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Decentralized Water Supply Management Model: a Case Study of Public Policies for the Utilization of Rainwater

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Abstract

The growing population has resulted in the need for new alternatives that guarantee water supply to the population. Among the alternatives, there is the individual system for capturing and utilizing rainwater. The objective of this article was to test a municipal policy that makes it mandatory to implement the system and to attest how much it can optimize the current public water supply system through the construction of a simulation model. The simulation considered the policy implementation in one city, and the analysis of the results showed the effectiveness of the policy, which can optimize an average of 114,275.00 m^3 in 2030, with demand reduction. However, it was verified that the isolated initiative is not sufficient to solve the problem of supply and demand. There is a need to expand the implementation of the policy to other cities supplied by the studied macro public system. Also, if the current management practices remain, the projection is that the current system will not guarantee supply for the coming years, mainly due to the strong impact of tourism on demand, needing new sources of supply, techniques and management strategies.

Keywords Water · Systems dynamics · Public policies and rainwater

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1 Introduction

Safe drinking water and adequate sanitation are crucial for poverty reduction and sustainable development according to the Human Right Obligations (UN 2010). In Brazil, basic sanitation is one of the main attributions of the Public Power. The Brazilian National Policy of Basic Sanitation (Law No. 11,445) that came into force in 2007 recommends the universalization of access to basic sanitation and adoption of methods, techniques, and processes that include local and regional singularities. This Policy considers the activities of waste collection, urban drainage, water supply, and sanitary sewage as basic sanitation (Brazil 2007), defining the Water Supply System (WSS) as constituted by the activities, infrastructures, and facilities necessary for the public supply of drinking water, from collection to building and residence connections (Brazil 2007).

Individual solutions for water supply, such as rainwater, are not in the scope of WSS law. However, state and municipal policies have been working with decentralized solutions, making mandatory the collection of rainwater depending on the area or purpose of the property. The benefits of on-site retention are flood control, inhibition of clandestine rainwater connections to the collective sewage collection network, replenishment and protection of groundwater, and the guarantee of water supply stability and quality (Baki et al. 2018; Bashar et al. 2018).

The projection of water demand worldwide by 2030 exceeds supply capacity by 40% if current resource management practices are maintained (2030 WRG 2009). Furthermore, in 2018, 16.4% of Brazilians have no access to treated water (SNIS 2019). These facts highlight the need for system expansion and process optimization. Restricted water resources and limited budgets lead engineers, researchers, and decision makers to rethink the way urban water is managed (Sitzenfrei et al. 2017). As the population increases and public supply systems fail to keep pace with this growth, access to water becomes a problem (Bashar et al. 2018).

Another fact that emphasizes the need for improving public supply systems is the lack of water supply, which is common in Brazil in periods of high heat, such as summer, due to the increase in average consumption per inhabitant. The situation is worse in tourism regions, with tourists significantly increasing local demand. The lack of water in supply results in financial losses in the tourism sector, limiting its potential for growth and affecting the reputation of the area. This paper aims to present a model using a Systems Dynamics (SD) that shows the future scenario of public WSS with the implementation of a public policy for rainwater collection and use in single-family residences through a case study in a Brazilian region. The objective is to understand whether the initiative can prolong the WSS operability in a way that guarantees the efficiency in water supply in critical situations, such as the increase of the resident population and variations in periods of greater demand, as occurs in the summer.

The contributions of the study can be summarized as follows: (1) a clear description of dynamic interconnections of WSS with a growing population and tourism inflow and their key role in successfully developing government policies; and (2) the long term tendencies of three scenarios, including rainwater harvesting and use in single-family residences policy, from the technical and managerial perspectives. To the authors' knowledge, this topic is rarely reported in the literature.

The SD modeling has proved to be a robust alternative operating framework for understanding the dynamics of complex system variables (Alcalá et al. 2015) to provide quantitative and uncertainty assessments. SD has been employed to evaluate water resource management in many aspects (Winz et al. 2009; Sahin et al. 2018; Baki et al. 2018). The use of SD is justified since the method allows simulating current and future water supply and demand, demonstrating the behavior of the system in different scenarios.

