An integrated approach to decision-making variables on urban water systems using an urban water use (UWU) decision-support tool

Hoepers, Taiane Regina; Leithold, Juliana; Monteiro, Michel Marques; Corzo Perez, Gerald A.; Fernandes, Cristovão V. Scapulatempo; Zevenbergen, Chris; Santos, Daniel Costa dos

DOI
10.1016/j.scitotenv.2023.168865

Publication date
2024

Document Version
Final published version

Published in
Science of the Total Environment

Citation (APA)
Hoepers, T. R., Leithold, J., Monteiro, M. M., Corzo Perez, G. A., Fernandes, C. V. S., Zevenbergen, C., & Santos, D. C. D. (2024). An integrated approach to decision-making variables on urban water systems using an urban water use (UWU) decision-support tool. *Science of the Total Environment*, *912*, Article 168865. https://doi.org/10.1016/j.scitotenv.2023.168865

Science of the Total Environment 912 (2024) 168865

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

An integrated approach to decision-making variables on urban water systems using an urban water use (UWU) decision-support tool

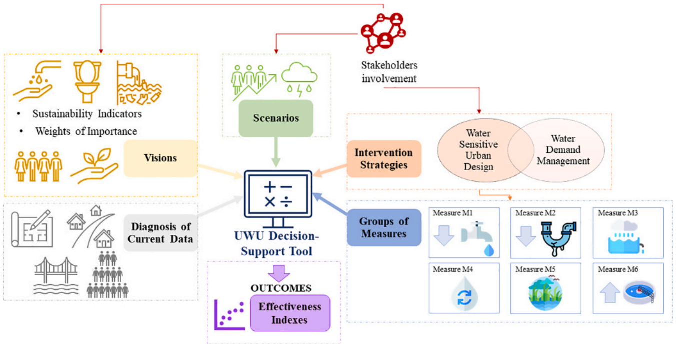
Taiane Regina Hoepers [a,b], Juliana Leithold [a], Michel Marques Monteiro [a], Gerald A. Corzo Perez [b], Cristovão V. Scapulatempo Fernandes [a], Chris Zevenbergen [b,c,*], Daniel Costa dos Santos [a]

[a] *Universidade Federal do Paraná, Programa de Pós-Graduação em Engenharia de Recursos Hídricos e Ambiental (PPGERHA), Avenida Coronel Francisco Heráclito dos Santos, 100, Jardim das Américas, Caixa Postal 19011, CEP: 81531-980 Curitiba, Paraná, Brazil*
[b] *IHE Delft Institute for Water Education, Westvest 7, 2611 AX Delft, PO Box 3015, 2601 DA Delft, the Netherlands*
[c] *Technische Universiteit Delft, Department of Urbanism, Julianalaan 134, 2628 BL Delft, P.O. Box 5043, 2600 GA Delft, the Netherlands*

HIGHLIGHTS

- Involving stakeholders is key to UWU to ensure a thorough decision-making process.
- The case study revealed the interconnections among all decision-making factors.
- The UWU tool is designed to simulate the complexity of urban water systems.
- The tool allows to evaluate the effectiveness of interventions across scenarios.
- This tool has the potential to facilitate the execution of strategic planning.

GRAPHICAL ABSTRACT



ARTICLE INFO

Editor: Ashantha Goonetilleke

Keywords:
Integrated urban water management
Scenarios
Measures
Indicators
Effectiveness index

ABSTRACT

In response to pressing global challenges like climate change, rapid population growth, and an urgent need for sustainable infrastructure, cities face an immediate and crucial necessity to transition swiftly toward an integrated approach to managing urban water resources. This shift is not merely an option but an imperative, driven by the rapidly evolving urban landscape. In addressing this imperative, a crucial decision support tool that has emerged as an asset in the domain of urban water planning and management is the Urban Water Use (UWU) tool. This tool offers an integrated approach for strategic planning, promoting urban water conservation and environmental health through the investigation of interventions in urban infrastructure under different scenarios. In this study, the latest version of this UWU tool was deployed in a case study conducted in Almirante Tamandaré, Brazil. The objective was to evaluate how an integrated decision-making approach concerning urban water systems influences the efficiency and effectiveness of interventions, ultimately contributing to achieve widespread adoption, accessibility, and relevance of urban water services. The refined UWU tool evaluates a spectrum of measures across diverse scenarios, incorporating various drivers, focusing on the stakeholders' visions for the locality. These visions are composed of sustainability indicators, specifying different sets of target values and

---

* Corresponding author at: Technische Universiteit Delft, Department of Urbanism, Julianalaan 134, 2628 BL Delft, P.O. Box 5043, 2600 GA Delft, the Netherlands.
E-mail addresses: taihoepers@ufpr.br (T.R. Hoepers), c.zevenbergen@tudelft.nl (C. Zevenbergen).

https://doi.org/10.1016/j.scitotenv.2023.168865
Received 17 July 2023; Received in revised form 22 November 2023; Accepted 23 November 2023

importance weights for each indicator. The approach followed in this study demonstrates how the effectiveness indexes can vary based on stakeholders' perception. Measures under Water Sensitive Urban Design and Water Demand Management strategies were deployed to simulate the response of urban water systems under three distinct scenarios, embracing the complexities of social dynamics and of climate change. The findings of the study emphasize that realizing a desired vision through selected measures relies significantly on the adoption of an integrated approach within the decision-making process. The stakeholders' perception of how indicators should be weighted while defining the vision was found to significantly impact the effectiveness range of these measures.

1. Introduction

In the rapidly evolving urban landscape, cities worldwide are confronted with a myriad of complex challenges. These challenges, including climate change, rapid population growth, and the pressing need for sustainable infrastructure, underscore the urgency of transforming how the urban water resources are approached (Bakhtiari et al., 2020; Chhipi-Shrestha et al., 2019; Fu et al., 2017; Goodwin et al., 2019; Maurya et al., 2020). A paradigm shift toward an integrated approach is no longer a choice but a necessity (Nieuwenhuis et al., 2022; Pokhrel et al., 2023). The integrated approach refers to a holistic and comprehensive way of addressing complex urban water management challenges (Bakhtiari et al., 2020; Fu et al., 2017; Nieuwenhuis et al., 2021). Instead of dealing with different aspects of urban water (such as water supply, wastewater, drainage, and environmental considerations) in isolation, an integrated approach considers all these aspects together as interconnected components of a larger system (Nieuwenhuis et al., 2021). This approach acknowledges that decisions made in one area of urban water management can have implications and consequences in other areas. This concept has been recently studied in the framework of Integrated Urban Water Management (IUWM) (Fu et al., 2017; Kirshen et al., 2018; Nieuwenhuis et al., 2022, 2021; Pokhrel et al., 2023), a holistic strategy that holds the potential to address climate change (Kirshen et al., 2018; Nieuwenhuis et al., 2022, 2021) and urban water and sanitation service challenges (Bahri et al., 2016; Bakhtiari et al., 2020; Kirshen et al., 2018).

IUWM aims to promote access to water and sanitation services by considering the entire water cycle within urban environments. It champions inter-institutional collaboration, acknowledges the intricate links between land use and water resources, and seeks economic efficiency, social equity, and environmental sustainability (Bahri, 2012). Ultimately, the overarching goal is to improve the quality of life, conserve the environment, and foster collaboration among various institutional components, including urban planning, public health, and environmental sectors (Tucci, 2009).

To harness the full potential of IUWM, it becomes imperative to identify the intricate interdependencies within urban water systems (Nieuwenhuis et al., 2021). This identification is pivotal in leveraging synergies, where actions aimed at improving one aspect of the system result in positive impacts elsewhere, and in mitigating trade-offs, where efforts to address one issue may inadvertently create challenges in other areas (Alcamo, 2019; Lv et al., 2020; Nieuwenhuis et al., 2022, 2021; Parikh et al., 2020; Zhao et al., 2021). For instance, the use of rainwater as an alternative source in households can alleviate pressure on the drinking water supply and reduce peak surface runoff (Campisano et al., 2014; Nachson et al., 2022; Richards et al., 2021). However, it is important to consider the groundwater recharge (Nachson et al., 2022), otherwise the volume and type of rainwater use can potentially impact groundwater recharge negatively.

Moreover, in managing integrated urban water systems, it is essential to consider the uncertainties that may arise. These uncertainties stem from technical challenges, such as simulations of long-term planning and factors like climate change, as well as socio-institutional barriers resulting from conflicts among various stakeholders (Bakhtiari et al., 2020; Nieuwenhuis et al., 2021).

At present, the field of urban engineering tends to generate isolated, non-systemic technical solutions for urban water-related challenges. This fragmented approach significantly complicates ensuring a desired level of sustainability in planning and managing urban water usage (Bakhtiari et al., 2020; Richter et al., 2020).

In response to these pressing challenges, decision support models and tools have emerged as pivotal assets in the field of urban water planning and management. Among these tools, such as WaterMet^2 (Behzadian and Kapelan, 2015), CityPlan-Water (Puchol-Salort et al., 2022), and Urban Water Use-UWU (Santos and van der Steen, 2011), the focus of this study lies on UWU. This tool represents a significant step toward strategic planning for both existing and new urban developments. It actively engages stakeholders and factors in uncertainties driven by multiple variables (Cárdenas, 2017; Costa dos Santos and Benetti, 2014; Destro, 2016; Ferreira, 2022; Hoepers et al., 2022, 2021; Richter et al., 2020; Santos and van der Steen, 2011).

The UWU decision-support tool is designed to select measures that promote the conservation of urban water resources and environmental health. It achieves this by facilitating integrated performance assessments across water supply, wastewater, and urban drainage systems, as well as their interactions with the environment (Santos and van der Steen, 2011).

Since its initial development in 2011 (Santos and van der Steen, 2011), the UWU tool has undergone significant enhancements. These refinements aim to foster greater integration, address the complexities inherent in urban water systems, and actively engage urban water stakeholders in the decision-making process (Cárdenas, 2017; Costa dos Santos and Benetti, 2014; Destro, 2016; Ferreira, 2022; Hoepers et al., 2022, 2021; Richter et al., 2020).

On the other hand, and despite the availability of these notable strides, Brazil still grapples with the challenge of achieving universal urban water services, particularly concerning wastewater (Brasil-SNS, 2022a) and urban solid waste (Brasil-SNS, 2022b). Although Brazilian planning instruments, like the National Basic Sanitation Plan – PLANSAB (Brasil-SNSA, 2013) and the Term of Reference for the Elaboration of Municipal Sanitation Plans of the National Health Foundation (Brasil-FUNASA, 2018), encourage an integrated approach encompassing all components of urban water systems, significant projects adopting such integration remain limited.

