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Urban Water Resilience: Strategies and Adaptation to Climate Change

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ABSTRACT

The term Resilience is present in both academia and management; however, Urban Water Resilience (UWR) is still a term that has been scarcely studied, addressed, systematized, and applied in research related to water resources management. The present work was motivated by the need to obtain interpretative data for the UWR, considering its potential and importance regarding the construction of Resilience in the face of climate change. The objective is to propose guidelines and strategies to incorporate UWR in municipalities based on the use of indicators. To this end, the researchers initially sought the direct or indirect presence of UWR in Municipal Plans of Brazilian cities. In the next stage, Urban Water Systems were analyzed based on the Components and Variables related to UWR and Indicators associated with the systematized Variables were suggested, the aforementioned having being used in the proposed method for incorporating UWR. The systematization carried out resulted in fifteen Components and thirty-nine Variables for which fifty-three Indicators were proposed that allow monitoring of UWR. The proposed methodology will enable cities to evaluate the present and build the future by becoming water-safe cities.

KEYWORDS: Urban water resilience; Urban water management; Indicators.

1 INTRODUCTION

The expectation regarding the deepening of the water access crisis, especially because of climate change in various parts of the world, has been stimulating not only material disputes, but, above all, symbolic struggles around the diagnosis of the crisis and the possibilities of its mitigation (MARTINS, 2013). Therefore, deepening studies related to this topic can help cities remain water safe and bring investments that could transform into opportunities and solutions to imminent challenges (UN, 2014a).

Recent work assesses the resilience of infrastructure in urban built systems and environments (ALLENBY and FINK, 2005) and investigates how cities recover after disasters and extreme events, thus demonstrating that resilience is essential to enable both adaptation efforts and mitigation of risks and disasters, and to develop new forms of urban governance. By including resilience as part of local development, climate uncertainties are treated not only as a threat to the city, but also as an opportunity to develop and commercialize an economy based on knowledge decision-making (LU and STEAD, 2013).

On this wise , Urban Water Resilience (UWR) emerges as the ability of a city to resist, absorb, adapt and recover from exposure to threats, producing effects in a timely and efficient manner, which includes preservation and restoration of its basic structures and functions in the face of climate change, therefore it is a tool for thinking about the new configurations of cities, allowing the urban environment to encompass all the processes which sustain natural, social and financial resources.

The literature on resilience is comprehensive and prolific in providing different interpretations of this topic. Separately, resilience has emerged as an attractive perspective in relation to cities, often theorized as highly adaptable and complex systems (BATTY, 2008) given that climate emergencies have significantly transformed urban systems.

The Resilience Alliance (2007) argues that urban systems are composed of four subsystems: governance networks, socioeconomic dynamics, metabolic flow (or material flow) and the built environment (Figure 1).

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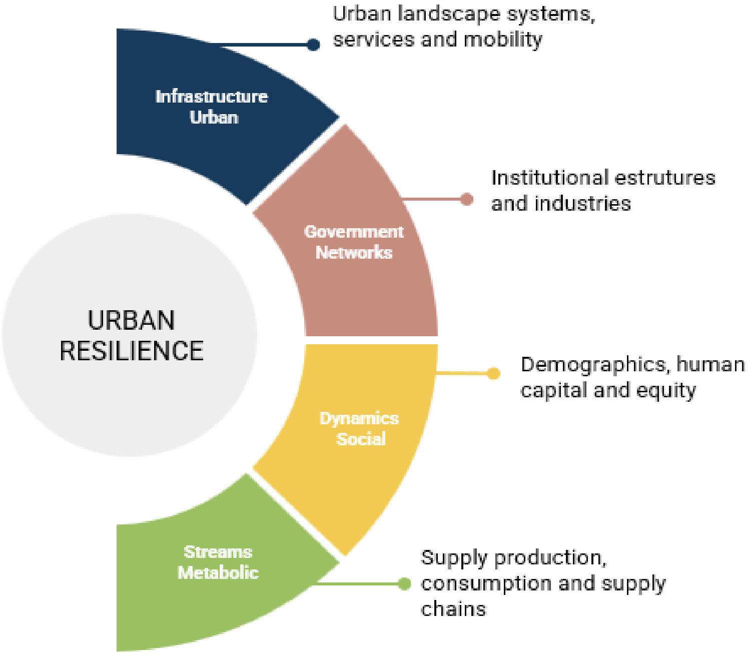
Figure 1 – Interrelationship of urban resilience with urban systems



Source: Adapted from Resilience Alliance, 2007.

Despite this interrelationship of the concept with urban systems, there is little research related to the management of water resources for water security, which can become an essential tool to support political strategies and ensure adequate management of water resources and consequently mitigate the effects of climate change.

