Water Resource Management Policies: A Study for Sustained Growth of the Visakhapatnam Urban Area, India.

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Abstract

Water is necessary essential for development and sustenance of healthy ecosystems. The rapid population growth and industrialization have significantly increased the water demand in developing countries. Meeting the growing demands is challenging owing to the simultaneous increase in consumption and continuous decrease in rainfall. Innovative water management practices should be focused on to provide sufficient water for the present and future generations. However, the planning and management of water resources and variables influencing them are dynamic and complex. Traditional approaches cannot capture the dynamic characteristics of variables and their effects on future water use. This study proposes a dynamic simulation model with real data on available resources, considering the future dynamics of the population, manufacturing, and service industries. In addition, recommendations for sustainable water supply are presented. The current situation in the Visakhapatnam urban area indicates that it cannot meet the water demands in the next 5 years, with a probable deficit of up to 40%. The deficit would increase to 55% from the sixth year onwards, indicating further deterioration. The deficits can be reduced to 28% with the proposed policy of increasing canal supplies or increasing industrial recycling and sewage plant efficiencies. Moreover, combining these policies can reduce the deficit to 5% of the current situation. Water supply organizations may consider these suggested policies during planning to meet fresh water demand.

Keywords:

Water resources management; sustainability; data collection; feedback loops; system dynamics; policy planning.

1. Introduction

Water is necessary for all organisms' development and sustaining healthy environment [1]. The rapid population growth and economic development have increased worldwide water demand. The increasing costs and difficulties in obtaining additional water resources create an imbalance between water availability and demand, intensifying the pressure on water resources. Substantial efforts should focus on studying innovative water management practices to provide sufficient water for the present and future generations [2]. Relevant measures should be implemented for effective consumption, such as increasing the efficiency of all water uses, lowering per capita domestic use, total water treatment and reuse, and reducing agricultural use by increasing irrigation efficiency. Meeting the growing water demands is challenging owing to increased consumption and limited availability of water resources; thus, researchers [3] have focused on planning and managing water resources.

Water resource management activities includes conventional practices of water resource planning, design and integrates these practices in a methodology to support a decision-making process using engineering and social sciences [4]. The domestic, agricultural, service, and industrial sectors are considered in estimating water demand [5]. Each sector depends on various factors, and many variables influence each factor. For example, domestic water consumption sector depends on the population and birth, death, and migration rates. Migration rates depend on feasibility facilities, such as industrial and agricultural growth. On the resource side, available resources depend on the rainfall and storage capacities of surface reservoirs and subsurface aquifers. Developing and implementing resource strategies and demand management practices are necessary to fulfill future needs and sustenance.

Many countries worldwide have increased water demand, including India. Many cases of rising in water demand are common at international and national levels, including increased population, rapid industrialization, and enhanced standards of living [6]. However, water availability has not increased. To accelerate economic development and growth of the country, government of India has given a paramount interest to initiate steps to fulfill fresh water demands. In fact, in the 12th five year (2012–17) plan of government of India [2] acknowledges two major challenges at the national level: major water crisis and water quality issues. In this back drop, author initiated to study water demand and supply, and develop a dynamic simulation model to propose certain policies for sustainable fresh water supply management of a city which has fast industrialization, agricultural and fast urbanization growth.

Visakhapatnam is one of the largest and financial capital of state of Andhra Pradesh. a greater city in India. It is the most populous city with a population of 30 million making it 14th largest city in the country. In terms of economy, it is the tenth largest city in the country with a GDP of $ 50 billion. Due to its fast growth, complex and various interrelations between activities, the production of goods, services, and the prosperity of the general population etc, resulted increase of fresh water demand significantly. Keeping in view of contribution in the economic development of India by Visakhapatnam greater city, researcher and government organizations focused on the need to study supply of required water resources for sustained growth and proposed various measures to fulfill the fresh water demands, however, due to rapid development in all the sectors, city is unable to cater the needs of the city.

In the visakhapatnam city region the rainfall trend continuously fluctuate, ground water levels are decreasing and freshwater is supplied externally. There is no correct scientific study on availability and assessment of water demands considering the all sectors and due to continuous shortage of availability of water sources effecting the growth of the city. For sustainable development of this urban city, all water demands should be addressed effectively with the available surface groundwater, considering population growth, industrialization, and agricultural growth. The variables influencing resources and consumption are dynamic [7] and vary with time [8]; all sectors should be studied under dynamic conditions to balance demand and supply. Traditional approaches [9] could not capture the dynamic characteristics of variables [10] and their effects on future water use.

