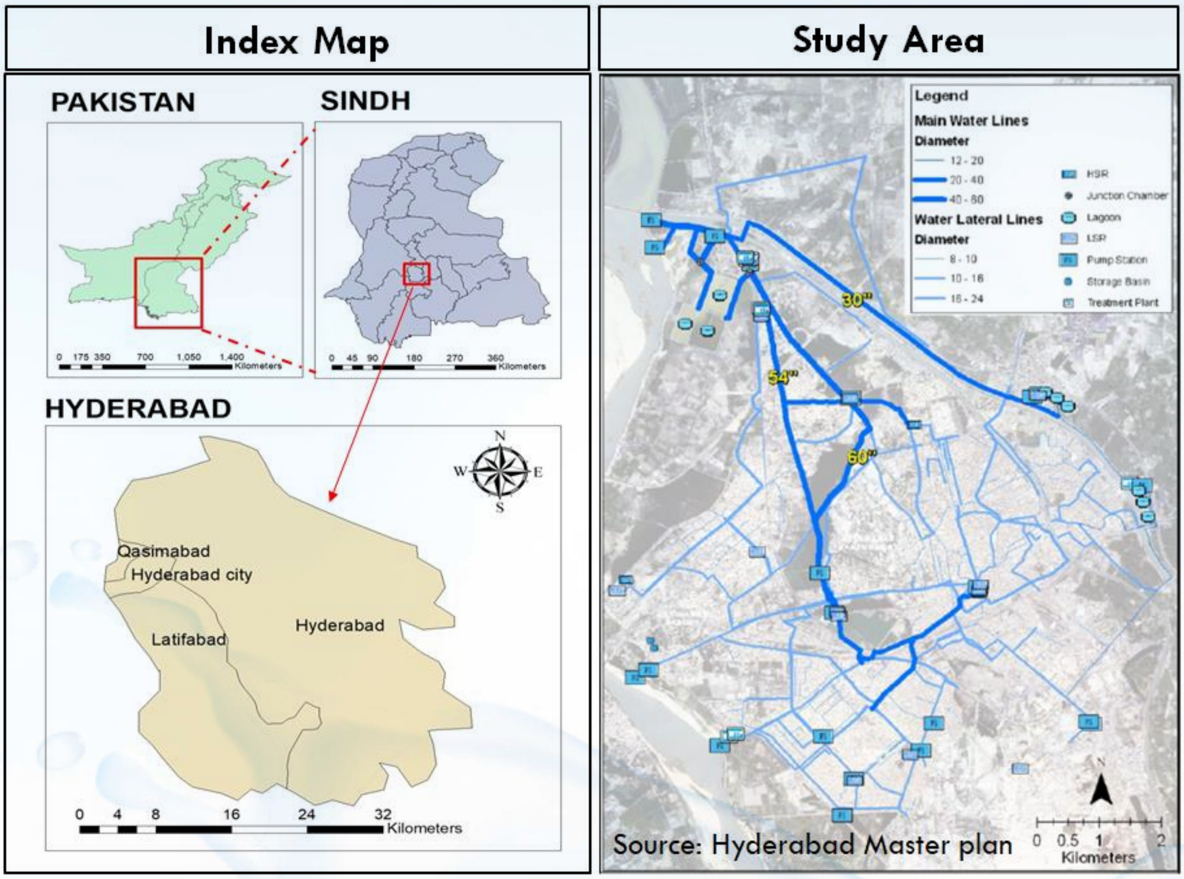
U.S.-Pakistan
Centers for Advanced Studies in Water

Estimating Sustainability Cost of Urban Water Supply System for Hyderabad City, Sindh, Pakistan

Final Report 2019



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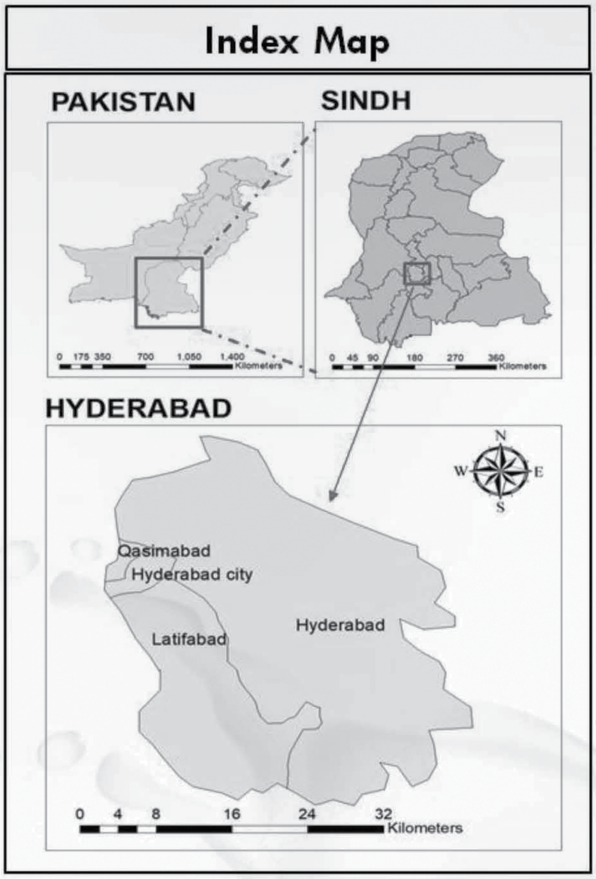

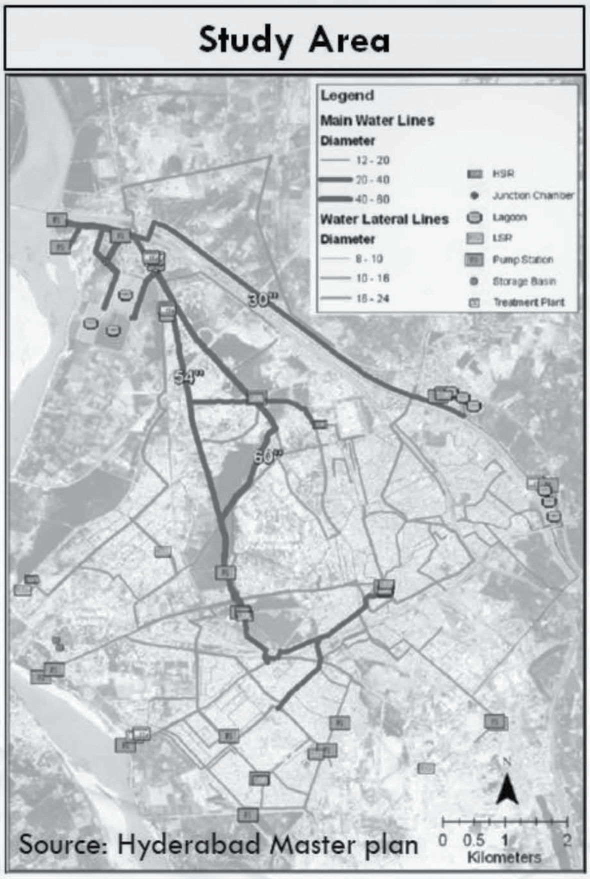

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We are grateful to the U.S-Pakistan Center for Advanced Studies in Water (USPCAS-W), Mehran University of Engineering and Technology, Jamshoro, for funding this study through the financial support provided by the United States Agency for International Development (USAID). We want to thank our team members especially Research Assistant Miss Uzma Jabeen, and Dr. Irfan Ali Memon and Mr. Waqas Ahmed, for their technical help in the implementation of the project plans, Mr. Aftab Ahmed Khoso and Mr. Rajoo Menghwar for their facilitation and invaluable support in project financing and maintainance of the project records. Without their technical and other support, this study would not have been possible.

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ACRONYMS AND ABBREVIATIONS

CapEx	Capital Expenditure
CLD	Causal Loop Diagrams
GPCD	Gallons per Capita per Day
GPD	Gallons per Day
HSR	High Service Reservoir
LSR	Low Service Reservoir
MGD	Million Gallons per Day
OpEx	Operational Expenditure
SD	System Dynamics
SDG	Sustainable Development Goals
SFD	Stock Flow Diagram
WASA	Water Supply and Sanitation Agency

EXEVUTIVE SUMMARY

While the share of the global population living in urban areas is increasing over time, understanding of the factors which could affect meeting future urban water demands is essential. Financial sustainability of urban water utilities plays a significant role in defining the future performance of the urban water infrastructure. Population growth trends, along with degrading infrastructure condition and capacity, present a complex system of interactions which may affect the financial sustainability of urban water utilities.

This report presents a research study designed and aimed at measuring the cost of sustainable water services in urban areas, integrating the factors which may affect meeting SDG 6.1, i.e., 'safe and affordable drinking water for all'. With a focus on Hyderabad city, Sindh, the study identifies major factors affecting the sustainability of water supply through key informant interviews; followed by system dynamics modelling using STELLA to demonstrate the impact of these factors on total water demand and utility finance and thus, the sustainability of domestic water supply in the city.

STELLA, a system dynamics modelling tool, employs an integrated approach to measure the impact of multiple factors on water system simultaneously. This research study estimates cost of implementing SDG 6.1 under current and future population growth scenarios and under other changing factors (which would be demonstrated by different situations) for short term (2017-2030) and long term periods (2017-2080). The study further included assessment of policy measures such as water tariff increase and external funding, for their effectiveness in ensuring the sustainability of the future water supply. Estimation of sustainability cost for the Hyderabad city would serve as a valuable source for the water policymakers in the city.

Results obtained through system dynamics modelling, present a huge gap between water supply and demand for Hyderabad city, along with a projected fiscal deficit of Rs. 4.3 million for Water and Sanitation Authority (WASA) till 2030. A zero utility fund balance is obtained by 2030 at 18% increase in the user fee with 80% recovery rate under a self-sustaining scenario. Since most of the development financing is done by government and non-government organizations, an external funding scenario is tested for capital work expenditures with a 28% increase in the annual water supply and 36% of the water pipes rehabilitation every five years till 2030.

1. INTRODUCTION

1.1 Background and Rationale

For the past several years, growing population and economic development have been increasingly inducing the human requirements for water resources (Wang et al., 2011). Because of these factors, water requirements are increasing, so is the demand for new water supplies (Bhatti and Nasu, 2010). Thus, increasing water demand results in serious water shortages and water quality problems (Zhang et al., 2009). In cities, this issue increases pressure on the limited supplies of accessible freshwater and cities to search for new, sufficient, and clean water sources (McDonald et al., 2014). Because of this reason, an effective approach is required to develop an objective framework for the assessment of sustainable water supply across the water sector (Rathnayaka et al., 2016). Thus, for sustainable consumption of water resources, a proper financial plan and management are very important to be considered (Rathnayaka et al., 2016).

UN has adopted the Sustainable Development Goals (SDGs), including SDG-6, which focuses on “clean water and sanitation for all.” And the target 6.1 of SDG-6 is meant to achieve universal and equitable access to safe and affordable drinking water for all by 2030 (Hutton and Varughese, 2016). However, the implementation of SDGs has remained a major issue, especially in developing countries (Udmale et al., 2016), where funding the sustainable management of water resources is a significant and challenging task. The cost of managing water resources is increasing with population growth, economic growth, and climate change. Usually, water resources management has been mainly supported by community funds, and foreign funds are mostly provided to developing countries to finance water infrastructure. Another approach is the water pricing, which serves an important source of financing the water system (Martín-Hurtado, 2012) as it plays a significant role in improving the sustainability of water resources (Liu, 2002). As such, the water pricing mechanism should provide financial sources for capital works and for improving the infrastructures of the existing water supply system. Thus, water pricing. Many researchers claim that users’ willingness to pay water charges plays an important role in the sustainability of a water supply system and that the charges are enough to bear all the costs (Kaliba, Norman, and Chang, 2003).

In contrast, Bhandari and Grant (2007) reported that a water supply system could not be sustainable if financial grants are not available from other sources and that capital expenditure costs are not provided. A basic strategy for the financial sustainability of a water supply system requires the revenue to be equal to all the expenses to maintain it. When a water supply service does not operate on full recovery cost of user fees, the system becomes economically inefficient. Therefore, economic efficiency can be achieved by the full-cost recovery through user fee (Rehan et al., 2014).

National governments are to incorporate SDG-6 targets in their national policies to provide safe drinking water to citizens (United Nations, 2018). One of the ways to accomplish SDG-6 targets is to estimate the accessibility of freshwater and the requirement for domestic water through competent and cost-effective approaches (Udmale et al., 2016).The water supply targets of SDGs need various service levels to estimate unit cost per capita based on the population to be served (Hutton and Varughese, 2016). From the perspective of Pakistan, the developmental goals “Vision 2025” is closely associated with the SDGs, and Pakistan has agreed with the UN Agenda 2030 for implementation of SDGs through undisputed legislative resolution 2016 (Ali, 2017). Pakistan has started working on SDGs at the provincial levels through creating provincial taskforces for SDG implementations. However, focusing SDGs at sub-provincial level is a challenging task for implementation. For this reason, SDG design, development, financial arrangements, and operations need to be very strong (United Nations, 2018).

This study focuses on the implementation of SDGs, particularly target 6.1 of SDG-6, in Hyderabad city, which is one of the emerging cities in Pakistan and acts as a first stop for the rural population of Sindh province. The population of this city stood at 1.1 million in the census of 1998. Currently, it is estimated to be approximately 1.7 million (Pakistan Bureau of Statistics, 2017). The city is facing water demand deficits due to various factors (Shah et al., 2016; Kalhoro, 2017; Peerzado, Magsi, and Sheikh, 2018) including decreasing water availability at sources, technical issues in the functioning of the system, increase in the number of inhabitants, urban sprawl, shifting of rural population to urban areas and lack of proper water supply schedules. Research studies conducted so far have focused more on quality assessment of water and wastewater (Ghanghro, Atta, and Buxghanghro, 2015; Mahessar et al., 2016) and socio-economic impacts of urbanization (Peerzadoa et al., 2014; Shah et al., 2016). However, studies that have focused on the sustainability of the filter water supply system have remained largely unexplored in Hyderabad, Sindh. For a better understanding of the costs to meet the requirements of SDG 6.1 target, this study estimates the costs required for additional water supply and network rehabilitation under baseline, self-sustaining and external funds scenarios by 2030. We have opted a System Dynamic (SD) approach to evaluate the financial sustainability of the urban water supply system in Hyderabad city. The interconnections and feedback loops of the model developed in this study focus on the importance of population, water balance and finance sectors on water management planning based on the proposed system dynamics model for Hyderabad city.

1.2 Limitations

This study covers the finance sector of the water supply network but does not consider the wastewater system and its network because of the scope of the study. It must be mentioned that this model is not completely a water service model as it is an integrated system dynamics model that can be helpful for water service providers and managers to be considered for short and long term planning and decisions.

1.3 Objectives

- ☐ Identify the factors affecting the sustainability of drinking water supply in Hyderabad city.
- ☐ Identify the impact of baseline, self-sustaining and external funding scenarios on the financial sustainability of the WASA Hyderabad to achieve SDG target 6.1 by 2030

2. MATERIALS AND METHODS

2.1 Study Area

This study focuses on Hyderabad, the second-largest city of Sindh. Hyderabad district has four sub-districts/Talukas/Tehsils viz. Qasimabad, Latifabad, Hyderabad City, and Hyderabad Rural, as shown in Fig. 2.1. The existing Water Supply Network covers urban areas comprising of three sub-districts of Hyderabad (Qasimabad, Latifabad, and Hyderabad City) and excludes Hyderabad Rural. Therefore, this study considered three urban sub-districts of Hyderabad, and the name 'Hyderabad city' is used instead of three sub-districts throughout the study for easiness. According to the Pakistan Bureau of Statistics, Hyderabad city grew from 1.1 million inhabitants in 1998 to the currently estimated 1.7 million people (Survey, 2017).