And, since water security remains a cyclical and interactive decision-making process, it can be enhanced by resilience, by offering flexibility to enable the application of the UWR concept at various levels of planning and adaptation to institutional contexts.

2 THEORETICAL FOUNDATIONS

2.1 Urban Water Resilience in the context of Climate Change

The concept of resilience can motivate an approach to planning and designing urban areas for the future by incorporating climate change and adaptation into the planning system.

A good example is the city of Rotterdam in the Netherlands, where climate change issues have raised challenges in dealing with flood risks (LU and STEAD, 2013). Some work includes efforts to: quantify resilience to hazards (ROSE, 2007), assess the resilience of infrastructure in urban built systems and environments (ALLENBY and FINK, 2005) and investigate how cities recover after disasters and extreme events (PAIS and ELLIOT, 2008).

Therefore, challenging existing paradigms, researching, and promoting more resilient alternatives to conventional urban water management is a strategic issue for a more sustainable development of urban areas (INTERNATIONAL COUNCIL FOR LOCAL ENVIRONMENTAL INITIATIVES, 2011) to promote local water security.

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Walker and Salt (2012) state that to assess the resilience of urban water services, it is necessary to define its system limits and the disturbances to which this system is being exposed; however, this is a challenge, since the urban water system involves multiple scales depending on user's institutions, technologies, and ecosystems.

The promotion of UWR is essential to enable both adaptation and mitigation efforts for risks and disasters as well as a series of interrelated issues with new forms of urban governance, to add resilience as part of local development, demonstrating that climate uncertainties can be an opportunity to develop new adaptation mechanisms.

2.2 Indicators as a Tool to Help in Building Urban Water Resilience

Indicators are tools that allow collecting data necessary for analyzing important information to measure urban development and can also be considered as a management tool (MILMAN and SHORT, 2008). For indicators to be instruments of a change process, they must encompass characteristics that allow measuring different dimensions, to cover the complexity of social phenomena; enable society's participation in the process of defining development; communicate trends, supporting the decision-making process; and relate variables, since reality is neither linear nor one-dimensional (SILVA, 2016).

Therefore, indicators are a means of providing plans and policies with information to demonstrate their performance over time and an attempt to make predictions and can be used to monitor spatial and temporal variations of actions (NAHAS et. al., 2006).

Thus, due to the growing demand for information that demonstrates environmental problems in urban areas, researchers, decision makers and governments can use indicators to measure environmental issues and corresponding damages, which is fundamental for sustainable management plans in different sectors.

In 2017, in order to establish a way to measure the sustainability of Brazilian cities, ABNT developed the ABNT NBR ISO 37120/2017 standard, it was the first Brazilian technical standard for the Sustainable Development of Communities - Indicators for Urban Services and quality of life (ABNT, 2017).

In 2021, NBR ISO 37123/2021 has emerged as a guide for cities to acquire significant data in disaster risk management and ratifies global agreements that support sustainability and resilience. The standard determines and establishes definitions and methodologies for a set of resilience indicators in cities (ABNT, 2021) and is divided into 24 thematic sections that bring a total of 68 resilience indicators for monitoring and can be applied in any city that is committed to measuring your performance in a comparable and verifiable way, regardless of size or location.

Such indicators can be used to track and monitor progress towards a resilient city, through the development of an urban resilience strategy or when applying an urban management system (ABNT, 2021).

Thus, indicators can be used as a tool to measure resilience, since such indicators measure the ability of a system to adapt to change and continue to function for a long period (MILMAN and SHORT, 2008).

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Through indicators it is possible to characterize areas of fragility in which additional actions can be taken to increase the resilience of the urban water system, considering how water supply, infrastructure, service provision, finance, water quality and governance affect the ability to maintain a given level of current and future access to water resources.

3 GOALS

The general objective of this research is to propose guidelines and strategies for the incorporation of UWR in municipalities using indicators. To develop the general objective, the following specific objectives were defined:

i) carry out a literature review through consultation and systematization of periodicals, scientific articles, theses, books and legislation to develop the theoretical basis of the research topic.

ii) identify and systematize the aspects of UWR based on the theoretical framework.

iii) identify medium-sized Brazilian cities that have joined the Making Cities Resilient: My City is Getting Ready program developed by the United Nations Office for Risk and Disaster Reduction (UNISDR, 2016), analyzing the presence of UWR in their municipal plans (plans of Sanitation, Drainage and Director).

iv) identify, propose, and systematize a set of indicators that can be applied to UWR.

v) propose guidelines and strategies for the incorporation of UWR by municipalities.

From this research it is possible to establish principles of integrated planning of urban water infrastructure, finding the best solutions, allowing cities to identify the risks to which they are subjected, facilitating preemptive planning of the UWR, highlighting the importance of using the tool developed for diagnosis, planning, monitoring, and control of UWR development to assist managers in defining priorities and making decisions for planning more resilient cities.