The objective of the paper is to propose policies for fresh water supply for sustainable growth of the Visakhapatnam urban city. A dynamic model is developed and collected and applied real-time data related to available resources, agriculture, population growth, manufacturing, and service industry fresh water requirements. Balancing the supply and demand data, water deficits for the coming years are estimated and three polices are proposed for sustainable water supply of the city. Water deficits can be reduced to 10 % by implementing the third policy.

2. Literature Review

The Global Water Report 2016 [11] presents a detailed analysis based on 184 water disclosures, in which 500 global corporations participated, including four major Indian companies. Almost three-quarters of the respondents identified water as a substantive business risk factor. Challenges include supply chain disruptions owing to water scarcity and damage to reputation. Two-thirds of the risks expected to affect the direct operations of supply chains were anticipated to occur within the next 5 years. India has experienced a 60% decline in the per capita water availability over the last 50 years. The prediction [11] revealed that the industrial water demand will increase from 40.86 Bm3 in 2010 to 91.63 Bm3 in 2030. The basic needs of cities are an adequate supply of fresh water and the disposal of contaminated water. Cities will be affected negatively if these requirements are not met.

The imbalance between water availability and demand has gained substantial research attention [12]. Moreover, the increasing scarcity of clean water is one of the most important issues facing civilization in the 21st century. Policymakers working on water supply and distribution face several issues regarding balancing availability and demand. Accordingly, the integrated water resource management concept was developed to balance water availability and demand [4]. Several advances [13- 14] have been made in developing mathematical models for integrated water resource management. Accurate variable data are necessary to apply the mathematical models. However, the applicability of mathematical models is limited owing to inadequate information on water resources and demands. Researchers [14-15] have developed simulation-based models to bridge the gap between availability and demand. These simulation models are primarily geared toward sustainability. Researchers have highlighted the importance of stakeholders in developing simulation models. Participatory and collaborative modeling approaches [16] have emerged according to stakeholder importance. To apply the simulation models Simonovic [4] reported that although water resource problems are global, solutions can only be formulated at regional levels because water is a regional resource.

During the latter part of the 20th century, traditional water balance modeling approaches [17] used projections of population growth, unit water demand, agricultural production, and industrial growth. These projections were used to estimate future water demand and balance, and demonstrated that future water projections are variants of current trends and subject to considerable uncertainty. Using different periods to make predictions results in high variability in the predicted variable values. These studies [12-13] are primarily limited in that the dynamic characteristics of the main variables and their effects on future water use were not captured through the traditional approach.

Considering the dynamic characteristics is a novel approach in which system dynamics offers a new method for modeling the future dynamics of complex systems. This approach was used in modelling world water development [18]. However, it has not been tested for addressing the global issues of future water availability, use, and balance. Studies on the global modeling of water resources considering dynamic interactions between the quantitative characteristics of available water resources and water use are limited [19]; however, some studies have been conducted at the regional level [4-5]. Most countries [3, 19] have developed water resource assessment models and proposed various policies for sustainable water resources using the basic world water model [4]. Based on the literature survey author noted that no simulation model has been applied to India's framed policies.

3. System Dynamics Simulation

System dynamics is an academic discipline introduced in the 1960s by researcher at the Massachusetts Institute of Technology [20]. It has gradually developed into a valuable tool for analyzing social, economic, physical, chemical, biological, and ecological systems. A system is a accumulating of all the factors that continuously interact each other over time. Structure is the hidden inter linkages among the elements of a system. Dynamics means changes over time. A dynamic system is one in which factors or variables interact each other and modify over time.

One feature common to all systems is that the system structure determines its behavior [21]. The system dynamics links the system behavior with its structure. It can be used to analyze how the structure of a physical, biological, or any other system influences the system behavior. The system dynamics simulation approach relies on understanding the complex interrelationships between different elements within a system by developing a model that can simulate and quantify the system behavior.

Another basic concept is the feedback

loop [22]. The feedback loop is a path connecting decisions controlling the action, system level, and information about the system level. A single-loop structure is the simplest form of a feedback system. Additional delays and distortions may sequentially appear in this loop. Several loops are interconnected. The primary skill required for reading a feedback diagram is to see the story behind the diagram–how the structure creates a particular behavior pattern and how that pattern might be influenced.