This article is structured in six sections. The introduction contextualizes the problem. The literature review presents the main concepts about WSS and individual systems, as well as an overview of the application and tendencies of the studies using SD models in the context of water resources management. The third section presents the methodological description applied. The fourth section presents the structure, construction of the model, while the fifth section analyzes the performance through the simulation of different scenarios. The article ends with conclusions drawn from the critical analysis of the results.

2 Literature Review

To ensure understanding, this section presents the main studies, concepts, and relevant legislation to construct the Systems Dynamics Model.

2.1 Water Supply in Urban Centers

A water supply system (WSS) should guarantee users good quality water, in adequate quantity and pressure. The main components of a WSS are source, abstraction, lift station, water treatment plant, reservoir, and distribution network (Tsutiya 2006). The decline of water resources combined with the increase in the demand for drinking water has already become a political issue in many locations (de Lima et al. 2018). Population habits, municipality characteristics, climatic conditions, devices to measure water consumption, price, and socio-economic factors affect water consumption and supply (Tsutiya 2006; Dias et al. 2018). In regions with a semi-cold and humid climate, consumption is approximately 100 l/inhab.day, reaching 300 l/inhab.day in the tropical dry climate (Tsutiya 2006).

Large urban centers already suffer from water scarcity (de Lima et al. 2018; Gao and Yu 2018). The use of rainwater is a widely disseminated strategy and accepted as an efficient approach to promote the economy of drinking water and mitigate scarcity (Geraldi and Ghisi 2018). Rainwater collection systems have been used since antiquity, with a first register dated 830 B.C., found in the Mohabite stone. Another example is the Templars Fortress, located in the city of Tomar, in Portugal, from 1160 A.D, which was supplied with rainwater (Tomaz 2007). Nowadays, changing climatic conditions, growing populations, and uncertain availability of water resources are challenging new policy strategies to guarantee access to clean water (Zeisl et al. 2018). Rainwater harvesting has received increasing attention as one of the most promising alternative sources of water, which can be used to partially offset the growing demand for clean water globally (Bashar et al. 2018). Zeisl et al. (2018) indicate that even small rainwater collection systems implemented at a local level can have remarkable effects when operated as clustered schemes. The authors also point out a potential reduction of potable water demand when adopting rainwater collection systems.

The Brazilian Technical Standard from the ABNT 15,527 (2007) defines rainwater as the water resulting from atmospheric precipitation collected on building penthouses and roofs, where there is no traffic of people, vehicles or animals. The use of rainwater can have potable and non-potable purposes. Potable water is understood to be water within the parameters established by Ordinance No. 2914 of the Ministry of Health (Brazil 2011), consisting of water that can be consumed by humans, without any health risks, such as tap water and water for the shower and washbasin. Non-potable water is water with parameters that are outside the standards of the Ordinance, such as water for gardening, carwash, pool, toilets, laundry sink, and washing machine.

In an individual rainwater collection system design, the main components are collection area, gutters and conductors, treatment, storage, pipelines, and points of use. The volume is determined by the formula presented by Tomaz (2007):

$$V = P \times A \times C \times \eta \text{ collection factor}$$

Where:

V = annual, monthly or daily volume of rainwater that can be used, in liters;
P = mean annual rainfall, monthly or daily, in millimeters;
A = collection area, in square meters;
C = runoff coefficient. Usually C = 0.95.
η collection factor = efficiency of the collection system, considering the disposal.
When we do not have data, a practical value is to adopt: C x η = 0.80.

In case the design does not consider the first flush (discharge of the first waters), we suggest the adoption of η = 0.90.

In Brazil seven states already have a policy to mandatory use of rainwater collectors in new buildings, according to municipal criteria. Furthermore, five states have incentive, study or partial obligation. Few laws present specific criteria for single-family buildings. Table 1 shows state and municipal legislation according to the mandatory criteria in each state or municipality.

2.2 System Dynamics

System Dynamics is a method that represents the structure and dynamics of complex systems from simulation models and scenario projection. This computer-based tool is often applied to support decision-makers to evaluate policy options and formulate more effective policies or strategies (Stave 2003; Sterman 2000). Such tools have been used in several areas, including manufacturing, public health, service management, technology management, climate change, and urban planning, including urban water management (Morecroft 2015).

