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Potential for Rainwater Harvesting In the Prison System of Santa Catarina, Brazil Using Dynamic System Modeling

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ABSTRACT

Water supply is crucial for maintaining health and hygiene in prison environments, aiding in disease control. The routine cleaning of prison facilities consumes a significant amount of potable water, resulting in high costs. Rainwater harvesting emerges as a more economical alternative for cleaning prison establishments since the water used for cleaning does not need to be potable. This study aimed to use dynamic system modeling as a tool to evaluate the potential use of rainwater for cleaning five prison complexes in the state of Santa Catarina, reducing costs and potable water supply for this purpose. The dynamic modeling was conducted using the Vensim software by Ventana Systems Inc., Massachusetts, USA. Simulations were based on historical average, minimum, and maximum precipitation recorded over the past 30 years compared to the current situation of the prison complexes. Significant reductions of over 80% in potable water consumption were observed at CRIC and COPE complexes when monthly precipitation reached historical maximum values. Considering historical averages, reductions were 508% and 465% for CRIC and COPE, respectively. In contrast, at CPVI, the reduction in potable water consumption was lower compared to the other complexes, with only a 428% reduction even under historical maximum rainfall conditions of 194 mm. On the other hand, SCS and CHAP, with high rainfall indices and large roof areas, can capture enough water to meet their needs even with the historical minimum precipitation (115 mm for SCS and 130 mm for CHAP), generating surpluses of 22,436 m³ for SCS and 27,091 m³ for CHAP. Historical averages and maxima result in even higher volumes, reaching 48,357 m³ in SCS and 75,188 m³ in CHAP. Due to high rainfall and large roof areas available for rainwater harvesting, the need for cleaning water can be met by installing rainwater harvesting systems on 33% of the available area in SCS and 44% in CHAP. The dynamic system model employed in this study is visually summarized in Appendix 2.

Keywords: *Prison System, Rainwater Harvesting, Dynamic Modeling*

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I. INTRODUCTION

Adequate, safe, and accessible water supply is essential for sustaining life (Perveen et al., 2023; Niknam et al., 2023; Penserini et al., 2023). Water, as a vital resource, becomes increasingly valuable to humans and animals. According to Kummu et al. (2016), climate change exacerbates water scarcity, posing a problem for both current and future generations. One of the significant global challenges this century is the development of new water sources (Ohlund et al., 2024).

According to Dwivedi (2022), Sustainable Development Goal (SDG) 6 ensures universal access to safe drinking water and sanitation, aiming for sustainable and accessible water and sanitation for all, while achieving efficient and sustainable management of water resources globally (Tortajada et al., 2018). Achieving sustainable water security has become a measure to reduce water risk, as water risk and water security are interconnected – as water risk increases, water security decreases (Cai et al., 2021).

Exponential population growth, lack of planning in human settlements in rural and urban areas, and anthropogenic contamination of water resources (Murei et al., 2022) hinder the achievement of SDG 6, necessitating the implementation of new technologies and concepts to address related threats (García-Ávila et al., 2021; Kakoulas et al., 2022).

Environmental protection is a responsibility encompassing both governmental and non-governmental entities, as well as each citizen. The Brazilian Constitution, in Article 225 §1°, assigns this role to the State, considering it the primary agent in formulating and implementing environmental public policies (Brazil, 1988).

Within the scope of public organizations, specifically the Ministry of Justice and Public Security of the Federal Government, lies the Brazilian prison system. The management of the federal prison system in Brazil is the responsibility of the National Penal Policy Secretariat (SENAPPEN), which supervises and regulates the application of the Penal Execution Law and the guidelines of the National Penitentiary Policy established by the National Council for Criminal and Penitentiary Policy (SENAPPEN, 2022).

According to the National Penitentiary Department (DEPEN), Brazil has an incarcerated population of approximately 671,000 inmates housed in facilities such as penitentiaries and federal and state prisons (DEPEN, 2022). This high number of incarcerated individuals results in significant water resource consumption and effluent generation. In the prison system of the state of Santa Catarina, water consumption by inmates in thirteen prison units in 2021 and 2022 totaled 1,352,788 m³ over two years, with a total cost of $1,806,451.21 (Brazil, 2023).

This volume of water was necessary to meet the needs of an average of 9,918 inmates in the thirteen prison units studied over these two years. Due to the high concentration of people in confinement, water consumption is essential for the hygiene of prison establishments and the health of inmates in state custody.

Water consumption by an incarcerated person can be divided into noble and non-noble uses. Noble use includes activities where potable water is necessary, such as food preparation, laundry, daily consumption, bathing, personal hygiene, and in-cell use. Non-noble uses, such as flushing and cleaning, can be supplied with other sources, such as rainwater. According to data from the State Secretariat for Prison Administration and Social Education (SAP) of Santa Catarina, water consumption in these prison establishments varies from 128 to 242 liters/inmate/day, encompassing all water uses by inmates (Brazil, 2023).

Cleaning prison establishments is essential for maintaining the health of both staff and inmates, as the confinement and physical structure of prison units facilitate disease proliferation. Water consumed in cleaning varies from 21 to 101 liters/inmate/day, depending on the unit analyzed. Guo et al. (2019) state that inadequate ventilation, overcrowding, and sharing of personal items contribute to health problems among inmates. During the COVID-19 pandemic, actions like hand washing, personal hygiene, and cleaning were crucial in combating the disease (Gine-Garriga et al., 2021). Hernando et al. (2023) report that, despite prisons being closed environments prone to spreading infectious diseases, measures established in Spanish prisons successfully contained the spread of COVID-19 during the pandemic.

In this context, rainwater harvesting for cleaning prison units presents a promising alternative to reduce the volume of treated water used and associated costs. Various configurations of rainwater harvesting systems exist, with the most common being those that provide water for external (non-noble) uses, such as garden irrigation, car washing, and pools. These systems have recently been incorporated into internal plumbing for broader uses, such as toilet flushing, contributing to potable water savings (Hdeib et al., 2023).

A rainwater harvesting system comprises three main components: collection, storage, and treatment (Stang et al., 2021). When the collected water is intended for noble use, treatment is necessary to eliminate contaminants harmful to human health. The first rain collected in urban areas is typically contaminated with dust from air pollution, dirt accumulated on collection roofs, and possibly animal feces. This concentration of contaminants can promote microbial species growth in stored water (Jamal et al., 2023).

However, the economic viability of implementing a rainwater harvesting system is closely linked to the cost of potable water (Amos et al., 2018; Abdulla, 2020; Bus and Szelagowska, 2021; Preeti and Rahman, 2021) and the region's available rainfall. A dynamic system simulation analysis tool created by Ventana Systems Inc., Massachusetts, USA, called Vensim, was used (Jian et al., 2023). This software utilizes dynamic system modeling. According to Chunga et al. (2023), dynamic system models are one of the tools used in multiple water use and planning studies, enabling the understanding of complex systems over time. Dynamic system models differ from other approaches as they can study complex systems using feedback loops, stocks, and flows (Garcia, 2020).

The objective of this study is to use dynamic system modeling as a tool to evaluate the potential use of rainwater for cleaning five prison complexes in the state of Santa Catarina, reducing costs and the supply of potable water for this purpose. A model will be developed and executed using Vensim software, comparing current consumption results with historical minimum, average, and maximum precipitation values recorded for each region.

II. METHODOLOGY

Study Area

The state of Santa Catarina houses 54 prison units across its various regions (Brazil, 2023). Studies were conducted in prison complexes in the following regions: Greater Florianópolis, Vale do Itajaí, South, Serrana, and West. Figure 1 shows the geographical distribution of the municipalities where these prison complexes are located.

