-theoretical model (Hamlet et al., 2013) and is carried out utilising parameter estimation (PEST). PEST is a program that has WEAP already installed. It primarily uses the stream flow, reservoir, and catchment snowpack forms. This flow data were used in the reservoir approach. Data on stream flows collected from the UNDP (1987) were used for calibration. By comparing the output of the model with the observed

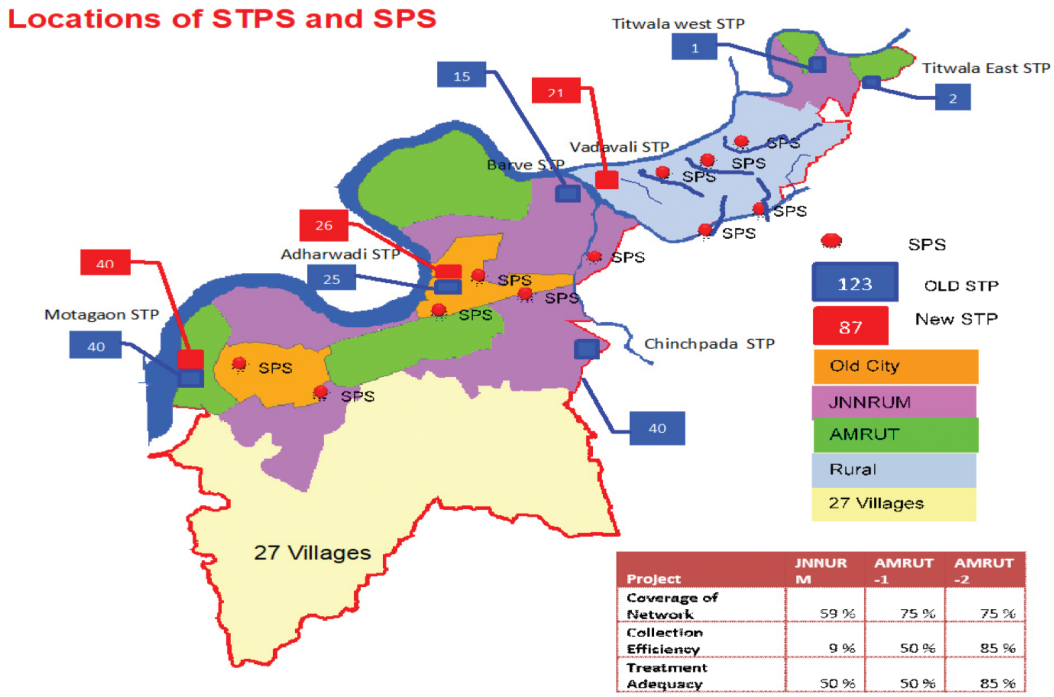
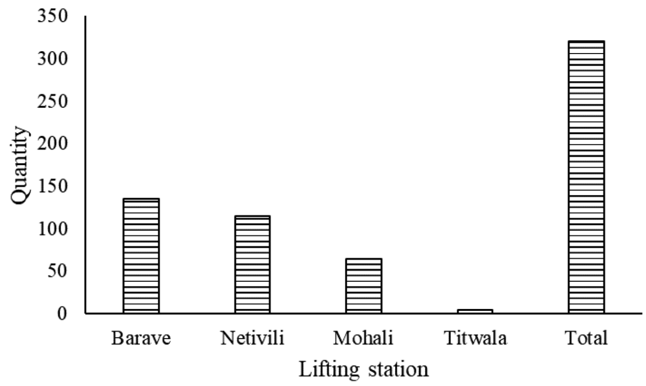


Figure 5: The location of STPs with-in KDMC.

Table 6: The water sources of KDMC area



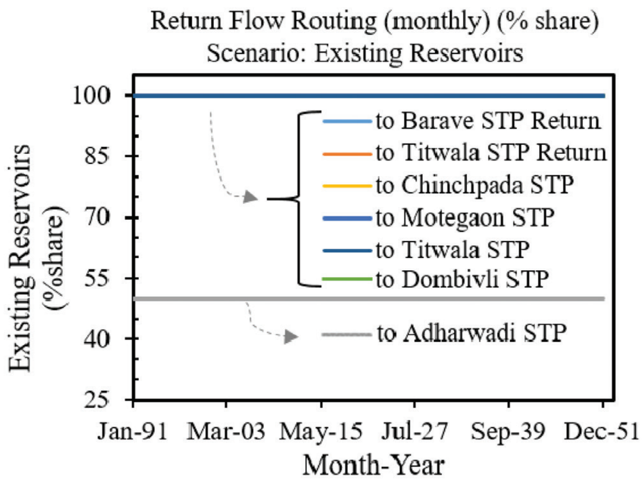


Figure 6: Return flow routing (monthly) (% share).

Table 7: Capacity (MLD) of STP for the KDMC region

Sr No	*STP Location*	*Treatment capacity*	*Treated effluent*
1	Adharwadi	25	21
2	Barave	15	11
3	Titwala (east)	2	1
4	Titwala (west)	1	0.5
5	Chinchpada	40	15
6	Motha gaon	40	0
7	Dombivali (east)	66	17.5
8	Wadavli	21	0
	Total	210	66

data from 2012 to 2021, the model was found to be valid. The model's prediction was followed through to 2051 with scenarios such as

- Existing reservoirs
- Increased reservoir capacity
- New reservoirs and STP
- Recycling of rooftop rainwater was considered.

