ZIBELINE INTERNATIONAL™ PUBLISHING

ISSN: 2521-0904 (Print)
ISSN: 2521-0440 (Online)
CODEN: EHJNA9

Engineering Heritage Journal (GWK)

DOI: http://doi.org/10.26480/gwk.01.2025.07.11

CrossMark

REVIEW ARTICLE

WATER SUPPLY ADEQUACY OF CASAY RURAL WATERWORKS AND SANITATION ASSOCIATION, INC. (CARWASAI): SYSTEM DYNAMICS MODELING APPROACH

Milcarl P. Sandoval[a*], Daisy Wahing[b], Erwin Alegado[c]

Department of Industrial Engineering, University of San Carlos, Talamban, Cebu City Philippines.

****Corresponding Author Email : 24104660@usc.edu.ph***

ARTICLE DETAILS

Article History:

Received 17 August 2025
Revised 20 September 2025
Accepted 23 October 2025
Available online 05 November 2025

ABSTRACT

Water is among the most vital natural resources that a nation must consistently protect, conserve, and manage sustainably. It is essential to all forms of life, and any significant shortage can result in a decline in the quality of life and substantial economic losses. Effective water resource management helps overcome this challenge. This study made use of System Dynamic Modeling (SDM) to examine the factor such as water demand, water supply, distribution leaks and water price, to provide a comprehensive understanding of the existing water supply system. A number of scenarios were evaluated, including water price increase, conservation campaigns and reduction of non-revenue water (NRW). Results show that over time, the groundwater supply will no longer be sufficient to meet the demand and that exploration of alternative water resource is recommended. Water conservation campaigns, price increase and NRW reduction will be able to help delay the depletion of the groundwater supply.

KEYWORDS

Water resource management, groundwater conservation, system dynamics modeling

1. INTRODUCTION

Water is a crucial resource for sustaining an adequate food supply and ensuring a productive environment that supports all forms of life. It is fundamental to life and serves as the backbone for the societal development. As global human population and economy grow, water demand also grow. The combined impacts of global population growth, climate change, and evolving lifestyle patterns have intensified pressures on water resources, resulting in water shortages across numerous countries.

As a result, there is growing realization of the urgent need to conserve water and evaluate current situation of water resources. Sustainable water resource management (WRM) become a crucial factor in achieving stability between economic growth, environmental and human development (Xian et al., 2022). Successful WRM plays a vital role in addressing numerous sustainable development goals (SDGs), including Clean Water and Sanitation (goal #6) (Lahlou et al., 2023).

In the Philippine context, the National Water Resources Board (NWRB) has identified seven major metropolitan areas facing critical challenges due to the anticipated surge in water demand. By 2025, the water demand in Metro Cebu is projected to reach approximately 342 million cubic meters, accompanied by one of the fastest population growth rates in the country (Raymundo, 2015). However, the available exploitable groundwater in Metro Cebu remains insufficient to meet this projected demand, as it was estimated at only 60 million cubic meters in 1998. This is a gap of 282 million cubic meter for Metro Cebu. This is even discounting the effect of pollution and fecal contamination to the exploitable groundwater.

This study aims to evaluate the water supply adequacy of CARWASAI, a barangay-based water utility provider, focusing on its ability to meet the daily water needs of its served population. By examining factors such as water demand, water supply, distribution leaks and water price, the research provides a comprehensive understanding of the existing water supply system. The findings aim to guide local authorities and policymakers in designing more effective water management strategies to address the growing demand for water and enhance the resilience of the barangay and the local water utility provider itself to water-related challenges.

2. LITERATURE REVIEW

Clean Water and Sanitation is a specific Sustainable Development Goal (SDG 6) within the suite of 17 interconnected SDGs adopted in 2015 by the United Nations, to address water scarcity issues and improving sanitation for all people (Kookana et al., 2020). It emphasizes guaranteeing universal access to clean water and sanitation. The goal is to ensure that by 2030, all individuals have access to safe and affordable drinking water, adequate sanitation facilities, and improved hygiene practices, with particular attention to the needs of marginalized and vulnerable populations.

Undeniably, access to water supply is crucial for the demographic, social, and economic advancement of a community. Hence, it is imperative to ensure reliable access to high-quality water for all purposes.

Water scarcity is a global challenge that affects both developing and developed nations. Currently, over one-fourth of the world's population—approximately 2.1 billion out of 7.5 billion people—lack access to safely managed drinking water. This shortage largely stems from rapid population growth and inadequate governance, which have hindered the development of essential water supply infrastructure and systems needed to meet the escalating demand for water (Tan, 2020).