Computational models are applied to urban water management since such systems are complex and dynamic, that is, they are constantly adapting to changes and evolutions in the urban environment, aiming to maintain existing services and provide additional services (Urich and Rauch 2014). The instrument also assists in the interpretation of data and communication (Stave 2003).

The SD modelling has been employed in water management with a wide range of applications, for example, to evaluate the sustainability of the water resource system (Xu et al. 2002), to explain the relationships that inherently characterize the price of water (Sahin et al. 2018), to predict future water demands by obtaining useful results for urban infrastructure planning (Ghasemi et al. 2017; Sun et al. 2017; Qin et al. 2018), to predict water supply risks (Feng et al. 2008), to diagnose water crisis (Mello and Randhir 2018), and to allocate water resources and obtain the lowest cost under the minimum water demand (Lin et al. 2018).

Table 1 Brazilian legislation on the collection and use of rainwater

Legislation in states and municipalities	Criteria
Bahia (BA): State Law No. 13,581/2016	All housing units built by the Government of the State of Bahia
• Salvador: Law No. 7,863/2010	All buildings
Distrito Federal (DF)	
• Brasília: Law No. 4,181/2008	Buildings over than 200m^2
Espírito Santo (ES)	
• Vitória: Law No. 8,947/2016	Public and low-income housing
Goias (GO)	
• Goiania: Law No. 17,128/ 2010	Fuel stations, car wash providers
Paraiba (PB): State Law No. 12,417/ 2012	Commercial establishments offering wash and clean of "quick-wash" type for vehicles and similar
Parana (PR)	
• Curitiba: Decree No 293; Law No. 10,785/2003	In collective housing buildings whose total constructed area per unit is equal to or greater than 250m^2 and in the construction of single-family dwellings in series and housing complexes regardless of the constructed area
• Londrina: Law No. 11,471/2012	Constructions over than 200m^2 and for activities that use more than 30m^3 of water per month
• Maringa: Law No. 6,574/2004	Implantation of cisterns in the squares of the Municipality, with the purpose of capturing the rainwater and reuse them for the cleaning of the municipal ones and watering of the flowerbeds and public gardens
Rio de Janeiro (RJ): State Law No. 7,463/2016	Public or private buildings, with an area over than 500 m^2
• Niteroi: Law No. 2,626/2008	Buildings with waterproofing areas over than 500m^2. (Devices for delay and/or use)
Rio Grande do Sul (RS)	
• Porto Alegre: Decree No. 16,305/2009	Industrial and commercial buildings that individually display roof or cover area equal to or over than 500m^2
Santa Catarina (SC)	
• Biguacu: Law No. 3,182/2011	Buildings over then 150m^2
• Blumenau: Supplementary Law No. 691/2008	Buildings of non-residential use with built area greater than 750.00m^2
• Chapeco: Supplementary Law No. 324/2008	Building (single-family over than 150m^2), multifamily or commercial is obliged to build adequate mechanisms for collecting, reserving, and infiltrating rainwater.
• Florianopolis: Supplementary Law No. 561/2016	Single-family, multifamily residential or commercial buildings or mixed-use buildings, over 200m^2
• Joinville: Supplementary Law No. 220/2006	Buildings over than 750.00m^2
São Paulo (SP): State Law No. 12,526/2007	In batches, whether or not built, having a waterproofed area over than 500 m^2
• Guarulhos: Law No. 6,046/2004	Stormwater Holding Reservoir
• Santo André: Law No. 7,733/1998	Stormwater Holding Reservoir. Use for residential multifamily Vila type

Literature analysis also presents SD studies about the use of rainwater collectors (Morales-Pinzón et al. 2015; Rozos et al. 2016; Baki et al. 2018), most of them focused on reused water (Huang et al. 2006). It is possible to notice a lack of publications that analyze the impact in the WSS when individual systems for rainwater collectors are used in single-family houses.

Computational models can be useful to formulate effective public water management policies regarding rainwater collectors since the SD simulation allows the understanding of interrelationships, resource constraints, and how different policy options can affect the system (Stave 2003). Therefore, this paper presents a case study using SD to demonstrate the potential efficiency of a policy for individual systems use.