Results are based on contrasting the unusual case modelled with the typical scenario. From 2022, possibilities, including increasing reservoir capacity, new reservoirs, and recycling, were considered as

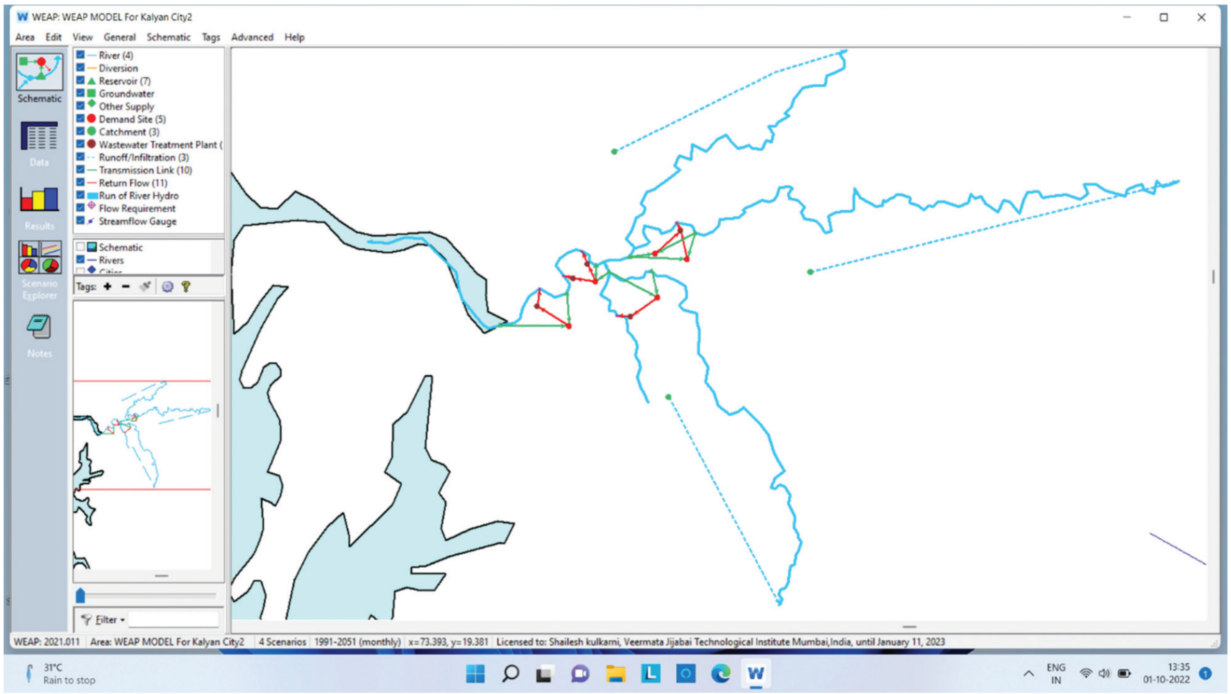


Figure 7: Schematic representation of KDMC.

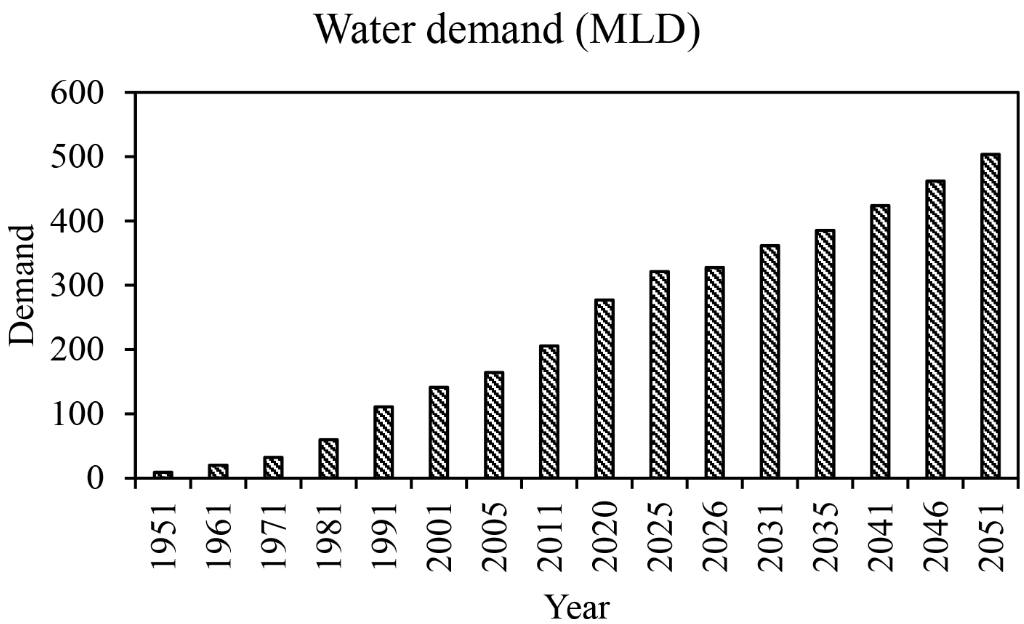


Figure 8: Water demand and population growth.

they are expected to be operational by that time. The increased water needed for Supply from these was therefore included in the model to simulate their effects from 2022 to 2051. From 1998 to 2022, the computed average monthly rainfall was based on data from the previous thirty years. Figure 9 shows the demand for water considered in the WEAP model. The inflows, outflows, and precipitation for 1991 to 2051 are with recycling scenarios. Figure 10 represents the demand site with existing reservoirs for KDMC up to 2051. Figure 11 gives us an idea about the Demand site Inflows Out flows-increased reservoir scenario. Figure 12 explains Demand Site Inflows Out flows-new reservoir scenario with population. WEAP gives Supply delivered for KDMC under all scenarios 1991-2051, as shown in Figure 13 with the expected population.