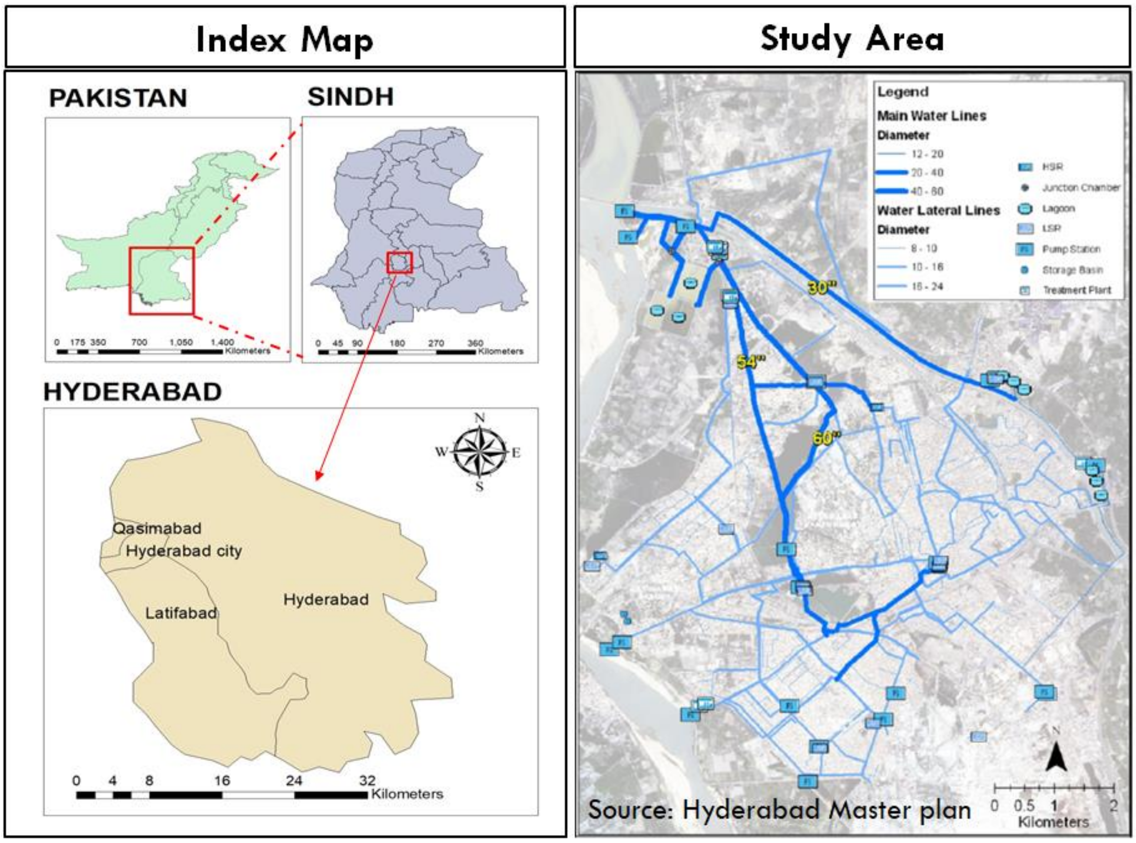

Fig. 2.1: Map of the study area

Population data and growth rates were obtained from the Bureau of Statistics, Government of Sindh. The per capita water demand, filter water supply, and finance data were collected from the Water and Sanitation Agency (WASA) Hyderabad Sindh.

2.2 Water Supply System of Hyderabad

2.2.1 Water sources and existing water supply system of Hyderabad city

The main water supply source in Hyderabad city is the surface water from Indus River. Surface water is extracted from upstream and downstream of Kotri Barrage located near Hyderabad, Sindh. The upstream distributaries of Kotri barrage are Akram Wah, Phuleli Canal and Pinyari Canal whereas downstream water extraction is directly from Indus River. Groundwater is brackish, therefore, not suitable for domestic use. Water and Sanitation Agency (WASA) Hyderabad manages the water supply and sewerage system in Hyderabad. The water supply system includes five filter plants with a total 60 million gallons per day (MGD) filtration capacity. The total water supply network extends to 1100 km and 51 pumping stations. The filtration process includes Rapid Sand Filtration (Plan, 2007) but partial sedimentation and mixing of Alum through settlement procedures (Kalhoro, 2017). The reservoirs in Hyderabad are groundwater Low Service Reservoirs (LSR) except for three, which are High Service Reservoirs (HSR). Raw water from canals is pumped to the settling tanks of the filter plants for filtration via transmission mains. After that, filtered water is stored in reservoirs and driven to the distribution system through distribution pipes and house networks (Plan, 2007).

2.2.2 Water tariff

In Hyderabad, water connections are unmetered, and water charges are based on an area (square yards) of a building and diameter of pipe connections. Water tariff is based on various categories from A to F (Table 2.1) following area, monthly water charges, and diameter of pipe connections. Pipe diameters vary from 0.5 to 2 inches (0.5”, 0.75”, 1”, 1.5”, 1.75”, and 2”). Each category A to F is further divided into subcategories based on the number of floors of a building. Table 2.2 provides subcategories of category A with water charges and diameter; further, all categories are shown in Appendix B 1. Table 2.1 monthly water charges from A to F categories are used for the calculation of water pricing in this study.

Table 2.1: Area wise categories of water charges in Hyderabad

Category	Area (Sq. yard)	Water charges (PKR)	Dia (Inch)
A	≤ 80	120	0.5
B	81-120	140	0.5
C	121-200	185	0.5
D	210-400	325	0.5
E	401-600	435	0.5
F	> 601	545	0.5

Table 2.2: Subcategories of water charges in Hyderabad

Category	Water charges (PKR)	Dia (Inch)
A	120	0.5
AG+1	180	0.5
AG+2	240	0.5
AG+3	360	0.5

2.3 Major Problems of the Water Supply System in Hyderabad

Many major problems exist in the water supply system of Hyderabad. One of the filter plants situated in Jamshoro is non-utilitarian after numerous long stretches of no support.. Power shortage reduces the pumping capacity of water pumping machines; therefore, the water availability in the system also decreases. The filtration process employs partial sedimentation and mixing of alum throughout the settling period but without following scientific procedures. The long-time negligence of WASA has resulted in rusting and a non-operational condition of mechanical and electrical devices, as well as solidified sedimentations forming in the settling tanks and lagoons.

Additionally, no rehabilitation and replacement processes have been taken on the existing network. Corroded junctures, rusted metallic pipelines, and illegal breaks result in water losses; also, leaked sewage and soil mix with water pipelines in several places. Thus, unsafe water is supplied to the consumers (Kalhoro, 2017).

According to WASA, the non-payment of water charges by the Government based departments in Hyderabad causes financial problems. The money provided is less than the overall expenditures, which causes various problems in the water supply sector. Further, the major problems of the Hyderabad water supply system are summarized in Table 2.3.

Table 2.3: Summary of major problems and consequences of a water supply system

S. #	Major Problems	Symptoms	Consequences
1.	Poor condition of the water distribution system	☐ Rusted joints ☐ Corroded metallic pipes ☐ Unauthorized punctures ☐ Leakage	☐ High leakages in the system ☐
2.	Poor water quality treatment	☐ No proper filtering and chlorination ☐ Nonfunctional filter beds ☐ Nonfunctional clarifiers ☐ Solidified sedimentation in lagoons and clarifiers	☐ Contaminated drinking water
3.	Low infrastructure capacity	☐ Too few in numbers ☐ Nonfunctional (old filter plant, Jamshoro)	☐ Requirements of the city not fulfilled
4.	Electricity outage	☐ Inoperability of the electrical and mechanical devices	☐ Low pumping capacity ☐ Shortage of water
5.	Lack of autonomy	☐ Tanker supplies ☐ Illegal connections ☐ Low tariffs	☐ Insufficient revenues ☐ Low self-esteem of WASA staff
6.	Poor management	☐ Failure to overcome the shortage of drinking water ☐ Poor maintenance and operation of a water supply system ☐ Failure to devise a mechanism to collect outstanding dues from government departments and agencies	☐ Insufficient revenues ☐ Deteriorating services ☐ Deteriorating assets ☐ Political interference ☐ Distrust of customers in WASA services ☐ Unwillingness to pay for the service
7.	Paucity of funds	☐ Failure to maintain and operationalize filter plants ☐ Delay in system rehabilitation and expansion ☐ Poor water treatment	☐ Contaminated drinking water ☐ Deteriorating services ☐ Deteriorating assets ☐ Low self-esteem of WASA staff
8.	Commercialization	☐ Additional burden on the existing water supply	☐ Water shortage

2.4 System Dynamics Approach

The system dynamics modeling developed by Forrester is a computer simulation model based on relationships among various modules (Sterman, 2001). The system dynamics approach consists of two main tools, Causal Loop Diagram (CLD) and Stock-Flow Diagram (SFD). CLDs are valuable for interconnecting complex outlooks of a system to understand systems thinking or system dynamics. They are easy to understand and a first step to evaluate a problem of a system through developing connections and feedback loops between variables (Binder et al., 2004). SFDs are the base of system dynamics modeling. They are more detailed and differentiate variables into stocks and flows. They help to create stock-flow diagrams and build a computer model of a system that needs to be studied (Park and Kim, 2016). The application of system dynamics approach is used to study various sustainable urban water demand management (Bagheri, 2006; Zhang *et al*., 2009; Wang *et al*., 2011; Huanhuan *et al*., 2016) and urban water supply management and quality improvement studies (Willuweit and O'Sullivan, 2013; Sveučilište, 2015; Park and Kim 2016;). This approach is based on the connections among variables of a system, which helps the planner to understand the relation between the elements. System dynamics have also been used for studies, including financial sustainability for urban water management and water infrastructure managements (Xi & Leng, 2013; Rehan *et al.,* 2014; Mistry et al., 2018). These studies focused on the effects of financing and rehabilitation policies on system services for long term and short term planning based on different investments plans.

2.5 Causal Loop Diagram (CLD)

Initially, CLDs with feedback loops for the Hyderabad water supply system and population and finance sectors were developed and then related to a stock-flow diagram. The purpose of developing CLDs is to show the 'bigger picture' of the interconnections that exist within a water supply network.

2.5.1 Population growth, urbanization and water demand

The population growth rate is an important factor for calculating the increase of population in an area in a particular period. Mostly, the rural population shifts to urban areas because of urban attractiveness such as medical care availability, more food and water sources, better schools and more jobs, etc. Migration rates increase because of this, and finally, immigration rates also increase, and so does the demand for more water. These factors create reinforcing loops and have a positive impact on each other. This situation also exists in Hyderabad city where urbanization and increasing water demand put additional pressure on existing water supply of WASA. When the total water supply is less than total water demand, water deficit (shortfall) exists, but if filter plants capacity is increased and total water supply equals total water demand, zero water deficits exist, and it shows a balancing loop as shown in Fig. 2.2.

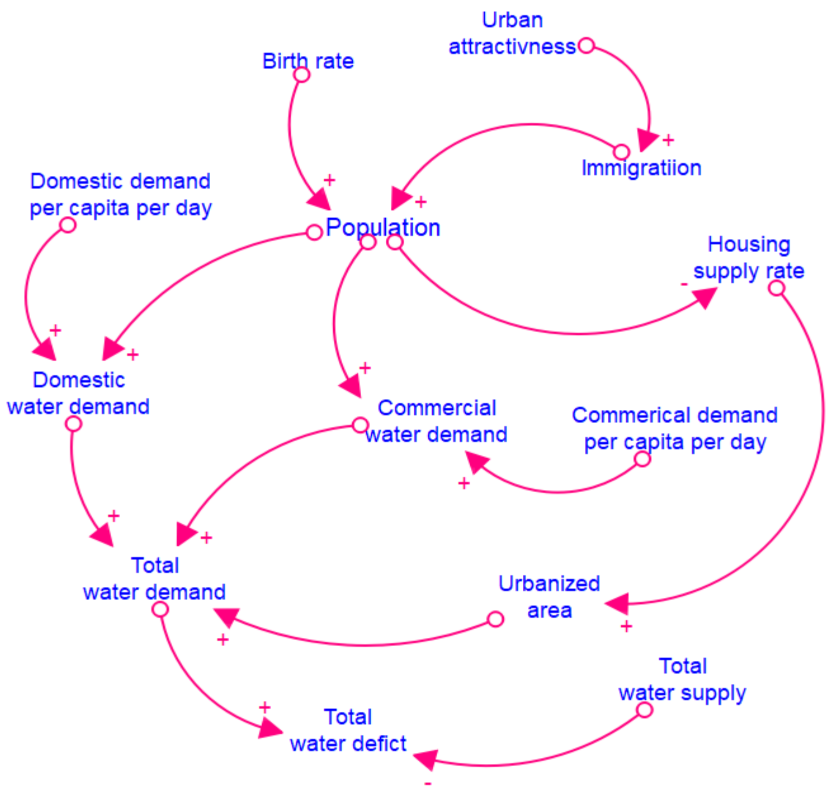

Fig. 2.2: Causal loop diagram of population urbanization and water demand

2.5.2 Water consumption and user fee adjustments

To achieve the desired service level, utility service managers make new plans to satisfy customers; thus, an achievable long-term plan can increase user fees with new water projects, as shown in Fig. 2.3. A balancing loop can be created by customers' willingness to pay for water charges. Willingness to pay mostly depends on household income and desired service level. Customers can accept fee hikes to some extent and in return they expect the utilities to fulfill their water requirements. Thus, accepting fee hikes increases the revenue which reduces the revenue shortfall. Funding agencies, especially the government, can also provide further financial support. Hence water shortage problems can be solved, and service performance can be improved.

2.5.3 Physical condition of the water supply system

In Hyderabad, the total water requirement is more than its supply, where the increase in demand and a reduction in the water supply is due to low service performance, which along with network deterioration, causes water shortage (deficit). In order to fulfill the water demand, additional water supply and pipes network rehabilitation are important components to be considered. In the water supply network, water loss (mainly leakage) and aging of pipes cannot be neglected; water loss depends on the water network condition and non-revenue water ratio (physical or real losses) whereas aging of pipes network depends on the deterioration rate. The deterioration rate causes poor network condition and low service performance creating reinforcing loop. To improve the service performance, network rehabilitation is required, which balances the loop, as shown in Fig. 2.4.