3 Method

This study aims to simulate the behavior of a WSS when integrating the policy for the mandatory use of rainwater in one municipality. To this end, dynamic simulations were performed to test the policy by varying the scenarios data, and to analyze the sensitivity by varying the uncertain data (Ford 2009). The simulation model construction was based on the SD steps proposed by Sterman (2000) and carried out in Stella 9.0.1 software. Excel software was used for analysis and results presentations.

The simulation model was built using the following steps:

- Definition of the problem: The problem defined in this paper is the increasing behavior in the water demand based on the population growth and tourism inflow associated with the decreasing availability of water resources.
- Dynamic hypotheses: the parameters and relations were determined based on historical data, projections, and standards considered fundamental in the design of a WSS. The river capacity was considered a limiting factor to public WSS expansion.
- Formulation and construction of the model: Construction took place after the survey of the variables that affect supply and consumption and literature and legislation analysis. Relevant works in the area also influenced the construction of the model.
- Verification: The model was validated with historical population growth data of the years between 2010 and 2016 and IBGE projections for the year 2030. Historical data and projections of tourism growth and demand behavior were also considered and adjusted in the verification. Based on these, the model fits adequately to the historical data.
- Policy formulation: After the survey of existing policies in Brazil, the data were crossed with the behavior of the growth of the studied municipalities. The proposed policy is to incorporate the individual system as a project requirement for the construction authorization granted by the municipality, covering all new constructions.

The object of study is a macro WSS with three Water Treatment Plants (WTP) responsible for supplying five municipalities located in the southern region of Brazil. The study is limited to the WTP which is responsible for 85% of the WSS. Growing and floating population data refer to the region supplied from this WTP.

4 Model Development, Structure and Analysis of Experiments

This article considers the behavior of population growth tied to the current centralized supply model as the main challenge in ensuring quality supply over the years. The problem has a dynamic behavior because it changes over time and presents dependence between the variables that affect the supply, consumption, and individual production. The time horizon defined for construction and simulation is 20 years, determined based on the project scope used in the design of water supply systems ranging from 10 to 30 years. The population growth of the area of study was 20% in 25 years. The study area is a tourist region and suffers from problems of interruption in water supply.

The causal loop presented in Fig. 1 is defined in a mental way, in which the increase of the Population generates the increase of the Demand, and the increase of Demand negatively affects the Supply Capacity. The reduction in Supply Capacity indicates the need to increase abstraction and treatment, which negatively affects the extraction capacity of the resource due to the limitation of river flow. Reducing the capacity to capture the water resource comprises the feedback of the entire system, which, when reaching its limit or minimum level, indicates the need for complementary sources of supply. The Individual system enters negatively into the effective demand (Demand - Individual System) because the higher the Individual system, the lower the consumption of water coming from the public system. This relationship positively affects the supply capacity that tends to optimize its balance between supply and demand and, consequently, optimizes the capacity of the river.

Table 2 shows the relations between variables, units, formulas, parameters, and input values established in the construction of the model. The number of new residences and its available area to water collection were obtained through interviews with two teams in charge of the hydraulic connections in the study area, and refers to one of the municipalities supplied by the WTP. The existing policies in Brazil were analyzed, demonstrating that, when the rainwater collection is mandatory, it covers only buildings with areas of approximately 200 m^2. However, residences with an average area of 70 m^2 compound the majority of new buildings in the study location. Thus, the policy considers for constructing the model that all the new constructions are single-family residences and have a minimum collection area of 70 m^2.

In the studied area the price of water is calculated through a fixed rate, plus the cost per cubic meter consumed. The cost per cubic meter varies as follows: lower cost for residences with lower consumption, higher price for residences with higher consumption (CASAN 2020). In this study, the price of water was determined considering the water cost in 2017 for an average residence with 5 people, which consumes 200 l/inhab.day, applying a monetary correction through future years. The water pricing requires an in depth study, which is out of the scope of this paper and should be considered for future work. Changes in the climate were indirectly presented in the parameters "capturing capacity river" and "monthly rainfall", variations in river level and water consumption will be discussed in the sensitivity analysis.