Given this context, the hypothesis of this study is that, by jointly applying principles of systemic thinking and strategic planning, it is possible to design and manage urban water systems holistically, thereby contributing to the universalization of services. To test this hypothesis, a comprehensive case study in Almirante Tamandaré, located in the southern region of Brazil, was conducted. The study evaluates the performance of water conservation and environmental health interventions using the latest version of the UWU decision-support tool. The objective of this study is to assess how an integrated approach to decision-making variables in urban water systems influences the efficiency and effectiveness of interventions, ultimately contributing to the universalization of services. In this endeavor, the refined UWU tool was employed to consider a combination of drivers across various scenarios and evaluate a series of measures—both individually and in groups. Central to this assessment were four distinct visions, each representing stakeholders' perspectives, concerning key sustainability indicators such as water supply system coverage, wastewater system coverage, and pollutant concentrations in the urban river.

In summary, this research sits where pressing world problems meet innovative solutions. It navigates the intricate landscape of urban water management, where sustainability is the compass guiding the path. It indicates that the integration of IUWM principles, the UWU tool, and the case study in Almirante Tamandaré collectively offer an opportunity to achieve universal urban water services and to address the complexities of the urbanizing world. In a time where the pursuit of sustainable urban development is paramount, this study sheds light on the transformative potential of integrated water management in reshaping the urban environments of tomorrow.

2. Materials and methods

Fig. 1 provides an overview of the application of the Urban Water Use (UWU) decision-support tool in the case study. The methodology employed in this study begins with a focus on the Sustainability Indicators. These indicators offer insights into the current water sustainability situation by considering factors such as river flows, population density, water consumption patterns, and more. Each indicator is not merely observed; instead, it is assigned a specific Importance Weight. This weighting system enables a ranking and prioritization of the indicators based on their significance in the overall water sustainability context.

A fundamental aspect of the methodology involves the creation of Scenarios. These hypothetical situations enable the exploration of diverse future conditions, prompting questions like “How would water management be influenced by a surge in population?” or “What implications arise from alterations in annual rainfall?”. With these scenarios in hand, attention turns to the intervention strategies section, such as WSUD (Water Demand Management) and WDM (Water Demand Management). Here, a range of actionable measures is examined to enhance water management, spanning activities like rainwater harvesting and reduction of wastage. Finally, the evaluation of the effectiveness of any adopted measures is conducted using Effectiveness Indexes. These indexes assess the extent of coverage provided by water supply and wastewater systems, alongside the quality of urban river water, offering a comprehensive post-implementation assessment. The methodology flow ensures a thorough, step-by-step approach to sustainable water management within urban areas.

2.1. Study area

The study area is located in Almirante Tamandaré municipality, situated in the southern region of Brazil, in Paraná state, more precisely in the Metropolitan Region of Curitiba, the capital city of the state.

Placed above a karst aquifer, Almirante Tamandaré has a difficult

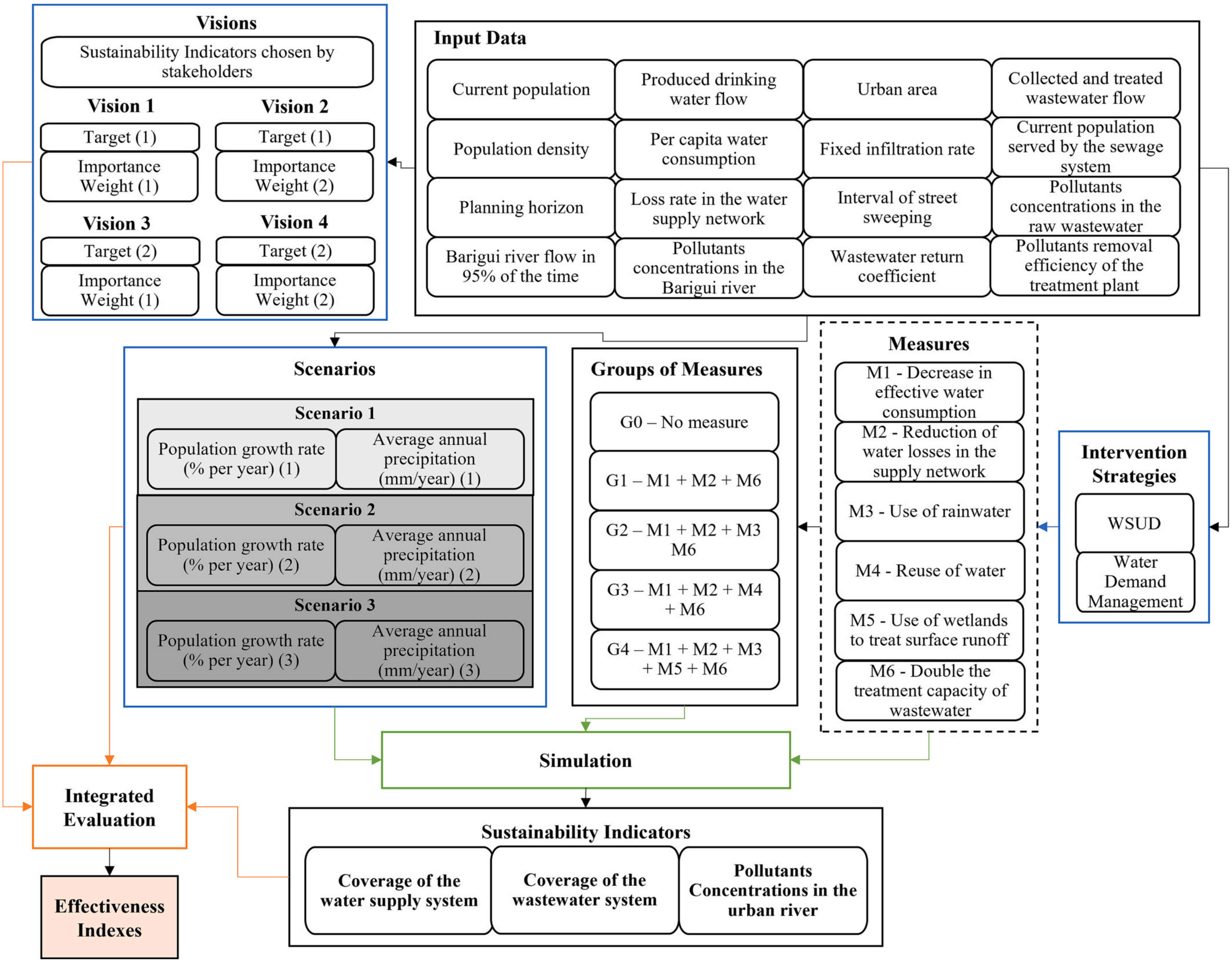


Fig. 1. Application of UWU decision-support tool in case study.

relief and is located at the upstream of river basins (Barigui, Passaúna, Assungui, Atuba and Capivari) with a high degree of anthropization. This municipality was chosen because of the complexity of its current urban water situation, as it has not yet achieved universal access to urban water services. For instance, the water supply system has a high rate of water loss (54 %) compared with the Brazilian average (40 %), and the coverage of the wastewater sewage system in the urban area is 58 % and 55 % in the Barigui basin (Brasil-SNS, 2022a,c), slightly above the national average (51.2 %) but below the average for Paraná state (75.2 %). It is crucial to highlight that the sewage system in Brazil is not combined, with wastewater and rainwater being drained by separate systems.

Almirante Tamandaré's urban area is mainly located in the Barigui river basin; therefore, this basin was chosen as the focus area of the study. Fig. 2 shows the land use map of the Barigui River basin in Almirante Tamandaré. This map was prepared using QGIS free software.

2.2. Urban water use (UWU) decision-support tool

The UWU decision support tool assesses the efficiency of water conservation and environmental health measures using a holistic approach to urban water systems. Based on this intention, the UWU tool works by comparing how these systems respond to pre-selected groups of measures in different scenarios in relation to sustainability indicators that shape the vision of stakeholders for a location.

The general framework of UWU (Fig. 3) comprises eight main steps, namely: (i) diagnosis of the current data, (ii) construction of scenarios, (iii) definition of vision, (iv) development of intervention strategies, (v) selection of measures, (vi) simulations (linking the scenarios, measures, and vision), (vii) results assessment, and (viii) integrated evaluation. The final steps shown in Fig. 3, namely construction of an integrated strategy, an implementation plan, and previsions for continuous evaluation of the strategic planning, are only elaborated after decision-makers choose the group of measures that best meets their expectations. The remaining steps will be outlined in Sections 2.2.1 through 2.2.8.

Concerning the main steps, the diagnosis of the current situation requires data on population, land use, current urban water services, and urban rivers. The scenarios are built to evaluate urban water services under uncertainties arising from climate change, economics, and social dynamics.

The definition of vision is based on understanding the perceptions and desires of stakeholders for the future of the location. The indicators are called sustainability indicators because of the dimensions of sustainability that the stakeholders want to improve. The referred sustainability dimensions are technical, social, and environmental. The technical dimension is explored through the selection of measures that technically assess which measures are most appropriate for each location. The social dimension is explored by assessing the extent of population that will benefit from the implementation of the measures and, in opposition, the extent that will continue without access to urban water services. Finally, the environmental dimension is explored by assessing the impacts of urban water services on urban rivers.

With respect to the intervention strategies, various urban water management approaches fall under the integrated framework. Each approach encompasses a spectrum of measures that can be implemented within the urban infrastructure or influence changes in urban water consumption behavior.