4 METHODOLOGIES

4.1 Systematization of UWR Components and Variables

The UWR was evaluated based on the literature review; the aspects of resilience were divided into four Components that began to be considered for the evaluation of the UWR. The adopted Components integrate urban water management and are part of the following systems:

i) Water Supply System (WSS).

ii) Sanitary Sewage System (SSS).

iii) Urban Drainage System (UDS).

iv) Management and Participation (M&P).

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Then, supported by 15 Components, 39 variables were established to evaluate UWR, being: 10 WSS variables; 5 SSS variables; 10 variables from UDS and 14 variables from M&P. The number of variables for each system relates to specific aspects of them.

For this research, the variables were defined based on the assumption that they have a correlation with the themes chosen for the construction of the UWR to cover all systems that involve urban water resources to configure a monitoring instrument that can adapt to according to the intended objectives in each case and adapt in different aspects.

In general, for all Components, groups of variables with their subgroups were described to cover the quantitative, qualitative, management and participation aspects, considering the characterization needs of each system.

For each of the systems, external aspects (climate changes, lack or excess of rain, impacts on the quality of water resources, among others) and internal aspects (collapses, failures, insufficiencies, among others) were considered. Table 1 presents a list of the Components and Variables adopted for the Systems. It should be noted that the Management and Participation System is not mentioned in this Table, since it covers all three Systems, thus this system is found in a separate Table.

Table 1 - Components and variables adopted for WSS, SSS and UDS.

Systems	Components	Variables
WSS	1. Reduction in the availability of water sources	1a. Water scarcity or stress (significant drought)
		1b. Excessive abstraction of surface water
		1c. Insufficient reserve capacity
		1d. Excessive exploitation of aquifers
	2. Deficiencies or insufficiency of the WSS	2a. Failures (damage, collapse, ruptures) in the system
		2b. Loss of capacity to meet demand (saturation and flexibility)
	3. Compromising water quality for supply	3a. Compromise of water quality in surface springs
		3b. Compromising the quality of groundwater (aquifers)
		3c. Faults or deficiencies in the water treatment system
		3d. Compromising quality in water storage and distribution
SSS	4. SSS deficiencies or insufficiency	4a. Failures (damage, collapse, ruptures) in the system
		4b. Loss of capacity to meet demand (system saturation)
	5. Compromise of the conditions of the receiving body	5a. Failures in sewage treatment systems
		5b. Loss of dilution or self-clearance capacity of receptor bodies
	6. Impacts of Cross Links on SSS	6a. Rainwater overload in SSS and UDS
UDS	7. Worsening effects of climate change	7a. Increased rainfall intensity
		7b. Increased frequency of intense precipitation
	8. Occupations of risk areas	8a. Occupation of areas at risk of flooding and flooding
		8b. Occupation of slip and slide areas
	9. Deficiencies or insufficiency of the UDS	9a. Failures (damage, collapse, ruptures) in the system
		9b. Loss of capacity to meet demand (system saturation)
		9c. Change in urban characteristics that affects rainwater (impervious area, removal of vegetation, etc.)
	10. Compromising the	10a. Compromising the quality of surface releases

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Systems	Components	Variables
	quality of rainwater	10b. Compromising the quality of infiltrated water
	11. Erosion and siltation	11a. Sediment transport by rainwater

Source: Corrêa, 2021.

The WSS variable groups address issues related to the reduction in the availability of water sources, deficiencies, or insufficiency of the WSS and compromised water quality for supply.

The SSS variable groups recommend questions regarding the efficiency or insufficiency of the SSS, the conditions of the receiving body and the impacts of cross-links on the SSS. The variables related to service capacity losses (saturation) for the three systems are reflected in resilience both due to the possibility of service interruptions and the worsening of the effects of other impacts on them.

Groups related to the USD consider the following aspects of worsening: the effects of climate change, deficiencies, or insufficiency of the UDS, compromising the quality of rainwater, impacts of cross-connections on the UDS and erosion and siltation. This item addresses issues relating to vulnerability related to precipitation, occupation of inappropriate areas, as well as the fragility of rainwater management structures and the compromise of receiving bodies. Below, Table 2 demonstrates the Components and Variables related to M&P and refer to topics of legislation, planning, society involvement and organizational structure of management and participation.