In the Philippines, approximately one in ten individuals still lack access to clean water. Even Metro Manila, the nation's capital, continues to

Quick Response Code	Access this article online	
	Website: www.gwk.com.my	**DOI:** 10.26480/gwk.01.2025.07.11

Cite the Article: Milcarl P. Sandoval, Daisy Wahing, Erwin Alegado (2025). Water Supply Adequacy Of Casay Rural Waterworks And Sanitation Association, Inc. (Carwasai): System Dynamics Modeling Approach. Engineering Heritage Journal (GWK), 8(1): 07-11.

experience water shortages. In March 2019, the region faced a significant water crisis that underscored its vulnerability to water scarcity. The city struggles with limited and uneven water distribution, further aggravated by declining water levels in major reservoirs such as Angat Dam and La Mesa Dam. On June 29, 2019, the water level at Angat Dam dropped to a historic low of 157.98 meters, surpassing the previous record of 157.56 meters set on July 18, 2010. This figure was well below its normal level of 212 meters, operational level of 180 meters, and critical level of 160 meters. Similarly, La Mesa Dam reached an all-time low of 68.74 meters on March 14, 2019, falling below its critical threshold of 69 meters (Lee et al., 2020).

It used GALDIT index to determine the vulnerability of Mandaue City's groundwater to seawater intrusion (Condor et al., 2022). It revealed that 59.97% of the area was moderately vulnerable and 32.67% was highly vulnerable. These findings justify the need to develop groundwater quality monitoring network to distinguish trends in groundwater quality of Mandaue City .

Also, it made use of Urban Water Security Index (UWSI) to develop a methodical way to investigate the mechanics of urban water security in Ibb, Yemen. He utilized various perspectives including water access, availability, affordability, quality, and management (Alwathaf et al., 2023). The study revealed that even though the local water network supply covers 56% of the city, the produced water only serves 21% of the Population.

This developed Water Security Assessment Tool (WATSAT) to help city authorities and decision-makers make an objective evaluation of the water security situation of the city (Babel et al. 2023). It uses indicator-based methodology that measures five distinct dimensions of water security. Together, these dimensions culminate into a Water Security Index (WSI). WATSAT results in quantitative assessment of water security of an area, wherein WSI provides overall picture of the water security situation of the area.

Most, if not all, of the tools developed to investigate issues related to water supply focuses on the current situation of the area and recommends actions for improvement.

The main objective of this study is to evaluate in advance using System Dynamics approach the water supply adequacy of Dalaguete and challenges faced by its local water district.

This will enable the formulation and implementation of targeted interventions aimed at ensuring long-term sustainability and equitable access to clean water.

3. Model Construction

3.1 Study Area

CARWASAI is a barangay-based water utility provider located in Barangay Casay, Dalaguete, Cebu. It was created in 1983 thru a grant from United States of America (USAID) and thru the effort of the provincial government under the administration of then Governor Eduardo Gullas.

The present service area covers whole Barangay Casay and portions of adjacent barangays. Barangay Casay has a total land area of 353 hectares (Fig. 1) and bounded in the north by Barangay Casay Argao, in the south by Barangay Cawayan, and in the west by Barangay Lumbang. It has a population of 4,845 people. The area experiences a tropical climate, with an average annual precipitation of approximately 2,000 mm. As surface water (SW) sources are absent in Casay, the barangay primarily depends on groundwater as its main water supply.

Figure 1 : Map of Barangay Casay, Dalaguete

3.2 System dynamics modelling (SDM) approach

This study integrates the SDM approach and unique scenario-design methodology to develop a framework to assess the impact of various policies on long-term water resource sustainability. The model covers a 15-year time horizon, from 2023 to 2038. Baseline data is from year 2022 actual figures, while policies are implemented from 2028 to 2038 (10 years). The average water price (P15 per cubic meter) is used in the model. Due to unavailability of data and appropriate measuring equipment, the current groundwater volume is assumed to be 50, 000 cubic meters.

3.2.1 Causal loop diagram (CLD)

Causal relationships among the model components are defined using a qualitative tool within the System Dynamics Modeling (SDM) framework, known as the Causal Loop Diagram (CLD) (Madani and Mariño, 2009).

The primary purpose of a CLD is to develop a comprehensive understanding of the system and its problem scope. However, it does not allow for the quantitative representation of system behavior over time. To address this limitation, a quantitative analysis is conducted through the Stock and Flow Diagram (SFD), as discussed in the following section.