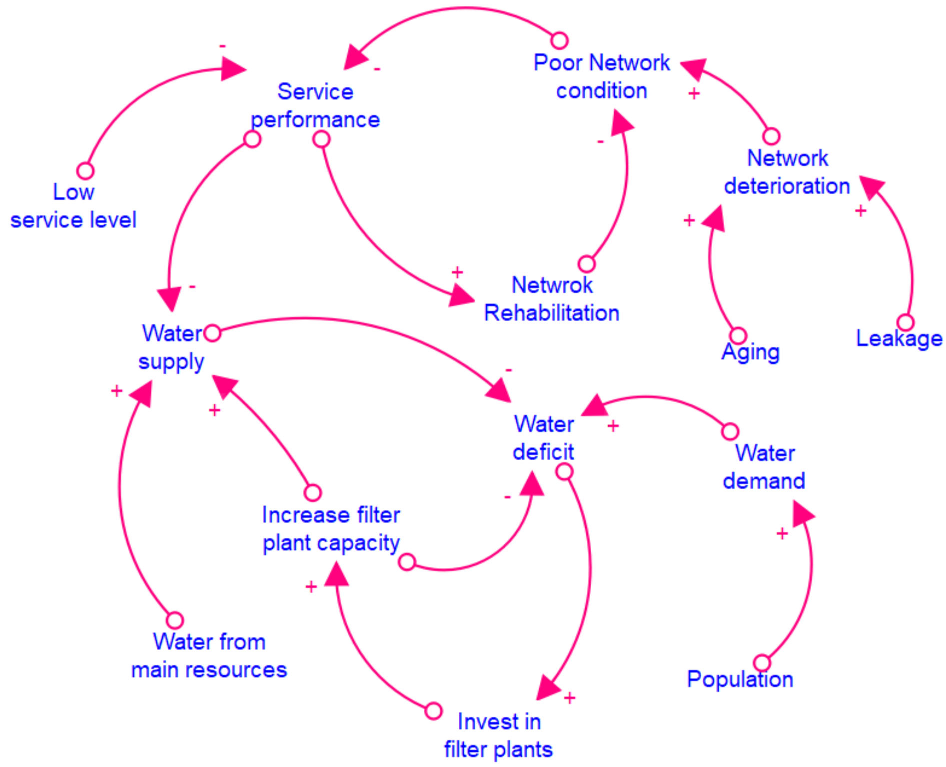

Fig. 2.3: Causal loop diagram for water consumption and user fee adjustments

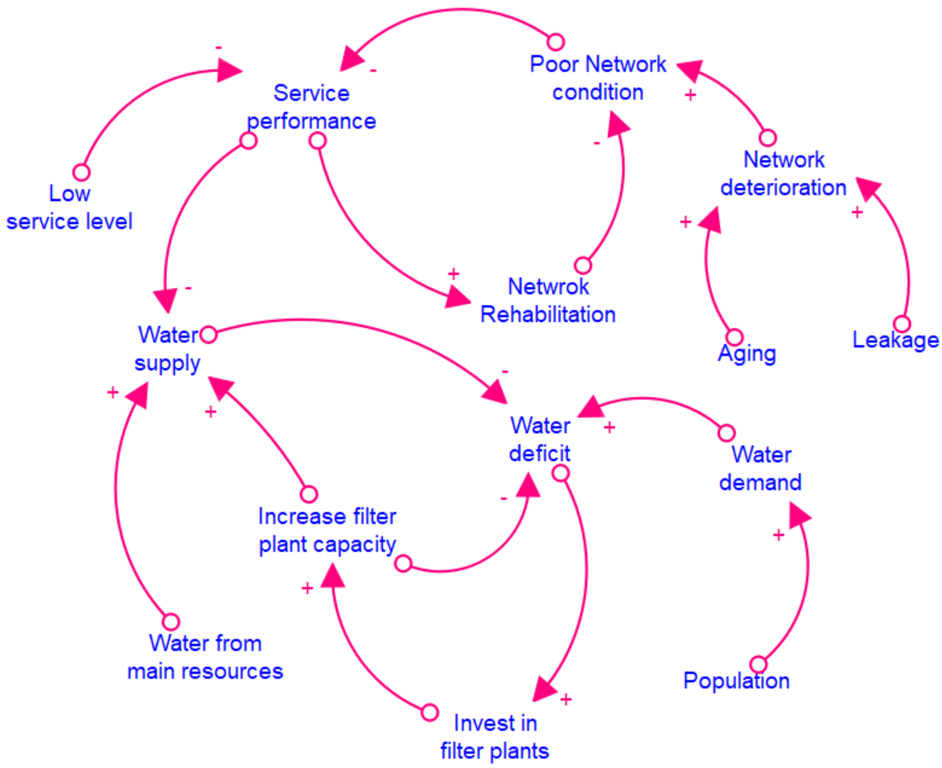

Fig. 2.4: Causal loop diagram for the physical condition of the water supply system

2.5.4 Revenue and expenditures

Infrastructure deterioration, population growth, and water shortage reduce the service performance of a water supply system. Furthermore, these factors put pressure on the utility to improve service performance, making a reinforcing loop. To improve the service performance, rehabilitation of network (the water mains) and additional water supply is necessary, which creates balancing loops. These require investment, which can be made through short-term or long-term planning. Investments in these components will increase the total expenditure of a utility including: capital expenditures, and operations and maintenance expenditure. For water service sustainability, revenues must be equal to or above the expenses of a utility to overcome the expenditures, making a balancing loop. Revenues (recovery) are generated through user fee, water service charges and construction charges. If the overall recovery is less than expenditures, fund balance is negative; reduced fund balance is caused by insufficient revenues, therefore more revenue is required to decrease the revenue shortfall. Customers are ready to accept fee hike in return for a better water supply service. Thus customers may have increased willingness to pay which could result in utility's better future service. Increases in user fees generate more revenue. Besides an increase in user fees, the government can also subsidize utilities to create a zero or positive fund balance, as shown in Fig. 2.5.

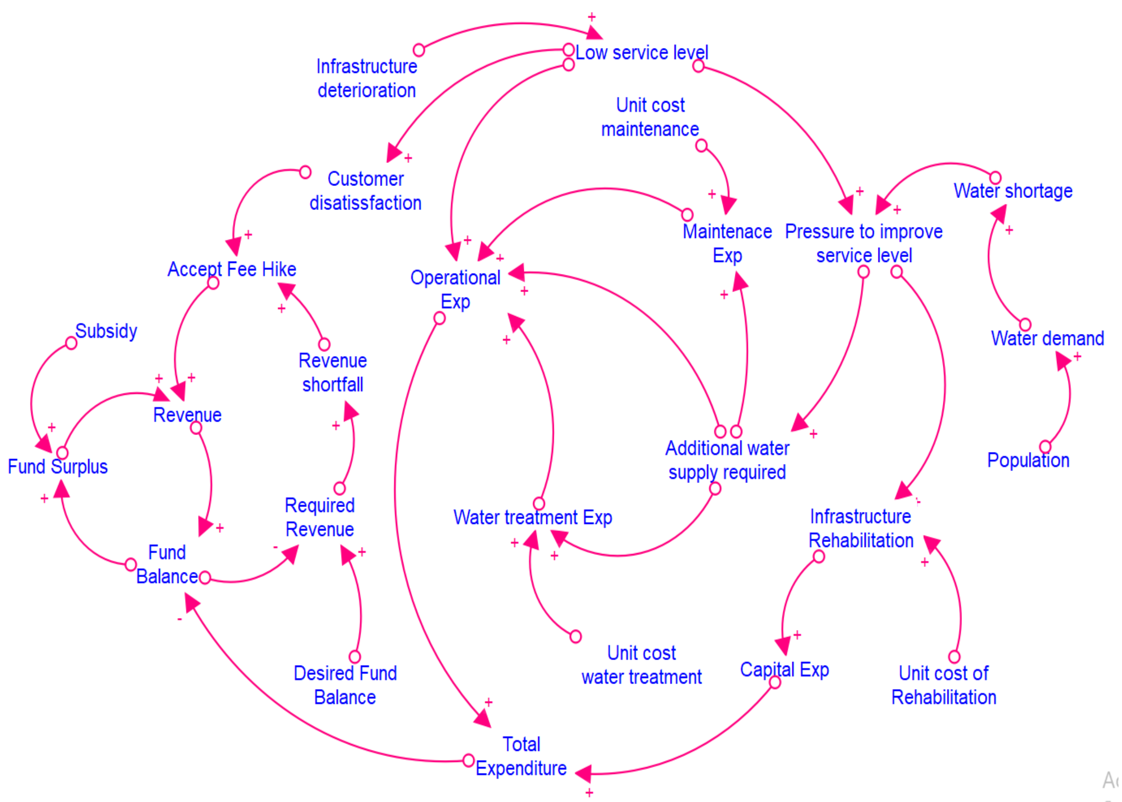

Fig. 2.5: Causal loop diagram for revenue and expenditure

Some of the variables such as willingness to pay, household income, desired service level, and customer dissatisfaction are presented in the CLD, but these are not further incorporated in detail in the stock-flow diagrams because of research limitations and data unavailability. However, the CLD gives a complete picture of the water supply system networks with all parameters and variables that are directly or indirectly connected with each other. The purpose of developing CLD is to show the 'bigger picture' of the interconnections that exist within a water supply network. The stock-flow diagram specifically describes the objectives of this study. Nevertheless, the variables in the CLD which are not incorporated in the stock-flow diagram are discussed qualitatively in the CLD section and the results chapter.

2.6 Stock-Flow Model

The model developed in this study focuses on the importance of population, domestic water supply system, and finance sector interconnections and feedback loops on water management planning based on the proposed system dynamics model for Hyderabad city.

2.6.1 Population sector

The population sector includes population growth rate, number of households, household size, and water demand per person, as shown in Fig. 2.6. Currently, Hyderabad has a population of 1.7 million, and the per capita water demand is 40 GPCD (gallons per capita per day). The number of households is calculated by dividing the population with household size. The annual water requirement is obtained by multiplying the population with per capita water demand.

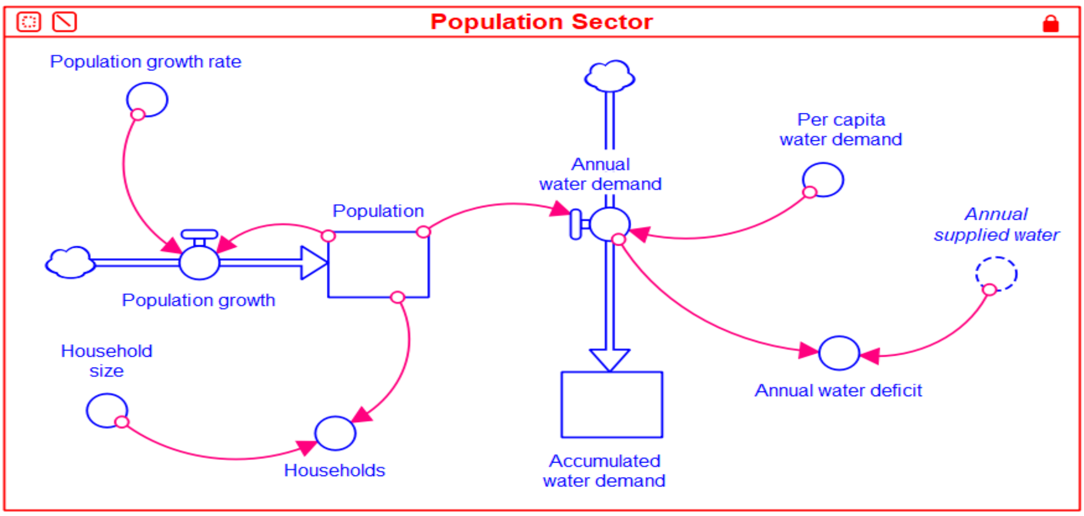

Fig. 2.6: Stock-flow model for the population sector

2.6.2 Water balance sector

In the water balance sector, annual water requirement is obtained by multiplying serviced population with water demand per person. According to WASA Hyderabad, the total water supplied in Hyderabad is 60 MGD, with 25% of leakage loss in the network. Water deficit is calculated by subtracting total water demand from total supplied water (Fig. 2.7). In this model, filter plant capacity is considered by adjusting increase in filter plant capacity every 5 years with leakage loss. Leakage loss is assumed constant throughout the simulation period, which WASA is using for its calculations.

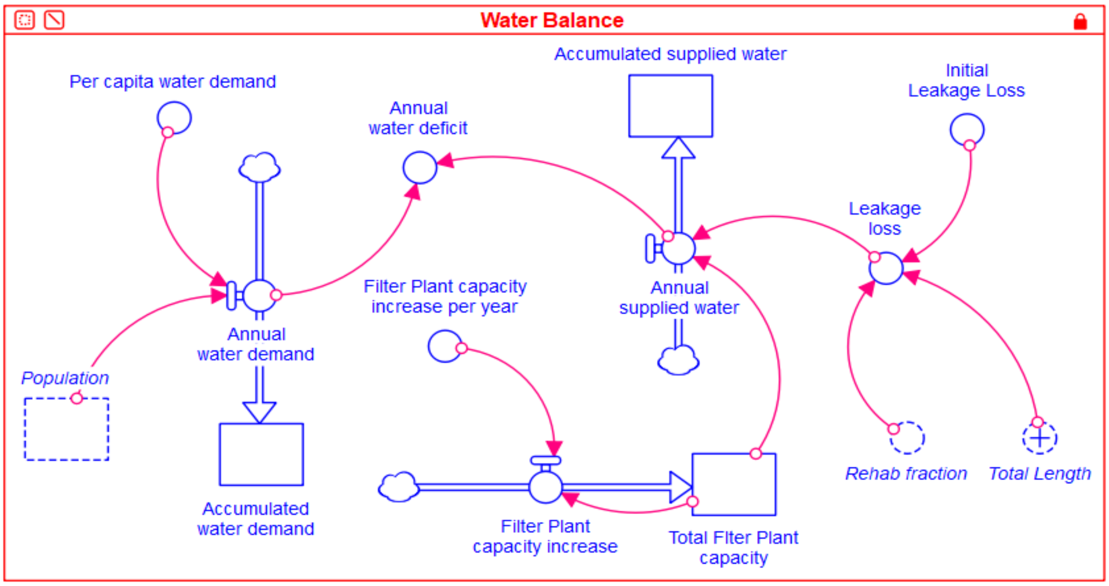

Fig. 2.7: Stock flow model for the water balance sector

2.6.3 Physical infrastructure sector

The physical infrastructure sector in the demonstration model includes pipe stocks grouped into Condition Group stocks (Condition Group 20 refers to age 0 to 20, Condition Group 40 refers to age 21 to 40 and Condition Group 60 refers to age 41 to 60). Rehan et al. (2011) and Rodríguez et al. (2012) mentioned that various types of deterioration functions could be carried out to characterize pipes deterioration from one state to another, as shown in Fig. 2.8. In this model, deterioration function is based on the 'age of pipes' as reported in various published articles (Environment, 2007,

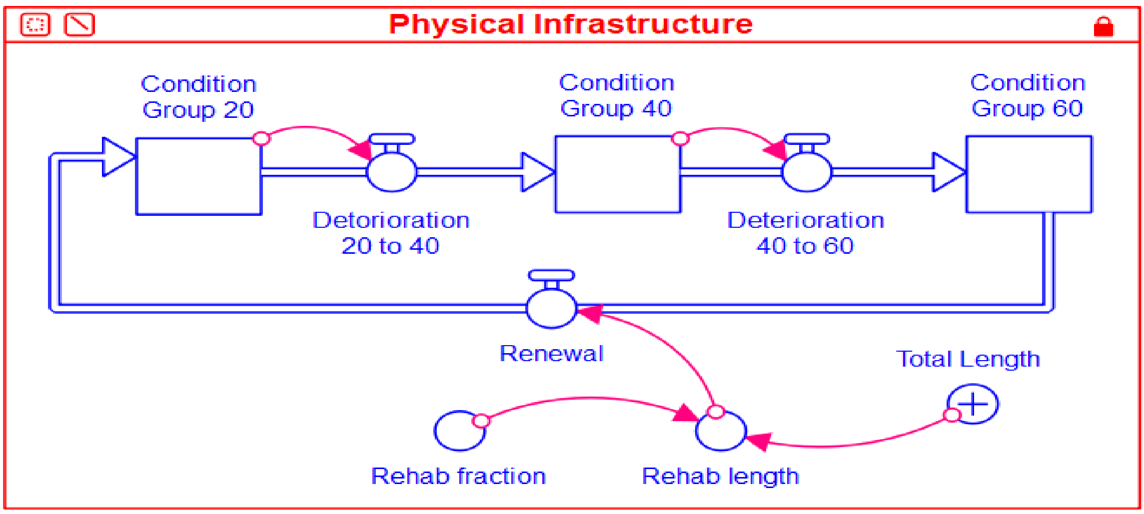

Fig. 2.8: Stock-flow diagram based on physical infrastructure sector

Rehan et al., 2011). Pipes stocks are developed and connected through inflows and outflows. Pipes are allowed to move from one age group to another age group after rehabilitation of pipes. The pipe group (Age 0 to 20) shows best condition whereas the group (Age 40 to 60) shows worst condition. The deteriorated pipes lead to water leakages in system, the Condition Group 60 leads to annual average of 25% water leakages in the network. The pipes (water mains) are made up of ductile iron and steel pipes. The service life for these pipes is assumed 50 years as reported in Richard et al. (2005) and NCSPA (2010). Therefore, pipes are assumed to rehabilitate in the Condition Group 60 (Age 40 to 60).