Table 2 - Components and variables adopted for the M&P System

Systems	Components	Variables
M&P	12.Legislation	12a. Laws and regulations that consider UWR
	13. Planning	13a. Updated specific plans considering UWR
		13b. Redundancy capacity of urban water systems (WSS, SSS, UDS)
		13c. Adoption of contingency plans
		13d. Provision of financial resources for emergencies and recovery
	14. Organizational management structure	14a. Effective coordination between water systems and with other bodies
		14b. Training of personnel to work in relation to UWR
		14c. Monitoring of water systems
		14d. Data availability
		14e. Risk assessment, prediction, and prevention (risk maps, alert systems, and structured Civil Defense)
	15. Participation and involvement of society	15a. Community awareness and preparation in relation to UWR (Environmental Education, training)
		15b. Instances of society participation (councils, committees, working groups)
		15c. Emergency assistance for vulnerable population
		15d. Proactive collaboration between governmental and non-governmental bodies (companies, universities, NGOs)

Source: Corrêa, 2021.

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The purpose of this group of variables is to estimate how management and society are preparing and contributing UWR. At this stage, subgroups stand out that demonstrate the importance of laws as a guiding instrument for public authorities, how this structure can adapt to local vulnerabilities and the importance of the participation of all social actors so that the city becomes more resilient.

4.2 Selection of Cities studied and Evaluation of their Municipal Plans

From the global map of Resilient Cities available on the Global Water Partnership (GWP) website, Brazilian cities which are part of the program and that also have a Municipal Master Plan (MMP), Municipal Sanitation Plan (MSP) and Urban Drainage Plans (UDP) available for online consultation have been selected.

Next, an analysis of the texts of the cities MMPs, MSPs, and UDPs was carried out, using the previously proposed variables as a reference, to identify the presence or absence of aspects of resilience and climate change.

This analysis considered both a direct approach (aspects that were explicitly included in the Plans, motivated by the search for resilience or concern about climate change) and an indirect approach (aspects that, even without direct reference to resilience or climate change, meet the variables associated with them).

4.2.1 Cities Selection Criteria

The Global map of resilient cities had more than 4,360 cities registered across the world in 2020. Of the Brazilian cities participating in the campaign, medium-sized cities, that is, between 100 and 500 thousand inhabitants, totaled 159 municipalities.

The option for medium-sized cities resulted from the fact that, in addition to concentrating a significant portion of the population, such cities begin to present problems typical of large cities without, often, having the structures of the latter.

After the initial analysis of the Plans, which aimed to verify whether the concepts of Resilience or Climate Change were present, it was discovered that there were not many differences in the Plans in relation to these aspects. Therefore, the analysis ended up being limited to 11 cities (Figure 2).

As there was no intention of carrying out a statistical analysis, the final number of cities was not the result of a sample selection. It is worth noting that most of the selected cities belong to the state of São Paulo, as this is the state with the most cities which have joined the program.

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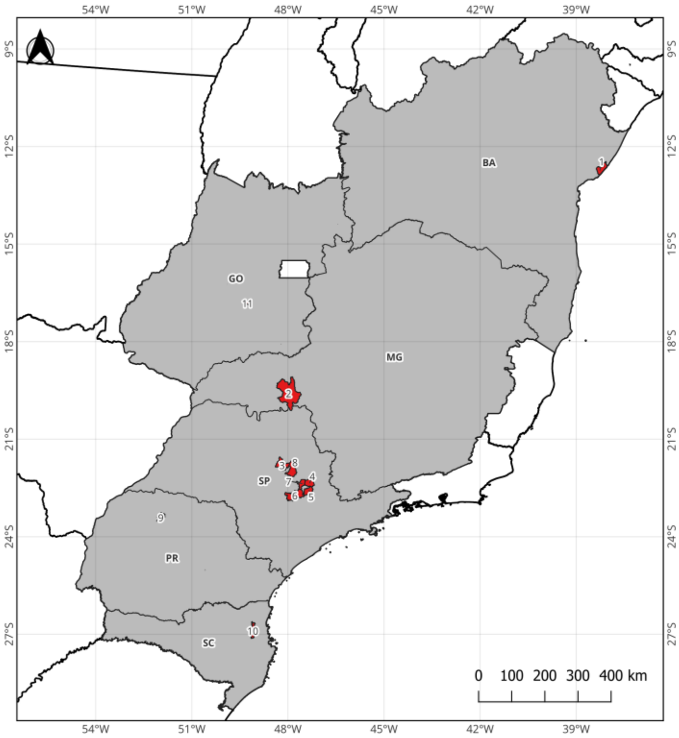
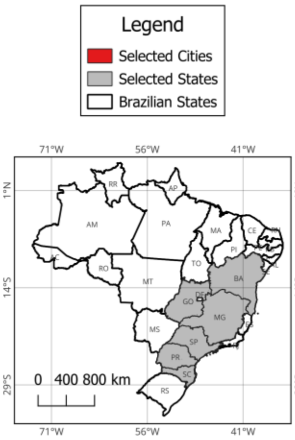
Figure 2 - Maps of selected cities



ID	City Name	State
1	Camaçari	BA
2	Uberaba	MG
3	Araraquara	SP
4	Araras	SP
5	Limeira	SP
6	Piracicaba	SP
7	Rio Claro	SP
8	São Carlos	SP
9	Maringá	PR
10	Blumenau	SC
11	Aparecida de Goiânia	GO



Source: Author, 2024.