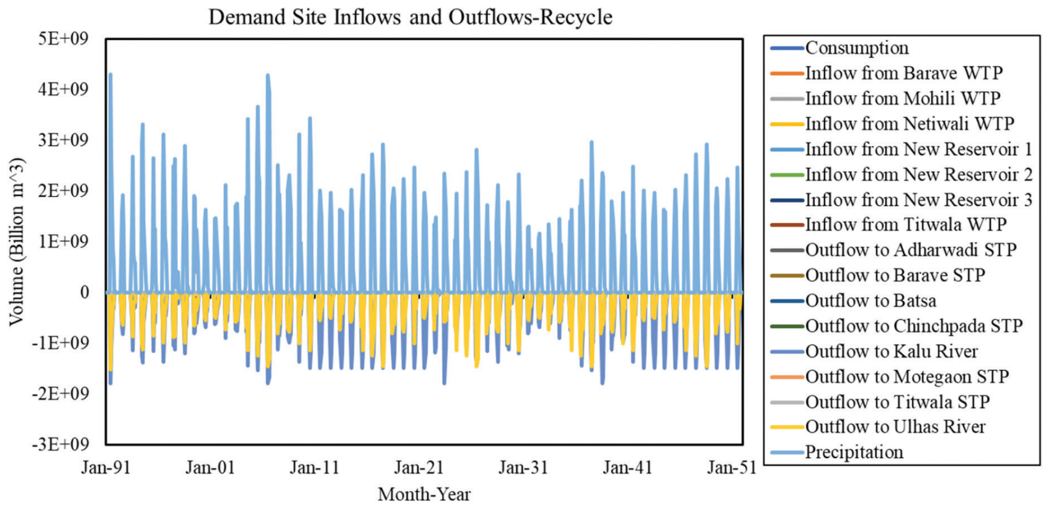


Figure 9: Demand site inflows outflows - Recycle.

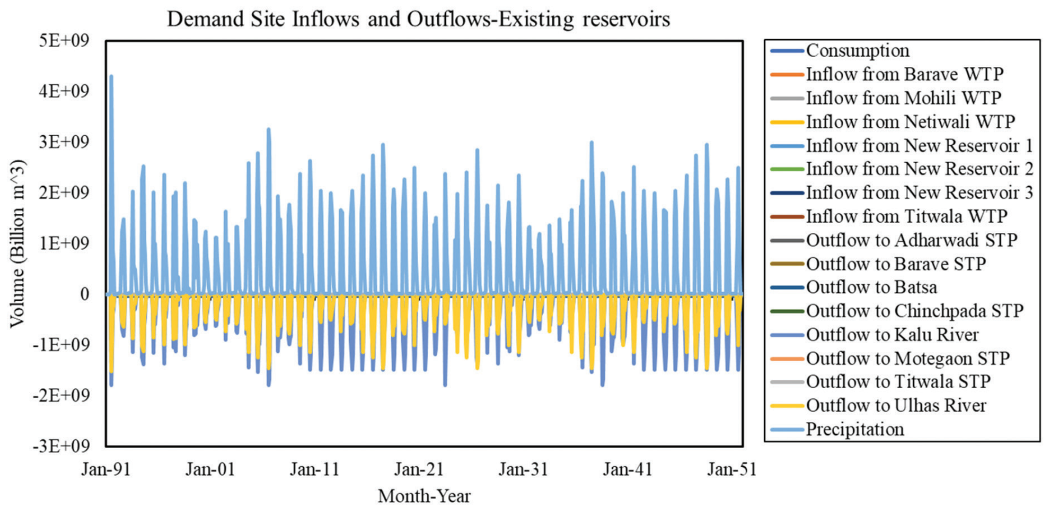


Figure 10: Demand site inflows outflows - existing reservoirs.

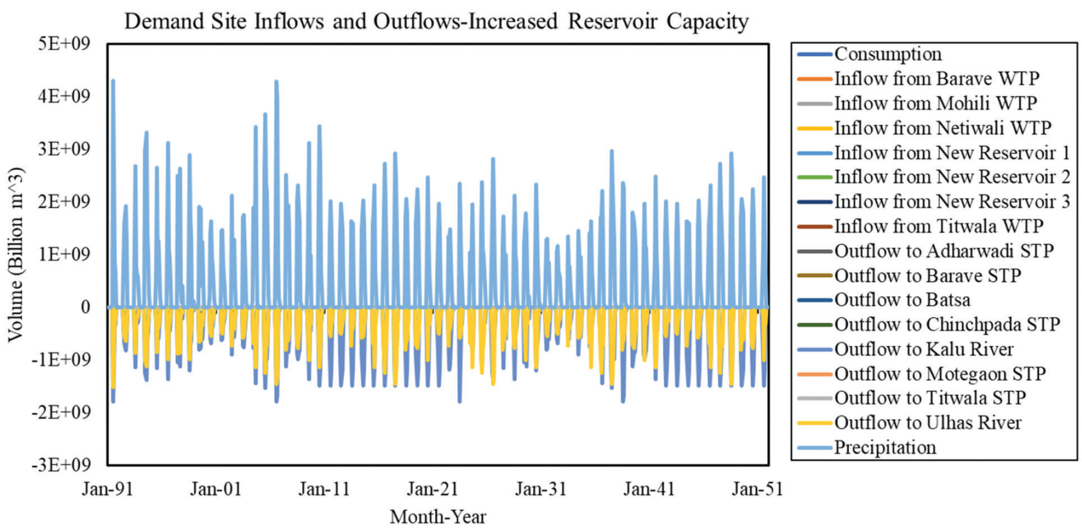


Figure 11: Demand site inflows outflows - increased reservoir capacity.