2.6.4 Finance sector

In this study two mechanisms for finance sector are developed using system dynamics modeling. WASA Hyderabad follows two approaches to finance the water supply sector; the first one is the water fees from users, and the second approach is external funds i.e., subsidy from government or funds from other agencies.

2.6.5 Financing based on water user fees

In this sector, stocks such as fund balance, user fees, accumulated recovery, and total expenditure with their respective flows: revenue, increases in price, recovery, and operational and capital expenditures are developed, as shown in Fig. 2.9. WASA Hyderabad collects its revenue through water user fees. The user fees are not based on volumetric charges, i.e., users do not pay proportional to their water consumption, but each household has to pay a specific amount for water consumption instead of individual users' consumption, as discussed in Section 2.2.2. According to WASA, water user fees are not collected completely, as some users do not pay their fees. As a result, the average recovery rate is almost fifty percent less than the total average operation and maintenance cost. In the model, the fund balance shows the remaining funds after investment in the water sector that is reloaded through revenue. Revenue is achieved by multiplying user fees of each category with number of households and recovery rate during the model simulation. Operational expenditures (OpEx) represent the utility's overall annual operational expenditures such as establishment (pay of officers and officials, allowances, pay of work charge, etc.), operation and maintenance (commodities and services, repair and maintenances of works, electricity charges, etc.), chemicals (chemicals used for water treatment) and fuel for machineries. The capital expenditures (CapEx) characterize the rehabilitation costs of pipes and the costs needed for additional filtered water supply. The rehabilitation cost of pipes is represented through flow renewal function and rehabilitation unit price for pipes (unit price CapEx network, rupees per unit length), whereas the cost for additional filtered water supply is represented through (filter plants capacity increase per year) and (unit price CapEx filter plant). The total expenditure to date (Total Ex to Date) shows the total increasing expenditure for both the flows capital and operational expenditures in the simulation time step. In this model, a financially self-sustainable scenario is developed to keep a “zero fund balance.” Stock User fee is obtained by household water charges. User fees are kept constant during the simulation period or changed at each time. To keep the ‘Fund balance’ zero or positive (surplus), the recovery and stock user fees are adjusted using rate change in user fee and recovery rate which makes revenue equal to expenditures

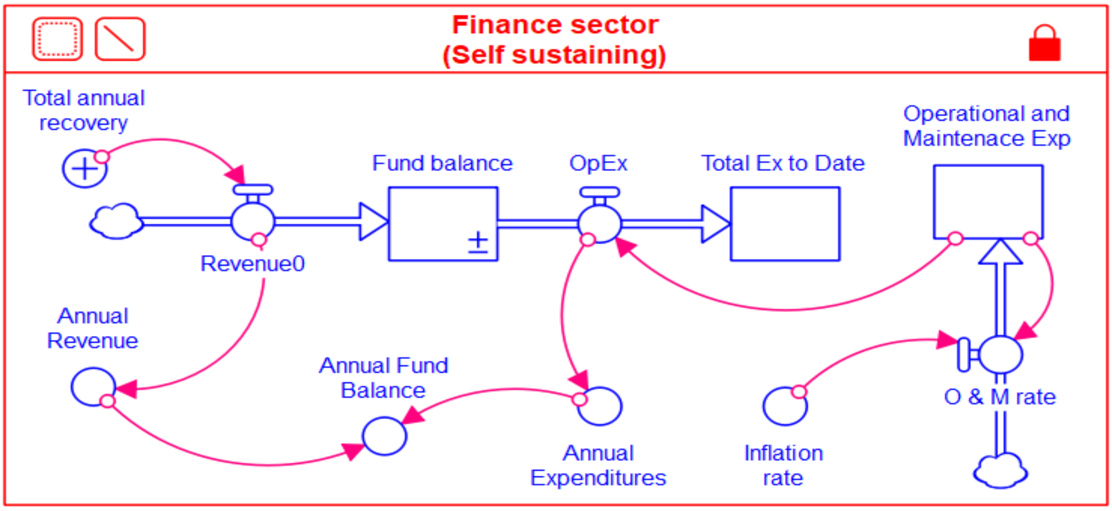

Fig. 2.9: Stock-flow model for financing based on water user fees

2.6.6 Financing based on external funds

For improving the services of the water supply system, investments on new water supply projects are required. One of the financing approaches for these investments is the external funding approach, i.e., government subsidies or funds from other agencies, as shown in Fig. 2.10. In this model, the external financing approach is developed; revenue is obtained from funds provided by external agencies. The funds are used for capital expenditures (CapEx) such as pipe rehabilitation and extension of filtered water supply. In this sector, revenue is only based on external funds; no user fee contribution is considered for financing capital works. An increase in revenue through external sources can make a positive or surplus fund balance, as shown in Fig. 2.10.

2.7 Model Setups

The period for the model simulation is 2007-2080, with one-year time steps. The initial values in the model for the year 2007 show the past, and 2017 shows the existing situation in the study area. The model is simulated for scenario analysis until the year 2030. For the self-sustaining scenario, the model is simulated from 2017 to 2080 to obtain zero fund balance after the target year 2030. However, besides this scenario, the simulation period 2017 to 2030 is used throughout the study. For calibration of

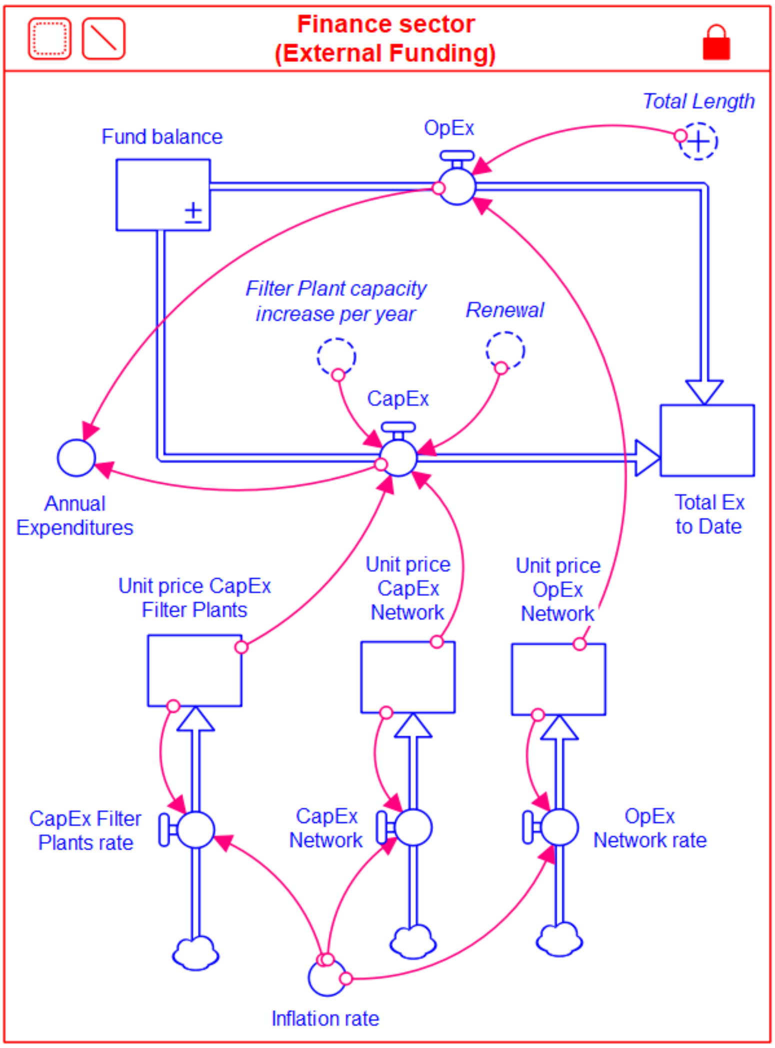

Fig. 2.10: Stock-flow diagram based on external funds

the model, historical population values for the year 1998-2017 are compared with the model values.

2.7.1 Calibration to historical data

A calibration step is necessary before the simulation of the model. Past and simulated population data are compared for the period from 1998-2017. The record of population value 1.2 million in 1981 and current census record 1.7 million based on a 2% growth rate is taken from the Bureau of Statistics, Government of Sindh. The population value (1,204,434) for the year 1998 is used for the model simulation and compared to the actual population data to determine the consistency and precision of the model simulation. The model simulation results show that the model values are almost similar to the historical values with a maximum related error of 1.17%. Thus, the model results can be used in prediction for the analysis of the water supply system based on various scenarios.

2.7.2 Initial conditions and assumptions for model simulation

The population considered for the initial year 2017 is 1.7 million, and the population is increasing every year with a 2% growth rate, according to the Sindh Bureau of Statistics. For rehabilitation of network, 182 km of water mains are considered. The materials of the water mains are ductile iron and steel pipes having a service life of 50 years. The water demand per capita per day is 40 GPCD, which is assumed constant throughout the simulation. The total capacity of the filter plants is 60 MGD for the initial year, but it can be increased during the simulation period depending on the users' input mentioned. The monthly user fees are based on categories according to WASA (Table 2.2). All daily and monthly average values are converted to annual values in the model. For the model simulation, 7% of the inflation rate, according to the Bureau of Statistics, is considered for all costs. The annual unit price operational expenditure of the WASA is Rs.1.8 billion, whereas unit cost capital expenditure for extension of filter plant is assumed as Rs. 0.1 billion. The unit cost capital expenditure for pipe rehabilitation is assumed as Rs.115,000, which is the cost of one meter of an old pipe for rehabilitation. The unit cost operational expenditure for pipe rehabilitation is Rs. 5,750, which is the unit price to maintain and operate the water pipes per year mentioned.

2.8 Scenarios Design and Strategies

2.8.1 Baseline scenario (S1)

Baseline scenario, termed as S1 hereafter, models the Hyderabad water supply system for years 2007 to 2017. Variables such as population growth rate, per capita water demand, water leakage, filter plant capacity, user fee, water tariff recovery rate, and expenditures are kept constant for the simulation period. S1 helps in determining the existing water supply and demand gap for Hyderabad city under no capital work expenditure.

2.8.2 Self-sustaining scenario (S2)

The self-sustaining scenario is developed to represent the zero fund balance, which can be achieved by making revenue equal to total expenditures. Therefore, the user fee is allowed to increase, and the fee recovery rate is assumed to increase up to 80%. Table 3.1, appearing in the next chapter, lists the ranges of the variables used for sensitivity analysis. The simulations allow us to determine the time when a zero fund balance can be achieved

2.8.3 Financing infrastructure through external funds (S3)

This scenario considers a zero fund balance and capital works expenditures during the simulation period. Capital work expenditures are considered to improve the performance of the water supply system. In this scenario, the source of revenue is from external funds, and only the capital work expenditures are considered, which differentiate this scenario from the previous self-sustaining scenario.

2.9 Limitations

Reliability of the data from different sources was the major challenge in this study. This was overcome through consultation with the city water experts for the validation of the data being collected. Diversified data collection methods were used to ensure relevance to the variables and research questions. Furthermore, the validity and reliability of data were ensured through multiple checks and quality control measures. This included triangulation of data sources, expert consultation for the reliability and validity. The primary and secondary data collection methods were employed to conduct the research work. Different stakeholders were contacted multiple times for discussion regarding the study design. Besides, reviews on initial results were taken and discussed at length in a workshop organized at the Center.

3. RESULTS AND DISCUSSION

3.1 Population Projection for Hyderabad City

Multiple factors put a burden on the existing water supply of a city, but in this study, only population is modeled from which water demand is driven. In Hyderabad, the population is growing at a growth rate of 2% from 1998 to 2017. The population was 1.4 million in 2007 and reached 1.7 million in 2017. The population is projected to be 2.2 million by 2030, as calculated by the model (Fig. 3.1).

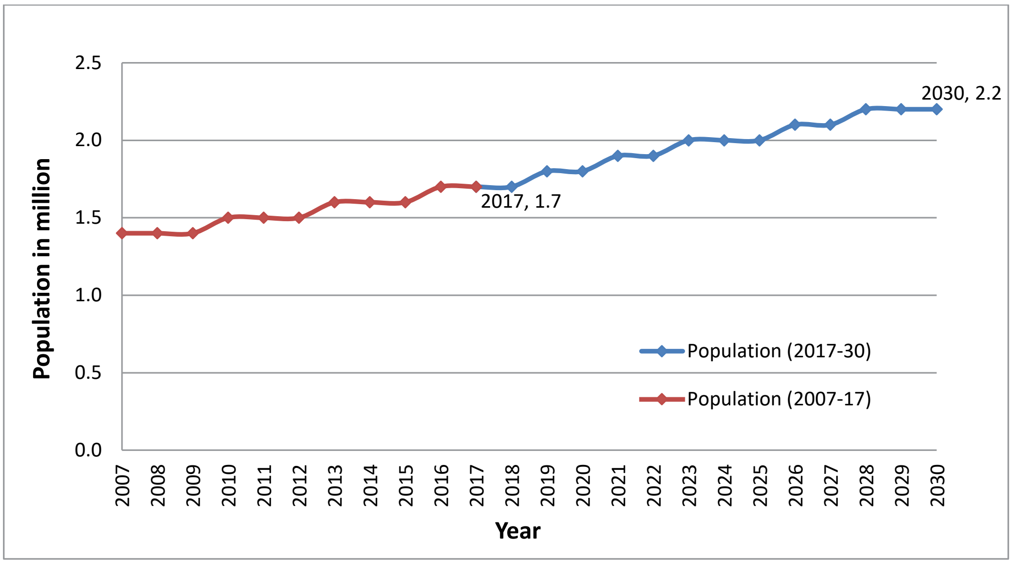

Fig. 3.1: Population projection for Hyderabad

3.1.1 Existing situation of water supply system in Hyderabad

According to WASA Hyderabad, the combined capacity of filtration plants is 60 MGD (Million Gallons per Day), and the water demand per person is 40 GPCD. The existing situation of the water supply system in Hyderabad, considering 25% water leakage from 2007 to 2017, is shown in Fig. 3.2.

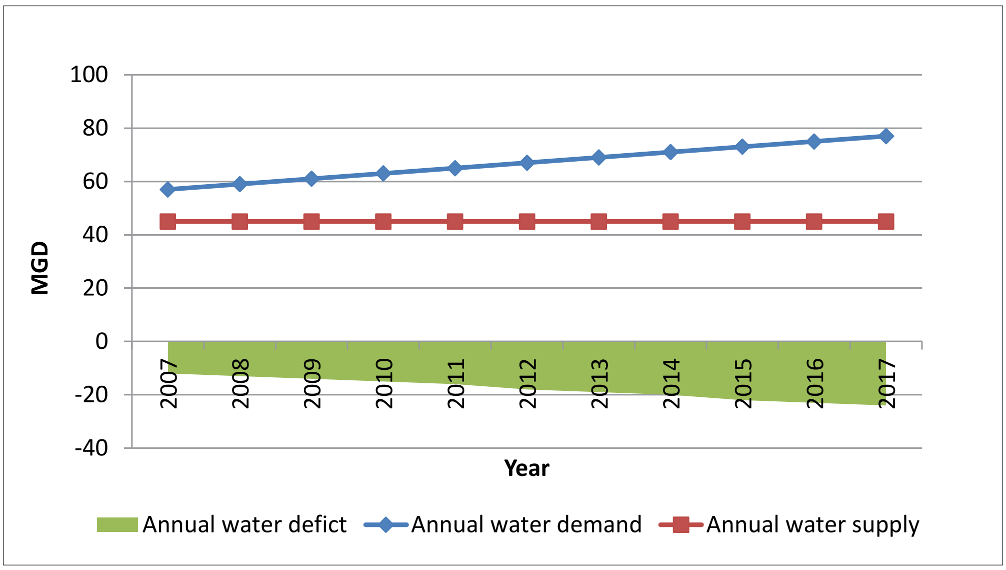

Fig. 3.2: Water supply and demand in Hyderabad (2007-17)

The increase in population has increased the demand for water in Hyderabad city for the last several years. In 2007, the annual water demand was 57 MGD, and the annual water supply was 45 MGD. The demand increased with time and but the supply is constant because there has been no additional water from 2007 to 2017. The annual water demand reached 69 MGD in 2017, and supply is the same. Thus, the shortfall in 2007 is 12 MGD and 24 MGD in 2017.