This feedback concept provides a basis for viewing water management problems in various ways [23]. Water resources are complex systems. They exhibit the following important characteristics:

1. Cause and effects are often separated in terms of both time and space,
2. Problem resolutions that improve a situation in the short-term often create larger problems in the long-term,
3. The subsystems and parts of the system interact through multiple nonlinear feedback loops. The complex flow of interactions often results in counter intuitive behaviors,
4. Owing to the time delay between cause and effect, system managers tend to reduce their goals and objectives to accommodate what was originally considered unacceptable.

The model focuses on two characteristics: time and complex interactions. The feedback concept is a valuable tool for enhancing the understanding of these interactions. It enables seeing interrelationships rather than linear cause–effect chains and change processes rather than snapshots before and after changes.

3.1. Positive or reinforcing feedback

Positive or reinforcing feedback reinforces changes. This can lead to an ever-increasing growth rate. This growth pattern is often referred to as an exception. Note that the growth rate starts slow and then accelerates in the early growth stages. Therefore, growth in a water resource system with a positive feedback loop is deceptive. A potentially major problem may seem minor in the early stages of the exponential growth process because it grows slowly. When the growth accelerates, it may be too late to solve any problems associated with this growth. Sometimes, positive feedback loops are called viscous cycles depending on the type of behavior, including bandwagon effects and snowballing. In summary, growth forces are found in the positive feedback form of a system structure.

3.2. Negative or balancing feedback

Negative or balanced feedback look to achieve goals. The loop structure pushes its value down when the current level of the variable of interest exceeds the goal. By contrast, the loop structure pushes its value up when the current level is below the goal. Many water resource system processes hold feedback loops of negative category that impart valuable steadiness and can oppose the required changes. It exhibits a similar behavior in an external environment that dictates a system to change.

4.System Dynamics Model Development

The steps for developing a dynamic simulation model comprises the following:

1. Developing structure of the system and its boundaries,
2. Recognizing the key influencing variables,
3. Mapping the model structure,
4. Formulating the relationships between variables,
5. Simulating the model for its behavior.

4.1. System and boundaries

Fig. 1 shows the basic water sources and consumption system, according to expert opinions in the literature and a questionnaire survey.

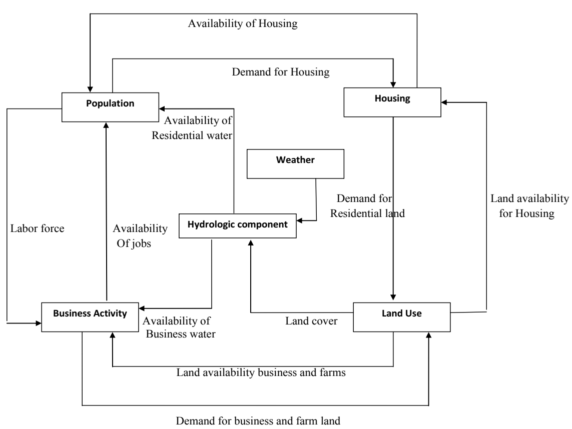

Fig. 1. Sectorial view diagram of the socioeconomic model

The system diagram shown in Fig. 1 comprises blocks and the interconnections between each block. The blocks represent the factors of water consumption. The sources and interconnections between the blocks indicate the influence of each factor.

4.2. Identifying key variables

The succeeding sections explain the key variables involved in each sector.

4.2.1. Dynamics of agriculture water demand

Population density increases the need for food production, increasing the focus on agricultural output that depends on available sources. However, an increased population density decreases agricultural land, reducing the water demand. The higher the population growth, the more rapid the agricultural land deterioration. According to the survey, the entire agricultural production depends on various factors, such as sources, agricultural land deterioration, addition of new agricultural land, and crop selection, as shown in Fig. 2.

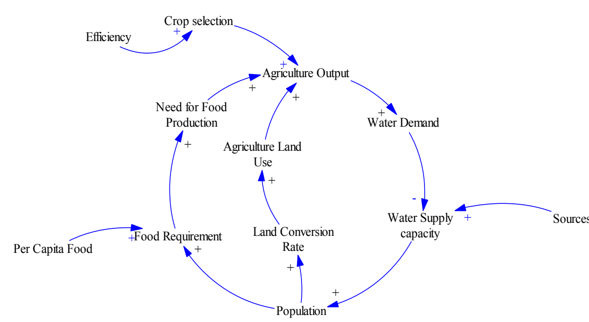

Fig. 2. Agriculture water requirement

4.2.2. Dynamics of domestic water demand

Population significantly influences domestic water demand. The availability of water sources also influences population levels. The potential for development increases as the number of water sources increases. Urbanization is another factor to consider. The factors influencing urbanization were considered because economic development and growth depend on urbanization. Urbanization comprises many factors, such as migration rate, industrial development, and service sector growth. Several dimensions influence urbanization. Fig. 3–5 show the dynamics of urbanization, according to the author survey and literature [24 -26].