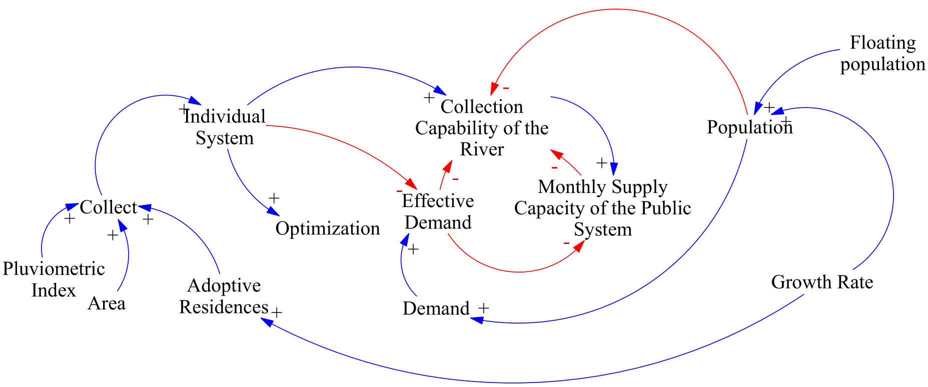

Fig. 1 Causal loop

Table 2 Model parameters and variables

Variables	Value/Relation	Units	Standard value	Source
Growth rate	0.0022	%/month	–	Interviews
Population	719,446.00	Inhabitants	–	IBGE (2010)
Tourist growth	Graphic Function	People/month	900,000.00 People	SANTUR (2017)
Floating population	Pulse Function	m^3/month	–	–
Demand	Per Capita × (Population + Floating Population)	m^3/month	–	–
Per capita	6	m^3/inhab.month	200 L/Inhab. Day	Tsutiya (2006)
Effective demand	Demand - Individual System + Losses	m^3/month	–	–
Losses	33	%	–	CASAN (2020)
Capacity of the WTP public system	11,145,600.00	m^3/month	–	CASAN (2020)
Monthly water supply	Collection Capability of the River + ETA Capacity + Inventory Adjustment	m^3/month	–	–
Consumption	Effective Demand	–	–	–
Cost per m^3	Graphic Function	BRL/m^3	–	CASAN (2020)
Adoptive residences	Graphic Function	month	110 unit/month	Interviews
Area	70	m^2	–	Interviews
Monthly rainfall	Graphical Function	mm/month	–	ANA (2020)

Figure 2 shows the stocks and flows constructed to simulate four scenarios. These scenarios aim to show: i) The need to change the current management; ii) The efficacy of a rainwater collection and use policy.

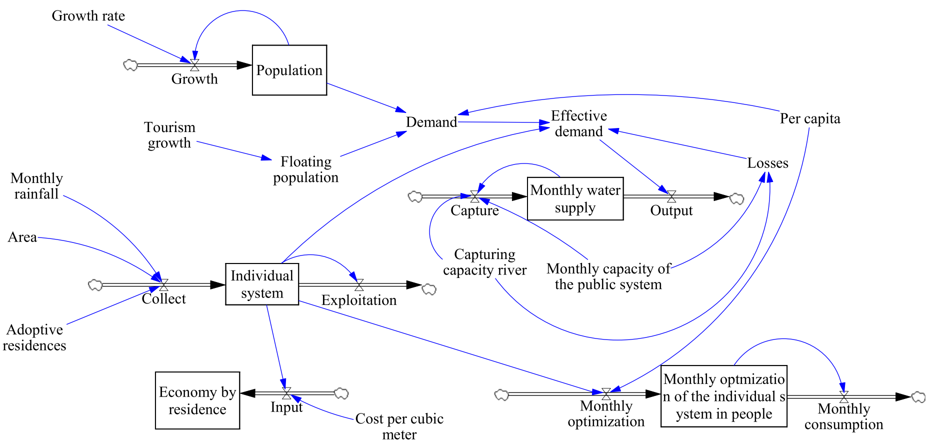

Fig. 2 Stocks flows

The simulation was done in four distinct scenarios, of which objectives were to attest: (i) the influence of the floating population on supply and demand with no expansion (Scenario Business as usual - BAU); (ii) the system capacity with no expansion (Scenario 01); (iii) the optimization with the individual rainwater collection and use (Scenario 02); (iv) capacity to expand the public system in relation to the river's collection capacity (Scenario 03).