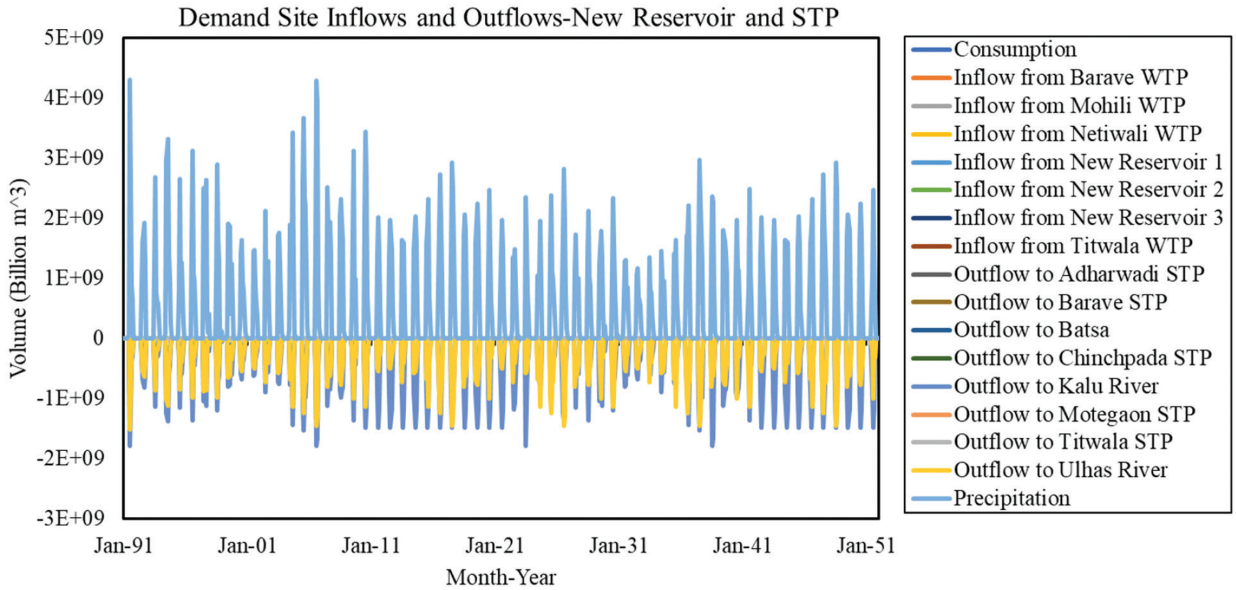


Figure 12: Demand site inflows outflows - new reservoir and STP.

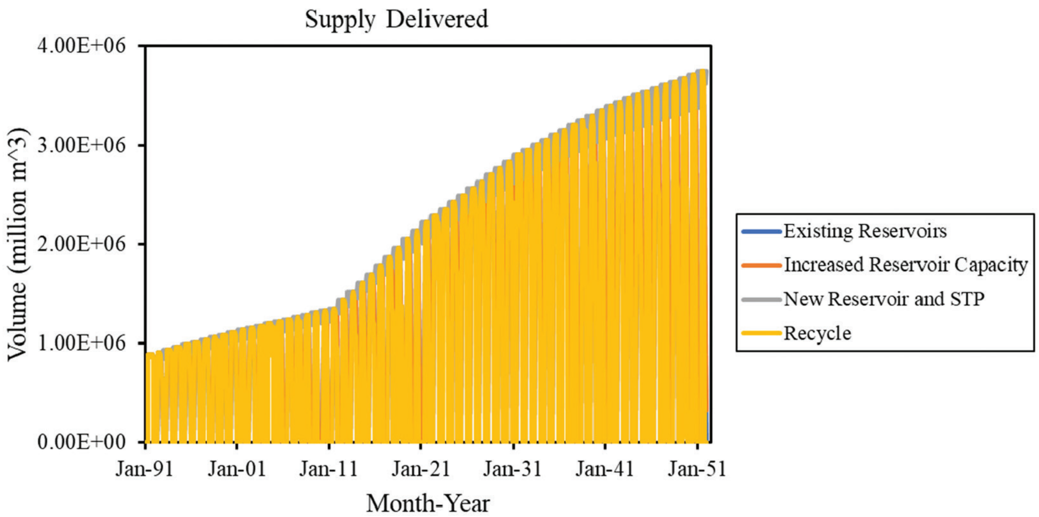


Figure 13: Supply delivered for KDMC under all scenarios 1991-2051.

Result and Discussion

The WEAP model provides information on water supply, water demand, unmet demand, coverage of demand, inflow and outflow, and the research area's dependability for the supply system. With the existing scenario, water supply and demand were estimated for KDMC. The output of the existing scenario was compared to values received from the other three situations. Figure 8 depicts the estimated water consumption for the city of Kalyan Dombivili with population growth for the years 1991 to 2051. The various scenario predictions that resulted in WEAP are shown in Figures 14-17. Figure 13 shows the supply delivered to the KDMC area under all scenarios from 1991 to 2051.

The Existing Reservoirs Scenario

Using both alternatives, i.e., the annual and monthly averages, future water demand and supply were predicted under the existing reservoir scenario. Since 2020, the demand-supply imbalance has been expanding, and by 2051, it will have about doubled. The supply can only expand to 550 MLD because there aren't any new water sources to meet the demand, which is determined to increase by more than 10 MLD annually. The anticipated monthly demand coverage changes from month to month.

Increased Reservoir Capacity Scenario

KDMC is planning to increase the reservoir capacity of all basins, which will generate 50 MLD capacities by 2025. Figure 16 shows the annual water fulfillment for the increased reservoir capacity scenario for KDMC. With the existing scenario, the city of Kalyan Dombivili's unmet water demand will be about half what it needs to be by 2051. The water supply-demand mismatch was projected by the model between 1991 and 2011. Actual KDMC data was used to validate this anticipated gap. The data supplied with actual data that was calculated from 2012 to 2021 was used to validate the model. By 2025, it is anticipated that the enhanced reservoir capacity will close the supply-demand gap.