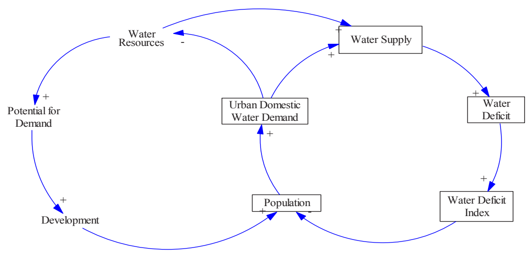

Fig. 3. Dynamics of domestic water demand

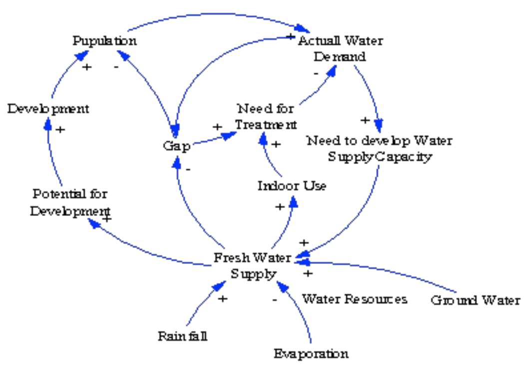

Fig. 4. Dynamics of fresh water supply

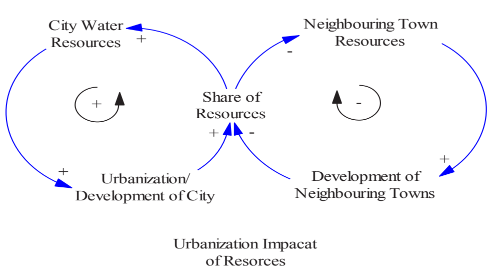

Fig. 5. Dynamics of urbanization

4.2.3. Fresh water supply and its dynamics

Fig. 6 shows the supply channels from three sources–reservoirs, canals, and groundwater–to industry and population.

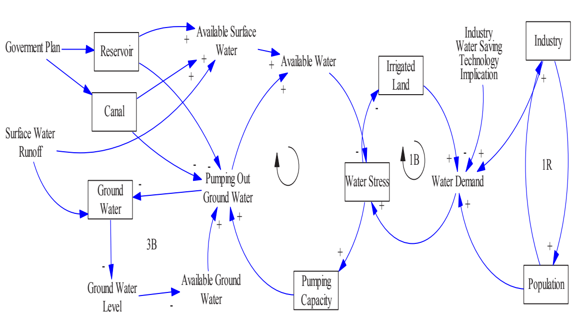

Fig. 6. Fresh water flow dynamics

The fresh water supply dynamics consists of 4 loops one is the positive or reinforcing loop (1R) and the other three are negative or balancing loops (1B, 2B and 3B). The more growth in industrialization leads the more increase in population known as positive loop (1R) . Increase in industrialization reduces irrigated land, so, water requirement for agriculture reduces (1B), reduction in ground water pumping (2B), and ground water levels requirement also reduces (3B).

4.3. Model structure

The various sectors of consumption and sources considered to build a dynamic simulation model are as follows:

Consumption

- Population sector
- Agriculture sector
- Manufacturing and service sectors
- Ecological sector

Sources

- Groundwater
- Canal water supply
- Recycling water
- Desalination water
- Storm water

An overall stock flow dynamic simulation model was developed using STELLA software by integrating the consumption and source sectors. Fig. 7 shows the model.

4.4. Variables and their relationships

Fig. 7 shows the interrelationships between the variables. The value of each variable was obtained from the Andhra Pradesh State Ground Water Department (APSGWD) in Visakhapatnam, India [27].