- Scenario BAU: This scenario aimed to observe the influence of the floating population (tourists) in the monthly supply of water. It considered the months of December, January, and February as the high tourism season in the region.
- Scenario 01: The simulation was performed to observe the behavior of the monthly supply of water. The growth of the resident population was considered, disregarding the floating population and with no WTP expansion or implantation of the individual system.
- Scenario 02: This scenario shows the influence of the policy implantation in one municipality supplied by the WTP considering the adhesion of all new single-family residences from 2018. The floating population and the growth of the resident population was also considered.
- Scenario 03: This scenario aimed to observe the behavior of the supply capacity considering the policy implementation in one municipality and WTP expansion, until reaching the maximum capacity of the river. The growth of the resident population and floating population was considered.

5 Results

5.1 Model Sensitivity Analysis

There are several established tests to help verify the usefulness of the model considering its purpose, which include structural and behavioral tests (Barlas 1996). Our model has undergone behavior sensitivity (Ford 2009). The sensitivity analysis was performed considering the data variation regarding the water consumption per capita and river capturing capacity. Therefore, the sensitivity analysis was based on the experimental design presented in Table 3.

Eight simulations were run and compared against the business-as-usual (BAU) scenario with increases in the simultaneous percentage of the values of the parameters per capita and capturing capacity river. Thus, each scenario represents the combination of specific values for per capita and capturing capacity river and identifies the effect of such combination on monthly water supply.

The sensitivity analysis allowed us to track the influence intensity of the two most uncertain parameters (Luna et al. 2020) in our model since the river capacity is related to weather and the

Table 3 Experimental design to sensitivity analysis

		Per capita (m^3/inhab.month):		
		3.00	6.00	9.00
Capturing capacity river (m^3/month):	$1.11*10^7$ (no WTP expansion)	Scenario A	BAU	Scenario F
	$1.65*10^7$ (Q98)	Scenario B	Scenario D	Scenario G
	$3.90*10^7$ (Q50)	Scenario C	Scenario E	Scenario H

water consumption per capita involves environmental education and population comprehension. In this sense, we can test the model's sensitivity to a wide range of values for both parameters.

In Brazil public water supply projects adopt the variation of water consumption per capita value from 100 l/inhab.day to 300 l/inhab.day (Tsutiya 2006). The historical series of monthly flow of the river under study was used for the "capturing capacity river" parameter (ANA 2020). Through the flow permanence curve, we identified Q50 (flow equaled or exceeded in 50% of the time) and Q98 (flow equaled or exceeded in 98% of the time), since Q98 is the standard flow for allowing the use of the river. The results are presented in Fig. 3.

Figure 3 shows a range for sensitivity, offering a good confidence level for the forthcoming policy tests. Only Scenario F is pessimist when compared to Scenario BAU, with less capturing capacity and more consumption per inhabitant. The most optimistic scenarios present a difference of more than 22 million m^3/month of water to supply when compared to BAU in 2030.

It is worth noting that water consumption per capita has greater strength than the river's capturing capacity in this model, as we can see the negative numbers of water supply during the tourism season. Finally, the sensitivity analysis confirms that the chosen values for "per capita" and "capturing capacity river" parameters are trustworthy since no large variations in the simulations were found.

5.2 Simulation Results

Figure 4 demonstrates the simulation of the four scenarios. In Scenario 02, water supply remained positive, which means that the system has the capacity to supply the resident population if the population growth rate is maintained. However, in Scenario BAU, where the floating population was considered, the supply presented negative values in the projections corresponding to the tourism season from 2014, indicating the need to increase WTP's capacity or alternative sources of water supply in the summer.

