Dottorato di Ricerca in Architettura XXXVII ciclo
Architecture:
Urban Regeneration

ABSTRACT ENG

Abstract: Cities and territories worldwide are facing serious water-related challenges aggravated by the climate crisis and high levels of urbanization. Water security is a concept that comprehensively addresses the issue by considering the relationships between the multiple aspects that guarantee a reliable and sustainable supply of drinking water, safe management of wastewater and rainwater, and harnessing the economic potential of water. The research project proposes a series of increasers and reducers of water safety in cities and their surrounding territories from a systemic approach. To achieve this, a comprehensive water security assessment framework is proposed that covers the five main dimensions of water safety using a mixed exploratory sequential methodology. Afterward, this framework is applied to four case studies (Mexico City, San Diego, Reggio Calabria, and Ruston), which allows to obtain the common determinants that increase or decrease the water safety of cities. Once the determinants have been identified, it is possible to create a framework that establishes how they interact and determine which nuclear elements are needed to develop an efficient water security strategy. Identifying increasers and reducers for water security can help to understand better the urban water system and how various factors interact with each other that can positively or negatively impact water security; it allows decision-makers to prioritize interventions by identifying the elements that, if intervened, will have the greatest benefit or the elements that if not properly addressed could have the more negative consequences; it stimulates sustainable and resilient planning by anticipating potential risks and vulnerabilities in the water system that can be integrated into future risk management plans, and finally, it can help to increase awareness levels of the global water crisis and facilitates the adoption of more water wise consumption habits in communities.

Armando Cepeda Guedea

Determinants of Water Security in Cities

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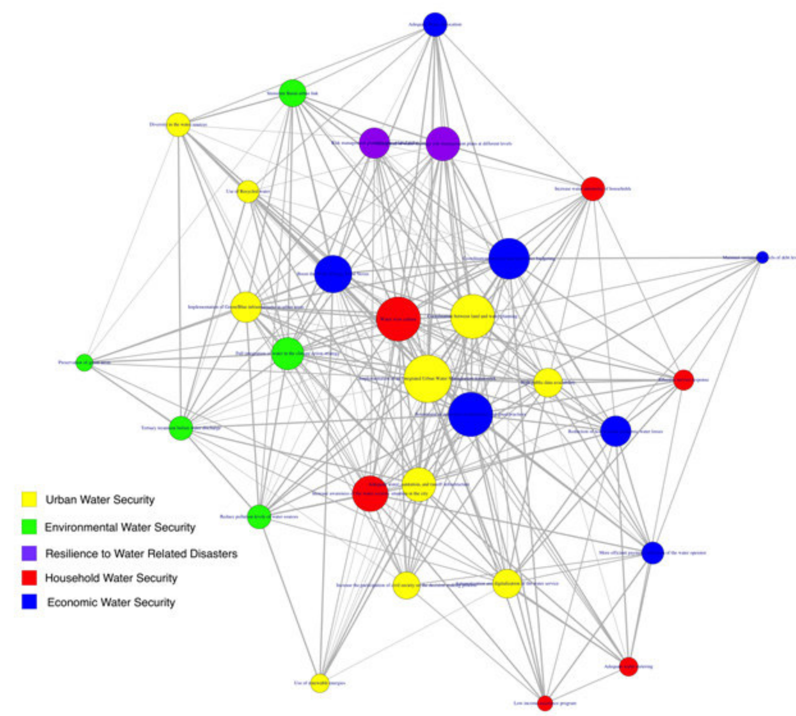
Armando Cepeda Guedea

Determinants of Water Security in Cities

Strategies to face water insecurity from a systemic approach



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XXXVII CICLO

DETERMINANTS OF WATER SECURITY IN CITIES

Strategies to face water insecurity from a systemic approach

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Armando Cepeda Guedea

DETERMINANTS OF WATER SECURITY IN CITIES

Strategies to face water insecurity from a systemic approach

Index

Abstract

Cities and territories worldwide are facing serious water-related challenges aggravated by the climate crisis and high levels of urbanization. Water security is a concept that emerged in the early 2000s and comprehensively addresses the issue by considering the relationships between the multiple aspects that guarantee a reliable and sustainable supply of drinking water, safe management of wastewater and rainwater, harnessing the economic potential of water, and being better prepared to water-related contingencies. In recent years, frameworks have been developed that attempt to evaluate the water security of cities and territories to assess and prioritize action regarding water resource management. After reviewing multiple evaluation frameworks for water safety, it can be seen that they do not encompass the various dimensions of water security and focus only on one or some of them, losing the multidimensionality with which the concept of water security was initially developed.