3.2 Baseline Scenario (S1)

3.2.1 Projection of water supply and demand of Hyderabad

In the baseline scenario, water supply and demand are projected from 2017 to 2030 based on the existing conditions in Hyderabad. In the existing situation, the total filtration plants' capacity is 60 MGD, and water leakage in the network is 25%, according to WASA, which cannot be neglected because 25% of the water is lost as leakage in the network. Thus, the total water supply available to the consumers reduced to 45 MGD. The annual water demand is calculated through per capita water demand (40 GPCD) with 1.7 million people for the year 2017. The model shows a 69 MGD annual water demand and a 45 MGD of annual water supply for the initial year 2017, whereas projected simulation shows a 90 MGD of annual water demand and a 45 MGD of water deficit in 2030. However, the supply remains constant until 2030, as there is no additional water supply in this scenario. Thus, the water deficit is 24 MGD in the initial year 2017 and 45 MGD in 2030 (Fig. 3.3).

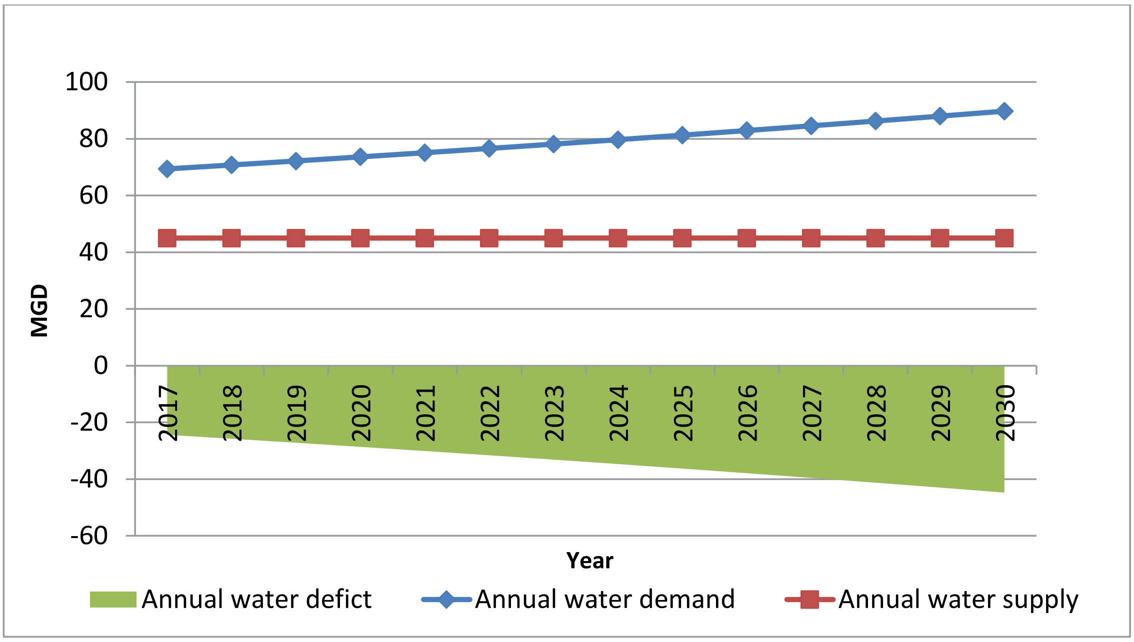

Fig. 3.3: Projection of water supply and demand for Hyderabad city (2017-30)

3.2.2 No capital work

In the baseline scenario, no capital work expenditure is considered; thus, there is 0% of rehabilitation in the network length. In 2017, 182 km of water mains were in the

Condition Group 60 (Age 41 to 60), whereas no pipe exists in the Condition Groups 20 (Age 0 to 20) and 40 (Age 21 to 40). If there is no rehabilitation of pipes in the existing situation, the pipes will remain in the same age group till 2030.

3.2.3 Existing expenditures and revenue based on a 25% recovery rate

In the baseline scenario, only the operational expenditures are considered. It is assumed that if no rehabilitation of network and no additional water supply are added to the system, then there is zero capital work expenditure; thus, the annual expenditures will be the operational expenditures. The annual water fees based on the categories from A to F with a 25% recovery rate are used for the calculation of this study. The annual operational expenditure for the initial year 2107 is 1.8 billion, and the annual recovery is Rs.1.0 billion. The annual shortfall is Rs. 1.6 billion. Based on the existing situation of expenditures and revenue of the utility, when projected till 2030, the annual operational expenditure is 4.3 billion, whereas the annual revenue is Rs. 0.2 billion and shortfall Rs. 4.1 billion. The revenue is calculated by multiplying the number of households with water fee of each category and recovery rate. Therefore, with an increase in population and number of households, the annual revenue increased from Rs.0.1 billion to Rs.0.2 billion but with a 25% recovery rate, as shown in Fig. 3.4.

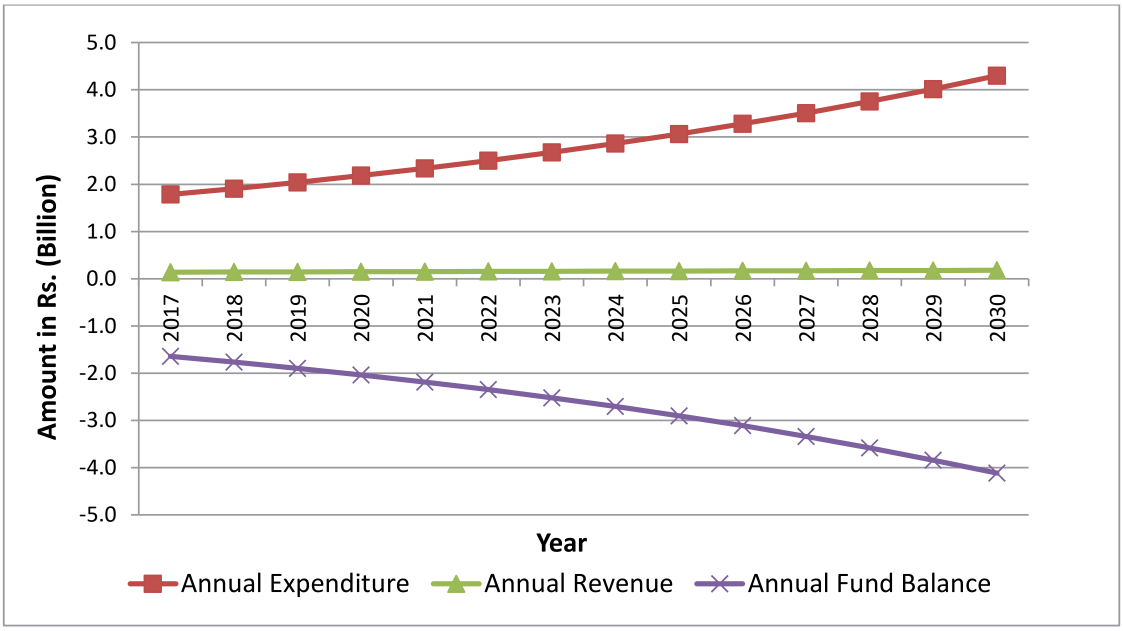

Fig. 3.4: Projection of cost estimation of Hyderabad city based on the existing expenditures and 25% recovery rate

3.3 Self-Sustaining Scenario (S2)

For a self-sustaining scenario, a utility must focus on ways to generate revenue by providing services. The utility itself should achieve revenue without support from external sources. In this regard, if a utility is running out of income and the expenses are more than the incomes, the only way out of this situation is a fee hike for self-sustainability. It is observed that on existing user fees, if 50-80% recovery takes place, the total expenditures (operational expenditures) of the department will not be covered, so an increase in price is needed. In this scenario, the annual expenditures include the operational expenditures only as no capital investments are considered. An assumption for fee hike is created based on various rates. The water prices are allowed to increase annually from 2% to 18% and 25% to 80% recovery rates. The result shows that an annual increase from 2% to 6% in the user fees does not show any positive or zero fund balance till 2080. Therefore Table 4.1 shows the result of an increase in user fees from 8% to 18% with each recovery rate. This scenario identifies the year of zero or positive fund balance until 2030, based on these rates. From Table 3.1, it is observed that an 18% increase in user fees with an 80% recovery rate, the

Table 3.1: Model simulation based on different rates to achieve zero or positive fund balance for the existing expenditures and revenues

Increase in user fee	Recovery rate	Year of zero or positive fund balance	Monthly user fee (Rs.)					
(%)	(%)		A	B	C	D	E	F
8	25							
8	50							
8	80	2065	4825	5629	7439	13068	17492	21915
10	25	2059	6572	7667	10131	17798	23822	29846
10	50	2057	5431	6336	8373	14709	19688	24666
10	80	2047	2094	2443	3228	5671	7590	9510
12	25	2071	9970	11631	15370	27001	36140	45279
12	50	2046	3210	3745	4949	8694	11636	14579
12	80	2039	1452	1694	2239	3933	5264	6595
14	25	2048	6970	8132	10745	18877	25266	31655
14	50	2040	2443	2851	3767	6618	8857	11097
14	80	2034	1113	1299	1716	3015	4035	5056
16	25	2043	5690	6638	8772	15410	20625	25841
16	50	2036	2013	2349	3104	5452	7298	9143
16	80	2031	959	1118	1478	2596	3475	4353
18	25	2039	4577	5340	7056	12396	16592	20787
18	50	2033	1695	1978	2614	4592	6146	7700
18	80	2029	875	1020	1348	2368	3170	3972

expenditures become equal to revenue in 2029. Therefore, it is concluded that an 18% increase in the user fee of each category with an 80% recovery rate can overcome the utility's operational expenditures till 2030.

3.3.1 Increase in the annual user fee

From Fig. 3.5, it is observed that the annual expenditure (operational) is Rs.1.8 billion in 2017 and Rs.2.0 billion in 2019, whereas, in 2030, the annual expenditure has increased to Rs.4.3 billion. The reason behind the increased expenditure from 2017 to 2030 is due to the consideration of the inflation rate. As discussed earlier in this scenario, an annual 18% increase in water user fees is assumed to increase the annual revenue. In the initial year 2017, the model calculates Rs. 0.4 billion revenue and fund balance is negative (Rs. -1.3 billion). In the final year of simulation, the model calculates Rs. 5.0 billion revenue and a positive fund balance Rs. 0.7 billion is achieved in 2030. In 2029, the increase in price makes fund balance positive to Rs. 0.1 billion, where expenditure Rs. 4.0 billion equals revenue Rs. 4.1 billion based on 80% recovery rate.

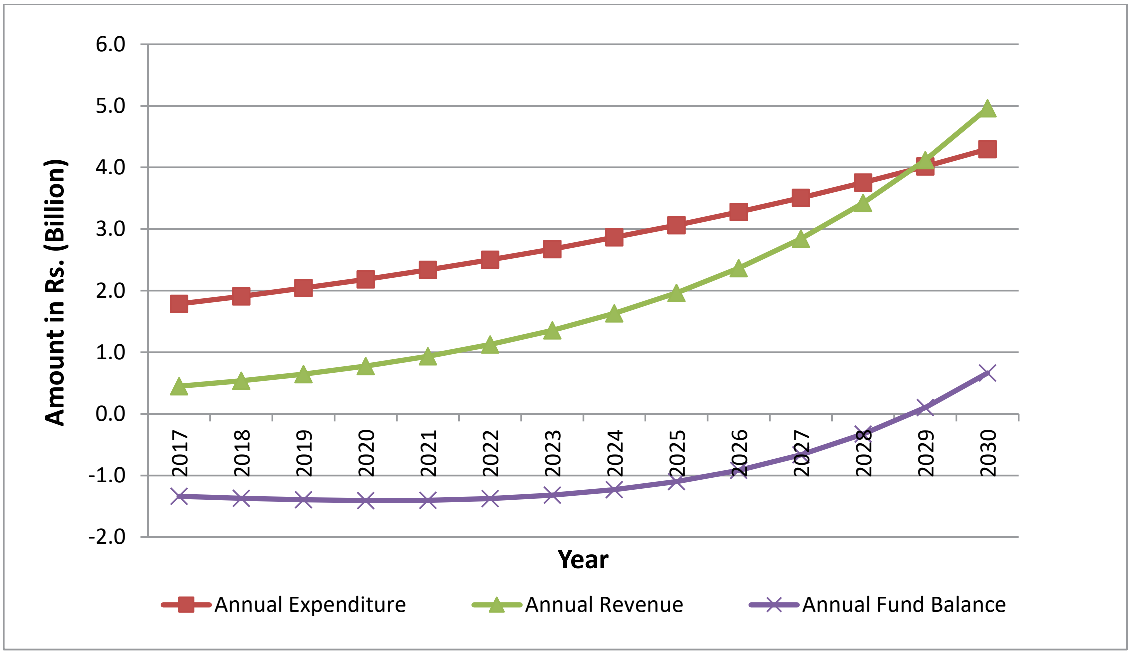

Fig. 3.5: Achieving zero or positive fund balance for existing expenditures and revenue through water pricing (18%) and recovery rate 80%

The annual expenditures, annual revenue, and annual fund balance from 2017 to 2030 are shown in Appendix B 5, whereas the accumulated revenue is shown in Appendix B 9.

The water user fees in each category are allowed to increase 18% annually based on an 80% recovery rate to achieve the zero or positive fund balance. Figure 3.6 shows that the monthly water fee in each category is increasing from 2017 to 2030. Table 3.2 shows the monthly water fees only for the year 2017 and 2029, whereas user fees for each year from 2017 to 2030 are given in Appendix B 6.

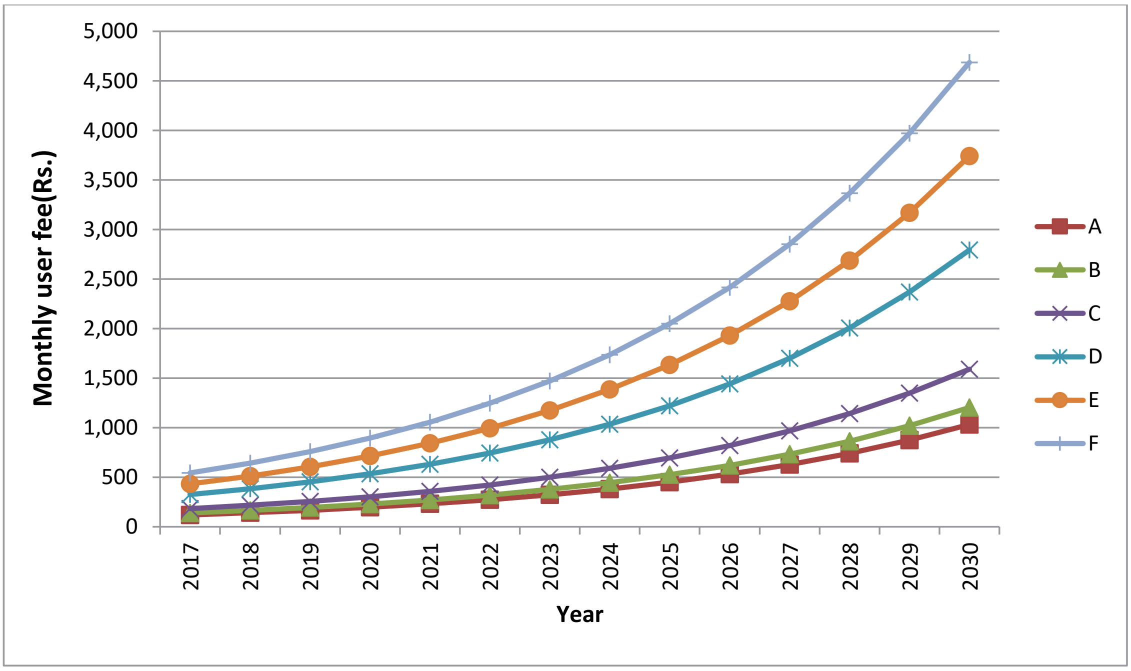

Fig. 3.6: Monthly increase in the user fee for achieving zero or positive fund balance

Table 3.2: Actual monthly water fee in 2017 and an annual increase of 18% in the user fee until 2030

Year	A	B	C	D	E	F
2017	120	140	185	325	435	545
2029	875	1020	1348	2368	3170	3972

Each household is allowed to pay the water fee based on the categories of water charges, as discussed in Section 2.2.2. According to the Bureau of Statistics, the average household size is 6 in Hyderabad city. Therefore, the per capita cost is also calculated by dividing the above monthly water fee with the number of household sizes. This calculation categorizes the water charges per head of each household, which determines the importance of per person water charges. The monthly per capita water charges are given in Appendix B 7.