Accordingly, simulations are conducted and coded in a spreadsheet, considering integrated urban water systems, to identify which selected group of measures meet the pre-established vision and in how many of

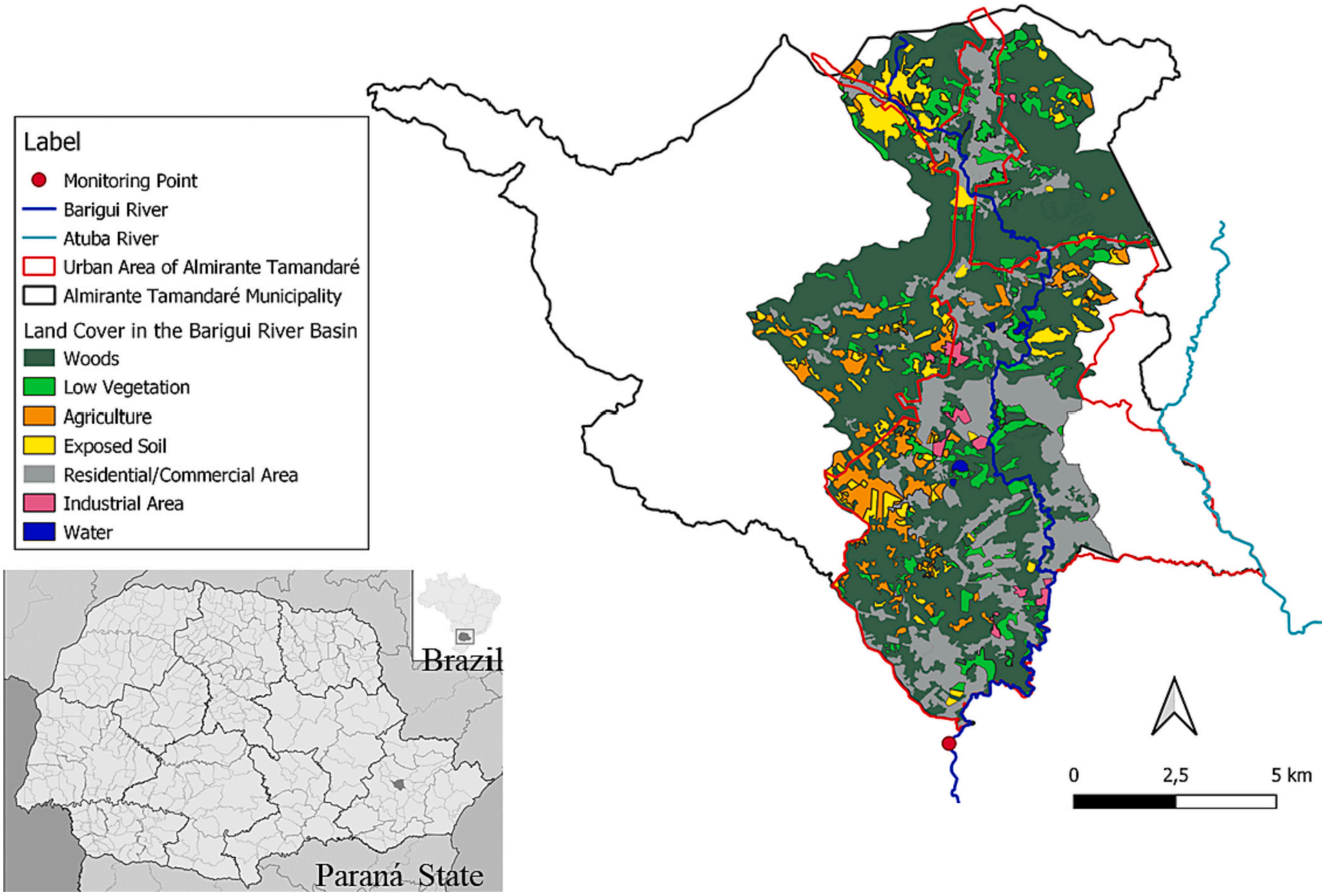


Fig. 2. Land use map of the Barigui River basin in Almirante Tamandaré.

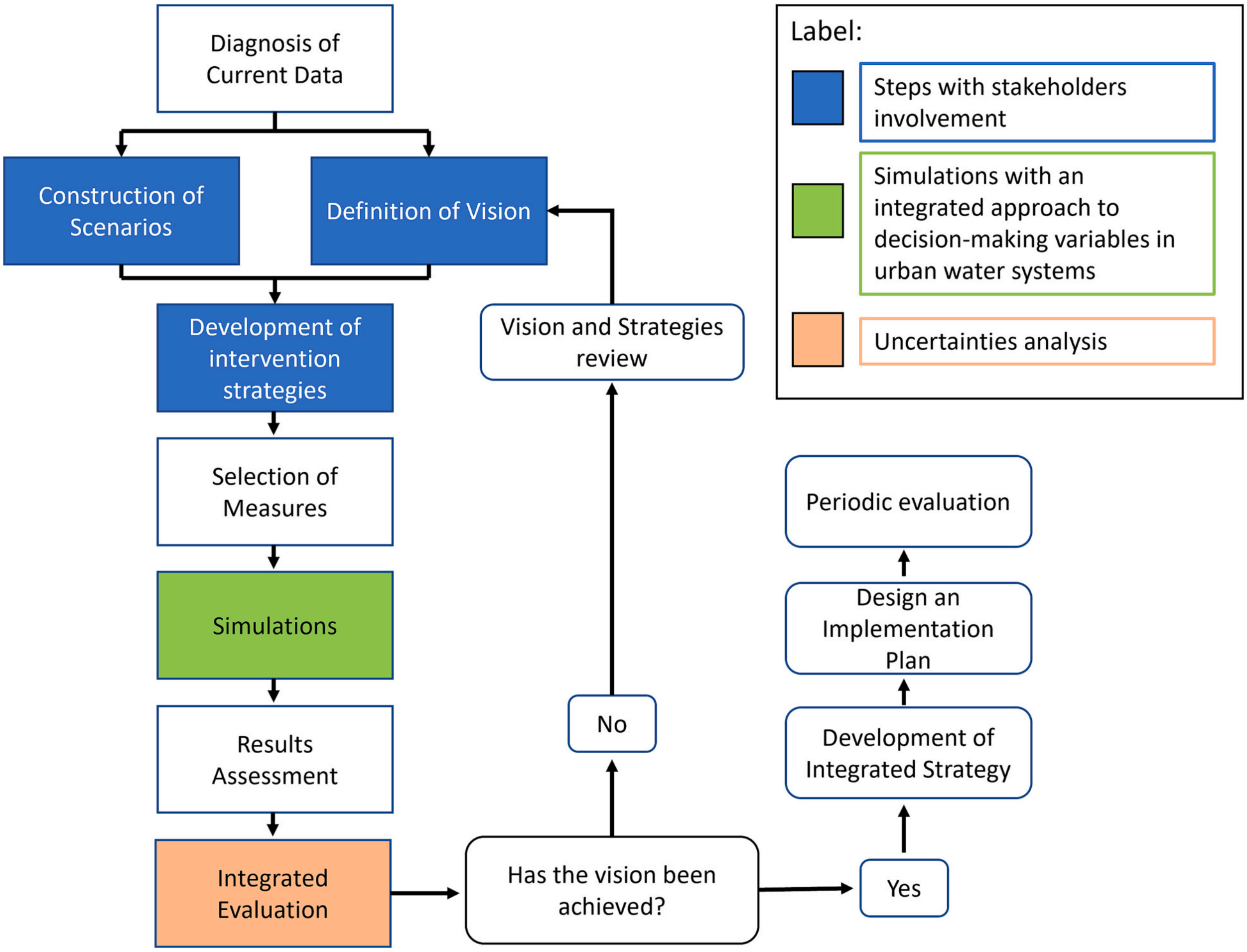


Fig. 3. General framework of UWU decision-support tool emphasizing steps with integrated approach.

the different scenarios that occurs. The simulation results are evaluated in an integrated way, focusing on the performance of each group of measures in each sustainability indicator, under the different scenarios, through an effectiveness index.

2.2.1. *Diagnosis of the current data*

To assess the current state of urban water systems in the municipality of Almirante Tamandaré, Brazil, a comprehensive evaluation was conducted. This involved technical site visits, consultations with stakeholders, a review of the Municipal Basic Sanitation Plan (SMPG-PMAT, 2022), and data from the National Information System on Sanitation (Brasil-SNS, 2022c). Fig. 4 shows the diagnosis of Almirante Tamandaré's Urban Water Systems.

Overall, the UWU input data required are: Current population; Population density; Planning horizon; Produced drinking water flow; Per capita water consumption; Loss rate in the water supply network; Fixed infiltration rate; Interval of street sweeping; Urban area, Barigui river flow in 95 % of the time; BOD, TSS, TN and TP concentrations in the Barigui river; Wastewater return coefficient; Collected and treated wastewater flow; Current population served by the sewage system; Wastewater treatment plant configuration; BOD, TSS, TN and TP concentrations in the raw wastewater; and BOD, TSS, TN and TP removal efficiencies of the treatment plant. These data are presented in supplemental file.

2.2.2. *Construction of scenarios*

Scenarios are composed of drivers, such the effects of global warming, the economy, and the social dynamics. In many of these factors, there is no possibility of human control, which results in a cycle subject to unpredictability (Nieuwenhuis et al., 2022, 2021; Richter et al., 2020).

As mentioned in Fig. 3, this is a step with stakeholder involvement. In this case study, two drivers were chosen by stakeholders from technical background to compose each scenario. The drivers are population growth rate (p_{gr}) and average annual precipitation ($\overline{P}$), being the first one to simulate possible social dynamics and the latter to simulate possible climate changes. On the first scenario it was used the current value of each driver for the study area ($p_{gr(1)} = 1,41\%\textit{per year}$ and $\overline{P}_{(1)} = 1400\textit{mm}/\textit{year}$), as to simulate what would occur if these current values of drivers would continue to be the same in the planning horizon. As a way of assessing uncertainties regarding the chosen drivers, the technical stakeholders consulted established different values for each driver in second ($p_{gr(2)} = 1,0\%\textit{per year}$ and $\overline{P}_{(2)} = 1500\textit{mm}/\textit{year}$) and third ($p_{gr(3)} = 2,0\%\textit{per year}$ and $\overline{P}_{(3)} = 1300\textit{mm}/\textit{year}$) scenarios.

2.2.3. *Definition of vision*

As stated before, the vision definition is based on the perception and aspirations of the stakeholders for the future of the location under study, which are translated into sustainability indicators and their respective weights of importance for stakeholders.

At this stage, various stakeholders involved include the community to be served, professionals from administrative, environmental, and social organizations, political representatives, as well as non-governmental organizations, among others. For this case study, consultations were limited to stakeholders with a technical background. Three sustainability indicators were select to build the vision for the