The research proposes a comprehensive water security evaluation framework for cities that aims to encompass the five main dimensions of water safety (Economic Water Security, Household Water Security, Urban Water Security, Environmental Water Security, and Resilience to related disasters) from a systemic approach after reviewing existing key indicators frameworks. To test the framework, it is proposed to apply it in four different cities as case studies (Mexico City, San Diego, Reggio Calabria, and Ruston) selected for their diversity in size, socioeconomic context, regulatory frameworks, drinking water situation and data accessibility that permits to obtain a more complete and global vision of water security. The results of the case studies permit the identification of possible common determinants that can increase or decrease the water security of cities. Once the determinants have been identified, it is possible to create a scheme that establishes how they interact and determine which nuclear elements are needed to develop an efficient water security strategy. The application of the proposed framework in cities can help to understand better the urban water system and how various factors interact with each other that can positively or negatively impact water security; it allows decision-makers to prioritize interventions by identifying the elements that, if intervened, will have the most significant benefit or the elements that if not adequately addressed could have the more negative consequences; it stimulates sustainable and resilient planning by anticipating potential risks and vulnerabilities in the water system that can be integrated into future risk management plans, and finally, it can help to increase awareness levels of the global water crisis and facilitates the adoption of more water wise consumption habits in communities.

Abstract (IT)

Le città e i territori di tutto il mondo si trovano ad affrontare gravi sfide legate all'acqua, aggravate dalla crisi climatica e dagli elevati livelli di urbanizzazione. La sicurezza idrica è un concetto emerso all'inizio degli anni 2000 e affronta la questione in modo multidimensionale considerando le relazioni tra i diversi aspetti che garantiscono una fornitura affidabile e sostenibile di acqua potabile, la gestione sicura delle acque reflue e piovane, lo sfruttamento del potenziale economico dell'acqua ed essere meglio preparati in caso di disastri legati all'acqua. Negli ultimi anni sono stati sviluppati quadri che tentano di valutare la sicurezza idrica di città e territori per valutare e dare priorità alle azioni riguardanti la gestione delle risorse idriche. Dopo aver esaminato molteplici quadri di valutazione per la sicurezza idrica, si può vedere che essi non comprendono le varie dimensioni della sicurezza idrica e si concentrano solo su una o alcune di esse, perdendo la multidimensionalità con cui il concetto di sicurezza idrica è stato inizialmente sviluppato.

La ricerca propone un quadro integrale di valutazione della sicurezza idrica per le città che mira a comprendere le cinque dimensioni principali della sicurezza idrica (Sicurezza Idrica Economica, Sicurezza Idrica Domestica, Sicurezza Idrica Urbana, Sicurezza Idrica Ambientale e Resilienza ai disastri correlati all'acqua) da un approccio sistemico dopo rivedere i quadri di indicatori chiave esistenti. Per testare il quadro, si propone di applicarlo in quattro diverse città come casi di studio (Città del Messico, San Diego, Reggio Calabria, e Ruston) selezionati per la loro diversità in termini di dimensioni, contesto socioeconomico, quadri normativi, situazione dell'acqua potabile e accessibilità ai dati che consente di ottenere una visione più completa e globale della sicurezza idrica. I risultati dei casi studio permettono di identificare possibili determinanti comuni che possono aumentare o diminuire la sicurezza idrica delle città. Una volta identificati i determinanti, è possibile creare uno schema che stabilisca come interagiscono e determini quali elementi nucleari sono necessari per sviluppare un'efficiente strategia di sicurezza idrica. L'applicazione del quadro proposto nelle città può aiutare a comprendere meglio il sistema idrico urbano e come i vari fattori interagiscono tra loro che possono avere un impatto positivo o negativo sulla sicurezza idrica; consente ai decisori di dare priorità agli interventi identificando gli elementi che, se intervenuti, porteranno il beneficio più significativo o gli elementi che se non adeguatamente affrontati potrebbero avere le conseguenze più negative; stimola una pianificazione sostenibile e resiliente anticipando potenziali rischi e vulnerabilità nel sistema idrico che possono essere integrati nei futuri piani di gestione del rischio e, infine, può aiutare ad aumentare i livelli di consapevolezza della crisi idrica globale e facilita l'adozione di un consumo idrico più saggio abitudini nelle comunità.