3.4 Financing Sustainability Through External Funds (S3)

In this scenario, the extension of the water supply and rehabilitation of the network length requires capital work and capital work expenditures. The total expenditures include capital expenditures and operational expenditures. It is assumed that operational expenditures, along with capital expenditures, are also required for extension of water supply and rehabilitation of network length.

3.4.1 Capital works for additional water supply and rehabilitation of network

In this scenario, the extension of water supply and rehabilitation of the network is assumed every five years. It is obvious that for a utility, it mostly requires at least five years for capital works. Therefore, capital works are assumed after every five years, from 2019 to 2080. The model is simulated from 2% to 36% to identify the year of zero demand deficits and the year of completely network rehabilitation. The model simulation showed that zero water demand deficit in 2030 could be achieved at 28%, and all network rehabilitation can be achieved at 36% every five years during the model simulation. Therefore, goals can be achieved until 2030 based on these rates.

3.4.2 Projection of additional water supply

Figure 3.7 shows that the water supplied is assumed to increase every five years throughout the simulation. Based on an assumption, a 28% annual increase in the filter plant capacity is considered to increase the annual water supply every five years

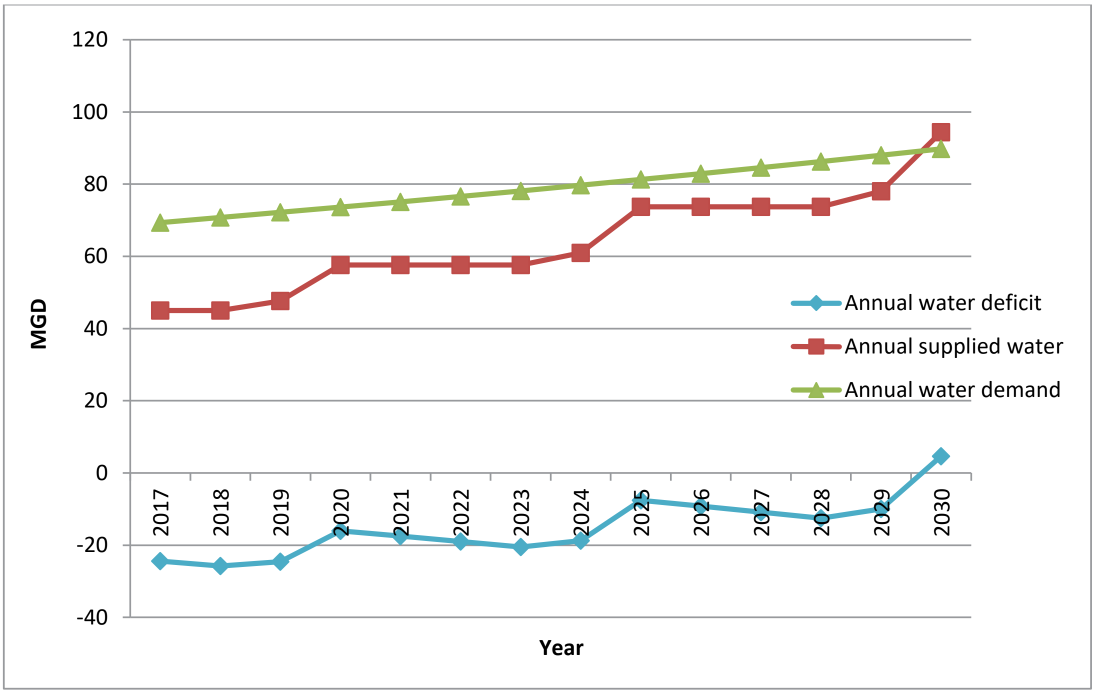

Fig. 3.7: Projection of water supply based on a 28% increasing rate every five years

in the simulation period from 2019 to the target year 2030.

In the baseline scenario, the total annual water deficit is 45 MGD in 2030. Thus, to reduce the water deficit, water supply is required to increase till 2030 to equal the water demand. The 28% increase in the filter plant capacity every five years increased the annual water supply from 45 MGD in 2017 to 94 MGD in 2030. The demand is the same as in the baseline scenario. However, the increase in the filter plant capacity every five years reduced the annual water deficit from -24 MGD in 2017 to 5 MGD surplus in 2030. The annual water deficit reduced to zero, and 5 MGD become surplus water in 2030.

3.4.3 Rehabilitation of network

In this scenario, rehabilitation of water mains with 182 km length is considered from 2017 to 2030. Condition Group 20 is considered the best group, and Condition Group

80 is considered the worst. For that reason, network lengths in the Condition Group 80 are assumed for rehabilitation. A rehabilitation rate of 36% for the water mains network is assumed after every five years. The result of the model shows that with 36% rehabilitation of network, 66 km of the network length moves from Condition Group 60 to other condition groups each year, as shown in Fig. 3.8 and Table 3.4.

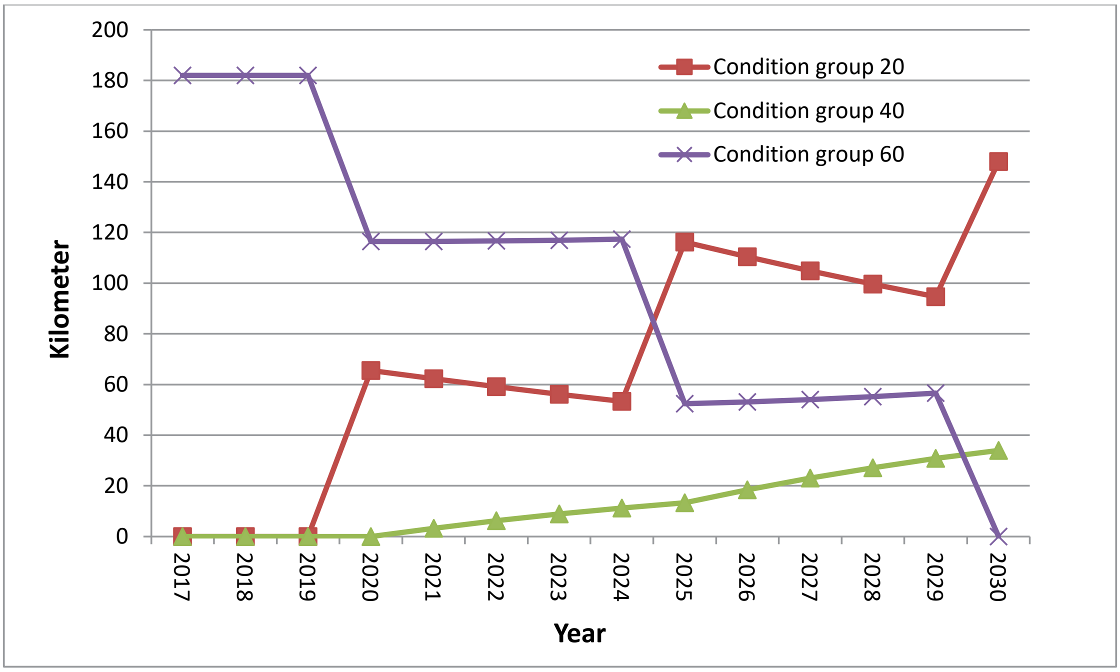

Fig. 3.8: 36% rehabilitation of water pipes every five years

Table 3.4: Summary of rehabilitation (36%) of water pipes every five years

Year	Condition group 20	Condition group 40	Condition group 60	Rehab Length (km)
2017	0	0	182	0
2018	0	0	182	0
2019	0	0	182	66
2020	66	0	116	0
2021	62	3	116	0
2022	59	6	117	0
2023	56	9	117	0
2024	53	11	117	66
2025	116	13	52	0
2026	110	18	53	0
2027	105	23	54	0
2028	100	27	55	0
2029	95	31	57	66
2030	148	34	0	0

3.4.4 Capital work expenditures

The model simulated the annual capital, operational, and total expenditures for the capital works. The total annual capital expenditures required for the capital works are Rs. 2.6 Billion from 2019 to 2023, Rs. 3.6 billion from 2024 to 2028, and Rs. 4.7 billion from 2029 to 2030. The operational expenditure required in 2019 is Rs. 1.2 billion and increased to Rs. 2.5 billion in 2030, as shown in Fig. 3.9 and 3.10. Operational costs are required along with the capital works because operational expenditures are also required in the rehabilitation of pipe networks.

The model calculates an increasing annual expenditure from 2019 to 2030, as shown in Fig. 3.10. The reasons for increasing annual expenditure are the operational and capital expenditures of the capital works. The operational expenditure for the network rehabilitation increases per year, whereas the capital expenditure for the rehabilitation of network and additional filter plant capacity increase after every five years, as discussed above.

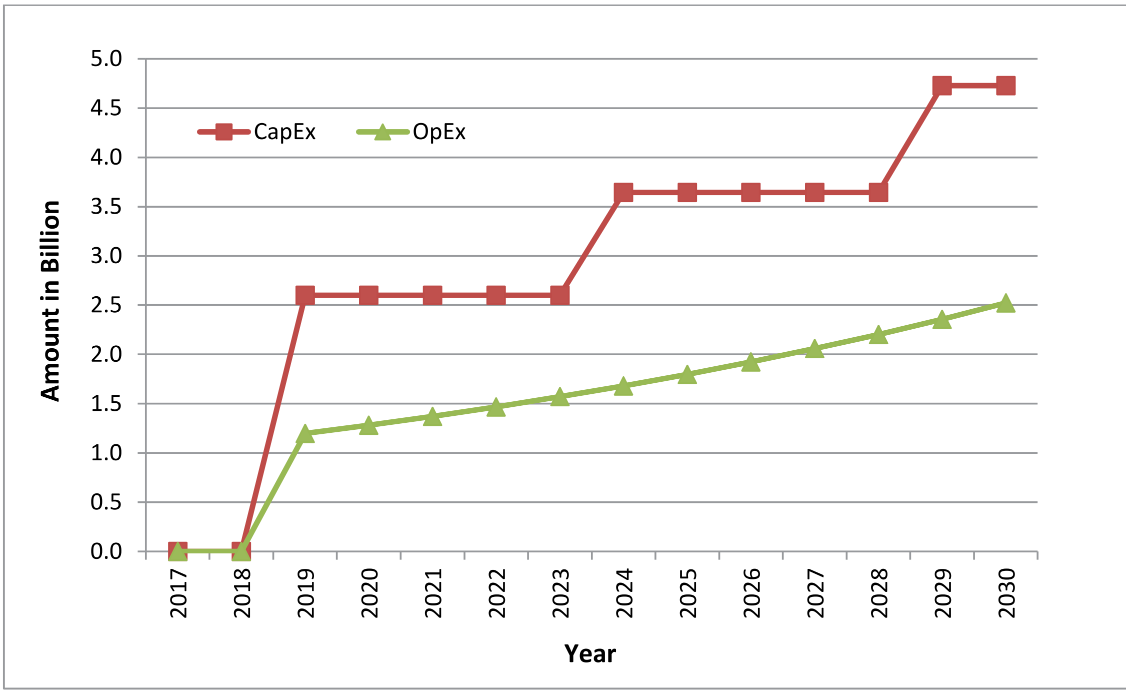

Fig. 3.9: Annual operational and capital expenditures required for capital repair

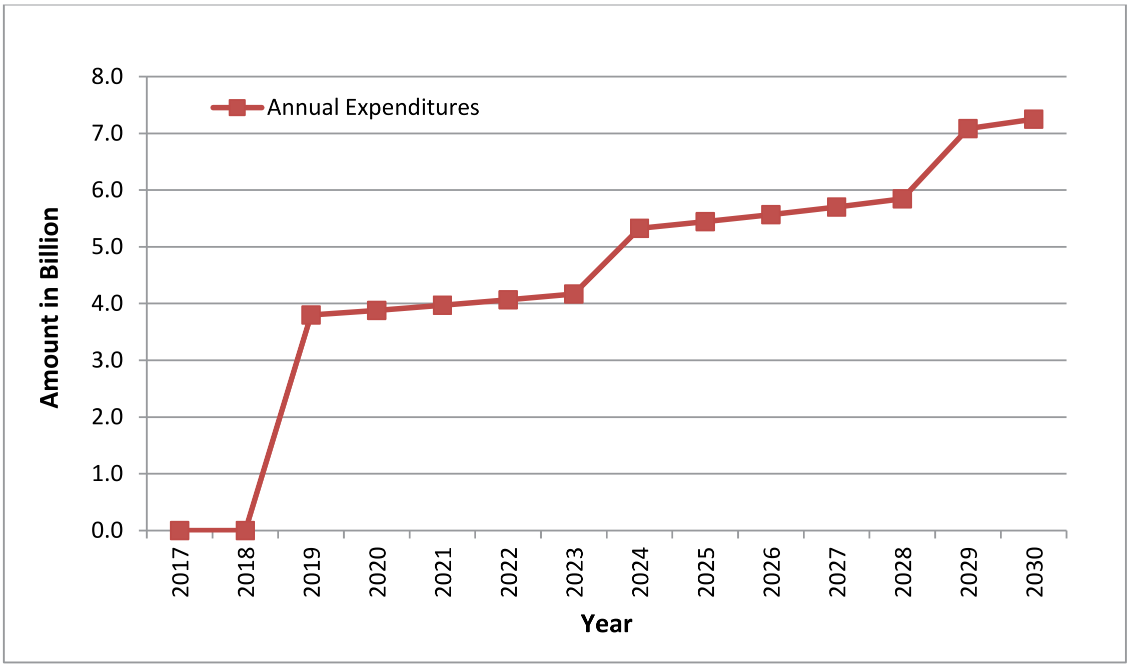

Fig. 3.10: Annual operational and capital expenditures required for capital repair

3.5 Dissmination of Research Results

3.5.1 Project-based papers/ posters presented in conferences/ workshops

Conference Paper: System Dynamics Modeling for Domestic Water Management: A case study of Hyderabad City Sindh, Pakistan. Presented in 2nd Young Researchers' Conference, USPCAS-W, MUET on August 02-03, 2018.

3.5.2 Papers published in journals

Jabeen, U., Ahmed, W., Bano, R., Ansari, K. (2019). Application of system dynamics model for assessing the financial sustainability of the drinking water system, as case study of urban districts of Hyderabad, Sindh. Urban Water Journal, NURW-2019-0138 (under preparation for submission).

3.6 Research Output/Impact

3.6.1 MS Thesis

Jabeen, U. Application of System Dynamics Model for assessing the financial sustainability of drinking water system, A case study of urban districts of Hyderabad, Sindh.

3.6.2 Research partnerships established

Good partnership has been established with the Water and Sanitation Agency Hyderabad. One more research /consultancy project was awarded to the Center because of this partnership. They are interested in carrying out further research in near future as well.

3.6.3 Project impact

The results of the study can be helpful for the decision makers so as to make policies for starting new projects. It will help the WASA in overcoming the water shortages in Hyderabad and help in achieving the SDG Target 6.1.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

Various factors that affect the sustainability of drinking water supply in Hyderabad have been identified through key informant interviews and surveys.