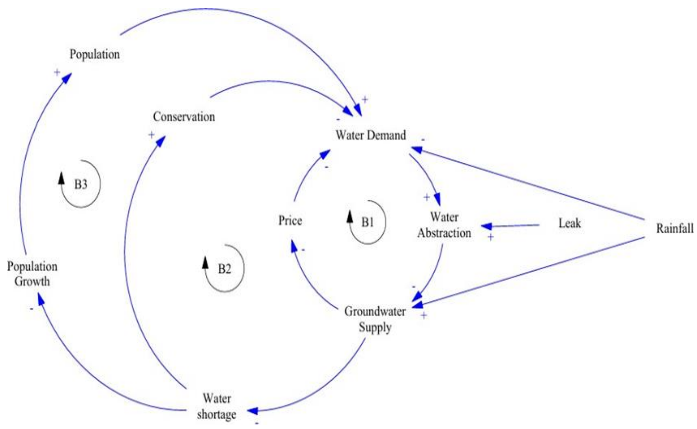

Figure 2 : Causal Loop Diagram

3.2.2 Decision support system (DSS) using stock-and-flow diagram (SFD)

A Stock and Flow Diagram (SFD) serves as a quantitative tool within the System Dynamics Modeling (SDM) framework, facilitating the modeling and analysis of system behavior over time (Datola et al., 2022). In this study, a Decision Support System (DSS) simulation model for CARWASAI was developed using STELLA software (Version 3.7.3), as illustrated in Figure 3. The SFD characterizes the system through the concepts of stocks and flows, wherein stock denote the accumulation of a variable over time, and flows represent the rates of inflow or outflow affecting the stock (Zare et al., 2019). The simulation utilizes "year" as the temporal unit.

Demand can also be affected by the water price. In this study, a mean elasticity value of - 0.51 was applied after a critical review of the literature (Sahin et al., 2016).

The key variables and subsystems employed in the developed SFD simulation model are presented in Table 1.

Table 1: Key variables used in CARWASAI SFD model development

Subsystem	Stock	Key Variables
Water Supply	Ground Water	Rainfall Rainfall to GW conversion rate Land area Water loss Rate of water returned to GW
Water Demand	Number of Household	Household growth rate Water consumption per household Current annual consumption

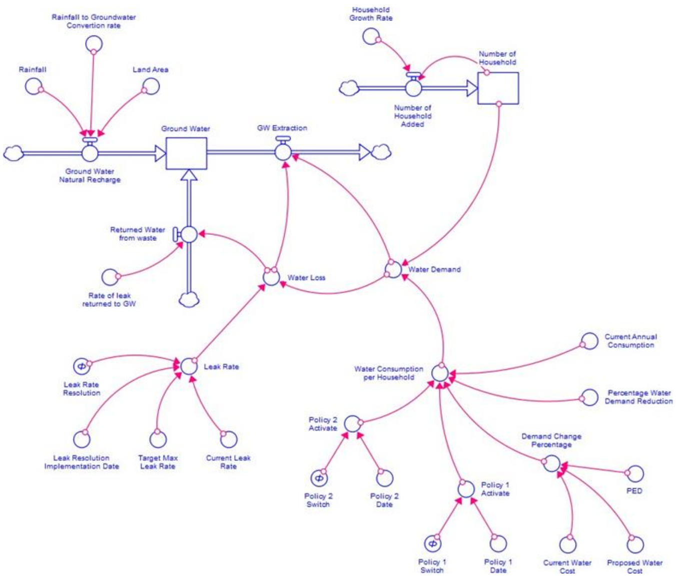

Figure 3 : CARWASAI SFD Model

4. Results And Discussion

Three (3) types of policies are considered in this paper: Water Conservation Education, Leak Reduction and Water Price increase.

4.1 Policy Scenarios

The policy mix tree in Fig. 4 classifies different policies or mechanisms. There are five (5) scenarios, namely: *Status quo (Baseline), Kick-off, Conservation, Demand reduction, and Comprehensive.*

Under the Status quo scenario, no policy is implemented. Under the Kick-off scenario, leak reduction is implemented. Repairing water leaks within the distribution pipeline should be performed including implementing measures to monitor future leaks through clustering of consumers. The maximum leak rate should be no more than 20%. A 5% reduction form the current leak rate. Under the Conservation scenario, water conservation campaigns are implemented. It is expected that a 5% decrease in demand will be achieved through strategic water conservation campaigns. Under the Demand reduction scenario, both price increase and conservation campaigns is implemented. The demand is expected to decrease if price is increased. Under the Comprehensive scenario, all policies are implemented and is expected to deliver the most reduction in demand and water loss.