New Reservoir and STP Scenario

A fifth reservoir, Bhoper, which would hold water from the Kalu river, is being built in order to meet the rising water demand. Water from the Kalu River will be used to fill the new reservoir, which will have a storage capacity of 250 MLD. The project is approved under AMRUT 2.0 with Rs. 350-crore budget. The WEAP model was used to simulate the project's effects because completion is anticipated in 2025. The unmet water demand will almost be satisfied by this new reservoir and STP effluent.

Recycle of Rooftop Runoff Scenario

Although KDMC's reliance on rainfall is unpredictable, if treated and reused, this offers a consistent source of

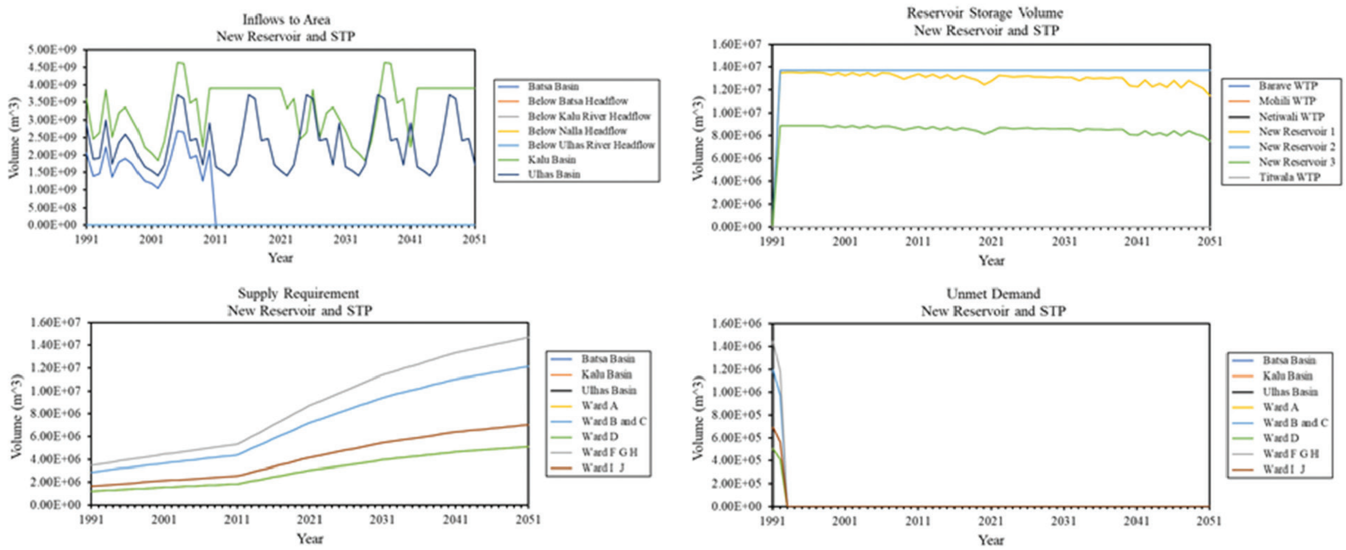


Figure 14: New reservoir scenario 1991-2051.

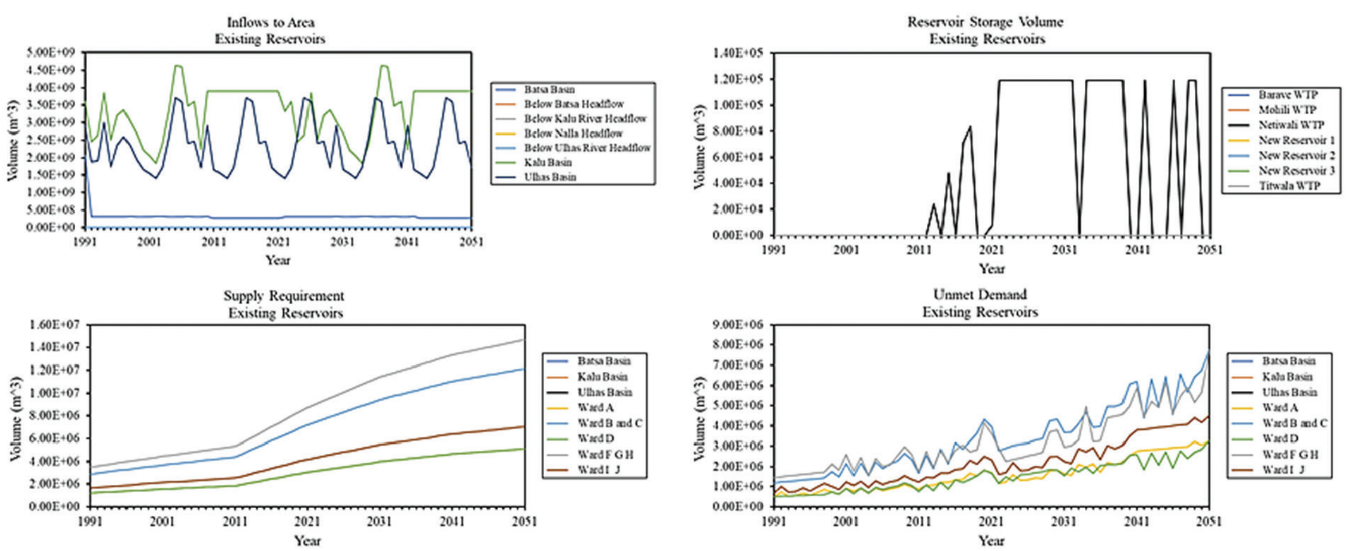


Figure 15: Existing reservoir scenario 1991-2051.