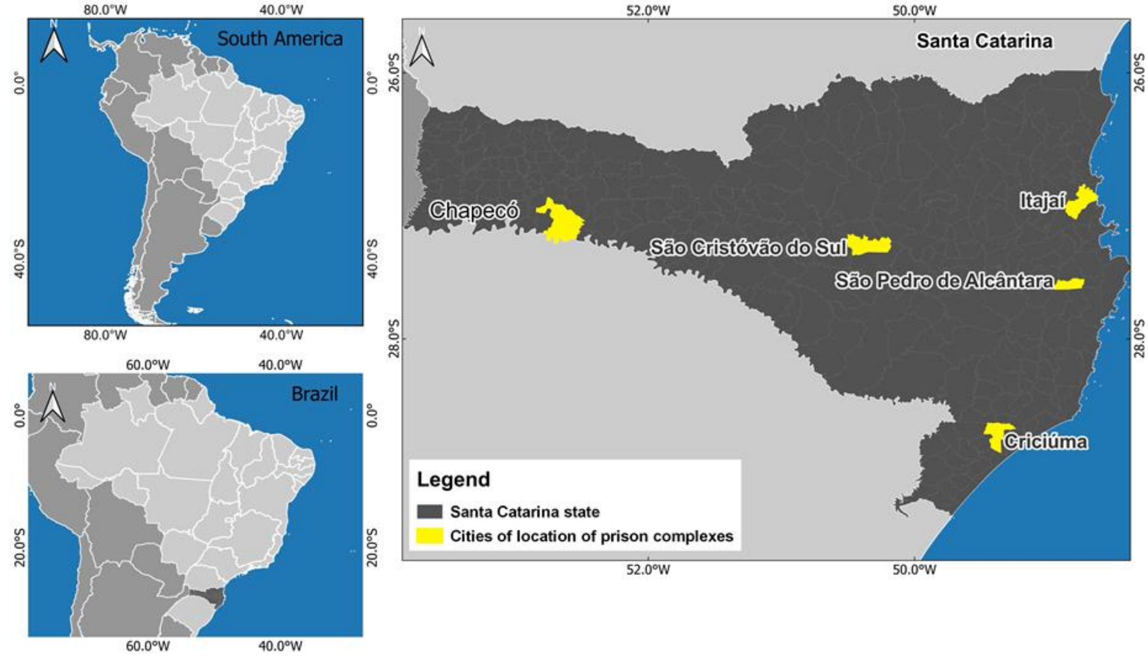


Figure 1: Location of Prison Complexes in Municipalities.

The following nomenclature will be adopted for the prison complexes to simplify understanding: COPE (Complexo Penitenciário do Estado): Located in São Pedro de Alcântara, Greater Florianópolis, with a capacity for 1,300 inmates in a closed regime. It has its own sewage treatment plant (ETE) and water treatment plant (ETA). Geographical coordinates: UTM: 721763.57 E; 6947220.63 S.

CRIC (Complexo Penitenciário de Criciúma): Situated in Criciúma, comprising the Penitenciária Sul and the Penitenciária Feminina, with a total capacity of 1,122 vacancies. It has its own ETE and is supplied by Companhia Catarinense de Água e Esgoto (CASAN). Coordinates: UTM 659527.97 E; 6807773.96 S.

CPVI (Complexo Penitenciário do Vale do Itajaí): Located in Itajaí, coordinates UTM 728702.13 E; 7014649.40 S, with a capacity for 2,790 inmates distributed across various facilities, including Penitenciária, Presídio Regional, and Presídio Feminino. It has its own ETE and is supplied by Serviço Municipal de Água Saneamento Básico e Infraestrutura (SEMASA).

SCS (Complexo Penitenciário de São Cristóvão do Sul): Located in São Cristóvão do Sul, coordinates UTM 556136.33 E; 6983903.30 S, comprises three prison units with a capacity of 1,756 vacancies. It has its own ETE and is supplied by CASAN and two internal wells.

CHAP (Complexo Penitenciário de Chapecó): The largest prison complex in the state, located in Chapecó, with 2,526 vacancies distributed across four prison units and one socio-educational unit. It receives water from CASAN, underground, and surface sources, all treated at its own ETA, and has its own ETE. Coordinates: UTM 334152.44E; 7000397.98 S.

Data Collection

Data on the number of vacancies, number of prison units, and number of people under state custody were obtained from the State Secretariat for Prison Administration and Social Education (SAP) through the IPEN – Prison Information System management software. Rainfall data for the study locations were obtained from the Ministry of Agriculture and Livestock's Meteorological Institute (INMET) website. Water consumption in the prison complexes was obtained from monthly bills for 2021 and 2022, as well as the costs incurred by the state of Santa Catarina for supplying water to inmates.

Modeling

The work was developed through modeling and model analysis using VENSIM software from Ventana Systems Inc. The software allows dynamic simulations. Dynamic system simulation is a methodology used to transform real phenomena into more tangible models, with systems changing over time and enabling the prediction of different scenarios (Hadiwibowo et al., 2021). The full documentation of the developed and used modeling (necessary information for replicating the modeling) can be found in Appendix 1.

III. RESULTS

Due to their large roof areas, prison complexes are excellent options for rainwater harvesting and reuse. However, public resource investment should always observe the constitutional principles of efficiency and economy (Brazil, 1988). Dynamic system modeling is a highly potential tool that can support managers and public agents in decision-making and public policy formulation.

Considering the possible rainwater harvesting areas in the prison complexes, the region's precipitation, the number of inmates in the establishments, and the per capita water consumption, a model was created to estimate the savings in potable water currently used for cleaning the complexes if a rainwater harvesting and reuse system is installed. Figure 2 shows the developed model.

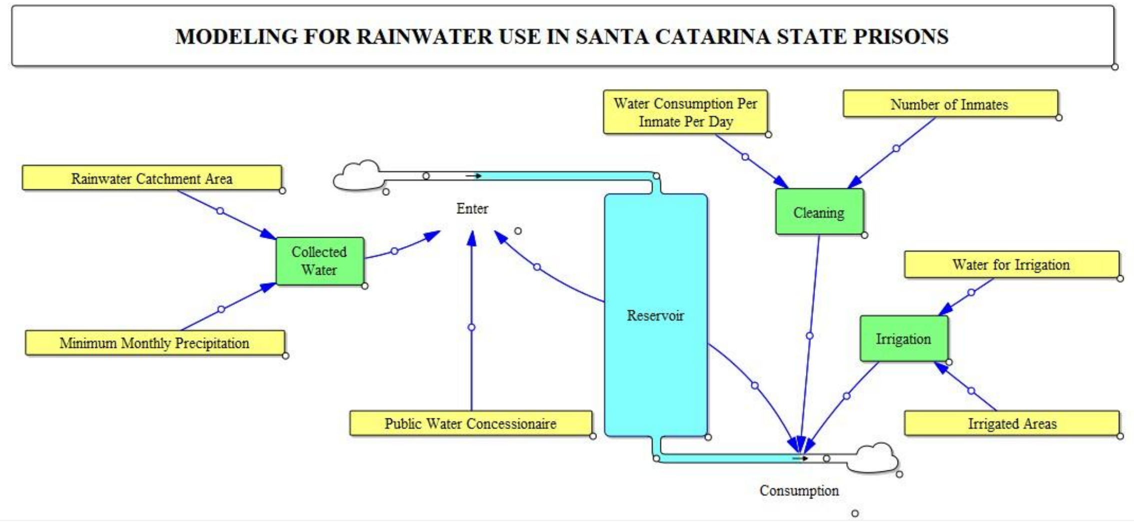


Figure 2: Modeling for Rainwater Use in Prison Units in Santa Catarina.

Currently, the studied prison complexes do not have a rainwater harvesting and reuse system installed. Therefore, all cleaning water used in the complexes comes from water companies or the complexes' own water treatment plants.

The estimated consumption of potable water for cleaning was obtained by subtracting the water used for food preparation, bathing, flushing, laundry, and personal hygiene from the per capita water consumption per inmate in each prison complex. This difference was defined as the water volume for cleaning.

To obtain the values of water consumption for inmate food preparation, two values from the literature were observed: Silva Filho (1996) presented a value of 28 liters per meal prepared in a popular restaurant, and De Souza et al. (2012) presented a consumption of 11 liters per meal. The higher value of Silva Filho can be justified by considering the use of showers by kitchen staff. For prison complexes, 40 liters of water per inmate per day were used for food preparation.