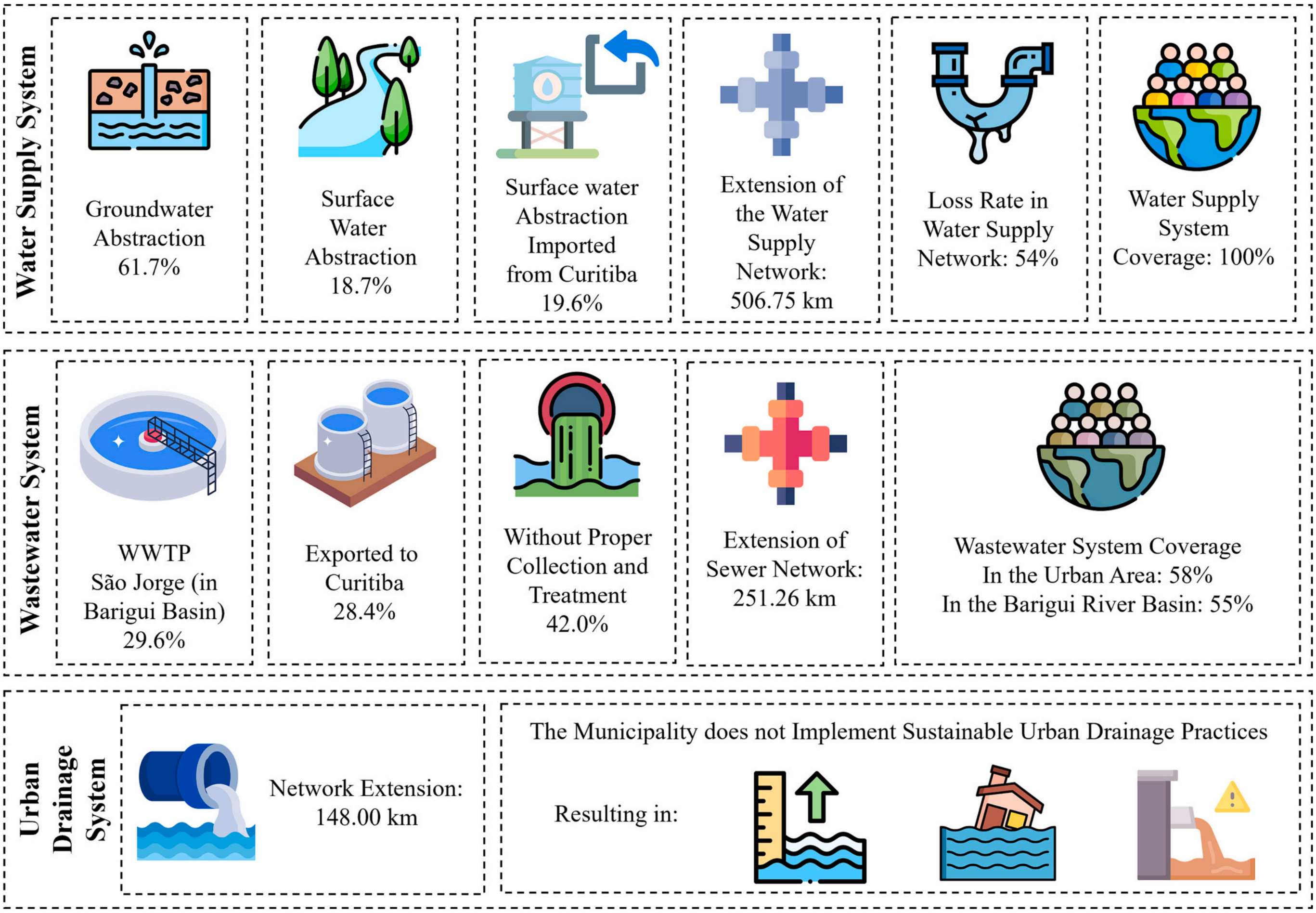


Fig. 4. Panorama of current situation of Almirante Tamandaré's Urban Water Systems.

study area, which are (i) "Coverage of the water supply system", (ii) "Coverage of the wastewater system" and (iii) "Pollutants concentrations in the urban river".

Stakeholders selected these indicators because they encompass technical, social, and environmental dimensions. The technical dimension was considered as it enables a quantitative assessment of the vision. The social dimension is reflected in the ability to evaluate population coverage by urban water services, including drinking water supply and proper wastewater collection and treatment, ultimately affecting the community's quality of life. Lastly, the environmental dimension allows for an assessment of the impacts of urban water systems on the Barigui river.

To assess these impacts of pollution on the Barigui river, on indicator (iii) "Pollutants concentrations in the urban river", four pollutant parameters were selected, which are Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), and the nutrients Total Nitrogen (TN) and Total Phosphorus (TP).

In order to define a vision for these parameters, the Brazilian legislation was consulted. Brazilian freshwater bodies are classified into five different classes, according to the quality of water required for their main uses, which are Special Class, with higher quality required, Class 1, 2, 3 and 4, the latter being with the lower quality required of them all (Brasil-CONAMA, 2005). Regarding the Barigui River, illustrated in Fig. 2, it is classified as Class 2 and Class 3 along its course. Each of these classes has a maximum concentration allowed for a several pollutant parameters, including the ones selected as indicators (BOD, TSS, TN and TP).

To demonstrate how the effectiveness indexes can vary depending on the construction of the vision, four different visions were defined for this case study, with two sets of target values for each indicator, and two sets of importance weight for them. The stakeholders established the target for coverage of the water supply system indicator in order to not decrease the currently existing coverage in the study area, equal to 100 %. Regarding the coverage of the wastewater system, the stakeholders established one target to meet Brazilian legislation (Brasil, 2020), equal to 90 %, and other more realistic to achieve in their opinion, equal to 80 %. Concerning the pollutant concentrations, the established targets were due to classifications of Brazilian legislation (Brasil-CONAMA, 2005) for rivers class 2 and 3. It is essential to highlight that the pollutant concentrations are evaluated in the mixing of wastewater and surface runoff with Barigui river, and that all visions were defined for the planning horizon of 20 years.

Concerning the sustainability indicators weights of importance to stakeholders, one set prioritizes the social dimension while the other prioritizes the environmental dimension. That is, one set granted a high importance to water supply coverage, while the other set prioritized wastewater coverage and the impacts of urban water on the receiving body, in this case, the Barigui River. The built visions are presented in Table 1.

2.2.4. Development of intervention strategies

As modalities of intervention strategies, there are Water Sensitive Urban Design – WSUD (Fletcher et al., 2015), Blue Green Infrastructure – BGI (Suleiman, 2021); ECOSAN (Mwase, 2006), Alternative Combined Systems (Hoepers, 2019; Lobato, 2020), Water Demand Management – WDM (Butler and Memon, 2006; Cominola et al., 2015), etc. In this paper, the stakeholders selected measures under WSUD and WDM strategies.

Table 1
Built visions.

Sustainability indicators	Unity	Vision 1		Vision 2		Vision 3		Vision 4	
		Target	Weight	Target	Weight	Target	Weight	Target	Weight
Coverage of WSS	%	100 %	35 %	100 %	20 %	100 %	35 %	100 %	20 %
Coverage of WWS	%	80 %	25 %	80 %	30 %	90 %	25 %	90 %	30 %
BOD mixing concentration	mg/l	10	10 %	10	12,5 %	5	10 %	5	12,5 %
TSS mixing concentration	mg/l	60	10 %	60	12,5 %	30	10 %	30	12,5 %
TN mixing concentration	mg/l	13,3	10 %	13,3	12,5 %	3,7	10 %	3,7	12,5 %
TP mixing concentration	mg/l	0,15	10 %	0,15	12,5 %	0,1	10 %	0,1	12,5 %

Note: WSS: Water Supply System; WWS: Wastewater System; BOD: Biochemical Oxygen Demand; TSS: Total Suspended Solids; TN: Total Nitrogen; and TP: Total Phosphorus.

Water Sensitive Urban Design – WSUD is a strategy that aims to prevent flooding and erosion by managing the water balance in urban systems, to minimize the transport of pollutants in the surface runoff by treating this water, to encourage water conservation in buildings and households by reusing water, and to preserve natural resources to use them as recreational urban areas (Fletcher et al., 2015).

And Water Demand Management – WDM is a strategy that aims to adopt more efficient sanitary appliances, to have tariff control of urban water services, to regulate rational use of water, to invest in constant maintenance to control leaks in the network, and to invest in environmental education campaigns to raise awareness among water users (Cominola et al., 2015).

As evident, there are similarities in certain objectives between the two selected strategies. Nevertheless, it is apparent that WSUD places significant emphasis on environmental health, whereas WDM primarily focuses on optimizing water consumption efficiency. Both strategies are in accordance with the principles relating to water conservation and the promotion of environmental health, which are fundamental to this study.

2.2.5. *Selection of measures*

From the perspective of the chosen intervention strategies, six different measures were selected, as presented in Table 2. The selected measures were based on rational use of water, control of water losses in the supply network, water conservation in buildings and households by using alternative sources, minimizing the transport of pollutants in the surface runoff, and increasing the capacity of the current wastewater system by expanding the sewage network and the existing wastewater treatment plant while maintaining the same treatment configuration.

To illustrate the integrated approach with these selected measures, Table 2 also presents the location where each measure is implemented and the sustainability indicators that are affected by each one of them. Fig. 5 illustrate where the measures are applied in the urban water cycle.

The adopted values were based on the following: M1 represents the average decrease in effective water consumption achieved during a drought period in the study area in 2020. M2 corresponds to meeting the

Table 2
Selected measures: location versus affected indicators.

	Measure	Value adopted	Location	Sustainability Indicators		
				Coverage of Water Supply System	**Coverage of Wastewater System**	**Pollutants concentrations in the river**
M1	Decrease in effective water consumption	10%	Households	🚰	🚽	⚠
M2	Reduction of water losses in the supply network	40%	WSS	🚰	-	-
M3	Use of rainwater in the households	5% of q_e	Households	🚰	-	⚠
M4	Reuse of water in the households	15% of q_e	Households	🚰	🚽	⚠
M5	Use of wetlands to treat surface runoff		UDS	-	-	⚠
	BOD removal efficiency (ef_{BOD}) [1]	85%				
	TSS removal efficiency (ef_{TSS}) [1]	85%				
	TN removal efficiency (ef_{TN}) [1]	40%				
	TP removal efficiency (ef_{TP}) [1]	15%				
M6	Double treatment capacity of wastewater	200% of $Q_{WW,t}$	WWS	-	🚽	⚠

Note: q_e = effective per capita water consumption (l/inhab.day); $Q_{WW,t}$ = treated wastewater flow (l/s); WSS = Water Supply System; WWS = Wastewater System; UDS = Urban Drainage System; 🚰 = Affects the Coverage of Water Supply System Indicator; 🚽 = Affects the Coverage of Wastewater System Indicator; ⚠ = Affects the Pollutants concentrations in the river indicator; [1] Adopetd values (Von Sperling, 2017).