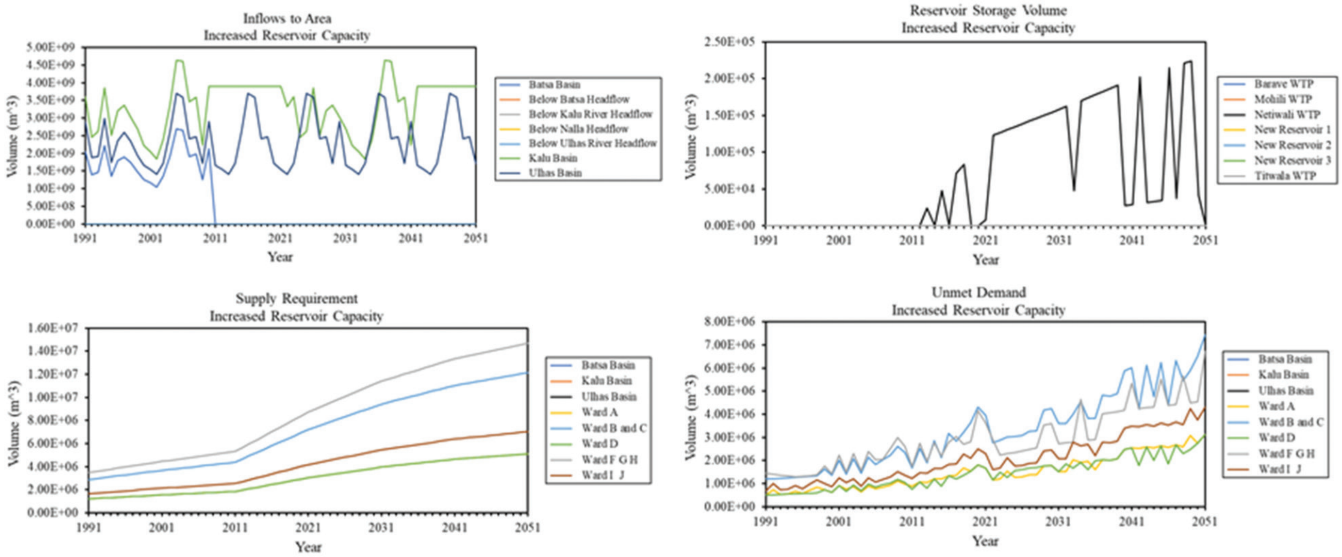


Figure 16: Increased reservoir capacity scenario 1991-2051.