In this study, factors like population, water demand and supply, and finance have been discussed using causal loop diagrams, which show connections among all the sectors and flow-stock diagrams, employing system dynamics modeling. Various scenarios are developed based on these sectors to create "what-if" scenarios for future years. Based on the model results, the following conclusions are drawn from the study:

i. The projection of the population from 2017 to 2030 shows a population of 2.2 million in 2030 if the growth rate remains constant at 2%.

ii. In the baseline scenario, the water demand increases from 69 MGD in 2017 to 90 MGD in 2030. The filtrations plants produced 60 MGD of water, but 25% of the water leaks from the network and reduces the actual supply to 45 MGD.

iii. In the baseline scenario, the expenditure is Rs. 1.8 billion, and revenue is calculated at Rs. 1.0 billion; the deficit in 2017 is Rs. 1.6 billion. When projected till 2030, the annual expenditure is 4.3 billion, whereas the annual revenue is Rs. 0.2 billion, and the shortfall is Rs. 4.1 billion in 2030. Unfortunately, there still exists a huge gap between expenditure and revenue.

iv. In the self-sustaining scenario, 18% annual increase in user fees with 80% recovery rate, the expenditures become equal to revenue in 2029. Therefore, this scenario can increase the user fee of each category to overcome the utility's operational expenditures until 2030.

v. For the financing sustainability through external funds scenario, a zero water demand deficit in 2030 can be achieved at 28%, and all network rehabilitation can be achieved at 36% every 5 years during the model simulation. Therefore, goals can be achieved until 2030 based on these rates.

4.2 Recommendations

Various policy recommendations can be planned from the results of this model. This study focuses on the additional water supply, rehabilitation of water mains, and the finance mechanisms to manage the water supply system sustainably. The results of the model can be helpful to the decision-makers so that they can make policies or decisions before starting new major water projects. Moreover, this study can be extended by including other components, and a complete system dynamic model can be prepared after consideration of all elements for water supply services and generating more results from the model. The main recommendations for the study are: An annual increase of 28% every five years (or it can be 6% per year) in the filter plants capacity can overcome the water shortage, especially in the target year 2030 shown by the model results. The extension of filtration water and pipe rehabilitation needs much investment in the water sector. The monthly expenditures are higher than the monthly revenue in WASA. The water price needs to be increased by promising improved water supply service to the consumers. According to this study, with 18% increase in price annually, more revenue can be generated, and the performance of the water supply sector can be increased. For capital work expenditures, WASA needs funds from external sources to sustain the water supply system. Regular monitoring and unbiased audits of the water utility are important factors to be considered.

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Appendix-A: Equations Used in the Model

A 1: Population Sector

A 1.1 *Population*

Type	Stock
Units	Persons
Equation	Population (t) = Population (t - dt) + (Populationgrowth) * dt.
Description	Number of persons each year Each year population is increasing based on 2% population growth rate
Initial Value	Value for initial year 2017 (1,734,309)
Reference for definition of independent variables	
Population growth	Object A1.2

A 1.2 *Population growth*

Type	Flow
Units	Persons per year
Equation	$Population\ growth =\ Population * Population\ growth\ rate/100$
Description	Population growth is achieved by multiplying population with population growth rate
Initial Value	Not applicable
Reference for definition of independent variables	
Population growth rate	Object A1.3

A 1.3 *Population growth rate*

Type	Convertor
Units	Percent per year
Equation	Not applicable because it is a constant
Description	It is the rate at which population grows in Hyderabad Sindh The value acquired from Sindh Bureau of Statistics
Initial Value	2

A 1.4 *Households*

Type	Converter
Units	Number of houses
Equation	Households = Population/Household size
Initial Value	Not applicable
Description	Households achieved by dividing population with household size each year

A 1.5 *Household_size*

Type	Convertor
Units	Average persons per household
Equation	Not applicable because it is a constant
Description	It is the average number of Household size in Hyderabad
Initial Value	6

A 1.6 *Days Per Year*

Type	Converter
Units	Days per year
Equation	$Days\ Per\ Year = 365$
Description	It is used to convert days into year.

A 2: Consumer Sector

A 2.1 *Annual_water_demand*

Type	Flow
Units	Gallons per year
Equation	*Annual_water_demand = Population*Per_capita_water_demand*
Description	It is the annual water demand achieved by multiplying population with per capita water demand
Initial Value	Not applicable
Reference for definition of independent variables	
$Per\ capita\ water\ Demand$	Object A 2.2
$Population$	Object A1.1

A 2.2 *Per capita water demand*

Type	Convertor
Units	Gallons per capita per day (GPCD)
Equation	Not applicable (constant)
Description	It is the per capita per daily water demand in Hyderabad Value obtained from WASA
Initial Value	40

A 2.3 *Accumulated_water_demand*

Type	Stock
Units	Million Gallons Per Day (MGD)
Equation	$Accumulated\_water\_demand(t) = Accumulated\_water\_demand(t - dt) + (Annual\_water\_demand) * dt$
Initial Value	0
Description	It is the total increasing water demand MGD is the average value of water demand for each year

A 2.4 $Annual\_water\_deficit$

Type	Converter
Units	Million Gallons Per Day (MGD)
Equation	$Annual\_water\_deficit = Annual\_supplied\_water - Annual\_water\_demand$
Description	It is the difference between annual water supplied and annual water demand A water shortfall exists, when annual water demand is more than annual supplied water,
Initial Value	Not applicable

A 2.5 $Annual\_supplied\_water$

Type	Flow
Units	Million Gallons Per Day (MGD)
Equation	$Annual\_supplied\_water = Filter\_Plant\_\_capacity * (1 - Leakge\_Loss)$
Description	It is the yearly supplied water with consideration of leakage loss
Initial Value	Not applicable
Reference for definition of independent variables	
$Filter\_Plant\_\_capacity$	Object A2.9
$Leakge\_Loss$	Object A2.7

A 2.6 $Accumulated\_supplied\_water$

Type	Stock
Units	Million Gallons Per Day (MGD)
Equation	$Accumulated\_supplied\_water(t) = Accumulated\_supplied\_water(t - dt) + (Annual\_supplied\_water) * dt$
Description	It is the total increasing supplied water
Initial Value	0
Reference for definition of independent variables	
$Annual\_supplied\_water$	Object A2.5

A 2.7 $Leakge\_Loss$

Type	Converter
Units	*Percent*
Equation	$Leakage\_loss = Initial\_Leakge\_Loss - (Initial\_Leakge\_Loss/Total\_Length * Rehab\_fraction)$
Description	It is the annual leakage loss in the network system which reduces with the rehabilitation of the network
Initial Value	Not applicable
Reference for definition of independent variables	
$Initial\_Leakge\_Loss$	Object A2.8
$Total\_Length$	Object A3.1
$Rehab\_fraction$	Object A3.6

A 2.8 *Initial leakage loss*

Type	Converter
Units	*Percent*
Equation	$Leakge\_Loss$
Description	It is the annual leakage loss in the network system and considered as constant throughout the simulation
Initial Value	25%

A 2.9 *Filter Plant capacity*

Type	Stock
Units	Million Gallons Per Day (MGD)
Equation	$Filter\_Plant\_\_capacity(t) = Filter\_Plant\_\_capacity(t - dt) + (Filter\_Plant\_capacity\_increase) * dt$
Description	It is the total capacity of filter plants in Hyderabad
Initial Value	60,000,000

A 2.10 *Filter Plant capacity increase*

Type	Flow
Units	Million Gallons Per Day (MGD)
Equation	$Filter\_Plant\_capacity\_increase = Filter\_Plant\_\_capacity * Filter\_Plant\_capacity\_increase\_per\_year/100$
Description	It is the increase in the capacity of filter plant
Initial Value	Not applicable
Reference for definition of independent variables	
$Filter\_Plant\_capacity\_increase\_per\_year$	Object A2.11

A 2.11 *Filter Plant capacity increase per year*

Type	Converter (Constant)
Units	Percent
Equation	Not applicable
Description	It is the rate at which filter plant capacity is increased per year
Initial Value	18%

A 3: Physical infrastructure sector

A 3.1 *Total Length*

Type	Convertor
Units	Kilometers
Equation	$Total\_Length = Condition\_Group\_20 + Condition\_Group\_40 + Condition\_Group\_60$
Description	The total length of the network for rehabilitation
Initial Value	182

A 3.2 $Condition\ Group\ 20$

Type	Stock	
Units	Kilometers	
Equation	$Condition\_Group\_20(t) = Condition\_Group\_20(t - dt) + (Renewal) * dt$	
Description	It is the Age Group 0 to 20 for the water mains but in Hyderabad, no water mains exist in this group Initially value is for this group is zero	
Initial Value	0	
Reference for definition of independent variables		
Renewal	Object A3.5	

A 3.3 $Condition\ Group\ 40$

Type	Stock	
Units	Kilometers	
Equation	$Condition\_Group\_40(t) = Condition\_Group\_40(t - dt) + (Renewal) * dt$	
Description	It is the Age Group 20 to 40 for the water mains but in Hyderabad, no water mains exist in this group Initially value is for this group is zero	
Initial Value	0	
Reference for definition of independent variables		
Renewal	Object A3.5	

A 3.4 $Condition\ Group\ 60$

Type	Stock	
Units	Kilometers	
Equation	$Condition\_Group\_60(t) = Condition\_Group\_60(t - dt) + (-Renewal) * dt$	
Description	It is the Age Group from 40 to 60 for network length (water mains) The water mains considered for rehabilitation exists in this group in Hyderabad. This is the total length of water mains	
Initial Value	182	
Reference for definition of independent variables		
Renewal	Object A3.5	

A 3.5 $Renewal$

Type	Flow	
Units	Kilometers	
Equation	$Renewal = Rehab\_length$	
Description	It represent the annual rehabilitation of water mains	
Initial Value	182	
Reference for definition of independent variables		
Rehab length	Object A3.6	

A 3.6 *Rehab length*

Type	Convertor
Units	Kilometers
Equation	$Rehab\_length \ = Total\_Length * Rehab\_fraction/100$
Description	Rehab length represents the length of water mains annually rehabilitated. The 100 in the equation converts percent into fraction
Initial Value	Not applicable
Reference for definition of independent variables	
Total length	Object A3.41
Rehab fraction	Object A3.6

A 3.7 *Rehab_fraction*

Type	Converter
Units	Percent per year
Equation	Not applicable
Description	It is the fraction of network length that needs to be rehabilitated every year
Initial value	Depends upon user's input

A 4: Finance Sector

A 4.1 *Fund Balance*

Type	Stock
Units	Rupees
Equation	*Fund_balance(t) = Fund_balance(t - dt) + (Revenue - OpEx - CapEx) * dt*
Description	Characterizes the funds balance of the utility
Initial Value	0
Reference for definition of independent variables	
$Revenue$	Object A4.2
$OpEx$	Object A4.9
$CapEx$	Object A4.12

A 4.2 *Annual Revenue*

Type	Flow
Units	Rupees per year
Equation	$Annual\_Recovery$
Description	It represents the income of the utility
Initial Value	Not applicable

A 4.3 *Recovery rate*

Type	Converter
Units	Percent
Equation	Not applicable
Description	It is the percent at which recovery rate can be input to acheive the required recovery
Initial Value	Depend upon user's input

A 4.4 $Annual\ Recovery$

Type	Flow	
Units	Rupees per year	
Equation	$Annual\_Recovery = ((Annual\_User\_fee * Households) * Recovery\_rate)$	
Description	It is the income of utility which is achieved by multiplying annual user fee with households and recovery rate	
Initial Value	Not applicable	
Reference for definition of independent variables		
$Annual\_User\_fee$	Object A4.6	
$Households$	Object A1.4	
$Recovery\_rate$	Object A4.3	

A 4.5 $Accumulated\ Recovery$

Type	Stock
Units	Pakistani Rupees
Equation	$Accumulated\_Recovery(t) = Accumulated\_Recovery(t - dt) + (Annual\_Recovery) * dt$
Description	It is the total income of a utility
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_Recovery$	Object A4.4

A 4.6 $Annual\ user\ fee\ for\ A\ Category\ users$

Type	Stock
Units	Pakistani Rupees per year
Equation	$Annual\_User\_fee(t) = Annual\_User\_fee(t - dt) + (Increase\_in\_user\_fee) * dt$
Description	It is the annual user fee charged from A category users
Initial Value	1440
Reference for definition of independent variables	
Increase in user fee	Object A4.12

A 4.7 $Annual\ user\ fee\ for\ B\ Category\ users$

Type	Stock
Units	Pakistani Rupees per year
Equation	$Annual\_User\_fee(t) = Annual\_User\_fee(t - dt) + (Increase\_in\_user\_fee) * dt$
Description	It is the annual user fee charged from B category users
Initial Value	1680
Reference for definition of independent variables	
Increase in user fee	Object A4.12

A 4.8 $Annual\ user\ fee\ for\ C\ Category\ users$

Type	Stock
Units	Pakistani Rupees per year
Equation	$Annual\_User\_fee(t) = Annual\_User\_fee(t - dt) + (Increase\_in\_user\_fee) * dt$
Description	It is the annual user fee charged from C category users
Initial Value	2220
Reference for definition of independent variables	
Increase in user fee	Object A4.12

A 4.9 $Annual\ user\ fee\ for\ D\ Category\ users$

Type	Stock
Units	Pakistani Rupees per year
Equation	$Annual\_User\_fee(t) = Annual\_User\_fee(t - dt) + (Increase\_in\_user\_fee) * dt$
Description	It is the annual user fee charged from D category users
Initial Value	3900
Reference for definition of independent variables	
Increase in user fee	Object A4.12

A 4.10 $Annual\ user\ fee\ for\ E\ Category\ users$

Type	Stock
Units	Pakistani Rupees per year
Equation	$Annual\_User\_fee(t) = Annual\_User\_fee(t - dt) + (Increase\_in\_user\_fee) * dt$
Description	It is the annual user fee charged from E category users
Initial Value	5520
Reference for definition of independent variables	
Increase in user fee	Object A4.12

A 4.11 $Annual\ user\ fee\ for\ F\ Category\ users$

Type	Stock
Units	Pakistani Rupees per year
Equation	$Annual\_User\_fee(t) = Annual\_User\_fee(t - dt) + (Increase\_in\_user\_fee) * dt$
Description	It is the annual user fee charged from F category users
Initial Value	6540
Reference for definition of independent variables	
Increase in user fee	Object A4.12

A 4.12 $\textbf{\textit{Increase in user fee for Category A}}$

Type	Flow
Units	Pakistani Rupees per year
Equation	$Increase\_in\_user\_fee = Annual\_User\_fee * Rate\_in\_Change\_in\_\_user\_fee/100$
Description	It is the increase in the annual user fee
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_User\_fee$	Object A4.6
$Rate\_in\_Change\_in\_\_user\_fee$	Object A4.18

A 4.13 $\textbf{\textit{Increase in user fee for Category B}}$

Type	Flow
Units	Pakistani Rupees per year
Equation	$Increase\_in\_user\_fee = Annual\_User\_fee * Rate\_in\_Change\_in\_\_user\_fee/100$
Description	It is the increase in the annual user fee
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_User\_fee$	Object A4.7
$Rate\_in\_Change\_in\_\_user\_fee$	Object A4.18

A 4.14 $\textbf{\textit{Increase in user fee for Category C}}$

Type	Flow
Units	Pakistani Rupees per year
Equation	$Increase\_in\_user\_fee = Annual\_User\_fee * Rate\_in\_Change\_in\_\_user\_fee/100$
Description	It is the increase in the annual user fee
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_User\_fee$	Object A4.8
$Rate\_in\_Change\_in\_\_user\_fee$	Object A4.18

A 4.15 $\textbf{\textit{Increase in user fee for Category D}}$

Type	Flow
Units	Pakistani Rupees per year
Equation	$Increase\_in\_user\_fee = Annual\_User\_fee * Rate\_in\_Change\_in\_\_user\_fee/100$
Description	It is the increase in the annual user fee
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_User\_fee$	Object A4.9
$Rate\_in\_Change\_in\_\_user\_fee$	Object A4.18