Water consumption for bathing was determined by considering an average bath period of 75 minutes, with 7 liters per minute, totaling 52 liters/day per inmate. Additionally, water consumption for toilet use was calculated, considering six flushes per day with 6 liters used per flush, totaling 36 liters/day per inmate. The water volume for laundry was estimated by the average water consumption by inmates in units with laundry, totaling 6 liters. Also considered were 2 liters of water per inmate per day for consumption and 5 liters for personal hygiene (handwashing and toothbrushing). Table 1 presents the water consumption values by type for inmates.

Table 1: Water Consumption Types for Inmates.

	Type of Water Consumption		
	Noble	Non-Noble	
	Kitchen = 40	toilet = 42	
	Bath = 52		
	In-cell Sink = 3		
	Laundry = 6		
	Consumption = 2		
	Toothbrushing = 2		
Total	105	36	141

The daily water consumption per inmate was determined by averaging the total water volume consumed in the prison complexes divided by the average number of inmates in the complexes. For calculations, values of water volumes consumed in 2021 and 2022, and the number of inmates in the same period, were used.

Utilizing the dynamic modeling presented in Figure 2, the collection area was defined as the total available area for rainwater harvesting system implementation. The number of inmates and the volume of water allocated for cleaning are shown in Table 2, along with the available roof areas used in the modeling.

Prison Complex	**Available Roof Area (m²)**	**No. of Inmates**	**Water Allocated for Cleaning (l/inmate/day)**
CHAP	38200	2800	26
COPE	9600	1300	82
CPVI	19400	2900	101
CRIC	9400	1200	50
SCS	29700	1800	21

Table 2: Initial Data Used in Dynamic Modeling.

The modeling aimed to obtain cleaning water volume values close to zero, as the goal was to observe how rainwater harvesting could reduce the use of potable water supplied by the concessionaire. Applying the developed model to all prison complexes, it was possible to simulate the excess water volume available for cleaning, reducing waste and lowering the costs of potable water for this purpose.

Starting the modeling with the collection area and precipitation values set to zero, the excess cleaning water was obtained at the end of thirty days. When considering a rainwater harvesting system and specific precipitation, the historical average, minimum, and maximum recorded for the region over the past thirty years were used, resulting in reduced water volumes for cleaning.

Figure 3 shows the excess water in four scenarios analyzed for CRIC.

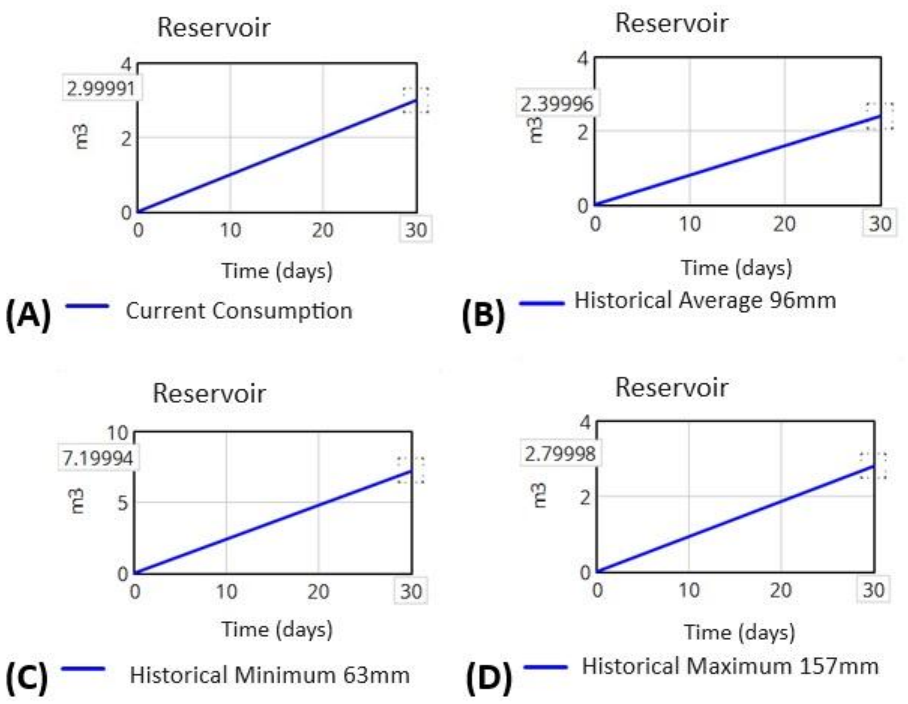


Figure 3: Excess Water in the Reservoir for Cleaning at CRIC – (A) Current Consumption, (B) Historical Average, (C) Historical Minimum, (D) Historical Maximum.

These results allowed for determining the reduction in current water usage in CRIC for each scenario. Figure 4 shows the observed reduction.

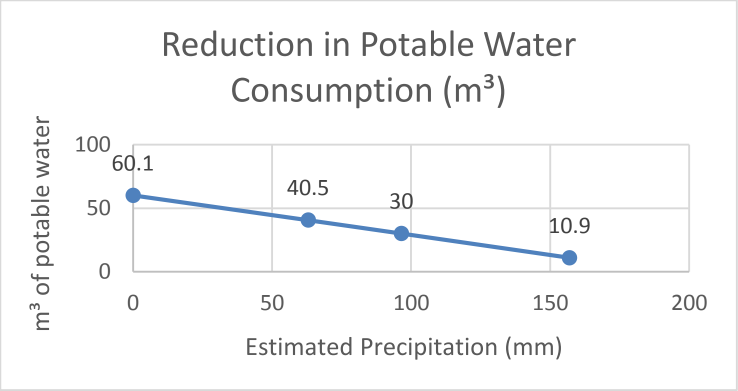


Figure 4: Reduction in Potable Water Consumption at CRIC.

The same procedure was applied to the other prison complexes studied. The graphs of excess water available for cleaning at CPVI, COPE, SCS, and CHAP can be seen in Figures 5-8, respectively.

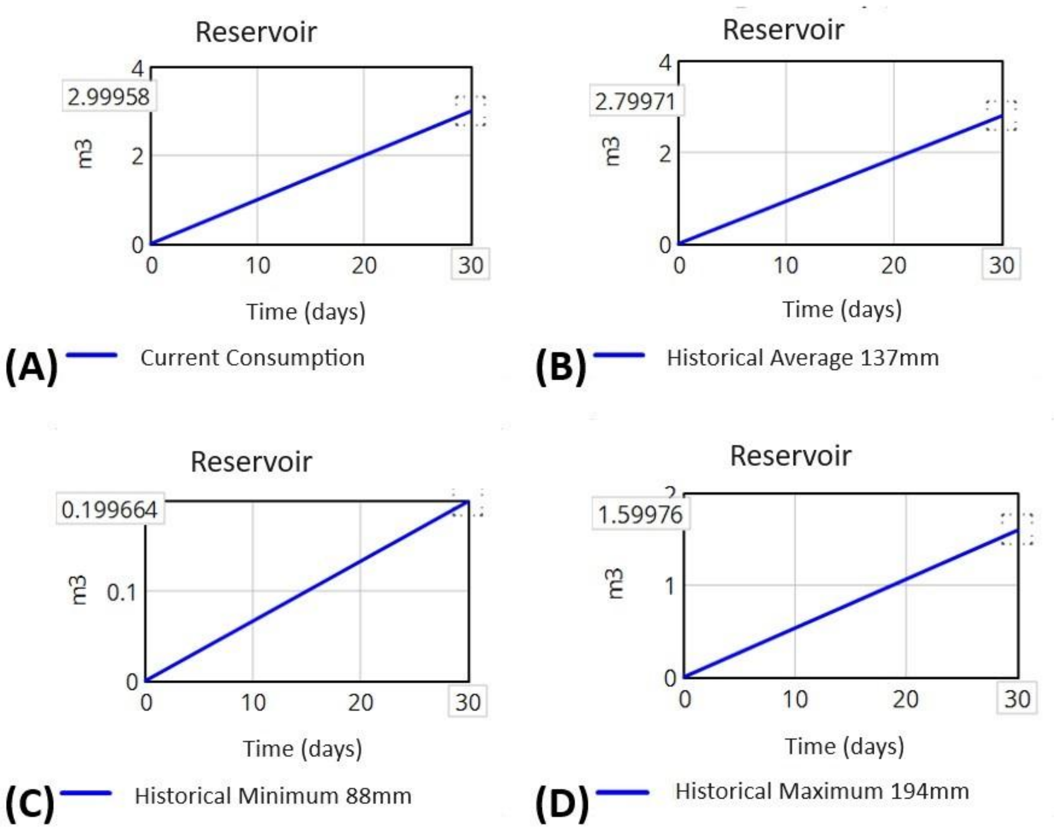


Figure 5: Excess Water in the Reservoir for Cleaning at CPVI – (A) Current Consumption, (B) Historical Average, (C) Historical Minimum, (D) Historical Maximum.