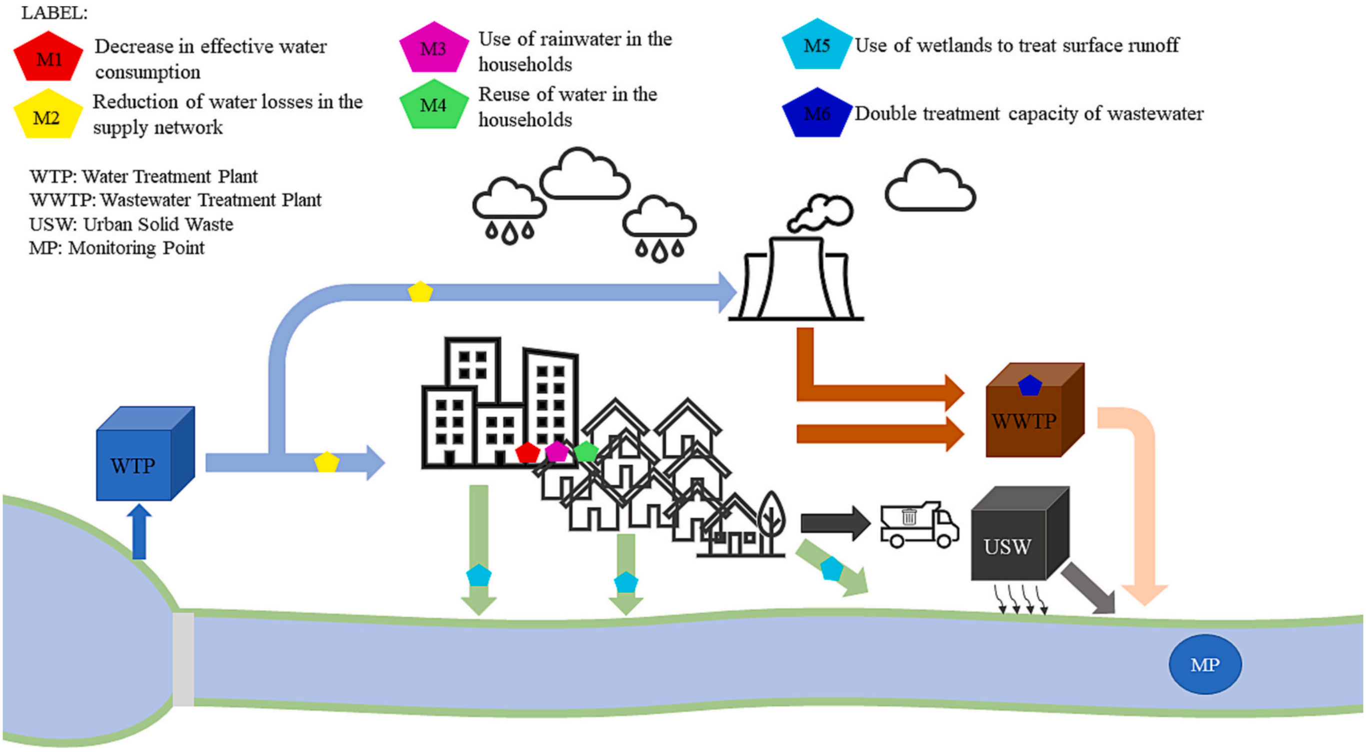
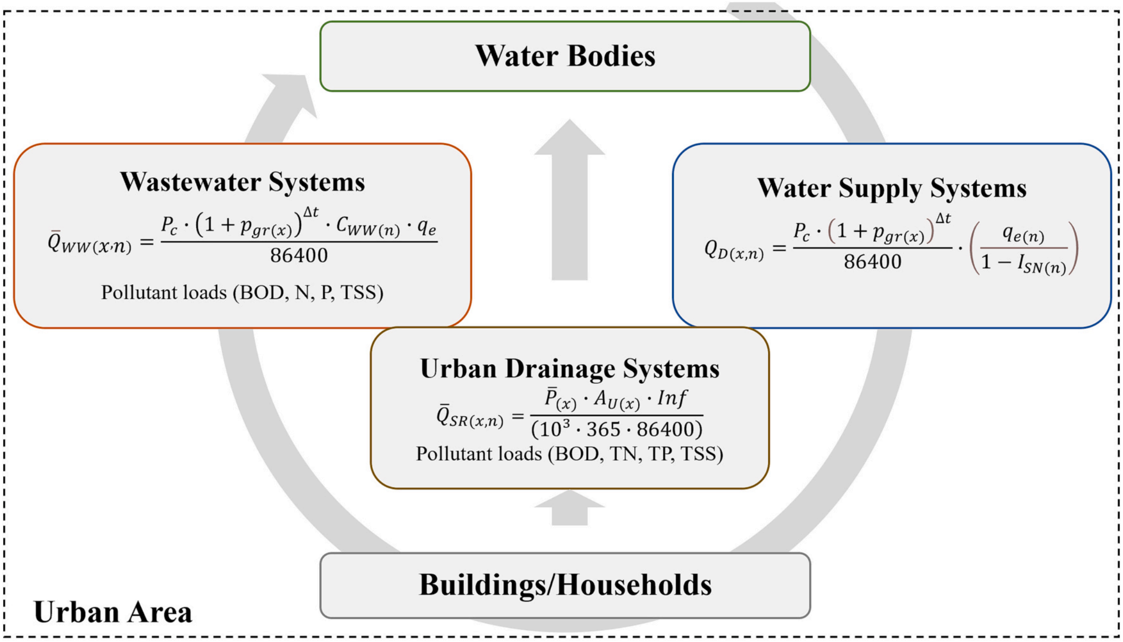


Fig. 5. Location of selected measures in the urban area.



Note: $Q_{D(x,n)}$: Demanded water flow in scenario "x" and in "n" groups of measures (l/s); P_c: Current population (inhab); $p_{gr(x)}$: population growth rate in scenario "x" (% per year); Δt: Planning horizon (years); $q_{e(n)}$: effective per capita water consumption in "n" groups of measures (l/inhab.day); $I_{SN(n)}$: Water losses index in supply system in "n" group of measures (%); $\bar{Q}_{WW(x,n)}$: wastewater average flow in scenario "x" and in "n" groups of measures (l/s); $C_{WW(n)}$: wastewater return coefficient in "n" groups of intervention measure (dimensionless); $\bar{Q}_{SR(x,n)}$: average surface runoff in scenario "x" and in "n" group of measures (m^3/s); $\bar{P}_{(x)}$: average annual precipitation in scenario "x" (mm/ano); $A_{U(x)}$: urban area in scenario "x" (m^2); Inf: fixed infiltration rate (%); BOD: biochemical oxygen demand; TSS: total suspended solids; TN: total nitrogen; and TP: total phosphorus.

Fig. 6. Water cycle in the urban environment.

average Brazilian water loss rate. M3 is related to the average amount of water used for watering gardens and washing external areas of households. M4 pertains to half the average amount of water used for flushing toilets. M5 is based on the values stipulated by Von Sperling (Von Sperling, 2017). M6 aims to work toward the universalization of wastewater services.

2.2.5.1. Groups of measures. We categorized the six selected measures into four distinct groups, labeled as G1 to G4.

Each group was carefully crafted to encompass measures aimed at enhancing water consumption awareness (M1), reducing water loss rates in the supply system (M2), and increasing the wastewater system's capacity (M6). This selection was formed due to previous successful consumption reduction endeavors, also in light of significantly higher loss rates in the study area compared to the Brazilian average, and to a notable deficiency in wastewater system coverage.

As a result, G1 comprises the fundamental trio of measures: M1, M2, and M6. For the other groups, we introduced an additional measure related to alternative water sources in each. G2 is dedicated to the use of rainwater, encompassing M1, M2, M3, and M6. G3 focuses on reuse of water, integrating M1, M2, M4, and M6. Lastly, G4 includes the use of wetlands to treat surface runoff and the use of rainwater in the households, involving measures M1, M2, M3, M5, and M6.

Furthermore, we established a control group, G0, devoid of any measures, to simulate the system's performance without interventions. Additionally, we evaluated the performance of individual measures when not combined with others.

2.2.6. Simulations

In IUWM context, Fig. 6 shows the urban water cycle and the key equations to estimate the flows in the systems. The urban water cycle involves several stages, beginning with the capture of water from either surface or underground sources for human consumption. Subsequently, this water undergoes treatment to ensure it meets drinkable and sanitary standards. After consumption, the resulting effluents are collected and transported for treatment or direct disposal into the soil or a water body (Carneiro, 2007).

Rainwater runoff in urban areas is another integral part of the urban water cycle. Notably, urbanized regions have a higher degree of soil sealing compared to natural areas, limiting rainwater infiltration capacity. This reduction in infiltration affects groundwater recharge while increasing surface runoff volumes. To mitigate this, rainwater galleries (conduits designed for transporting rainwater) are utilized to accelerate runoff, subsequently reducing travel time, and promoting increased maximum flow rates and advance of flow peaks. However, this acceleration can also lead to flooding issues (Tucci, 1997).

From these key equations, the main equations to estimate each sustainability indicator are the follow. Eq. (1) is used to estimate the coverage of the water supply system, Eq. (2) is used to estimate the coverage of the wastewater system, and Eq. (3) is used to estimate the pollutant concentration in the mixing of wastewater and surface runoff with the river.

$$C_{WSS(x,n)} = Q_P / Q_{D(x,n)} \tag{1}$$

where: $C_{WSS(x,n)}$ is the coverage of the water supply system in scenario "x" and in "n" groups of measures, in %; Q_P is the current produced drinking water flow, in l/s; Q_D is the demanded water flow in scenario "x" and in "n" groups of measures, in l/s.

In Eq. (1), the produced drinking water flow (Q_P) is maintained, and the coverage of the water supply system (C_{WSS}) will vary depending on the demanded drinking water flow (Q_D). Q_D will change in each scenario and with the application of measures, either individually or in groups. This is because each scenario has a different population growth rate (p_{gr}), and because most of the measures (M1 – Decrease in effective water consumption, M2 – Reduction of water losses in the supply network, M3 – Use of rainwater in the households, and M4 – Reuse of water in the households) changes the water demand [M1, M3, and M4 change q_e (effective per capita water consumption, in l/inhab.day), and M2 changes I_{SN} (water losses index in the supply system, in %)].

$$\mathrm{C_{WWS(x,n)}} = \mathrm{Q_{WW,t(n)}} / \overline{\mathrm{Q}}_{\mathrm{WW(x,n)}} \tag{2}$$

where: $\mathrm{C_{WWS(x,n)}}$ is the coverage of the wastewater system in scenario "x" and in "n" groups of measures, in %; $\overline{\mathrm{Q}}_{\mathrm{WW(x,n)}}$ is the average produced wastewater flow in scenario "x" and in "n" groups of measures, in l/s; $\mathrm{Q_{WW,t(n)}}$ is average wastewater flow collected and treated by the wastewater system in "n" groups of measures, in l/s.

In Eq. (2), measures M1(Decrease in effective water consumption) and M4 (Reuse of water in the households) will change the wastewater average flow ($\overline{\mathrm{Q}}_{\mathrm{WW}}$). As for measure M6 (Double treatment capacity of wastewater), it will change the wastewater average flow collected and treated ($\mathrm{Q_{WW,t}}$). Which means these three measures (M1, M4 and M6), either individually or combined with others, will affect the coverage of the wastewater system ($\mathrm{C_{WWS}}$). Also, the $\mathrm{C_{WWS}}$ will vary in the scenarios, because of the different values for the population growth rate (p_{gr}) in each one of them.

$$PC_{B(x,n)} = \left[\left(PC_{SR(x,n)} \cdot \overline{Q}_{SR(x,n)}\right) + \left(PC_{WW(x,n)} \cdot \overline{Q}_{WW(x,n)}\right) + \left(PC_R \cdot Q_{95}\right)\right] / \left(\overline{Q}_{SR(x,n)} + \overline{Q}_{WW(x,n)} + Q_{95}\right) \tag{3}$$

where: $PC_{B(x,n)}$ is pollutant concentration in the mixing of wastewater and surface runoff with the river in scenario "x" and in "n" group of measures, in mg/l; $PC_{SR(x,n)}$ is pollutant concentration in surface runoff in scenario "x" and in "n" group of measures, in mg/l; $\overline{Q}_{SR(x,n)}$ is average surface runoff flow in scenario "x" and in "n" group of measures, in l/s; $PC_{WW(x,n)}$ is pollutant concentration in wastewater in scenario "x" and in "n" group of measures, in mg/l; $\overline{\mathrm{Q}}_{\mathrm{WW(x,n)}}$ is average wastewater flow in scenario "x" and in "n" groups of measures, in l/s; PC_R is pollutant concentration in the river (adopted), in mg/l; and Q_{95} is Barigui river flow in 95 % of the time at the monitoring point, in l/s.