4.2.2 General considerations regarding the Plans analyzed

The analyzes carried out in the 11 cities showed that none of the Municipal Plans explicitly mentions the term Resilience. In general, most variables were not addressed.

Some Plans were drawn up before the emergence of the UN Campaign and even though cities showed interest in becoming more resilient, the Plans that underwent review did not directly address issues related to Resilience, UWR and Climate Change.

Even though cities play a central role in combating the risks associated with UWR, there was a certain limitation in incorporating such concepts into Municipal Plans. Therefore, this analysis indicates the need for a more integrated and predictive vision regarding the topic addressed, seeking to coordinate all social actors in the development of more robust plans and creating management structures that include the UWR.

4.3 Identification, proposition, and systematization of UWR indicators

From the previous steps, the indicators were grouped and associated with Urban Water Resilience and subdivided into Systems, Component, Variables, and Indicators.

The WSS, SSS and UDS variables considered the occurrence of events that may affect before during or after the UWR. In the M&P case, questions were considered in which the variables demonstrate that the city has mechanisms to increase UWR in the WSS, SSS and UDS.

Since the transformation of data into relevant information for public managers and society is the main role of indicators, it is necessary to analyze the indicators so that they are

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understood.

To this end, in the present work the criteria proposed by Miranda and Teixeira (2004) were adopted, such as:

i) data accessibility: ease of access to data related to the indicator.

ii) clarity in communication: quick understanding and acceptance by users.

iii) relevance: reflecting something basic and fundamental to describe the monitored phenomenon.

iv) geographic breadth: be sensitive to changes in space.

v) standardization: greater possibility of comparing one reality with others.

vi) predictability: preemptively warning about problems before they become difficult to solve.

vii) proactivity: showing what has been working in a way that motivates.

viii) temporal sensitivity: show changes and trends over time,

ix) goal setting: allow the establishment of goals to be achieved.

x) source reliability: having one or more reliable data sources; It is

xi) synthesis capacity: quickly transmit information, allowing access to details.

The first step, therefore, was to search the literature for possible indicators that could be used for UWR. More than 50 indicators were found. Based on this set of indicators, a first assessment was carried out, seeking to associate them with the Components and Variables previously defined.

Some of these indicators were used in their original form, while others were adapted to better reflect the UWR. Also, in many situations, new indicators had to be proposed, in cases where there were no suitable indicators among those identified in the literature. As a result of this process, Tables 3, 4, 5 and 6 are presented containing the selected indicators.

Table 3 - Urban Water Resilience Indicators associated with WSS

Systems	Components	Variables
1.Reduction in the availability of water sources	1a. Water scarcity or stress (significant drought)	1.Variation in rainfall
	1b. Excessive abstraction of surface water	2. Annual surface water withdrawal as a percentage of total available water
	1c. Insufficient reserve capacity	3.Variation in the reserve volume in the supply reservoirs
	1d. Excessive exploitation of aquifers	4. Lowering the water level in wells
2. Deficiencies or insufficiency of the WSS	2a. Failures (damage, collapse, ruptures) in the system	5. Variation in the annual frequency of supply interruption events due to failures
		6. Percentage of the population that can be supplied with drinking water from alternative sources for a short period
	2b. Loss of capacity to meet demand (saturation and flexibility)	7.WSS Saturation Indicator
		8.Number of different water abstraction sources for the WSS
3. Compromising	3a. Compromise of water quality in surface springs	9. Annual variation of AQI in the water source
		10. Number of occurrences affecting water

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Systems	Components	Variables
water quality for supply		quality in the source
	3b. Compromising the quality of groundwater (aquifers)	11.Variation in the quality of water extracted from the aquifer
	3c. Faults or deficiencies in the water treatment system	12.Number of times per year in which treated water exceeds the limits of the potability standard
	3d. Compromising quality in water storage and distribution	13.Number of times per year in which the water distributed exceeds the limits of the potability standard

Source: Corrêa, 2021.

Table 4 - Urban Water Resilience Indicators associated with the SSS.

Systems	Components	Variables
4. SSS deficiencies or insufficiency	4a. Failures (damage, collapse, ruptures) in the system	14. Variation in the annual frequency of collection interruption events due to failures
	4b. Loss of capacity to meet demand (system saturation)	15. SSS Saturation Indicator
5. Compromise of the conditions of the receiving body	5a. Failures in sewage treatment systems	16. Proportion of sewage that is sent to the Sewage Treatment Plant
	5b Loss of dilution or self-clearance capacity of receptor bodies	17. Annual occurrence of flows lower than the minimum flow that provides self-purification
6. Impacts of Cross Links on SSS	6a. Rainwater overload in SSS and UDS	18. Overload due to rainwater flows in the SSS

Source: Corrêa, 2021.