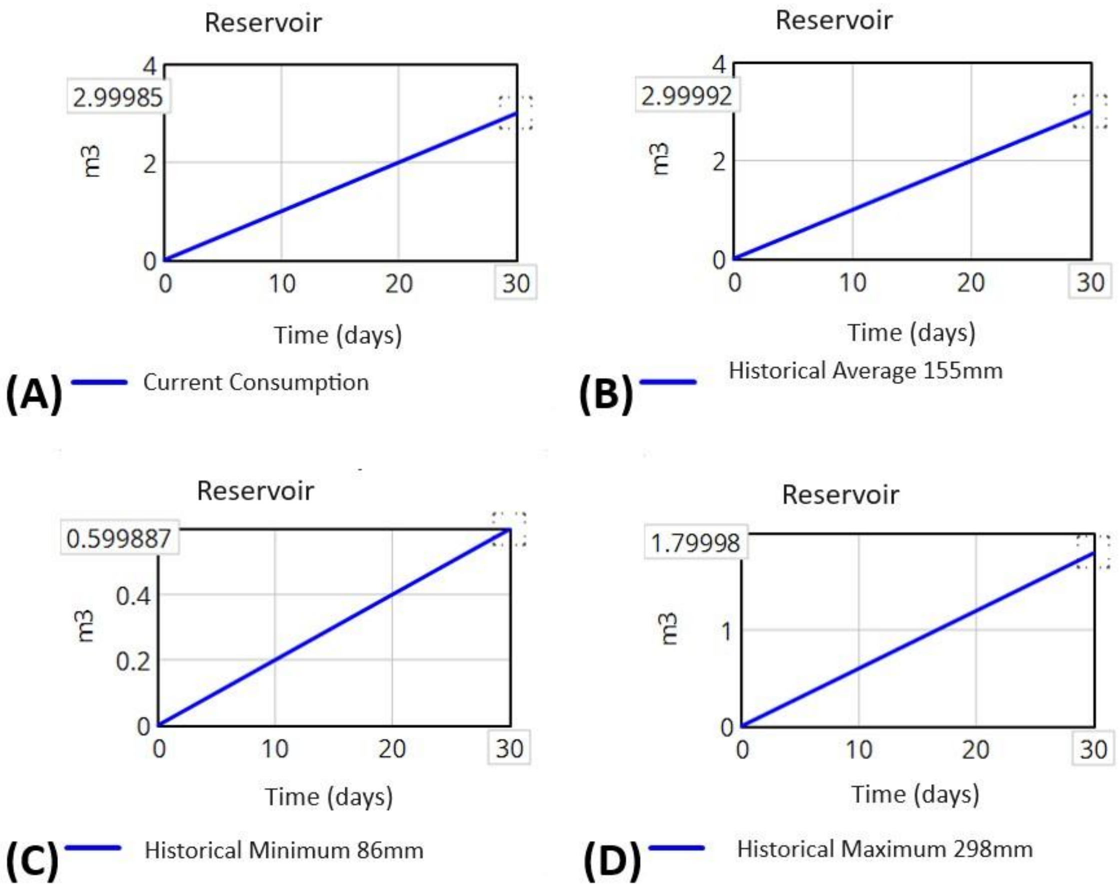


Figure 6: Excess Water in the Reservoir for Cleaning at COPE – (A) Current Consumption, (B) Historical Average, (C) Historical Minimum, (D) Historical Maximum.

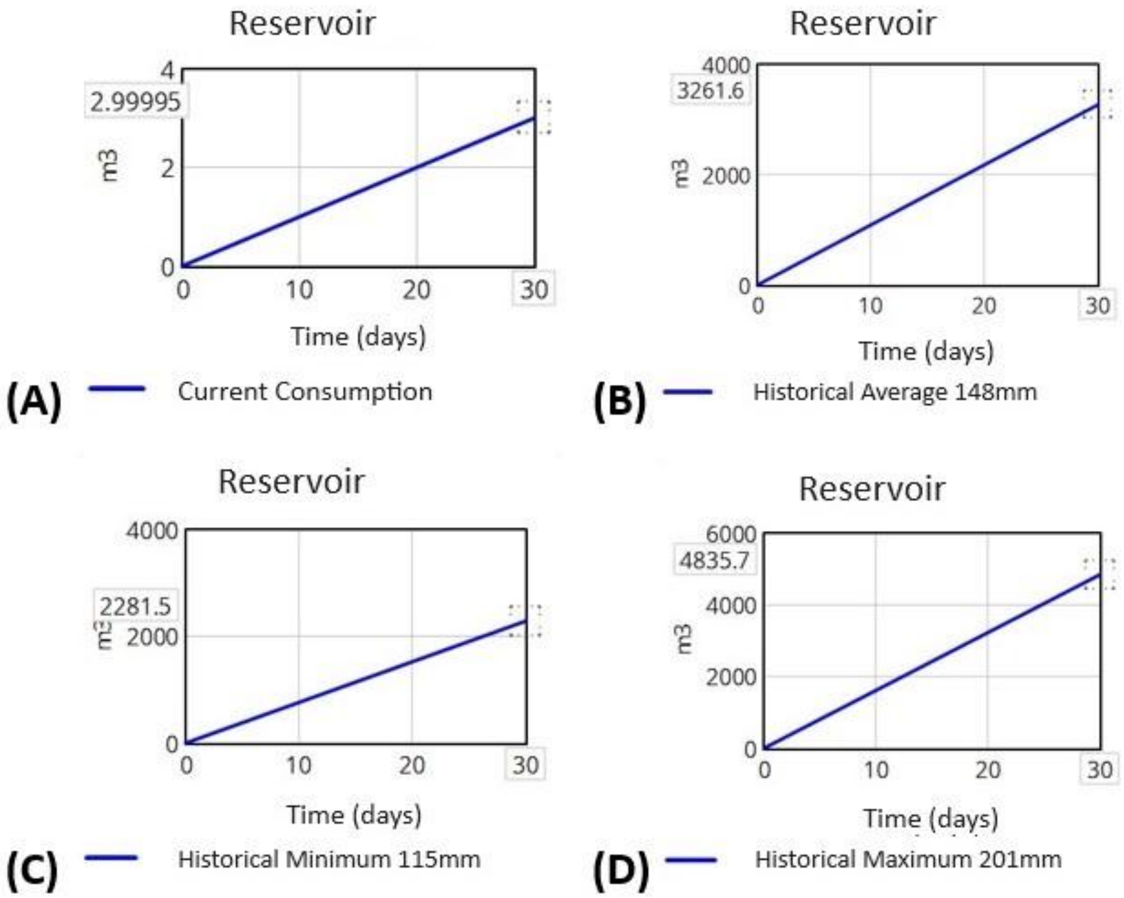


Figure 7: Excess Water in the Reservoir for Cleaning at SCS – (A) Current Consumption, (B) Historical Average, (C) Historical Minimum, (D) Historical Maximum.