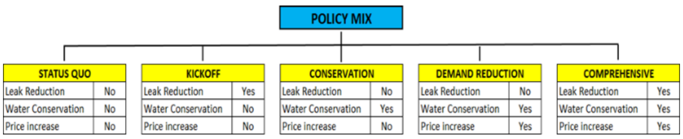

Figure 4 : Policy mix

4.2 Policy Implications

The simulation showed that there will be a notable increase in water demand from 234,000 cubic meters to 406,000. On the other hand, the system's groundwater supply is not enough to meet the demand. This is a limitation of the study as the groundwater initial volume is assumed at 50,000 cubic meters only. Actual groundwater volume can't be determined yet. This also indicates that as early as now, new or alternate water sources should be explored.

The kick-off scenario (Run 2) which focuses on resolving the distribution leaks, extends the availability of the groundwater supply by another year (2033).

The conservation scenario (Run 3) focuses on the implementation of water conservation campaigns with a 5% expected decrease in water demand. This scenario will be able to extend ground water supply until year 2034. The available groundwater supply is still not sufficient to meet the demand despite the decrease.

The demand reduction scenario (Run 4) focuses on both the water conservation campaigns and water price increase. With water conservation campaigns and additional P2 per cubic meter in water price, the demand is expected to decrease and extend ground water supply until year 2037.

The comprehensive scenario (Run 5), with all the policies implemented, delivers the best result. Ground water supply is expected to be available beyond year 2038. From year 2029 to year 2033, the groundwater supply is sufficient to meet the demand.

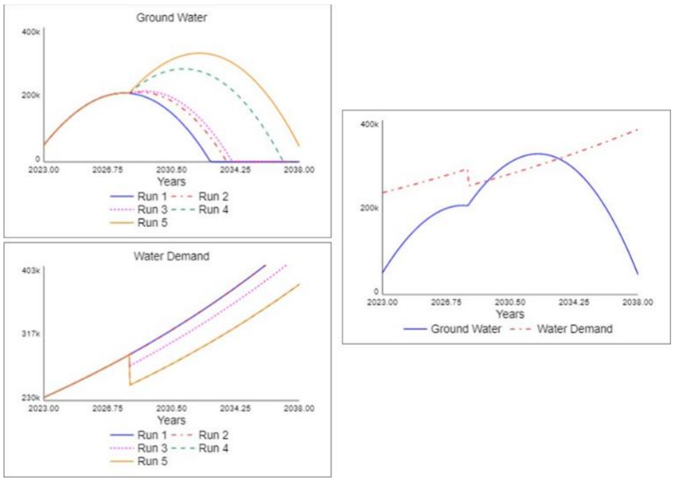

Figure 5 : Simulation result

4.3 Policy Recommendation

Achieving sustainable development necessitates maintaining a balance between water demand and supply. Solely focusing on the expansion of water infrastructure while disregarding conservation initiatives does not constitute a sustainable long-term strategy. This approach often results in the "fixes that backfire" phenomenon, wherein short-term solutions inadvertently promote increased consumption over time.

The primary recommendations to address these critical challenges are outlined as follows:

a) Groundwater conservation
- Reduce groundwater abstraction by repairing leaks in the distribution pipeline to reduce non-revenue water.
- Explore additional possible water source including investing in non-conventional water resources like desalination plants to ensure long-term water availability.

b) Effective water conservation campaign
- Raise awareness about the importance of water conversation including its environmental and social benefits.
- Encourage individuals to adopt water-saving habits such as fixing leaks, taking shorter showers and using water-efficient appliances.
- Provide information on water-saving fixtures and rainwater harvesting.

c) Water price increase
- Reduce water demand by increasing water price.
- If demand maintain on the previous level, the increase in water price will deliver additional revenue that may also be used to achieve infrastructure projects that will help water supply.

5. Conclusions

This paper detailed the development of an SDM developed to explore the behavior of Casay water resource system over the next 15 years.

The developed model represents a significant stride forward in engaging stakeholders and supporting strategic decision-making processes. Its significance extends beyond CARWASAI, offering valuable insights and applications for similar water utility providers in Cebu

Our findings underscore the critical importance of balancing water demand and supply levels to ensure sustainable development. Policy recommendations include:

- Prioritizing groundwater conservation measures.
- Investing in non-conventional water resource infrastructure
- Implementing effective water conservation campaigns

Further research opportunities include developing a way to accurately measure available groundwater supply and further examining customized water pricing schemes tailored to reduce demand and incentivize households that were able to reduce their monthly water consumption for a period of time.