In Eq. (3), for the parcel that represents the surface runoff, measure M5 (Use of wetlands to treat surface runoff) will directly affect the pollutant concentration in surface runoff (PC_{SR}). Measure M3 (Use of rainwater in the households) will affect both the PC_{SR} and the average surface runoff flow ($\overline{Q}_{SR}$), because of the amount of water used in households is not becoming surface runoff anymore, but rather is becoming an effluent collected by the wastewater system. Both drivers that composed the scenarios, population growth rate (p_{gr}) and average annual precipitation ($\overline{\mathrm{P}}$), affect the surface runoff pollutants concentration. For the wastewater parcel of Eq. (3), three measures affect the pollutant concentration in the mixing of wastewater and surface runoff with the river (PC_B), measures M1 (Decrease in effective water consumption), M4 (Reuse of water in the households), and M6 (Double treatment capacity of wastewater). As said before, measures M1 and M4 will change the wastewater average flow ($\overline{\mathrm{Q}}_{\mathrm{WW}}$). Measures M4 and M6 change the pollutant concentration in wastewater (PC_{WW}), the first by modifying the pollutants concentration in the effluent and the latter by providing treatment to a larger wastewater flow. The wastewater parcel is also affected by population growth rate (p_{gr}), which is a driver in the scenarios.

It is important to highlight that other equations used in the simulations are presented in the supplemental file.

2.2.7. Results assessment

At this step, it is possible to evaluate the intervention results with respect to the selected indicators. Each indicator elucidates the ramifications of implementing measures, either individually or in combination. Given that the simulations were conducted using an integrated approach, it is feasible to discern the manner in which an applied measure within one system can significantly impact other interrelated systems.

2.2.8. Integrated evaluation

The integrated evaluation is carried out through the analysis of effectiveness indexes (EI) of each group of measures in each constructed vision.

The EI measures the performance of each group of measures, or the measures acting individually, in relation to pre-established vision, or in the four pre-established visions in this case. This performance is evaluated in different scenarios, which represent the possible uncertainties of long-term planning. The group of measures, or the measures acting individually, that achieve the vision in a greater number of scenarios will have a greater EI.

The EI of each group of measures, under the three different scenarios, and in each of the four constructed visions is calculated through Eq. (4).

$$EI_{k,v} = \sum_{i=1}^{si} N_{i,k,v} \cdot W_{i,k,v} \tag{4}$$

where: $EI_{k,v}$ is the effectiveness index of "k" group of measures; *si* are the number of selected sustainability indicators; $N_{i,v}$: is the number of scenarios in which the sustainability indicators "i" achieved the vision "v"; $W_{i,v}$: is the sustainability indicator "i" weight in the vision "v".

The higher EI each group of measures achieves, the more efficient it is. From 0.00 to 0.59, is a poor efficiency, from 0.60 to 1.19 is an insufficient efficiency, from 1.20 to 1.79 is a reasonable efficiency, from 1.80 to 2.39 is a good efficiency, and from 2.40 to 3.00 is an excellent efficiency.

3. Results and discussion

Regarding the sustainability indicators that compose the vision, the performances results from groups of measures, and from measures acting individually in the different scenarios are presented in Tables 3 and 4, respectively. It is worth remembering that stakeholders attributed values more easily attainable to visions 1 and 2 compared to the values attributed to visions 3 and 4, as presented in Table 1.

When comparing the results of each measure acting individually with group G0, which simulates what would happen in the planning horizon if nothing were done, it can be observed the effects of each measure on sustainability indicators, as appointed by Table 2.

It is worth mentioning that measures M2 (Reduction of water losses in the supply network) and M6 (Double treatment capacity of wastewater) were capable of achieving one or more visions in some of the scenarios. This is mainly due to social dynamics considered, as scenarios with lower population growth rate and, consequently, with lower water demands, facilitate the achievement of visions. It is possible to observe synergies between systems with regards of the application of M4 (Reuse of water in the households), as this measure obtained better performances compared to G0 in all scenarios of almost all indicators, except for the concentration of TP. The later has improved by this measure only in the first scenario. While M3 (Use of rainwater in the households) shows slightly poorer results in the first scenario compared to those of G0, with regards to pollutants concentrations. This indicates a possible trade-off between the systems when M3 (Use of rainwater in the households) is applied. It is recommended to conduct a sensitivity analysis of the scenario variations in future work to indicate the sensitivity of these measures to these variations.

Based on the four visions (Table 1) and considering the multiples

Table 3
Performance of groups of measures (GM) in different scenarios (SC).

GM	Sustainability indicator	Unity	SC. 1	SC. 2	SC. 3	Scenarios where the vision (V) was achieved			
						V 1	V 2	V 3	V 4
G0	Coverage of WSS	%	76 %	82 %	67 %	0	0	0	0
	Coverage of WWS	%	41 %	45 %	37 %	0	0	0	0
	BOD mixing concentration	mg/l	17,21	15,96	18,99	0	0	0	0
	TSS mixing concentration	mg/l	53,63	52,22	55,86	3	3	0	0
	TN mixing concentration	mg/l	8,77	8,64	8,88	3	3	0	0
	TP mixing concentration	mg/l	0,39	0,36	0,43	0	0	0	0
G1	Coverage of WSS	%	109 %	118 %	97 %	2	2	2	2
	Coverage of WWS	%	92 %	100 %	82 %	3	3	2	2
	BOD mixing concentration	mg/l	9,03	7,86	10,78	2	2	0	0
	TSS mixing concentration	mg/l	44,05	42,71	46,27	3	3	0	0
	TN mixing concentration	mg/l	8,28	8,17	8,38	3	3	0	0
	TP mixing concentration	mg/l	0,22	0,19	0,26	0	0	0	0
G2	Coverage of WSS	%	115 %	125 %	102 %	3	3	3	3
	Coverage of WWS	%	92 %	100 %	82 %	3	3	2	2
	BOD mixing concentration	mg/l	9,04	7,70	10,48	2	2	0	0
	TSS mixing concentration	mg/l	44,12	39,32	39,95	3	3	0	0
	TN mixing concentration	mg/l	8,28	8,14	8,33	3	3	0	0
	TP mixing concentration	mg/l	0,22	0,18	0,24	0	0	0	0
G3	Coverage of WSS	%	129 %	139 %	114 %	3	3	3	3
	Coverage of WWS	%	94 %	102 %	83 %	3	3	2	2
	BOD mixing concentration	mg/l	8,78	7,63	10,50	2	2	0	0
	TSS mixing concentration	mg/l	43,79	42,47	45,99	3	3	0	0
	TN mixing concentration	mg/l	8,25	8,14	8,35	3	3	0	0
	TP mixing concentration	mg/l	0,21	0,18	0,25	0	0	0	0
G4	Coverage of WSS	%	115 %	125 %	102 %	3	3	3	3
	Coverage of WWS	%	92 %	100 %	82 %	3	3	2	2
	BOD mixing concentration	mg/l	7,62	6,43	9,31	3	3	0	0
	TSS mixing concentration	mg/l	22,13	20,33	23,02	3	3	3	3
	TN mixing concentration	mg/l	8,21	8,08	8,28	3	3	0	0
	TP mixing concentration	mg/l	0,21	0,17	0,24	0	0	0	0

Table 4
Performance of measures acting individually (M) in different scenarios (SC).

M	Sustainability indicator	Unity	SC 1	SC 2	SC 3	Scenarios where the vision (V) was achieved			
						V 1	V 2	V 3	V 4
M1	Coverage of WSS	%	84 %	91 %	75 %	0	0	0	0
	Coverage of WWS	%	46 %	50 %	41 %	0	0	0	0
	BOD mixing concentration	mg/l	15,53	14,39	17,15	0	0	0	0
	TSS mixing concentration	mg/l	51,88	50,59	53,94	3	3	0	0
	TN mixing concentration	mg/l	8,55	8,44	8,65	3	3	0	0
	TP mixing concentration	mg/l	0,35	0,32	0,39	0	0	0	0
M2	Coverage of WSS	%	98 %	107 %	88 %	1	1	1	1
	Coverage of WWS	%	41 %	45 %	37 %	0	0	0	0
	BOD mixing concentration	mg/l	17,21	15,96	18,99	0	0	0	0
	TSS mixing concentration	mg/l	53,63	52,22	55,86	3	3	0	0
	TN mixing concentration	mg/l	8,77	8,64	8,88	3	3	0	0
	TP mixing concentration	mg/l	0,39	0,36	0,43	0	0	0	0
M3	Coverage of WSS	%	80 %	86 %	71 %	0	0	0	0
	Coverage of WWS	%	41 %	45 %	37 %	0	0	0	0
	BOD mixing concentration	mg/l	17,26	15,84	18,73	0	0	0	0
	TSS mixing concentration	mg/l	53,68	48,83	49,59	3	3	0	0
	TN mixing concentration	mg/l	8,80	8,64	8,86	3	3	0	0
	TP mixing concentration	mg/l	0,39	0,36	0,42	0	0	0	0
M4	Coverage of WSS	%	89 %	96 %	79 %	0	0	0	0
	Coverage of WWS	%	42 %	46 %	38 %	0	0	0	0
	BOD mixing concentration	mg/l	16,95	15,72	18,70	0	0	0	0
	TSS mixing concentration	mg/l	53,35	51,96	55,56	3	3	0	0
	TN mixing concentration	mg/l	8,73	8,61	8,85	3	3	0	0
	TP mixing concentration	mg/l	0,38	0,36	0,43	0	0	0	0
M5	Coverage of WSS	%	76 %	82 %	67 %	0	0	0	0
	Coverage of WWS	%	41 %	45 %	37 %	0	0	0	0
	BOD mixing concentration	mg/l	15,78	14,54	17,54	0	0	0	0
	TSS mixing concentration	mg/l	31,80	30,43	33,66	3	3	0	0
	TN mixing concentration	mg/l	8,68	8,55	8,79	3	3	0	0
	TP mixing concentration	mg/l	0,38	0,35	0,42	0	0	0	0
M6	Coverage of WSS	%	76 %	82 %	67 %	0	0	0	0
	Coverage of WWS	%	83 %	90 %	74 %	2	2	1	1
	BOD mixing concentration	mg/l	10,73	9,44	12,64	1	1	0	0
	TSS mixing concentration	mg/l	34,97	44,36	48,21	3	3	0	0
	TN mixing concentration	mg/l	6,95	8,37	8,62	3	3	0	0
	TP mixing concentration	mg/l	4,84	0,22	0,30	0	0	0	0