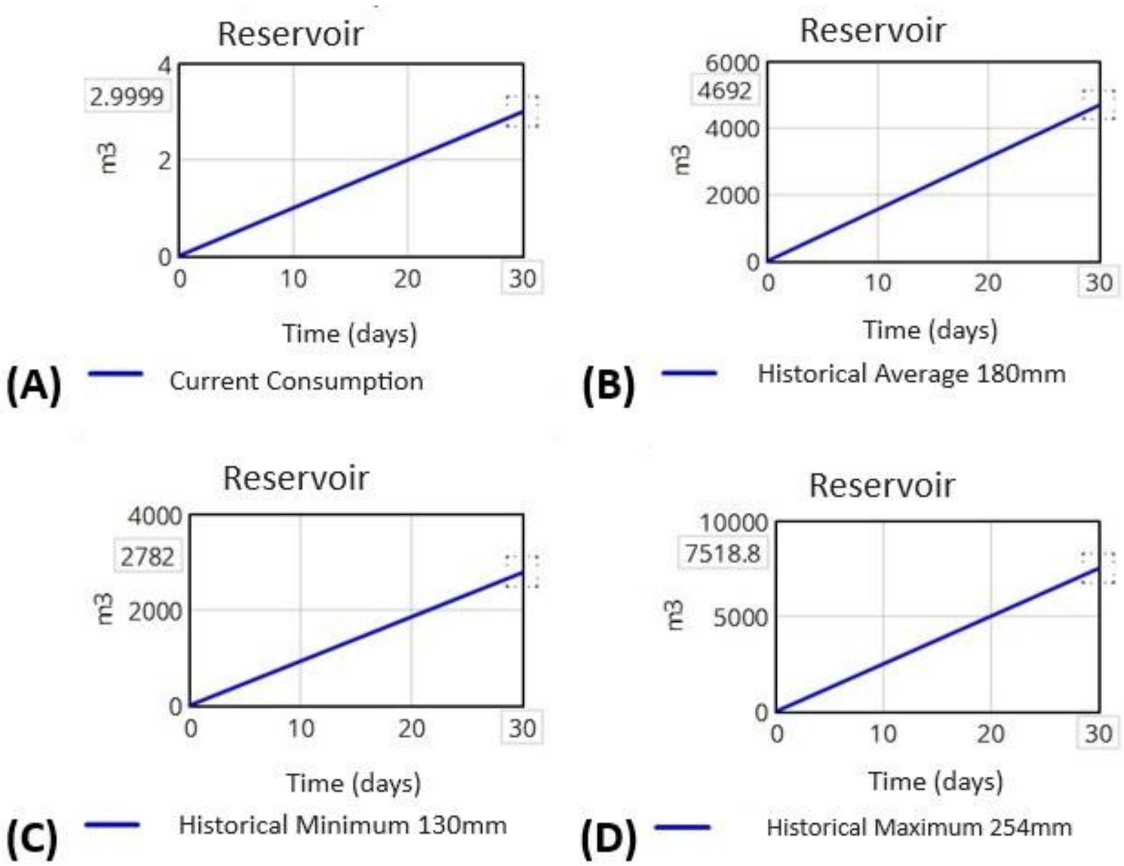


Figure 8: Excess Water in the Reservoir for Cleaning at CHAP – (A) Current Consumption, (B) Historical Average, (C) Historical Minimum, (D) Historical Maximum.

The potable water consumption reduction graphs for CPVI, COPE, SCS, and CHAP are shown in Figures 9-12, respectively.

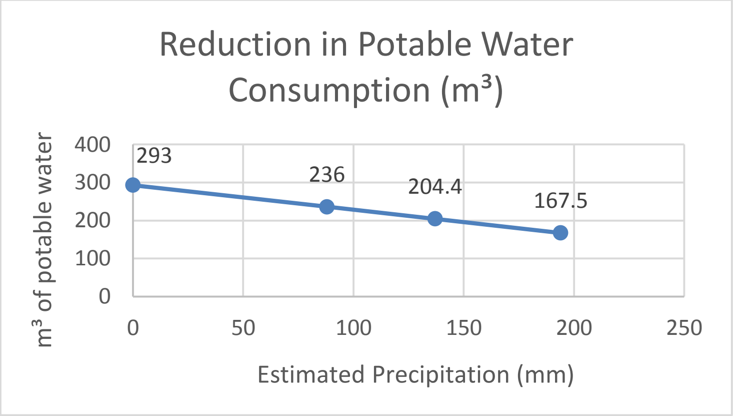


Figure 9: Reduction in Potable Water Consumption at CPVI.

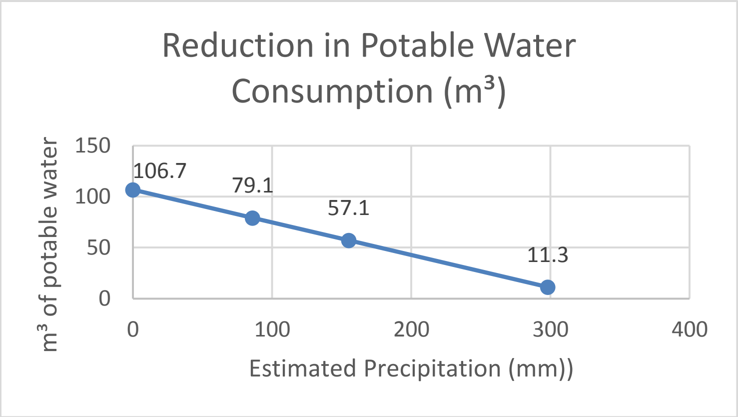


Figure 10: Reduction in Potable Water Consumption at COPE.

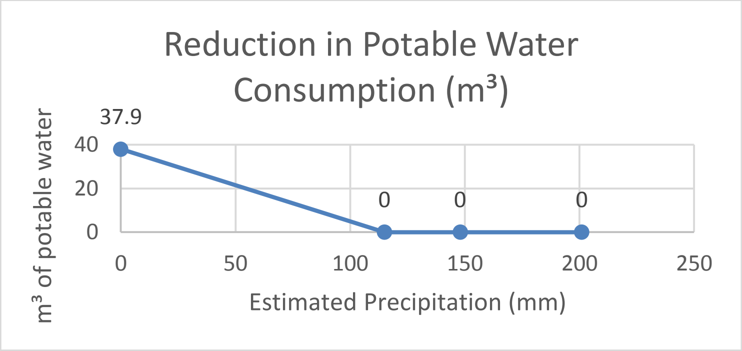


Figure 11: Reduction in Potable Water Consumption at SCS.

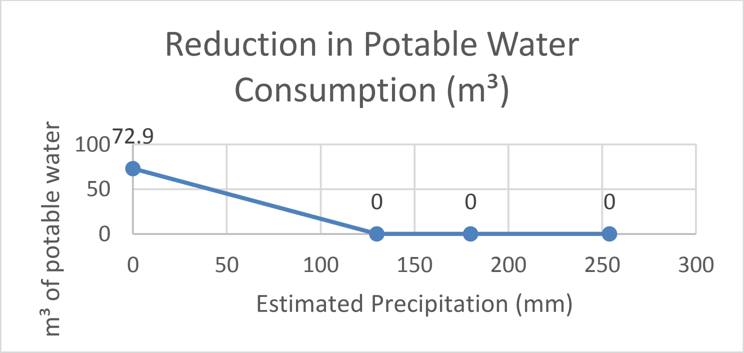


Figure 12: Reduction in Potable Water Consumption at CHAP.

Table 3: Reduction in Potable Water Consumption.

	Precipitation (mm)	**water utility (m³)**	**Consumption Reduction (%)**
		CRIC	
Current Consumption	0	61	0
Historical Min.	63	40,5	33,6
Historical Avg.	96,5	30	50,8
Historical Max.	157	10,9	82,1
		CPVI	
Current Consumption	0	293	0
Historical Min.	88	236	19,5
Historical Avg.	137	204,4	30,2
Historical Max.	194	167,5	42,8

		COPE	
Current Consumption	0	106,7	0
Historical Min.	86	79,1	25,9
Historical Avg.	155	57,1	46,5
Historical Max.	298	11,3	89,4
		SCS	
Current Consumption	0	37,9	0
Historical Min.	115	0	100
Historical Avg.	148	0	100
Historical Max.	201	0	100
		CHAP	
Current Consumption	0	72,9	0
Historical Min.	130	0	100
Historical Avg.	180	0	100
Historical Max.	254	0	100

Significant reductions of more than 80% are observed in CRIC and COPE if monthly precipitation reaches the maximum recorded values in the historical series. Although uncommon, historical averages still show a reduction in potable water consumption of 508% and 465%, respectively.