Table 5 - Urban Water Resilience Indicators associated with the UDS

Systems	Components	Variables
7. Worsening effects of climate change	7a. Increased rainfall intensity	19. Annual variation in rainfall intensity
	7b. Increased frequency of intense precipitation	20. Annual frequency of extreme storm events
8. Risky occupations	8a. Occupation of areas at risk of flooding and flooded area	21. Percentage of area with human occupation subject to flooding and flooded area
	8b Occupation of slip and slide areas	22. Percentage of area with human occupation subject to landslides
9. Deficiencies or insufficiency of the UDS	9a. Failures (damage, collapse, ruptures) in the system	23. Variation in the annual frequency of drainage interruption events due to faults
	9b. Loss of capacity to meet demand (system saturation)	24.UDS Saturation Indicator
	9c. Changes in urban characteristics that affect rainwater	25. Variation in vegetation cover
		26. Variation in soil waterproofing coverage
10. Compromising the quality of rainwater	10a. Compromising the quality of surface releases	27. Potential polishing load on the ground
	10b. Compromising the quality of infiltrated water	28. Vulnerability to groundwater contamination
11. Erosion and siltation	11a. Sediment transport by rainwater	29. Soil susceptibility to erosion

Source: Corrêa, 2021.

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Table 6 - Urban Water Resilience Indicators associated with M&P.

Systems	Components	Variables
12.Legislation	12a. Laws and regulations that consider UWR	30. Number of municipal legal instruments that consider the UWR
13. Planning	13a. Updated specific plans considering UWR	31. Existence of specific plan(s) for UWR
		32. Frequency of updating disaster management plans
	13b. Redundancy capacity of water systems	33. Existence of redundancy in WSS, SSS and UDS
	13c. Adoption of contingency plans	34. Existence of contingency plans for the WSS, SSS and UDS
	13d. Provision of financial resources for emergencies and recovery	36. Possibility of immediate access to sufficient financial resources for recovery actions
14. Organizational management structure	14a. Effective coordination between water systems and with other bodies	37. Existence of coordination between sectors related to UWR
	14b. Training of personnel to act in relation to UWR	38. Percentage of training of water systems professionals to work at UWR
		39. Percentage of emergency responders who have received disaster response training
	14c. Monitoring of water systems	40. Existence of updated monitoring actions in water systems
	14d. Data availability	41. Percentage of city electronic data backed up by secure, remote storage
		42. Percentage of city area covered by publicly available threat maps
	14e. Risk assessment, prediction and prevention (risk maps, alert systems and structured Civil Defense)	43. Existence of updated risk maps
		44. Percentage of city population covered by multiple threat early warning systems
		45. Existence of structured civil defense
15. Participation and involvement of society	15a. Community awareness and preparation regarding UWR (Environmental Education, training)	46. Percentage of schools that teach emergency preparedness and disaster risk reduction
		47. Percentage of population trained in emergency preparedness and disaster risk reduction
	15b. Instances of society participation (councils, committees, working groups)	48. Existence of spaces for society participation related to UWR
		49. Public participation in consultations, public hearings, technical meetings and workshops related to UWR
	15c. Assistance for emergencies and vulnerable populations	50. Vulnerable population as a percentage of the city's population
		51. Forecast of actions related to UWR aimed at vulnerable populations
	15d. Emergency assistance to populations	52. Existence of partnerships between governmental and non-governmental bodies focused on UWR
		53. Number of intergovernmental agreements intended for shock planning as a percentage of total intergovernmental agreements

Source: Corrêa, 2021.

It is worth highlighting that the indicators listed in this research are a proposal or

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recommendation. Some of them are robust indicators, with a more grounded methodological trajectory, while others are more recent and need to be better evaluated. Consequently, the indicators presented here can always be reevaluated and eventually modified.

5 RESULTS

5.1 Proposals for Guidelines and Strategies for the Incorporation of UWR by Municipalities

5.1.1 Scenarios considered

The objective at this stage was to develop a guiding process for the city to become more water resilient, helping decision makers to plan goals, identify vulnerabilities and risks and develop actions related to UWR.

Therefore, three scenarios were considered for the incorporation of UWR by municipalities, without prejudice to other possibilities. Such scenarios could be:

a) **Scenario 1:** adoption of UWR elements in municipal sectoral plans (WSS, SSS and UDS).
b) **Scenario 2:** adoption of UWR in a unified way, integrating the various components of urban water management; It is
c) **Scenario 3:** adoption of UWR as part of a broader Urban Resilience System.