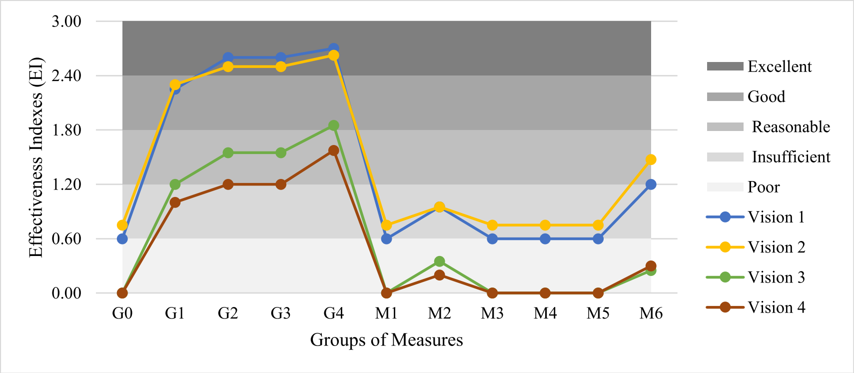


Fig. 7. Effectiveness Indexes (EI) of group of measures and measures acting individually regarding the four built visions.

scenarios, the effectiveness indexes of each group of measures or measures acting individually were calculated, as presented in Fig. 7.

While important for assessing the influences of an integrated approach, it can be verified that most of measures working individually do not have a good efficiency, which is the case of rational use of water (M1 - Decrease in effective water consumption), use of alternative water sources (M3 - Use of rainwater in the households and M4 - Reuse of water in the households) and treatment of surface runoff (M5 - Use of wetlands to treat surface runoff), that all had the same performance as the control group G0. Even the other two measures (M2 - Reduction of water losses in the supply network and M6 - Double treatment capacity of wastewater) that performed better than the control group were still not enough to guarantee high effectiveness.

Now evaluating the groups of measures, G1 obtained the least effective performance of all groups. When comparing this group to the others, it is the only one that does not contemplate the use of alternative sources of water. This may indicate the importance of this measure category in achieving the desired sustainability. Nonetheless, it is important to highlight that in order to use this category of measure, it may be necessary to work on its acceptance by the population, as indicated by Malisa et al., 2019 case study, where part of the community were reluctant to the idea of reusing water.

Regarding groups G2 and G3, they obtained the same EI in each relative built vision. It should be noted that both groups are composed of measures of rational use of water, control of losses in the supply network, use of alternative sources and increase in wastewater treatment capacity. The difference between them lies in the alternative source of water to be used in households, with G2 using rainwater and G3 reusing water as alternative sources.

In this case, for the decision maker to be able to better differentiate these groups, it would be necessary to evaluate the economic and social sustainability dimensions. Concerning the social dimension, as previously mentioned, the use of alternative sources may not be well accepted by the population, especially regarding reuse of water. In this case, it may indicate an advantage for G3 group that uses rainwater. In relation to the economic dimension, in theory the implementation and maintenance of a rainwater use system is cheaper than a reuse of water system. However, this strongly depends on the rainfall regime of the region. With regards to reuse of water in the households, it is also important to assess its effect on the hydraulic aspects of the existing wastewater system. For instance, in M4 (Reuse of water in the households) the existing sewage network will receive an effluent with a lower volume and a higher pollutants concentration than designed for. Hence, it is also essential to assess whether the current design of the network will be able to accommodate these future conditions with regards to the transport of wastewater. Therefore, it is recommended to include these assessments in future work.

Concerning group G4, it is the most complete of all, using measures of rational use of water, control of losses in the supply network, use of alternative sources, increase in wastewater treatment capacity, and treatment of surface runoff. That said, it is not a surprise that this is the group with the highest EI in all built visions.

Despite that, not even G4 achieved the vision for Total Phosphorus concentration in the river. In this case, it would be necessary to investigate whether the increase in wastewater treatment capacity, which already uses a configuration with high phosphorus removal efficiency (UASB + flotation), or whether the adoption of a more efficient phosphorus removal surface runoff treatment system or maybe a combination of both would be enough to achieve the vision.

In reference to the impacts of the importance weights attributed to each sustainability indicator by the stakeholders, these can be perceived by analyzing the results of EI 1 compared to EI 2, and of EI 3 compared to EI 4. It is important to note that the social dimension was prioritized in visions 1 and 3, with greater weight being given to services coverage, especially regarding water supply system. Thus, as most selected measures aimed to improve water supply management, the groups of measures achieved higher efficiency in visions 1 and 3 than they achieved in visions 2 and 4.

This is even more noticeable when comparing the EI of the groups in vision 3 and vision 4. In this case, the target values attributed to the sustainability indicators that compose these visions are more ambitious, especially regarding wastewater system coverage and water quality in the Barigui River. As in vision 4 stakeholders granted higher weights for those indicators whose values are more difficult to be achieved, the proposed groups of measures had worse performance in this vision, because measures focus is mostly with water supply system.

It is important to highlight a limitation of the UWU decision-support tool. The equations used in UWU in this work are based on average events. As a consequence, they do not allow to evaluate the occurrence of extreme events such as droughts or floods. It is also worth noting that the equations used aim to evaluate the water balance of urban water systems and do not capture the temporal features of the hydraulic and operational behavior of these systems. As the operation of these systems affects the efficiency of the applied measures, it is recommended to further pay attention to these omission in future work.

However, it is important to emphasize that the UWU decision-support tool aims to compare the efficiency of different measures. It considers the complexity of urban water systems under an integrated approach in a non-complicated way, without the need for extensive data and robust modeling. In contrast, WaterMet^2 (Behzadian and Kapelan, 2015) is based on the concept of metabolism, not just water balance, and it use long term series for validation. As for CityPlan-Water (Puchol-Salort et al., 2022), although it is also based on a holistic and integrated framework that combines urban planning and water management to address the pressing challenges of urbanization and climate change, it is primarily centered on the concept of Water Neutrality, that involves offsetting an expected rise in water demand from new urban developments by decreasing existing demand within the region.

Therefore, UWU can be a relevant tool to accelerate the development and implementation process of strategic planning to assist with decision-making and contribute to achieving the universalization of services.

4. Conclusion

This study looks into the complexity of urban water systems which are influenced by social dynamics, land use, and climate change. It actively includes stakeholders in strategic planning of urban water systems using the Urban Water Use (UWU) decision-support tool. Stakeholders are involved in establishing future scenarios with hydrometeorological conditions and population growth, in defining visions based on their desires for the future of the location under study, in this case Almirante Tamandaré-Brazil, which are translated into sustainability indicators, and in choosing intervention strategies.

In the case study, stakeholders defined four different visions aiming for universal access to urban water services. Two of these visions set more ambitious targets, while the other two aimed for more realistic goals. This revealed that as the targets became more ambitious, achieving high levels of effectiveness became increasingly challenging. In addition, the perception of the stakeholders on how to assign weight to the sustainability indicators when defining the vision can impact the range of effectiveness of measures, as happened with the group of measures G4, which achieved Reasonable Effectiveness Index in vision 4 and Good Effectiveness Index in vision 3. A key finding of this work is the adaptability of the UWU tool in response to unmet visions. When strategies do not achieve the intended vision, the tool prompts a reassessment of stakeholder perceptions, leading to the formulation of a more context-appropriate vision. This adaptability underscores the relevance of the UWU tool in simplifying the implementation of strategic planning, contributing significantly toward the universalization of water services. Ultimately, this study validates the importance of an integrated, adaptive, and stakeholder-centric approach in urban water system planning.

Moreover, the research delves into the complexity of the urban water system by comparing measures acting individually against the control group G0, uncovering synergies and trade-offs influenced by scenario variations, such as different population growth rates and annual average precipitation changes. Because of this, it is recommended that future work conduct a sensitivity analysis of the scenario variations to indicate the sensitivity of the measures to these variations.

Finally, given the proximity of Effectiveness Indexes among all groups of measures in achieving each vision, it is advisable for future research to place greater emphasis on economic and social aspects. This emphasis will assist decision-makers in better distinguishing between these groups and making more informed choices. Nonetheless, in this case study the group of measures who achieved the highest Effectiveness Index was the group G4, composed by measures M1 - Decrease in effective water consumption, M2 - Reduction of water losses in the supply network, M3 - Use of rainwater in the households, M5 - Use of wetlands to treat surface runoff, and M6 - Double treatment capacity of wastewater.

CRediT authorship contribution statement

Taiane Regina Hoepers: Conceptualization, Methodology, Investigation, Data Curation, Validation, Visualization, Writing - original draft. **Juliana Leithold:** Data Curation, Visualization, Writing - review &

editing. **Michel Marques Monteiro:** Writing – review & editing. **Gerald A. Corzo Perez:** Investigation, Writing - review & editing, Supervision. **Cristovão V. Scapulatempo Fernandes:** Investigation, Writing - review & editing, Supervision. **Chris Zevenbergen:** Investigation, Writing - review & editing, Supervision, Project administration. **Daniel Costa dos Santos:** Conceptualization, Methodology, Investigation, Writing - review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

We acknowledge the Brazilian Federal Foundation for Support and Evaluation of Graduate Education – CAPES for granting the scholarship for the first author to conduct this research in Brazil and as a visiting researcher in The Netherlands, at IHE Delft - Institute for Water Education. We also acknowledge Dr. Regina Tiemy Kishi, Dr. Julio Gomes, and Dr. Orestes Marraccini Gonçalves for their contributions to this work.

Formatting of funding sources

The research was financially supported by Brazilian Federal Foundation for Support and Evaluation of Graduate Education – CAPES, financing code 001.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2023.168865.

References

Alcamo, J., 2019. Water quality and its interlinkages with the Sustainable Development Goals. Curr. Opin. Environ. Sustain. 36, 126–140. https://doi.org/10.1016/j.cosust.2018.11.005.

Bahri, A., 2012. Integrated Urban Water Management, n. 16. TEC Background Papers Global Water Partnership (GWP) Technical Committee (TEC), Stockholm.

Bahri, Brikké, F., Vairavamoorthy, K., 2016. Managing change to implement integrated urban water management in African Cities. Aquat. Procedia 6, 3–14. https://doi.org/10.1016/j.aqpro.2016.06.002.