At CPVI, the reduction in potable water consumption is lower than at the other complexes. Even with the maximum recorded precipitation of 194 mm, the reduction in potable water consumption for cleaning would only be 428%. This is not due to lower precipitation values but because CPVI has the highest per capita water consumption among the analyzed complexes, surpassing SCS by 7,920% and CHAP by 7,420%. The high per capita consumption is also justified by the complex's highest prison population, with 2,900 inmates and the third largest rainwater harvesting area.

SCS and CHAP have unique characteristics due to high rainfall indices and large roof areas within the prison complexes. To meet the cleaning water needs using the total roof areas in these complexes, the historical minimum precipitation of 115 mm for SCS and 130 mm for CHAP would be sufficient, resulting in an excess of 22,436 m³ for SCS and 27,091 m³ for CHAP. Considering average and maximum historical rainfall, high water volumes are collected, reaching 48,357 m³ in SCS and 75,188 m³ in CHAP, as shown in Figures 7 and 8.

Based on this information, a new simulation with the dynamic modeling was conducted, reducing the rainwater harvesting areas in SCS and CHAP. Similar to the simulation with the total available roof areas, the simulation with reduced rainwater harvesting areas also showed values close to zero, demonstrating that even with reduced harvesting areas, the cleaning water needs are still met. Figures 13 and 14 present the results for SCS and CHAP, respectively.

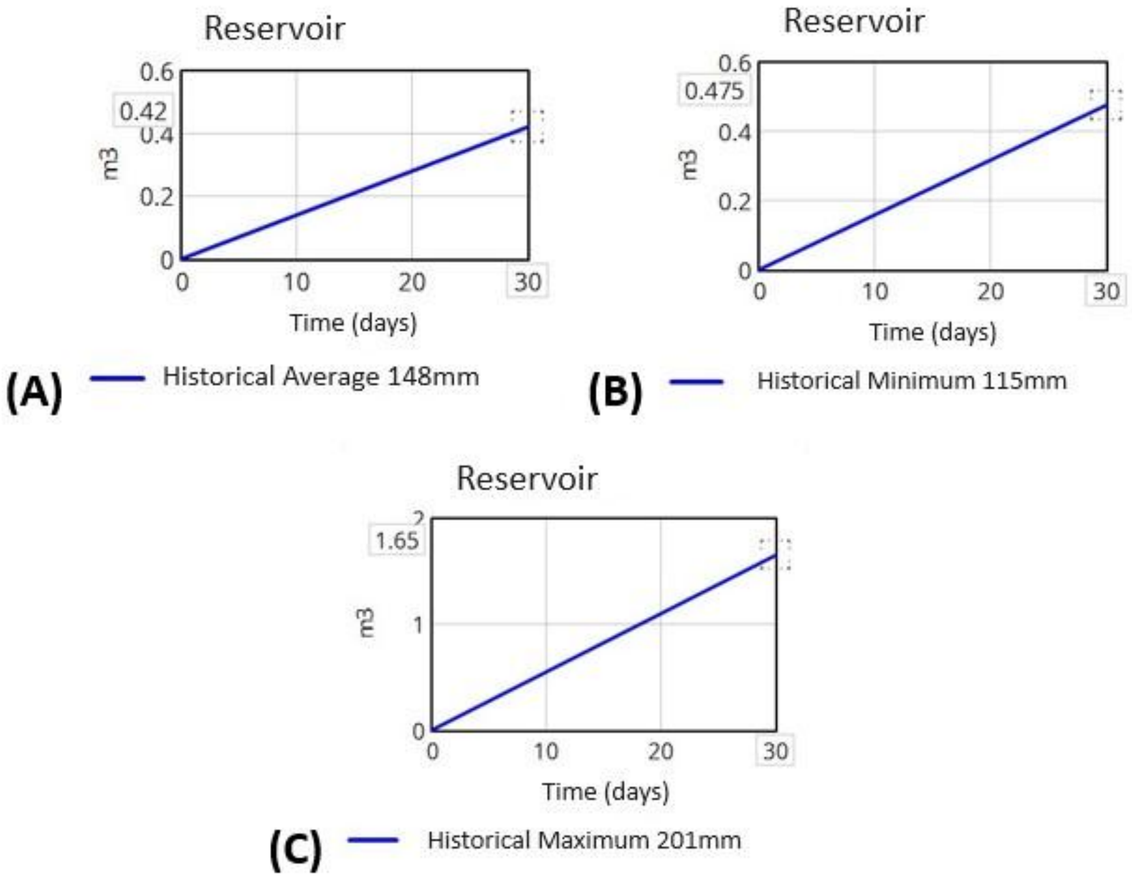


Figure 13: Excess Water in the Reservoir for Cleaning at SCS with Reduced Rainwater Harvesting Areas – (A) Historical Average, (B) Historical Minimum, (C) Historical Maximum.

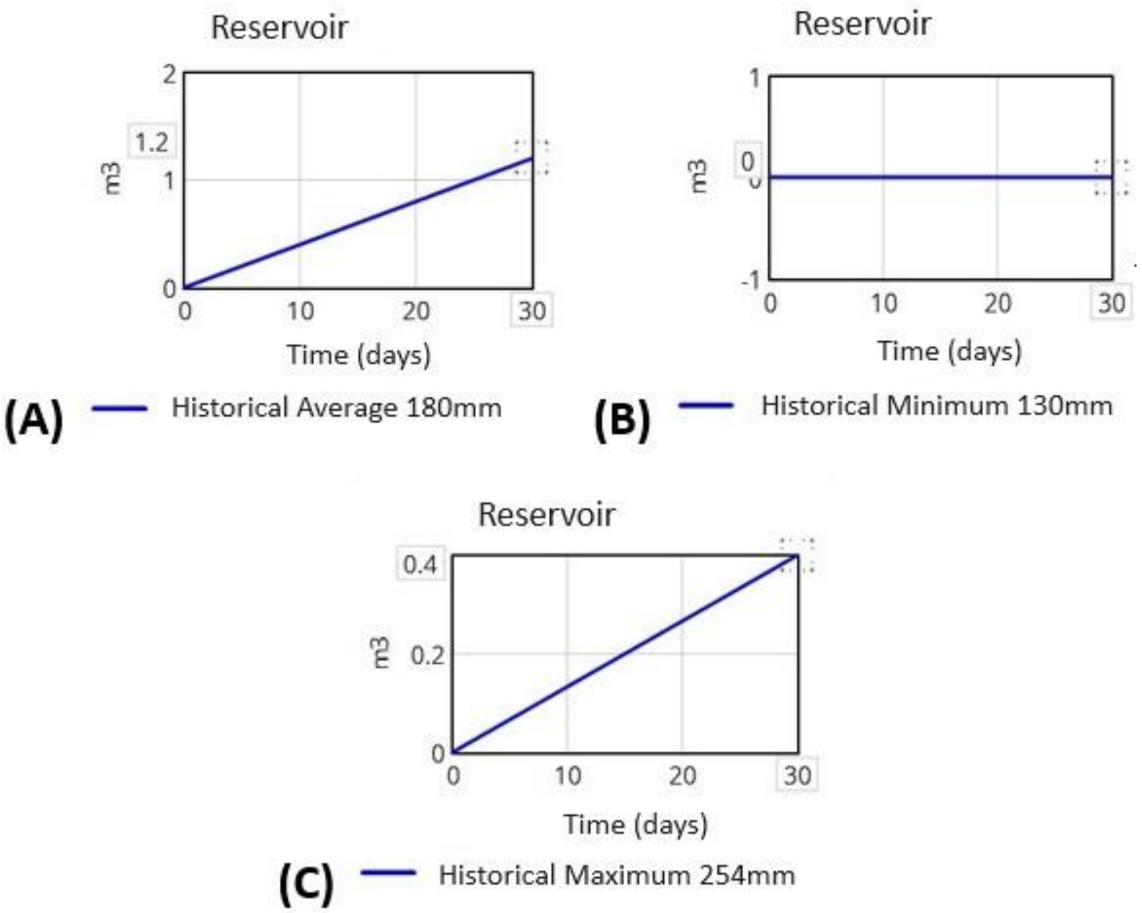


Figure 14: Excess Water in the Reservoir for Cleaning at CHAP with Reduced Rainwater Harvesting Areas – (A) Historical Average, (B) Historical Minimum, (C) Historical Maximum.