Scenario 1 has the advantage of the fact that sanitation or sectoral plans usually already exist, so it is sufficient to incorporate the UWR aspects and indicators in a review process. This can be done for each of the water systems or through a specific UWR chapter in the municipal sanitation plan.

Scenario 2 would be characterized by an integrated and unified approach to UWR and its indicators, in the form, for example, of the development of an Urban Water Resilience plan. In addition to giving a holistic sense and increasing the perception of UWR, this scenario favors coordination between municipal and regional levels, for example, through management by River Basins.

Scenario 3, in which UWR is part of the broader Resilience, it presents the same initial difficulty as Scenario 2, which is developing new instruments. However, if the city intends to become Resilient (such as those signatories of the "Building Resilient Cities" program) it would be mandatory to take this approach to Resilience in general.

It is worth noting that this research will not make an indication for a specific Scenario. Each city can present conditions that favor the adoption of one of them. For example, Scenario 1, with the most immediate implementation, may be the way UWR enters the water systems, later evolving into Scenarios 2 or 3.

5.1.2 Strategies for incorporating urban water resilience

In the present work, the methodology proposed by Matiazzi and Bragança (2018) was adapted, and the aforementioned, in addition to being specific to water aspects, the main adaptation concerns the use of UWR indicators.

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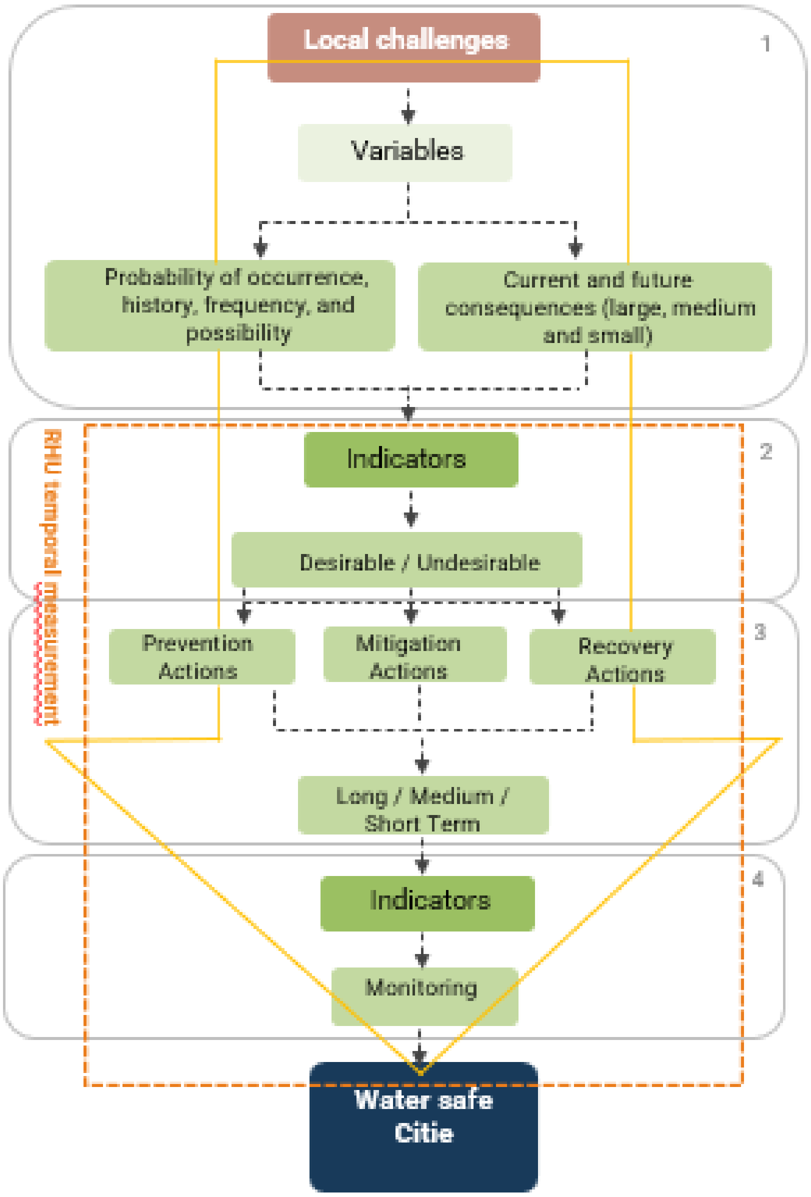
Figure 3 briefly outlines the general composition and phases of the method for building the UWR, which will be described below.

Figure 3 - Scheme of the method for Urban Water Resilience



Source: Author, 2024.

The details of each phase in Figure 3 are presented below.