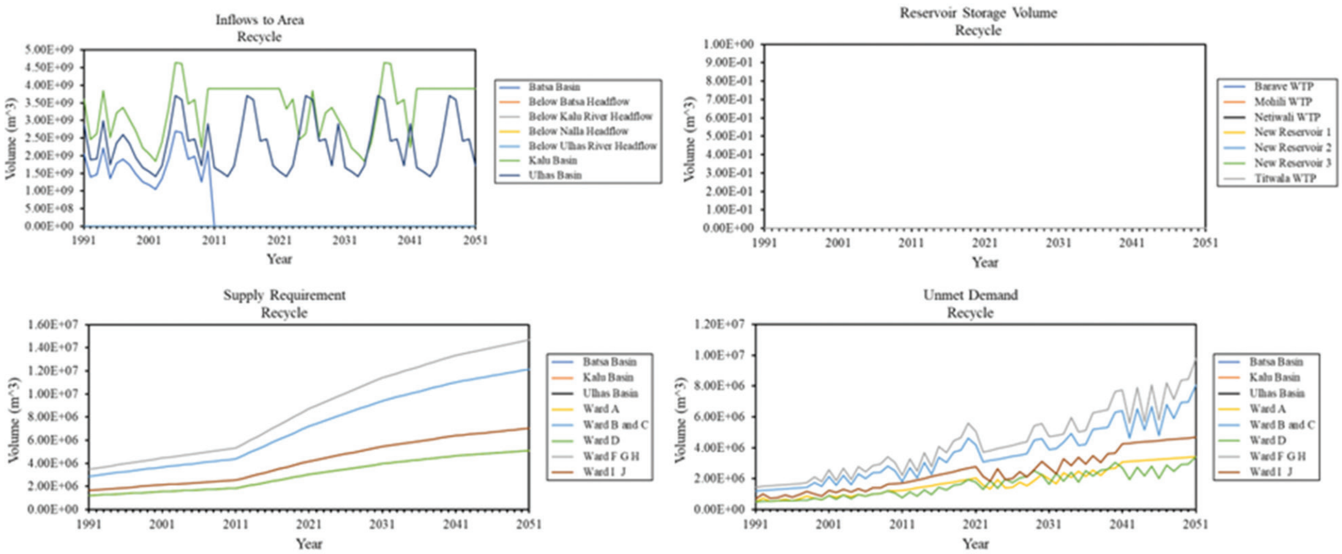


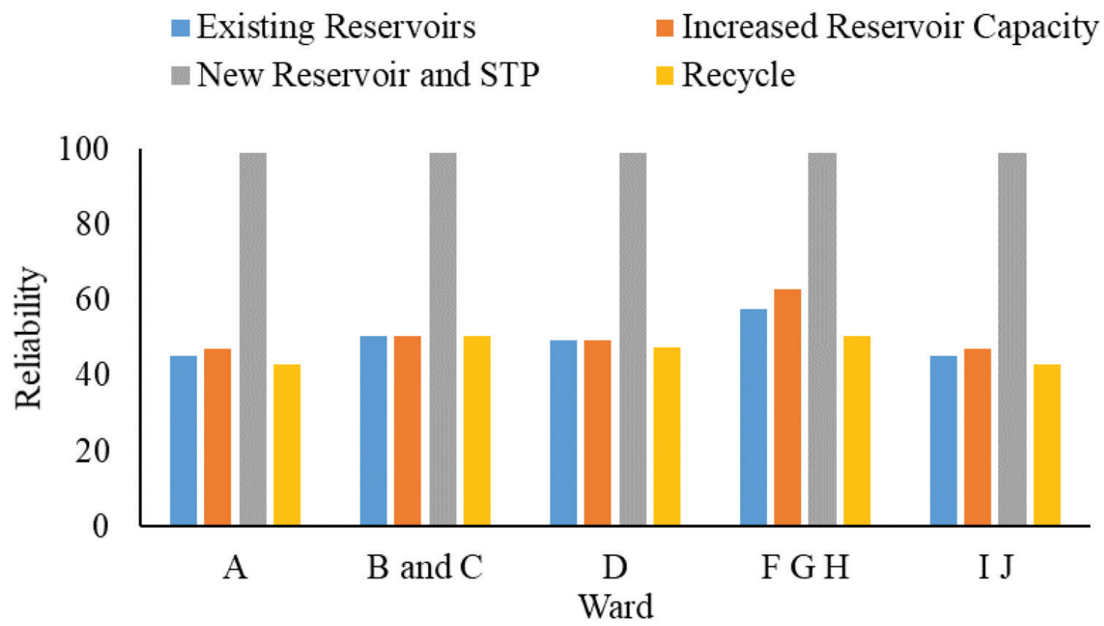
Figure 17: Recycle scenario annual 1991-2051.

water. By expanding the capability and effectiveness of treatment facilities, it is conceivable to treat 60% of the rainwater. About 15949 million litres of water can be reused, assuming that 60 percent of the rainfall is processed and put to use for various beneficial tasks, including cleaning, washing, and flushing toilets. It is feasible to effectively treat the water before releasing it into the Kalu and Ulhas rivers. Hence assuming about 60% of rainwater collected today is recycled, the water recycles scenario was studied using WEAP. The model's validation for the years 2011–2021 revealed that residents of KDMC recycled and used 96 mld of water, which decreased water demand. In the end, this minimised the difference between supply and demand.

Conclusion

For the Kalyan Dombivili megacity, WEAP modelling was done to forecast and quantify water management techniques under four scenarios. Considered scenarios include recycling rooftop runoff, increasing the capacity of current reservoirs, building additional reservoirs and STPs, and operating all of the scenarios together. It is inferred that out of all the new reservoirs, STP effluent is more promising than other scenarios. Table 8 shows ward-wise water supply-demand gap achievement with all scenarios. Figure 18 represents ward-wise achievement under considered scenarios. Figure 19 gives demand site reliability for all four scenarios against supply requirements up to 2051, as shown in Figure 20. The reliability of the future demand-supply gap, recycling rainwater, is 47%. Additionally, the water availability will improve by 51.2 percent with the enhanced reservoir capacity alone. The proposed new reservoir and STP of water alone would increase the existing reservoir's capacity by 99 percent and 49.4%, respectively. The combination of everything indicates improved water accessibility in the foreseeable future. The availability of water will exceed the demand with these four scenario alternatives in place, at least through 2051. Ahead of this time, it will be essential to explore new ways to expand the water supply and satisfy the

Table 8: Reliability for all scenarios, all wards



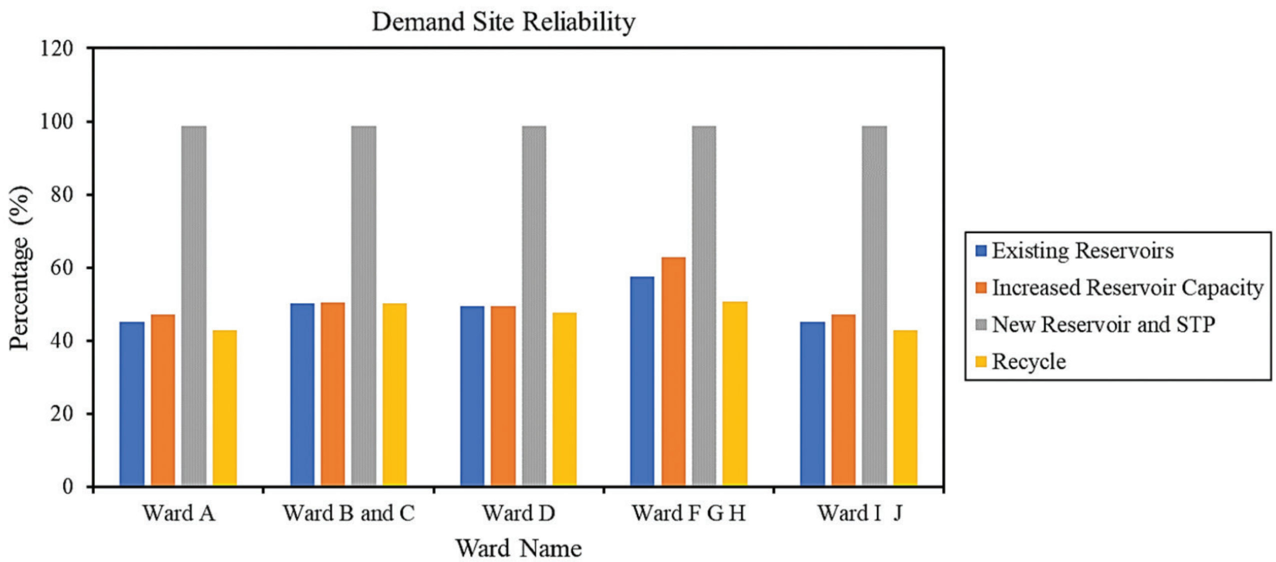


Figure 18: Ward-wise reliability for KDMC under all scenarios 1991-2051.