Table 04 presents the values in m² of rainwater collection area with the respective rainfall recorded for SCS and CHAP.

Table 04: Reduction in catchment area in relation to increased precipitation.

SCS		**CHAP**	
Rainwater Harvesting Area (m²)	**Precipitation (mm)**	**Rainwater Harvesting Area (m²)**	**Precipitation (mm)**
29700	0	38200	0
9856	115	16800	130
7665	148	12140	180
5650	201	8600	254

The values in Table 4 show that to meet the cleaning water needs, only 33% of the available area in SCS and 44% in CHAP need to be equipped with a rainwater harvesting system. This results in significant savings for public funds regarding the installation costs of the rainwater harvesting system. Furthermore, SCS and CHAP have areas for growing fruits and vegetables that are sold by the prison complexes, generating work and income for inmates. These crops require an irrigation system to meet the plants' water demand. Both SCS and CHAP have ponds where rainwater is already stored and pumped for irrigation when necessary.

Thus, installing a rainwater harvesting system on the total roof area is justifiable and viable, especially in CHAP, where the prison has its own water treatment plant (ETA) that provides part of the water to inmates. Due to water supply issues from the concessionaire in recent years, rainwater collection, storage, and treatment within the prison would minimize dependence on external suppliers.

IV. CONCLUSIONS

Dynamic system modeling is a highly useful tool for assisting public managers in decision-making, especially for decisions with medium- and long-term repercussions. This study shows that public investments in rainwater harvesting and reuse systems are highly feasible economically and environmentally, given that the state of Santa Catarina spent over $1,800,000 on water supply for the analyzed prison complexes in 2021 and 2022.

CRIC and COPE were the most promising complexes for installing rainwater harvesting systems, with 508% and 465% savings in potable water, respectively, if precipitation remains around the historical average. Savings can exceed 82% if precipitation approaches the maximum recorded for the regions. For CPVI, with the highest per capita water consumption, if precipitation remains close to the historical minimum of 88 mm, monthly treated water savings would be 195%. The expected average savings are 302% considering the historical average.

SCS and CHAP, using the total available roof area for rainwater harvesting with historical minimum precipitation, result in excesses of 22,815 m³ and 27,282 m³, respectively, of collected water available for cleaning. With average monthly precipitation in these regions, excesses of collected water can reach 32,615 m³ in SCS and 46,492 m³ in CHAP. These millions of liters of collected water can supply the ponds present in both prison complexes and be used for irrigating crops, reducing the need for water storage tanks.

Another point that makes CHAP an excellent option for installing a rainwater harvesting system is the existence of its own ETA, which supplies part of the potable water to inmates. Due to water supply problems from the concessionaire in recent years, internal water collection, storage, and treatment would minimize dependence on external suppliers.

However, due to the large roof areas available for rainwater collection (29,700 m² in SCS and 38,200 m² in CHAP), the initial investment may be slightly high. Considering the implementation costs and high rainfall indices in these regions, it was observed that with only the historical minimum precipitation, 33% of the available collection area in SCS and 44% in CHAP would suffice to meet the cleaning water needs.

REFERENCES

[1]. Abdulla, F. (2020). Rainwater harvesting in Jordan: potential water saving, optimal tank sizing and economic analysis. Urban Water Journal, 17(5), 446-456.

[2]. Amos, C. C., Rahman, A., & Gathenya, J. M. (2018). Economic analysis of rainwater harvesting systems comparing developing and developed countries: A case study of Australia and Kenya. Journal of cleaner production, 172, 196-207.

[3]. Brasil. [Constituição (1988)]. Constituição da República Federativa do Brasil de 1988. Brasília, DF: Presidência da República, [2016]. Disponível em: http://www.planalto.gov.br/ccivil_03/Constituicao/ Constituiçao.htm. Acesso em: 10 nov. 2023.

[4]. Brasil. Santa Catarina. Secretaria de Estado da Administração Prisional e Socioeducativa, 2023. Acesso em: 1 fev. 2023.

[5]. Bus, A., & Szelągowska, A. (2021). Green water from green roofs—the ecological and economic effects. Sustainability, 13(4), 2403.

[6]. Cai, J., Zhao, D., & Varis, O. (2021). Match words with deeds: Curbing water risk with the Sustainable Development Goal 6 index. Journal of Cleaner Production, 318, 128509.

[7]. Chunga, B. A., Marx, W., Cai, X., de Clercq, W., Watson, A., & Malota, M. (2023). Water allocation using system dynamic modelling in the aquaculture integrated with small-scale irrigation systems in Malawi. Physics and Chemistry of the Earth, Parts A/B/C, 129, 103355.

[8]. DEPEN – Departamento Penitenciário Nacional. (2022). Modelo de gestão da política prisional: Caderno II: arquitetura organizacional e funcionalidades. Brasil: Departamento Penitenciário Nacional, Programa das Nações Unidas para o Desenvolvimento, Conselho Nacional de Justiça.

[9]. de Souza, D. P., Santos, R. K., & Santos, R. F. (2012). Estimativa do consumo de água em restaurantes na cidade de Cascavel-PR. Acta Iguazu, 1(3), 50-63.

[10]. Dwivedi, P. P., & Sharma, D. K. (2022). Application of Shannon Entropy and COCOSO techniques to analyze performance of sustainable development goals: The case of the Indian Union Territories. Results in Engineering, 14, 100416.

[11]. García-Ávila, F., Valdiviezo-Gonzales, L., Iglesias-Abad, S., Gutiérrez-Ortega, H., Cadme-Galabay, M., Donoso-Moscoso, S., & Zhindón-Arévalo, C. (2021). Opportunities for improvement in a potabilization plant based on cleaner production: Experimental and theoretical investigations. Results in Engineering, 11, 100274.

[12]. García, J. M. (2023). Theory and practical exercises of system dynamics: modeling and simulation with Vensim PLE. Preface John Sterman. Juan Martin Garcia.

[13]. Giné-Garriga, R., Delepiere, A., Ward, R., Alvarez-Sala, J., Alvarez-Murillo, I., Mariezcurrena, V., ... & Jiménez, A. (2021). COVID-19 water, sanitation, and hygiene response: Review of measures and initiatives adopted by governments, regulators, utilities, and other stakeholders in 84 countries. Science of the Total Environment, 795, 148789.

[14]. Guo, W., Cronk, R., Scherer, E., Oommen, R., Brogan, J., Sarr, M., & Bartram, J. (2019). A systematic scoping review of environmental health conditions in penal institutions. International Journal of Hygiene and Environmental Health, 222(5), 790-803.

[15]. Hadiwibowo, J. C., Halim, S., Yahya, B. N., Agustin, K., & Sahputra, I. H. (2021, April). A policy strategy evaluation for covid-19 pandemic in the city of surabaya using vensim ventana dynamic system simulation. In 2021 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT) (pp. 215-221). IEEE.

[16]. Hdeib, R., & Aouad, M. (2023). Rainwater harvesting systems: An urban flood risk mitigation measure in arid areas. Water Science and Engineering.

[17]. Hernando, V., Vázquez, I., Díaz, A., Gómez-Pintado, P., Martínez-Aznar, C., & Acín, E. (2023). COVID-19 pandemic in prisons in Spain: characteristics of cases and implemented control measures, March 2020–June 2022. Public health, 218, 45-52.

[18]. Inmet. Site do Inmet, 2023. Gráficos Climatológicos. Disponível em https://clima.inmet.gov.br/GraficosClimatologicos/DF/83377 . Acesso em 17 jun. 2023.

[19]. Inmet. Site do Inmet, 2023. Gráficos Climatológicos. Disponível em https://portal.inmet.gov.br/servicos/gr%c3%a1ficos-climatol%c3%b3gicos . Acesso em 17 jun. 2023.