REFERENCES

Alwathaf, Y., Kawy, W. A. Abdel, Al-Areeq, N., Al-Areeq, A. M., and Al-Qatni, K. Y. 2023. Urban Water Security Index assessment for Ibb City, Yemen: Comprehensive vision. Water Conservation and Management, 7 (1), Pp. 28-35. https://doi.org/10.26480/wcm.01.2023.28.35.Urban Water Security Index Assessment For Ibb City, Yemen.

Comprehensive Vision. 2023. Water conservation and management, 7(1), Pp. 28–35. https://doi.org/10.26480/wcm.01.2023.28.35

Babel, M. S., Chapagain, K., & Shinde, V. 2023. How to measure urban water security?

An introduction to the Water Security Assessment Tool (WATSAT). 2023. 13(1), https://doi.org/10.30852/sb.2023.2166

Condor, B., Patiño, C., and Sinogaya, J. 2022. Design of groundwater monitoring network for coastal aquifers based on seawater intrusion vulnerability: A case study of Mandaue City, Philippines. IOP Conference Series: Earth and Environmental Science, 1094(1), 012002. https://doi.org/10.1088/1755-1315/1094/1/012002

Datola, G., Bottero, M., De Angelis, E., and Romagnoli, F. 2022. Operationalising resilience: A methodological framework for assessing urban resilience through system dynamics model. Ecological Modelling, 465, 109851.

Kookana, R. S., Drechsel, P., Jamwal, P., and Vanderzalm, J., 2020. Urbanisation and emerging economies: Issues and potential solutions for water and food security. Science of the Total Environment, 732, 139057. https://doi.org/10.1016/ j.scitotenv.2020.139057

Lahlou, F.-Z., AlNouss, A., Govindan, R., Hazrat, B., Mackey, H. R., and Al-Ansari, T. 2023. Water and sludge resource planning for sustainable agriculture: An energy–water–food–waste nexus approach. Sustainable Production and Consumption, 38, Pp. 130–148. https://doi.org/10.1016/j.spc.2023.03.027

Lee, H., Son, J., Joo, D., Ha, J., Yun, S., Lim, C.-H., and Lee, W.-K. 2020. Sustainable water security based on the SDG framework: A case study of the 2019 Metro Manila water crisis. Sustainability, 12(17), Pp. 6860. https://doi.org/10.3390/su12176860

Madani, K., and Mariño, M. A. 2009. System dynamics analysis for managing Iran's Zayandeh-Rud river basin. Water Resources Management, 23, Pp. 2163–2187. https://doi.org/10.1007/s11269-008-9376-z

Naeem, K., Aloui, S., Zghibi, A., Mazzoni, A., Triki, C., and Elomri, A. 2024. A system dynamics approach to management of water resources in Qatar. Sustainable Production and Consumption, 46, Pp. 733–753. https://doi.org/10.1016/j.spc.2024.03.024

Palanca-Tan, R. 2020. Global water shortages: A Philippines case study. The Journal of Social, Political, and Economic Studies, 45(1/2), Pp. 46–62. https://www.proquest.com/docview/2395271609?pq-origsite=gscholar&fromopenview=true

Raymundo, R. 2015. Presented at the DLSU Research Congress. DLSU Research Congress Proceedings, 3. https://www.dlsu.edu.ph/wp-content/uploads/pdf/conferences/research-congress-proceedings/2015/SEE/035-SEE_Raymundo_RB.pdf

Sahin, O., Siems, R. S., Stewart, R. A., and Porter, M. G. 2016. Paradigm shift to enhanced water supply planning through augmented grids, scarcity pricing and adaptive factory water: A system dynamics approach. Environmental Modelling & Software, 75, Pp. 348–361. https://doi.org/10.1016/j.envsoft.2014.05.018

Xian, C., Fan, Y., Zhang, J., and Zhang, L. 2022. Assessing sustainable water utilization from a holistic view: A case study of Guangdong, China. Sustainable Cities and Society, 76, 103428. https://doi.org/10.1016/j.scs.2021.103428

Zare, F., Elsawah, S., Bagheri, A., Nabavi, E., and Jakeman, A. J. 2019. Improved integrated water resource modelling by combining DPSIR and system dynamics conceptual modelling techniques. Journal of Environmental Management, 246, Pp. 27–41. https://doi.org/10.1016/j.jenvman.2019.05.033