- **Phase 1:** Risk Estimation (Probability versus Consequences). Events associated with UWR require quantification in terms of probability of occurrence and assessment of their consequences. The techniques used for this can be defined based on those usually used in risk assessments. For example, events associated with UWR may be more significant regarding water supply or the occurrence of floods.

- **Phase 2:** Definition and application of UWR indicators. By applying indicators to measure UWR, it is possible to measure and evaluate the past and build the future according

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to the available data. This phase involves determining what the desirable values are for each of the indicators, based on observations, measurements, calculations, or inferences. In addition to enabling better performance in the other phases of the methodology, the use of indicators in this Phase allows the adoption of actions.

- **Phase 3:** Define possible Prevention, Mitigation and Recovery Actions. In this phase of the method, the necessary actions for prevention, mitigation and recovery of the city must first be defined. For each of the variables associated with the indicators, actions are proposed at different times, that is, before, during and after the events. For this method, it is proposed that preventive actions be carried out in the long and medium term. Regarding recovery, actions can be short, medium, and long term, depending on each case.

In certain situations, it may be more advantageous for the city to invest in prevention than in mitigation or adaptation. Action choices need to consider each specific context and, of course, the issue of costs. In terms of recovery, actions such as: quality control of water resources with frequent monitoring.

- **Phase 4:** Continuous monitoring with indicators. As the city adapts to the UWR, the indicators are again applied for a continuous process of analysis, measurements, and perception of changing scenarios, whether positive or negative. The use of indicators in this stage aims to assist in monitoring, improving the decision-making process in prevention, mitigation, and recovery at different levels. As the city adapts to the UWR, the indicators are again applied for a continuous process of analysis, measurement, and perception of changing scenarios, whether positive or negative. Even without the event occurring, it is necessary to monitor the city.

- **Water Safe City:** A resilient city has a greater capacity to anticipate, prepare and adapt, becoming capable of organizing itself to deal with events and risks that affect its water systems. Adopting the paradigm of unification of Water Systems and taking UWR into account will allow cities to evaluate the present and build the future.

6 CONCLUSIONS

This This research proposed guidelines and strategies for incorporating Urban Water Resilience (UWR) in municipalities using indicators. Within this research, UWR was understood as the ability of an urban water system (its inputs and outputs) to continue to function or persist after being changed, but not necessarily to remain the same, however, maintaining the same basic structure and modes of operation.

It was discovered, through a literature review, that UWR is not yet addressed in an integrated manner in Urban Water Systems. There is generally an independent approach to each of these Systems, with an emphasis on the issues of flooding and water scarcity. As the conventional approach that divides Systems into Water Supply (WSS), Sanitary Sewerage (SSS) and Urban Drainage (UDS) still largely predominates, the researchers decided to maintain this division. However, to initiate an integrated approach between Water Systems and Resilience, this research advanced by unifying Management and Participation (M&P) into a single Component.

To verify whether this concept of Resilience has already been used in Brazil, the

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researchers sought for its presence in Municipal Plans of medium-sized cities that are signatories of the Making Cities Resilient: My City is Getting Ready program prepared by UNISDR, that is, cities that showed interest in the theme of Resilience.

From the analysis of the selected Plans, no direct mention of the term Resilience was found. However, it was possible to identify some aspects and variables directly or indirectly related to UWR. These aspects were observed mainly in M&P, which also presents the variable "instances of society participation" as the one most directly addressed by the Plans.

For each of the three Water Systems, the researchers sought to make approaches to the quantitative and qualitative aspects, both external and internal to the systems, always relating to events for which the UWR should be considered.

For the systematized variables, indicators were then associated. Some of them, already consolidated, were adopted from the literature, although they have undergone adaptations to better reflect UWR. Furthermore, new indicators were proposed throughout the research.

As the final stage of the research, the guidelines and strategies designed for the incorporation of UWR by Municipalities were consolidated in the form of a method considering the indicators. Three scenarios were considered in which UWR could be present: in Sector Plans (WSS, SSS and UDS), in a Plan unifying these Water Systems or, even, as part of a broader Urban Resilience System. Regardless of the scenario, the strategy of continuous monitoring of the UWR is maintained, considering moments before, during and after events related to Urban Water Systems.

With measurement by indicators, the city can, in each stage, improve its potential and correct its short, medium and long-term shortcomings by developing prevention, mitigation, and recovery actions, to improve the decision-making process.

The research carried out allowed us to deepen our knowledge regarding the application of indicators to measure UWR. Furthermore, an integrated approach to Water Systems was proposed, enabling greater evaluation performance and at the same time allowing a global view of the Systems. The presence of UWR and the unified approach to Urban Water Systems will favor the planning and adoption of strategies to have a water-safe city.

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