[20]. Jamal, A. S. I. M., Tarek, Y. A., Siddique, M. A. B., Shaikh, M. A. A., Debnath, S. C., Uddin, M. R., ... & Sultana, S. (2023). Development of a fabricated first-flush rainwater harvested technology to meet up the freshwater scarcity in a South Asian megacity, Dhaka, Bangladesh. Heliyon, 9(1).

[21]. Jian, Z., Abd Rahman, N. F., & Ong, J. (2023). Modelling the Carrying Capacity of Water Resources for Sustainable Water Ecology Using Vensim. International Journal of Professional Business Review, 8(9), e03846-e03846.

[22]. Kakoulas, D. A., Golfinopoulos, S. K., Koumparou, D., & Alexakis, D. E. (2022). The effectiveness of rainwater harvesting infrastructure in a Mediterranean island. Water, 14(5), 716.

[23]. Kummu, M., Guillaume, J. H., de Moel, H., Eisner, S., Flörke, M., Porkka, M., ... & Ward, P. J. (2016). The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. Scientific reports, 6(1), 38495.

[24]. Murei, A., Mogane, B., Mothiba, D. P., Mochware, O. T. W., Sekgobela, J. M., Mudau, M., ... & Momba, M. N. B. (2022). Barriers to Water and Sanitation Safety Plans in Rural Areas of South Africa—A Case Study in the Vhembe District, Limpopo Province. Water, 14(8), 1244.

[25]. Niknam, A., Zare, H. K., Hosseininasab, H., & Mostafaeipour, A. (2023). Developing an LSTM model to forecast the monthly water consumption according to the effects of the climatic factors in Yazd, Iran. Journal of Engineering Research, 11(1), 100028.

[26]. Ohlund, R. J., Dahdah, B. H., Guillen, G. R., & Childress, A. E. (2024). Augmenting ocean water desalination with potable reuse: Concept feasibility in terms of cost and environmental impacts. Desalination, 569, 116941.

[27]. Perveen, S. (2023). Drinking water quality monitoring, assessment and management in Pakistan: A review. Heliyon.

[28]. Penserini, L., Cantoni, B., Gabrielli, M., Sezenna, E., Saponaro, S., & Antonelli, M. (2023). An integrated human health risk assessment framework for alkylphenols due to drinking water and crops' food consumption. Chemosphere, 325, 138259.

[29]. Preeti, P., & Rahman, A. (2021). A case study on reliability, water demand and economic analysis of rainwater harvesting in Australian capital cities. Water, 13(19), 2606.

[30]. SENAPPEN – Secretaria Nacional de Politicas Penais. (2022). Recuperado em 27 de maio de 2023 de https://www.gov.br/senappen/pt-br/acesso-a- informacao/institucional.

[31]. Silva Filho, A. R. A. D. (1996). Manual básico para planejamento e projeto de restaurantes e cozinhas industriais. In Manual básico para planejamento e projeto de restaurantes e cozinhas industriais (pp. 232-232).

[32]. Stang, S., Khalkhali, M., Petrik, M., Palace, M., Lu, Z., & Mo, W. (2021). Spatially optimized distribution of household rainwater harvesting and greywater recycling systems. Journal of Cleaner Production, 312, 127736.

[33]. Tortajada, C., & Biswas, A. K. (2018). Achieving universal access to clean water and sanitation in an era of water scarcity: strengthening contributions from academia. Current opinion in environmental sustainability, 34, 21-25.

APPENDIX 1

(01) Captured Water=Contribution Area * (Minimum Monthly Precip. / 30) * 0.001
Units: m3 [0,80000,1]
Water captured by rooftops with average quarterly rain from the official INMET 30-year series.

(02) Daily Running Water=0
Units: m3 [0,500,1]
Additional running water (Company), in m3 per day, needed to balance consumption when rain or consumption is insufficient.

(03) Water for Irrigation=0
Units: m3/Ha [0,1000,1]
m3 of water per hectare per quarterly cycle to be irrigated (average quarterly value) (4 cycles in a year).

(04) Contribution Area=9400
Units: m2 [5000,40000,10]
Contribution area from economically viable rooftops due to size and location in the penitentiary complex.

(05) Irrigated Area=0
Units: Ha [0,20,1]
Area to be irrigated with rainwater.

(06) Consumption=Reservoir - Cleaning - Irrigation
Units: m3
Output is the tank content, each day, minus consumption/uses.

(07) Daily Consumption per Inmate=50
Units: liters/person [10,150,1]
Liters of water for cleaning per inmate per day (obtained by difference from known consumptions).

(08) Input=Reservoir + Captured Water + Daily Running Water
Units: liters
Input is recovered rainwater and running water, if necessary.

(09) FINAL TIME=30
Units: days
The final time for the simulation.

(10) INITIAL TIME=0
Units: days
The initial time for the simulation.

(11) Irrigation=(-1) * Water for Irrigation * Irrigated Area
Units: m3 [?,?,1]
Water in m3 used for irrigation per Ha of crops/gardens.

(12) Cleaning=(-1) * Daily Consumption per Inmate * Number of Interns * 0.001
Units: m3 [?,?,10]
Water in cubic meters per month used for cleaning (values must be negative).

(13) Number of Interns=1200
Units: people [500,4000,1]
Number of internal people.

(14) Minimum Monthly Precip.=0
Units: mm [0,1200,10]
Minimum average monthly precipitation from INMET time series. Month with the lowest average accumulation in the region in mm.

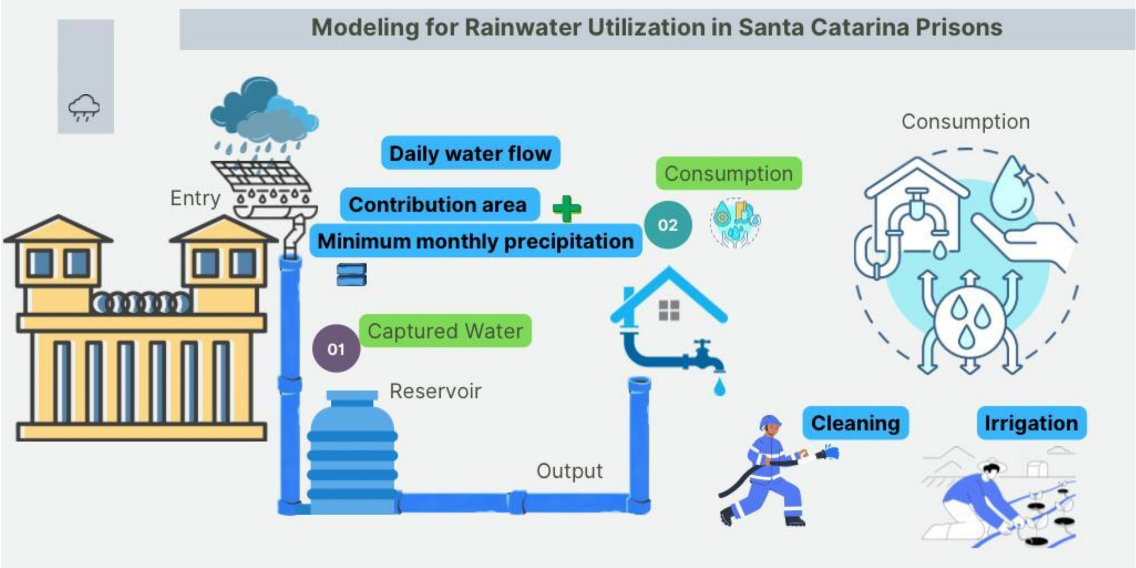
(15) Reservoir=INTEG (Input-Consumption,0)
Units: m3 [0,500000,5]
Water tank for rainwater recovery in m3 starting from zero.

(16) SAVEPER=TIME STEP
Units: days [0,?]
The frequency with which output is stored.

(17) TIME STEP=1
Units: days [0,?]
The time step for the simulation.

APPENDIX 2

Dynamic Modeling of Rainwater Harvesting Potential in Santa Catarina Prisons



This infographic illustrates the dynamic system model used to assess the potential of rainwater harvesting for cleaning purposes in five prison complexes in Santa Catarina, Brazil.