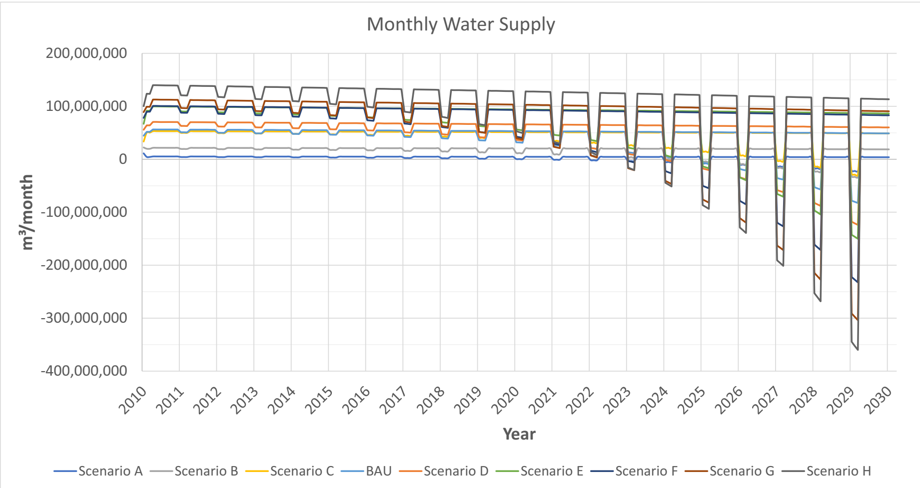

Fig. 3 Sensitivity analysis for rainwater harvesting adoption

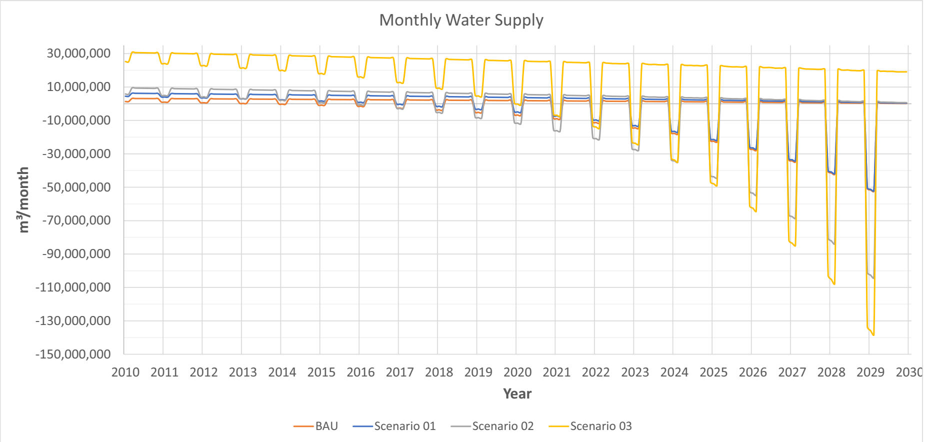

Fig. 4 Results of the scenario analysis

The policy implementation in Scenario 02 was able to optimize approximately 114 k m^3/month in 2030. However, this isolated initiative is not enough to meet the water demand in the summer season. The simulation carried out in Scenario 03, which considers the expansion of the WTP, indicated that, in 2025, the demand will exceed the capacity of the system, presenting a deficit of 3.8 million m^3/month, corresponding to the monthly supply of 639 thousand people. In this scenario, the expansion considered the maximum collection of the river. The deficit shows the need for a new collection point.

Table 4 shows the benefits of the collection system found in scenarios 02 and 03. The individual system implementation can collect up to 114 k m^3/month in 2030, which means that this amount of water was not consumed from the public WSS. In accumulated values, it is possible to save approximately BRL 9500 (USD 2375) until 2030 in water bills per residence. The individual system is optimized in terms of people per month for an easy understanding of these values. Considering that a person consumes 6 m^3/month, the individual system can supply water for 19 k people per month in 2030.

The results allow us to evaluate the capacity of supply and demand and how the individual system can optimize the public system. As shown in Table 4, the optimization was discrete but significant, optimizing 114,275.61 m^3/month. The policy has proven to be positive but not enough to ensure the supply quality of the current management model, which should be integrated with the other municipalities provided by the WSS, as indicated in Scenario 03.

Table 4 Analysis of the benefits of deploying the individual system

Variables	2020	2025	2030
Individual system (m^3/month)	23,634.80	31,631.60	114,275.61
Savings per residence (BRL)	1794.71	5994.15	9512.60
Optimization of the individual system (People/month)	3711	18,567	19,046

6 Discussion

The results indicate that integrating decentralized rainwater harvesting with conventional domestic water supply systems in urban areas brings positive outcomes. The rainwater harvesting system does not seek to supply the entire water demand since treatment is not expected. Consequently, no drinking water is obtained (Bashar et al. 2018). Moreover, Morales-Pinzón et al. (2015) showed that the implementation of rainwater as an alternative to the domestic water supply in urban areas would be better in environmental terms when compared to centralized systems.