Bakhtiari, P.H., Nikoo, M.R., Izady, A., Talebbeydokhti, N., 2020. A coupled agent-based risk-based optimization model for integrated urban water management. Sustain. Cities Soc. 53, 101922 https://doi.org/10.1016/j.scs.2019.101922.

Behzadian, K., Kapelan, Z., 2015. Modelling metabolism based performance of an urban water system using WaterMet2. Resour. Conserv. Recycl. 99, 84–99. https://doi.org/10.1016/j.resconrec.2015.03.015.

Brasil, 2020. Lei n° 14.026, de 15 de Julho de 2020. Novo marco legal do saneamento básico.

Brasil-CONAMA, 2005. Resolução CONAMA n° 357. Ministério do Meio Ambiente - Conselho Nacional do Meio Ambiente, Brasília.

Brasil-FUNASA, 2018. Termo de referência para elaboração de plano municipal de saneamento básico. Ministério da Saúde - Fundação Nacional da Saúde, Brasília.

Brasil-SNS, 2022a. Diagnóstico Temático Serviços de Água e Esgoto. Ministério do Desenvolvimento Regional - Secretaria Nacional de Saneamento, Brasília.

Brasil-SNS, 2022b. Diagnóstico Temático Manejo de Resíduos Sólidos Urbanos. Ministério do Desenvolvimento Regional - Secretaria Nacional de Saneamento, Brasília.

Brasil-SNS, 2022c. SNIS - Série Histórica Ministério do Desenvolvimento Regional - Secretaria Nacional de Saneamento. [WWW Document]. URL. http://app4.mdr.gov.br/serieHistorica/# (accessed 2.28.23).

Brasil-SNSA, 2013. Plano Nacional de Saneamento Básico - PLANSAB. Ministério das Cidades - Secretaria Nacional de Saneamento Ambiental, Brasília.

Butler, D., Memon, F.A., 2006. Water Demand Management. IWA Publishing, London.

Campisano, A., Di Liberto, D., Modica, C., Reitano, S., 2014. Potential for peak flow reduction by rainwater harvesting tanks. Procedia Engineering. 89, 1507–1514. https://doi.org/10.1016/j.proeng.2014.11.441.

Cárdenas, E.F.S., 2017. Avaliação dos sistemas urbanos de drenagem sustentável mediante o modelo urban water use (UWU) em área urbana da cidade de Curitiba (MSc Thesis). Universidade Federal do Paraná, Curitiba.

Carneiro, C.S.F., 2007. The Urban Water Cycle - A Pedagogical Approach. Master's thesis in Physics and Chemistry for Teaching. University of Trás-os-Montes and Alto Douro, Vila Real.

Chhipi-Shrestha, G., Rodriguez, M., Sadiq, R., 2019. Selection of sustainable municipal water reuse applications by multi-stakeholders using game theory. Sci. Total Environ. 650, 2512–2526. https://doi.org/10.1016/j.scitotenv.2018.09.359.

Cominola, A., Giuliani, M., Piga, D., Castelletti, A., Rizzoli, A.E., 2015. Benefits and challenges of using smart meters for advancing residential water demand modeling and management: a review. Environ. Model Softw. 72, 198–214. https://doi.org/10.1016/j.envsoft.2015.07.012.

Costa dos Santos, D., Benetti, A., 2014. Application of the urban water use model for urban water use management purposes. Water Sci. Technol. 70, 407–413. https://doi.org/10.2166/wst.2014.229.

Destro, C.A.M., 2016. The Urban Water Use Model as a Tool to Support the Evaluation of Sustainable Drainage Measures in Brazilian Cities (PhD Thesis). Universidade Federal do Paraná, Curitiba.

Ferreira, J.C., 2022. Estruturação de ferramenta baseada na infraestrutura verde e azul para a revitalização socioambiental de áreas urbanas (PhD Thesis). Universidade Federal do Paraná, Curitiba.

Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P.S., Rivard, G., Uhl, M., Dagenais, D., Viklander, M., 2015. SUDS, LID, BMPs, WSUD and more – the evolution and application of terminology surrounding urban drainage. Urban Water J. 12, 525–542. https://doi.org/10.1080/1573062X.2014.916314.

Fu, Z.H., Zhao, H.J., Wang, H., Lu, W.T., Wang, J., Guo, H.C., 2017. Integrated planning for regional development planning and water resources management under uncertainty: a case study of Xining, China. J. Hydrol. 554, 623–634. https://doi.org/10.1016/j.jhydrol.2017.08.022.

Goodwin, D., Raffin, M., Jeffrey, P., Smith, H.M., 2019. Collaboration on risk management: the governance of a non-potable water reuse scheme in London. J. Hydrol. 573, 1087–1095. https://doi.org/10.1016/j.jhydrol.2017.07.020.

Hoepers, T.R., 2019. Análise comparativa entre sistema separador absoluto e sistema combinado alternativo (MSc Thesis). Universidade Federal do Paraná, Curitiba.

Hoepers, T.R., Santos, D.C. dos, Fernandes, C.V.S., Razzolini Filho, E., Monteiro, M.M., 2021. Processo de tomada de decisão para a adoção de uma gestão integrada das águas urbanas: estudo de caso sobre a participação de stakeholders em Curitiba e região metropolitana. In: Presented at the 31^{o} Congresso da ABES. ABES, Curitiba.

Hoepers, T.R., Santos, Daniel Costa dos, Fernandes, C.V.S., 2022. Planejamento estratégico da infraestrutura sanitária urbana sob os princípios da gestão integrada das águas urbanas. In: Presented at the XIV Encontro Nacional de Águas Urbanas e IV Simpósio de Revitalização de Rios Urbanos, ABRHidro, Brasília.

Kirshen, P., Aytur, S., Hecht, J., Walker, A., Burdick, D., Jones, S., Fennessey, N., Bourdeau, R., Mather, L., 2018. Integrated urban water management applied to adaptation to climate change. Urban Clim. 24, 247–263. https://doi.org/10.1016/j.uclim.2018.03.005.

Lobato, M.B., 2020. Sistema de apoio à decisão para planejamento, implementação e gestão de ações estruturais de sistema convencional e único alternativo de esgotamento sanitário e drenagem urbana para municípios (PhD Thesis). Universidade Federal do Paraná, Curitiba.

Lv, H., Yang, L., Zhou, J., Zhang, X., Wu, W., Li, Y., Jiang, D., 2020. Water resource synergy management in response to climate change in China: from the perspective of urban metabolism. Resour. Conserv. Recycl. 163, 105095 https://doi.org/10.1016/j.resconrec.2020.105095.

Malisa, R., Schwella, E., Kidd, M., 2019. From 'government' to 'governance': a quantitative transition analysis of urban wastewater management principles in Stellenbosch Municipality. Sci. Total Environ. 674, 494–511. https://doi.org/10.1016/j.scitotenv.2019.04.194.

Maurya, S.P., Singh, P.K., Ohri, A., Singh, R., 2020. Identification of indicators for sustainable urban water development planning. Ecol. Indic. 108, 105691 https://doi.org/10.1016/j.ecolind.2019.105691.

Mwase, H., 2006. The Potential of Ecosan to Provide Sustainable Sanitation in Emergency Situations and to Achieve "Quick Wins" in MDGs 106.

Nachson, U., Silva, C.M., Sousa, V., Ben-Hur, M., Kurtzman, D., Netzer, L., Livshitz, Y., 2022. New modelling approach to optimize rainwater harvesting system for non-potable uses and groundwater recharge: a case study from Israel. Sustain. Cities Soc. 85, 104097 https://doi.org/10.1016/j.scs.2022.104097.

Nieuwenhuis, E., Cuppen, E., Langeveld, J., de Bruijn, H., 2021. Towards the integrated management of urban water systems: conceptualizing integration and its uncertainties. J. Clean. Prod. 280, 124977 https://doi.org/10.1016/j.jclepro.2020.124977.

Nieuwenhuis, E., Cuppen, E., Langeveld, J., 2022. The role of integration for future urban water systems: identifying Dutch urban water practitioners' perspectives using Q methodology. Cities 126, 103659. https://doi.org/10.1016/j.cities.2022.103659.

Parikh, P., Diep, L., Hofmann, Pascale, Tomei, J., Campos, L.C., Teh, T.-H., Mulugetta, Y., Milligan, B., Lakhanpaul, M., 2020. Synergies and Trade-offs Between Sanitation and the Sustainable Development Goals (Preprint). https://doi.org/10.14324/111.444/000054.v1.

Pokhrel, S.R., Chhipi-Shrestha, G., Mian, H.R., Hewage, K., Sadiq, R., 2023. Integrated performance assessment of urban water systems: identification and prioritization of one water approach indicators. Sustain. Prod. Consum. 36, 62–74. https://doi.org/10.1016/j.spc.2022.12.005.

Puchol-Salort, P., Boskovic, S., Dobson, B., Van Reeuwijk, M., Mijic, A., 2022. Water neutrality framework for systemic design of new urban developments. Water Res. 219, 118583 https://doi.org/10.1016/j.watres.2022.118583.

Richards, S., Rao, L., Connelly, S., Raj, A., Raveendran, L., Shirin, S., Jamwal, P., Helliwell, 2021. Sustainable water resources through harvesting rainwater and the effectiveness of a low-cost water treatment. J. Environ. Manag. 286, 112223 https://doi.org/10.1016/j.jenvman.2021.112223.

Richter, K., Santos, D.C. dos, Schmid, A.L., 2020. Efficiency analysis of water conservation measures in sanitary infrastructure systems by means of a systemic approach. Sustainability 12, 3055. https://doi.org/10.3390/su12073055.

Santos, D.C. dos, van der Steen, P., 2011. Understanding the IUWM Principles: An Activity Based on Role Play Approach (for Facilitator and Specialists). UNESCO-IHE, Delft.

SMPG-PMAT, 2022. Plano municipal de saneamento básico município de Almirante Tamandaré/PR. Prefeitura Municipal de Almirante Tamandaré.

Suleiman, L., 2021. Blue green infrastructure, from niche to mainstream: challenges and opportunities for planning in Stockholm. Technol. Forecast. Soc. Chang. 166, 120528 https://doi.org/10.1016/j.techfore.2020.120528.

Tucci, C.E.M., 1997. Water in the urban environment. In: Freshwater Book, pp. 1–40.

Tucci, C.E.M., 2009. Integrated Urban Water Management in Large Cities - A Practical Tool for Assessing Key Water Management Issues in the Large Cities of the Developing World.

Von Sperling, M., 2017. Introdução à qualidade das águas e ao tratamento de esgotos, 4^{a}. ed. UFMG.

Zhao, D., Liu, J., Sun, L., Ye, B., Hubacek, K., Feng, K., Varis, O., 2021. Quantifying economic-social-environmental trade-offs and synergies of water-supply constraints: an application to the capital region of China. Water Res. 195, 116986 https://doi.org/10.1016/j.watres.2021.116986.