A 4.16 $Increase\ in\ user\ fee\ for\ Category\ E$

Type	Flow
Units	Pakistani Rupees per year
Equation	$Increase\_in\_user\_fee = Annual\_User\_fee * Rate\_in\_Change\_in\_\_user\_fee/100$
Description	It is the increase in the annual user fee
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_User\_fee$	Object A4.10
$Rate\_in\_Change\_in\_\_user\_fee$	Object A4.18

A 4.17 $Increase\ in\ user\ fee\ for\ Category\ F$

Type	Flow
Units	Pakistani Rupees per year
Equation	$Increase\_in\_user\_fee = Annual\_User\_fee * Rate\_in\_Change\_in\_\_user\_fee/100$
Description	It is the increase in the annual user fee
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_User\_fee$	Object A4.11
$Rate\_in\_Change\_in\_\_user\_fee$	Object A4.18

A 4.18 $Rate\_Change\_in\_\_user\_fee$

Type	Converter
Units	Percent
Equation	Not applicable
Description	It is the rate at which user fee is allowed to increase according to the user’s input
Initial Values	Depend upon user’s input

A 4.19 $OpEx$

Type	Flow
Units	Rupees per year
Equation	$\mathrm{OpEx} = \mathrm{Unit\_price\_\_OpEx\_Filter\_plant} + (\mathrm{Unit\_price\_of\_\_OpEx\_Network} * \mathrm{Total\_Length} * 1000)$
Description	It is the annual operational expenditures required for filtration of water and network rehabilitation
Initial Value	Not applicable
Reference for definition of independent variables	
$\mathrm{Unit\_price\_\_OpEx\_Filter\_plant}$	Object A4.21
$\mathrm{Unit\_price\_of\_\_OpEx\_Network}$	Object A4.20
$\mathrm{Total\_Length}$	Object A3.1

A 4.20 ***Unit_price_of__OpEx_Network***

Type	Converter (constant)
Units	Rupees per meter per year
Equation	Not applicable
Description	It is the unit price to maintain and operate the water pipes per year
Initial Value	Pk. Rs. 5,750 Source: (Rehan et al., 2011)

A 4.21 ***Unit_price__OpEx_Filter_plant***

Type	Convertor
Units	Rupees per year
Equation	*Unit price Operational and Maintenance(t) = Unit price Operational and maintenance(t-dt)+(O&M)*dt*
Description	Unit price operational expenditures represent the utility's overall annual operational expenditures such as establishment (pay of officers and officials, allowances, pay of work charge etc.), operation and maintenance (commodities and services, repair and maintenances of works, electricity charges etc.), chemicals (chemicals used for water treatment) and fuel for machinery, etc. Value obtained from WASA Hyderabad
Initial value	Rs.1,783,451,907

A 4.22 ***CapEx***

Type	Flow	
Units	Rupees per year	
Equation	CapEx = (Renewal*1000*Unit price CapEx Network)+(Filter Plant capacity increase per year*Unit Price CapEx Filter Plant)	
Description	It is the annual cost for increase in the filter plants capacity and rehabilitation of water pipes. 1000 in the equation converts kilometers to meters	
Initial value	Not applicable	
Reference for definition of independent variables		
Renewal		Object A3.4
Unit price CapEx Network		Object A4.23
Filter Plant capacity increase per year		Object A2.11
Unit Price CapEx Filter Plant		Object A4.24

A 4.23 ***Unit_price__CapEx_Network***

Type	Convertor
Units	Rupees per meter
Equation	Not applicable
Description	It is the cost of one meter of an old pipe for rehabilitation Source: (Rehan et al., 2011)
Initial Value	Rs.115000

A 4.24 $\boldsymbol{Unit\_Price\_CapEx\_Filter\_Plant}$

Type	Converter
Units	Rupees per MGD
Equation	Not applicable
Description	It is the cost of extension of filtration water per MGD Source: Budget 2018 and 2019 Planning and development, Govt. of Sindh
Initial value	Rs.136,250,000

A 4.25 $\boldsymbol{Total\_Ex\_to\_Date}$

Type	Stock	
Units	Rupees per year	
Equation	$Total\_Ex\_to\_Date(t) = Total\_Ex\_to\_Date(t - dt) + (OpEx + CapEx) * dt$	
Description	It characterize the total accumulated expenditures of the utility	
Reference for definition of independent variables		
$OpEx$	Object A4.19	
$CapEx$	Object A4.22	

A 4.26 $\boldsymbol{Annual\ Fund\ Balance}$

Type	Convertor
Units	Dollars per year
Equation	$Annual\_Fund\_balance = Annual\_Recovery - Annual\_Expenditure$
Description	It is the annual fund balance of the utility, the annual income minus annual expenses
Initial Value	Not applicable
Reference for definition of independent variables	
$Annual\_Recovery$	Object A4.4
$Annual\_Expenditure$	Object A4.17

A 4.27 $\boldsymbol{Annual\ Expenditures}$

Type	Convertor
Units	Dollars per year
Equation	$Annual\_Expenditures = OpEx + CapEx$
Description	It is the annual expenditures of the utility. It includes operational expenditures and capital expenditures
Initial Value	Not applicable
Reference for definition of independent variables	
$OpEx$	Object A4.19
$CapEx$	Object A4.22

Appendix-B: Tables Generated from Model Simulation

B 1: Subcategories of water charges in Hyderabad

Category	Water charges (PKR)	Dia (Inch)
A	120	0.5
AG+1	180	0.5
AG+2	240	0.5
AG+3	360	0.5
B	140	0.5
BG+1	210	0.5
BG+2	280	0.5
BG+3	420	0.5
C	185	0.5
CG+1	280	0.5
CG+2	370	0.5
CG+3	555	0.5
D	325	0.5
DG+1	490	0.5
DG+2	650	0.5
DG+3	975	0.5
E	435	0.5
EG+1	655	0.5
EG+2	870	0.5
EG+3	1305	0.5
F	545	0.5
FG+1	820	0.5
FG+2	1090	0.5
FG+3	1635	0.5

B 2: Existing conditions of the water supply system in Hyderabad

Year	Population	Annual water demand (GPD)	Annual water supply (GPD)	Annual water deficit (GPD)
2007	1,431,488	57,259,520	45,000,000	-12,259,520
2008	1,460,118	58,404,710	45,000,000	-13,404,710
2009	1,489,320	59,572,805	45,000,000	-14,572,805
2010	1,519,107	60,764,261	45,000,000	-15,764,261
2011	1,549,489	61,979,546	45,000,000	-16,979,546
2012	1,580,478	63,219,137	45,000,000	-18,219,137
2013	1,612,088	64,483,520	45,000,000	-19,483,520
2014	1,644,330	65,773,190	45,000,000	-20,773,190

2015	1,677,216	67,088,654	45,000,000	-22,088,654
2016	1,710,761	68,430,427	45,000,000	-23,430,427
2017	1,744,976	69,799,035	45,000,000	-24,799,035

B 3: Projection of water supply and demand in Hyderabad

Year	Population	Annual water demand (GPD)	Annual water supply (GPD)	Annual water deficit (GPD)
2017	1,734,309	69,372,360	45,000,000	-24,372,360
2018	1,768,995	70,759,807	45,000,000	-25,759,807
2019	1,804,375	72,175,003	45,000,000	-27,175,003
2020	1,840,463	73,618,503	45,000,000	-28,618,503
2021	1,877,272	75,090,873	45,000,000	-30,090,873
2022	1,914,817	76,592,691	45,000,000	-31,592,691
2023	1,953,114	78,124,545	45,000,000	-33,124,545
2024	1,992,176	79,687,036	45,000,000	-34,687,036
2025	2,032,019	81,280,776	45,000,000	-36,280,776
2026	2,072,660	82,906,392	45,000,000	-37,906,392
2027	2,114,113	84,564,520	45,000,000	-39,564,520
2028	2,156,395	86,255,810	45,000,000	-41,255,810
2029	2,199,523	87,980,926	45,000,000	-42,980,926
2030	2,243,514	89,740,545	45,000,000	-44,740,545

B 4: Existing expenditures and revenue based on a 25 % collection rate

Year	Annual Expenditure (PKR)	Annual Revenue (PKR)	Annual Fund Balance (PKR)
2017	1,783,451,907	139,335,962	-1,644,115,945
2018	1,908,293,540	142,122,681	-1,766,170,860
2019	2,041,874,088	144,965,135	-1,896,908,954
2020	2,184,805,275	147,864,437	-2,036,940,837
2021	2,337,741,644	150,821,726	-2,186,919,918
2022	2,501,383,559	153,838,161	-2,347,545,398
2023	2,676,480,408	156,914,924	-2,519,565,484
2024	2,863,834,036	160,053,222	-2,703,780,814
2025	3,064,302,419	163,254,287	-2,901,048,132
2026	3,278,803,588	166,519,372	-3,112,284,216
2027	3,508,319,840	169,849,760	-3,338,470,080
2028	3,753,902,228	173,246,755	-3,580,655,473
2029	4,016,675,384	176,711,690	-3,839,963,694
2030	4,297,842,661	180,245,924	-4,117,596,737

B 5: An annual increase of an 18% user fee of each category based on 80% recovery rate

Year	Annual Expenditure (PKR)	Annual Revenue (PKR)	Annual Fund Balance (PKR)
2017	1,783,451,907	445,875,077	-1,337,576,830
2018	1,908,293,540	536,655,243	-1,371,638,297
2019	2,041,874,088	645,918,251	-1,395,955,838
2020	2,184,805,275	777,427,207	-1,407,378,068
2021	2,337,741,644	935,711,386	-1,402,030,258
2022	2,501,383,559	1,126,222,224	-1,375,161,335
2023	2,676,480,408	1,355,521,069	-1,320,959,339
2024	2,863,834,036	1,631,505,158	-1,232,328,878
2025	3,064,302,419	1,963,679,609	-1,100,622,810
2026	3,278,803,588	2,363,484,777	-915,318,811
2027	3,508,319,840	2,844,690,278	-663,629,562
2028	3,753,902,228	3,423,869,218	-330,033,010
2029	4,016,675,384	4,120,968,991	104,293,607
2030	4,297,842,661	4,959,998,278	662,155,616

B 6: Monthly user fee with an 18% annual increase in user fees by each categary

Year	A (≤ 80)	B (81-120)	C (121-200)	D (210-400)	E (401-600)	F (> 601)
2017	120	140	185	325	435	545
2018	142	165	218	384	513	643
2019	167	195	258	453	606	759
2020	197	230	304	534	715	895
2021	233	271	359	630	843	1,057
2022	275	320	423	744	995	1,247
2023	324	378	499	877	1,174	1,471
2024	382	446	589	1,035	1,386	1,736
2025	451	526	695	1,222	1,635	2,049
2026	532	621	821	1,442	1,929	2,417
2027	628	733	968	1,701	2,277	2,852
2028	741	865	1,143	2,007	2,687	3,366
2029	875	1,020	1,348	2,368	3,170	3,972
2,030	1,032	1,204	1,591	2,795	3,741	4,687

B 7: Monthly per capita user fee with an 18% annual increase in user fees by each categary

Year	A (≤ 80)	B (81-120)	C (121-200)	D (210-400)	E (401-600)	F (> 601)
2017	20	23	31	54	73	91
2018	24	28	36	64	86	107
2019	28	32	43	75	101	126
2020	33	38	51	89	119	149
2021	39	45	60	105	141	176
2022	46	53	71	124	166	208
2023	54	63	83	146	196	245
2024	64	74	98	173	231	289
2025	75	88	116	204	273	341
2026	89	103	137	240	322	403
2027	105	122	161	283	379	475
2028	124	144	190	335	448	561
2029	146	170	225	395	528	662
2030	172	201	265	466	623	781

B 8: Annual user fee with an 18% annual increase in user fees by each categary

Year	A (≤ 80)	B (81-120)	C (121-200)	D (210-400)	E (401-600)	F (> 601)
2017	1,440	1,680	2,220	3,900	5,220	6,540
2018	1,699	1,982	2,620	4,602	6,160	7,717
2019	2,005	2,339	3,091	5,430	7,268	9,106
2020	2,366	2,760	3,648	6,408	8,577	10,745
2021	2,792	3,257	4,304	7,561	10,120	12,680
2022	3,294	3,843	5,079	8,922	11,942	14,962
2023	3,887	4,535	5,993	10,528	14,092	17,655
2024	4,587	5,352	7,072	12,423	16,628	20,833
2025	5,413	6,315	8,345	14,660	19,621	24,583
2026	6,387	7,452	9,847	17,298	23,153	29,008
2027	7,537	8,793	11,619	20,412	27,321	34,229
2028	8,893	10,376	13,711	24,086	32,238	40,391
2029	10,494	12,243	16,178	28,422	38,041	47,661
2030	12,383	14,447	19,091	33,538	44,889	56,240

B 9: Accumulated revenue from 2017 to 2030 based on 80% recovery rate

Year	Accumulated Revenue (Billion PKR)
2017	0.4
2018	1.0
2019	1.6
2020	2.4
2021	3.3
2022	4.5
2023	5.8
2024	7.5
2025	9.4
2026	12
2027	15
2028	18
2029	22
2030	27

B 10: Projection of additional water supply based on a 28% increasing rate every 5 year

Year	Annual supplied water (GPD)	Annual water demand (GPD)	Annual water deficit (GPD)
2017	45,000,000	69,372,360	-24,372,360
2018	45,000,000	70,759,807	-25,759,807
2019	47,637,363	72,175,003	-24,537,641
2020	57,600,000	73,618,503	-16,018,503
2021	57,600,000	75,090,873	-17,490,873
2022	57,600,000	76,592,691	-18,992,691
2023	57,600,000	78,124,545	-20,524,545
2024	60,975,824	79,687,036	-18,711,211
2025	73,728,000	81,280,776	-7,552,776
2026	73,728,000	82,906,392	-9,178,392
2027	73,728,000	84,564,520	-10,836,520
2028	73,728,000	86,255,810	-12,527,810
2029	78,049,055	87,980,926	-9,931,871
2030	94,371,840	89,740,545	4,631,295

B 11: 36% of rehabilitation of network every 5 year (Km)

Year	Condition group 20	Condition group 40	Condition group 60
2017	0	0	182
2018	0	0	182
2019	0	0	182
2020	66	0	116
2021	62	3	116
2022	59	6	117
2023	56	9	117
2024	53	11	117
2025	116	13	52
2026	110	18	53
2027	105	23	54
2028	100	27	55
2029	95	31	57
2030	148	34	0

B 12: Annual total expenditures required for capital works (PKR)

Year	OpEx	Annual Expenditures	CapEx	CapEx per year
2017	1,046,500,000	1,046,500,000	0	0
2018	1,119,755,000	1,119,755,000	0	0
2019	1,198,137,850	1,198,137,850	12,994,386,020	2,598,877,204
2020	1,282,007,500	3,880,884,704	0	2,598,877,204
2021	1,371,748,024	3,970,625,228	0	2,598,877,204
2022	1,467,770,386	4,066,647,590	0	2,598,877,204
2023	1,570,514,313	4,169,391,517	0	2,598,877,204
2024	1,680,450,315	1,680,450,315	18,225,298,602	3,645,059,720
2025	1,798,081,837	5,443,141,558	0	3,645,059,720
2026	1,923,947,566	5,569,007,286	0	3,645,059,720
2027	2,058,623,895	5,703,683,616	0	3,645,059,720
2028	2,202,727,568	5,847,787,288	0	3,645,059,720
2029	2,356,918,498	2,356,918,498	23,635,996,812	4,727,199,362
2030	2,521,902,793	7,249,102,155	0	4,727,199,362

About the Authors

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Main thrust of Applied Research component of the Water Center is to stimulate an environment that promotes multi-disciplinary research within the broader context of water-development nexus to support evidence-based policy making in the water sector. This is pursued using the framework provided by the six targets of the Sustainable Development Goal on Water i.e. SDG-6.

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