The decentralized system requires an evaluation on municipality characteristics (Zeisl et al. 2018) and the sizing and selection of appropriate infrastructure (Morales-Pinzón et al. 2015) to identify opportunities and problems. Thus, the results also show that population fluctuation impairs the water supply to the local population and that the implementation of the rainwater system policy alone is not enough to overcome the water consumption and population growth. To resolve this issue, Zeisl et al. (2018) indicate that rainwater systems should be designed for larger clusters to achieve a higher efficiency. Bashar et al. (2018) show that the adoption of a rainwater harvesting system results in economic savings and the reduction of water stress. However, the government must take measures to educate residents on the benefits of water conservation (Bashar et al. 2018) and to control consumption impulses, improve the efficiency of conventional water production, and optimize the structure of water supply (Gao and Yu 2018).

The negative impacts of tourism on water resources are presented in scenarios 02 and 03. Lin et al. (2018) discussed that the impacts associated with the sector cause loss of revenue since the tourist's desire to visit the location can be reduced if the basic infrastructure of the municipality is not supplied. The structure of the tourism service (hotels, restaurants and so on) must be optimized since they are a high-water-consumption sector (Gao and Yu 2018). The impacts of tourism in water availability are also discussed by Köberl et al. (2016), according to whom increasing water scarcity may raise water costs and decrease tourism profits.

Despite the identification of tourism impact on water supply to the population, the literature regarding the management of public water supply systems does not consider the tourism activity in decision-making concerning the most sustainable use of the resource (Pluchinotta et al. 2018). In the current model of watershed management, the impact of tourism is discussed as non-consumptive use, i.e., it does not involve the direct consumption of water (ANA 2017). Although public supply system projects consider the floating population, the study highlights the need for more effective planning in the sector and its impact on water availability at the level of river basin and regionalized availability.

7 Conclusions

The objective of this study was to evaluate the behavior of the public WSS integrating the policy of mandatory rainwater collection and use system, covering all new single-family residences from January 2018. The SD simulation enabled the diagnosis for the scenarios, in a clear and easily understood manner, evidencing the need for new technologies and resources for water supply. The results of the simulation showed that the implementation of the individual system could be used as a complementary way to prolong the operation of the system, significantly reducing the water demand of the WSS, which means reducing the Effective Demand, as well as bringing economic benefits.

Despite the positive results, the individual system implementation as an isolated initiative is not enough to overcome the balance between supply and demand, mainly due to the strong impact of the tourism sector evidenced in the projection of future scenarios. These facts bring a common discussion in tourism regions regarding the sustainable growth of the sector according to the capacity of the municipalities.

The simulation results raised relevant points to be integrated into public policies, such as tourism control, individual systems benefit, and the need to improve public WSS. The legislation analysis revealed the initiatives on rainwater individual systems in the country, such as incentives to individual system use by means of subsidies in building permits. In seven states rainwater individual systems are mandatory for buildings of over 200 m^2. However, according to the interviews, most of the new residences in the study area have an average of 70 m^2. Federal government usually subsidizes residences with these characteristics through financing programs so, as a recommendation, the individual system can become a requirement for funding.

The proposed policy considered only one municipality. Future work should integrate all municipalities provided by the WSS. Further research is necessary to demonstrate changes in water consumption and the multi-purpose river development to explore the effectiveness of our modeling. We also recommend a more in depth monetary study of the use of the water supply system in conjunction with rainwater collection and the insertion of new relations in the model, such as the costs of the implementation of individual system, WSS loss reduction, and impacts in flood control. A possible barrier to the policy's efficiency is the occurrence of illegal buildings, those not authorized by the city hall. Finally, concepts such as ecotourism should be included in the water resources management strategies.

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Data Availability All data are openly available, and their sources were presented in this paper.

Compliance with Ethical Standards

Conflicts of Interest/Competing Interests The authors declare that they have no known competing financial interests or any kind of conflicts of interest that could influence this paper.

Code Availability Not applicable to this paper.

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