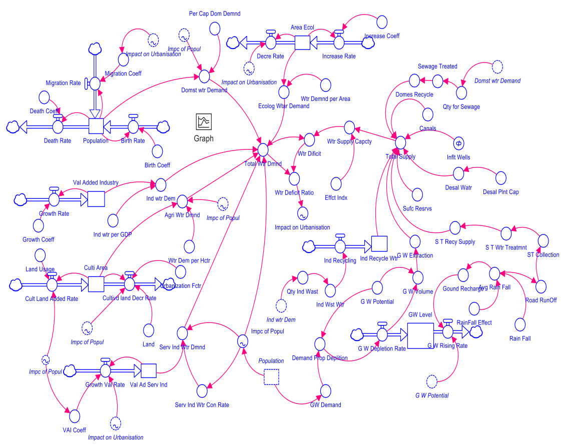

Fig. 7. Integrated stock and flow model

4.5. Base model

The overall system dynamics simulation model was arrived by combining all the sectors, as shown in Fig. 7. The model was run using the ISEE STELLA dynamic simulation software for a simulation period of 12 years considering a time interval of 0.05 months. Fig. 8–9 show the base-run simulation results for the total water demand and water deficit, respectively.

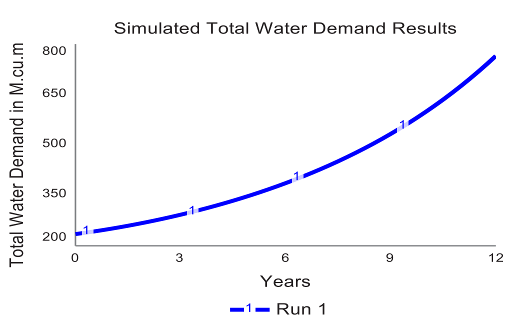

Fig. 8. Simulated total water demand results

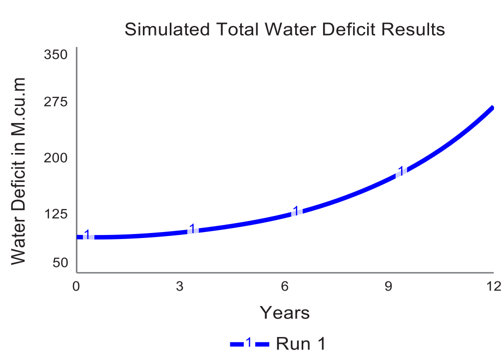

Fig. 9. Simulated total water deficit

The simulation results show that the initial water demand during the current year (2017–2018) is 210 Mm3 and will reach 350 Mm3 within 5 years, demonstrating a 60% increase. The average annual increase is 10%. The simulated results show that water requirement is likely to accelerate up to 675 Mm3 in the next 10 years (2027–28). The water deficit in the current year (2017–18) is 108 Mm3 and projected to increase to 210 Mm3 in the next 5 years (2022–23). By the end of the 10th year (2027–28), the projected water deficit is 442 Mm3, indicating a four-fold increase in the present deficits.

4.5.1. Policy experimentation

The base-run results indicate that the water supply organization (GVMC, Visakhapatnam) could not fulfill fresh water requirement in the existing scenario. The predicted water deficit values of the model were compared with available data for the current year to validate the system dynamics model. The predicted total water deficit for 2016–17 was consistent with the total water deficit data available in the GVMC. After several rounds of modeling and with various interventions of the data inputs, observations, and discussions held by GVMC engineers, the listed below policies are proposed:

1. Policy 1: Double the canal water supply,
2. Policy 2: Enhance water recycling by treating domestic sewage and industrial wastewater,
3. Policy 3: Develop a combined policy of canal water supply, and enhance

water recycling from domestic sewage and industrial wastewater.

Policy 1: Double the canal water supply

After several trial runs of the model and with input from the water supply organization, the first policy considered doubling canal water supplies. Currently, the canal water supply is 66 Mm3. An increase to 132 Mm3 was proposed for the canal water supply capacity. Fig. 10 shows the simulation results.

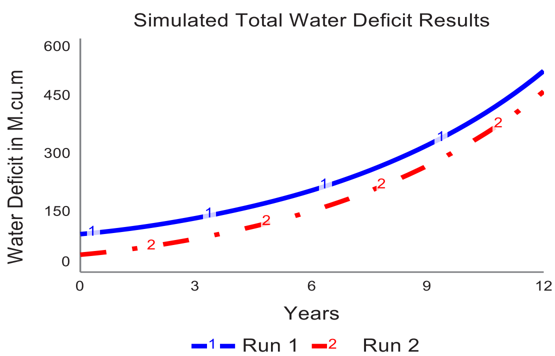

Fig. 10. Simulated total water deficit of base model (106 m3) and 1st policy.

The simulated results show that for the next 5 years (from 2017–18 to 2021–22), the total water deficit will decrease from 41% to 19%. Within 5 years, the total water deficit (with respect to the base model and Policy 1) will decrease from 52% to 37%. However, after 12 years, no significant improvement in the total water deficit from the base model to Policy 1 is projected; that is, only 68% to 61 %.