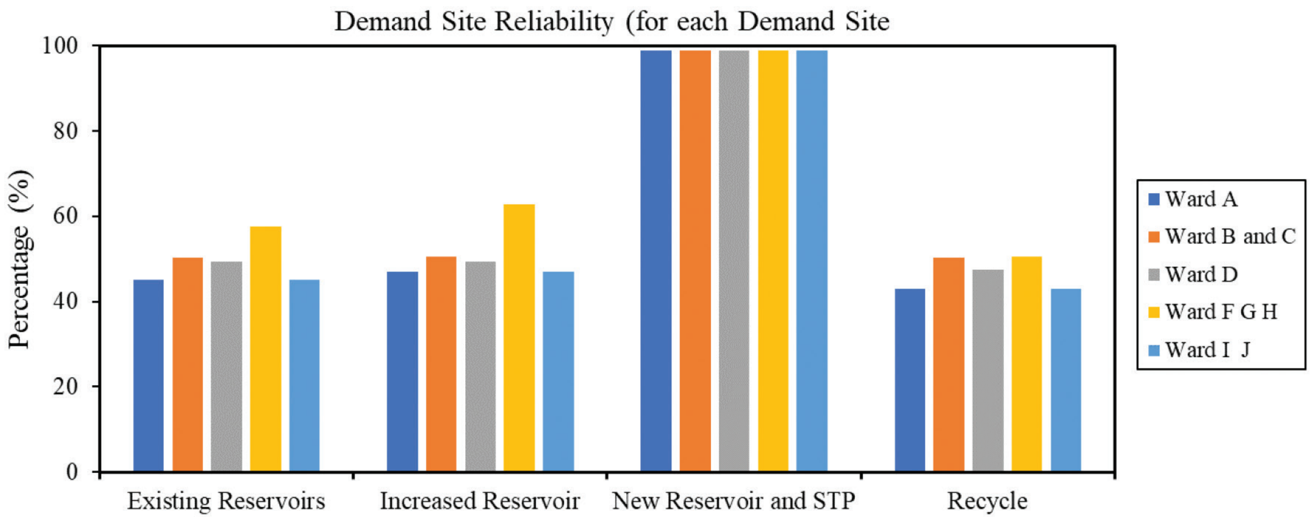


Figure 19: Supply delivered for KDMC under all scenarios 1991-2051.

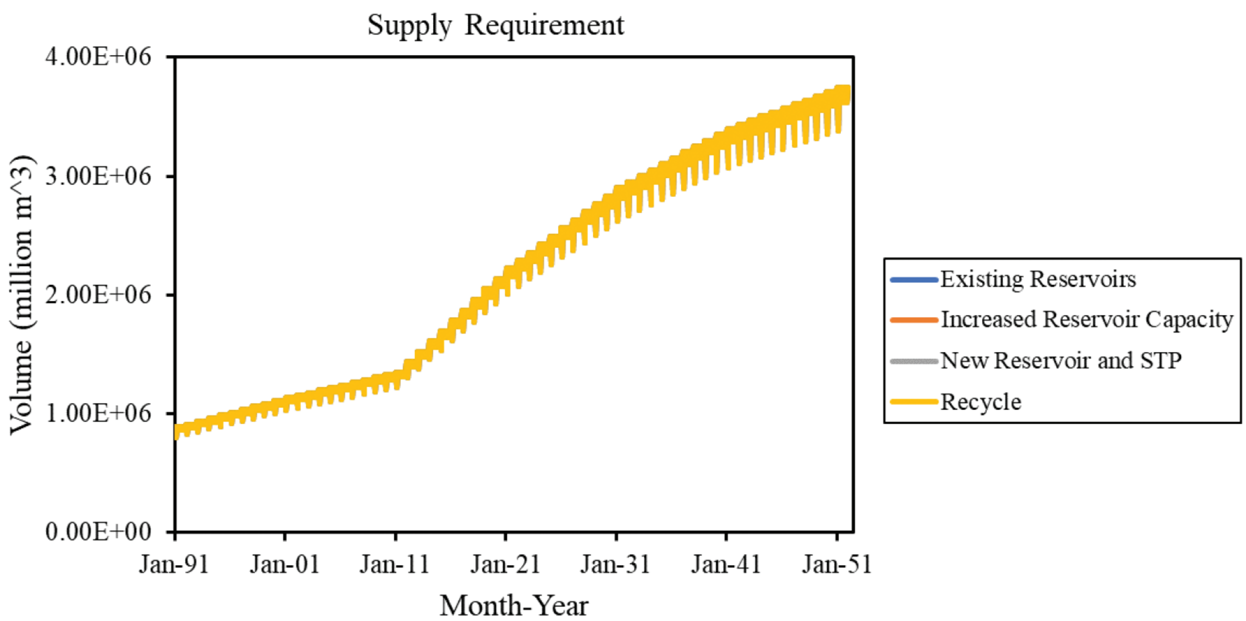


Figure 20: Supply requirement for KDMC 1991-2051.

rising water demand brought on by the expanding urbanisation of the world. With a stronger planning system, KDMC will be able to overcome its current issues and create efficient solutions to close the water supply-demand gap. The four scenarios that have been considered will not have any negative impact on the environment. The recycling and reuse of water will help in balancing out the environmental impact. The scenarios that have been considered will enhance the sustainability of the existing water supply system. The increased reservoir capacity, along with the addition of a new reservoir, has received the required environmental clearances, indicating that the environmental impacts have been assessed during the planning phase..As a result, WEAP was successfully applied to find solutions for the city's water resilience.

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