Policy 2: Enhancing recycling water by treating domestic sewage and industrial wastewater

After several trial runs of the model and with input and suggestions from the supply organization, a second policy was proposed to enhance the percentage of gray water utilization (recycling domestic wastewater). According to GVMC data, the current percentage of domestic sewage water collection, capacities, and usage of recycled water from domestic sewage are 30%, 30%, and 30%, respectively. An increase in these values to 50%, 70%, and 80% is proposed to reduce the water supply deficit.

The model was run exclusively by altering the proposed domestic sewage and industrial wastewater recycling efficiencies without altering the canal water supply to 66 Mm3. Fig. 11 shows the simulated values of water supply capacity and water deficit.

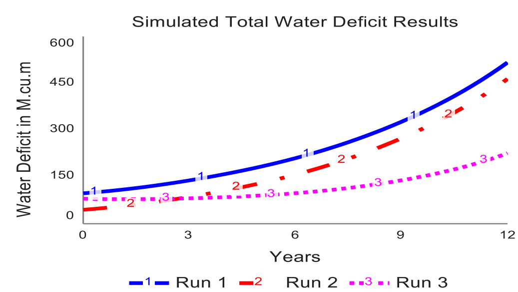

Fig. 11. Simulated total water deficit of base model, 1st policy, and 2nd policy

The simulated values of the model show that for the next 5 years (from 2017–18 to 2021–22), the average water deficit percentage will be approximately 29% for Policy 2, demonstrating no significant improvement over Policy 1. However, a significant reduction in the average water deficit percentage is projected in the next 5 years (2022–23 to 2028–29); that is, approximately 27% for Policy 2, demonstrating an improvement from the Policy 1 and base model deficits of 51% and 61%, respectively.

Policy 3: Combined effect of enhanced canal water supply and recycling of domestic sewage and industrial wastewater

First, the model was tested by enhancing canal water supplies alone as Policy 1. Subsequently, an enhanced percentage in the domestic sewage water and industrial wastewater recycling was used as Policy 2. Finally, the model combined the enhanced canal water supplies and recycled water values for Policy 3. Fig. 12 shows the simulation results.

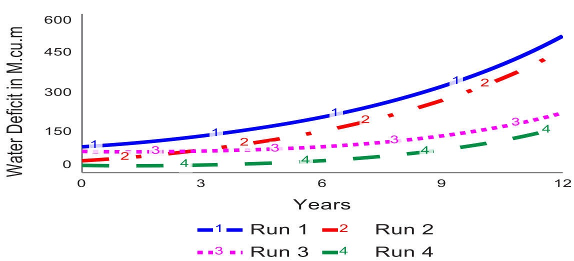

Fig. 12. Simulated total water deficit of base model and three policies

The simulated results obtained in Policy 3 by combining Policies 1 and 2 were remarkable. For the first 5 years, the average water deficit decreased to 10%. For the next 5 years, the average water deficit percentage was projected at 17%.

5. Conclusion

Several studies have been conducted and measures have been initiated to meet water demand and minimize water deficits in many countries. Based on the study and the author survey, no research work reported on use of the dynamic modeling approach to water modeling considering the conditions in India. This study developed a comprehensive system dynamic model by considering several dependent water supply and demand variables and proposed 3 policies to minimize water deficits.

Considering the current conditions, the dynamic model result reveals:

1. the average % fresh water deficit after 5 years would reached to 52% and after 12 years, % fresh water deficit would be increasing to 68%. With proposed policy 1, by doubling the external canal water supply, the average % fresh water deficit value after 5 years and after 12 years are reduced to 37% and 61%, respectively.
2. the proposed policy 2, by enhancing recycling efficiencies has better results obtained than the Policy 1. The average deficit for the first five years is more or less same as that of the doubling the supplies whereas for the rest of the period 2022-23 to 2028-29 the deficits are 27% drastically reduced to half the deficit by the policy 1.
3. The policy policy 3 was considered combining both options of enhancing the canal water supply and improving recycling of waste water by the existing treatment plants is considered. The third policy results reveal that during the first five years the deficits are reduced to 10% and for the rest of the periods it is maintaining average deficit of 17% only.The simulated results of obtained in Policy-3 by implementing the combined policies 1 and 2 are very impressive and the fresh water deficits are drastically reduced.

The proposed policies are the suggestions for sustainable supply of fresh water for the greater city of Visakhapatnam and the developed model can be readily applied and with new interventions can be done to minimize the water deficits of other cities.

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