Introduction

I Background

As the global population continues to grow and cities become bigger and more complex, water security becomes a critical factor to ensure the survival and development of cities (Fitzhugh & Richter, 2004). Climate change and water security are closely interlinked. Climate change affects where, when, and how much water is available due to worsening floods, rising sea levels, shrinking ice fields, wildfires, and droughts (United States Environmental Potection Agency 2024a). The Intergovernmental Panel on Climate Change (IPCC) estimates that water bodies worldwide will especially suffer from the impact of climate change since they fully absorb approximately 93 % of the heat trapped by greenhouse gasses (GHG) (Intergovernmental Panel on Climate Change 2014; UNESCO World Water Assessment Programme 2020). Climate change impacts have the potential to disrupt the stability of water resources at different levels, from the global level to the local level, leading to water insecurity and causing conflicts and competition between different users. On the other hand, water is a key element in fighting climate change since sustainable water management is central to building the resilience of human communities and ecosystems and reducing carbon emissions (UN Water 2024). Water is required to produce renewable, sustainable energy (hydropower and geothermal) and for the development of carbon sequestration sinks through reforestation, bioenergy production, and carbon capture and storage. Also, climate change adaptation measures such as water retention by forests, wetlands, and artificial storage facilities, soil improvement and water management in rain-fed agriculture, and flood protection measures are critical to contributing to water security.

Human activity also directly damages the available freshwater sources by polluting the sources and overexploiting the water mantles. Water shortage risk also directly affects the economic development of cities, costing up to 6% of their GDP (Dumont-Bergeron & Gramlich, 2021). Water insecurity and access problems are not confined to the global South or developing countries. Some research reports problems of insecure water access, quality, affordability, and trust experienced by households in developed countries such as Canada and the United States (Meehana, Jurjevichb, Chunb, & Sherrillc, 2020), despite the presence of water governance systems and a general assumption of universal network coverage. Most of the cities tend to continue to address the water security crisis still from an XX-century approach by using grey infrastructure, centralized water management systems, using technology to reach the water from farther sources and with usually poor data access (Organization for Economic Co-Operation and Development, 2015). This situation makes it difficult to face the current challenge and calls for innovative practices such as the use of green and blue infrastructures, decentralized water management systems, and the use of data and technology.

Before the beginning of the 21st century, the water paradigm focused on the axis of resource scarcity and abundance, using mainly water stress levels as the sole indicator without fully addressing the issue of water in a holistic manner (Ding & Ghosh, 2017).

This changes from time to time in the Ministerial Declarations of the Second World Water Forum in the Hague in 2000 when the concept of water security was introduced (World Water Council 2000). The declaration stated that water security is achieved when water resources and related ecosystems are protected and improving, sustainable development and political stability are promoted, every person can access enough safe water at an affordable cost, and vulnerable populations are protected from water-related hazards. The United Nations polished the concept in 2013 (UN-Water 2013)by defining water security as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability. From these definitions emerge the five dimensions of water security: economic water security, household water security, urban water security, environmental water security, and Resilience to Water-Related Disasters.

Full water security for a city or territory should be a desirable and priority objective for decision-makers and their communities. In this context, regulations, policies, legislation, and projects at different levels should contribute to achieving this much-needed water security objective. This provides a solid framework to approach the water crisis from a systemic approach, which views water as a group of interconnected and interdependent elements that are organized around the goal of water security. In this framework, water security goes beyond the conventional technical perspective. It fully incorporates the human dimensions of water since cultural and behavioral change is critical for the success or failure of any water management strategy. The water security of a city is not just an element only contained in the urban context but considers the interactions with its surrounding environment and the economic dimension of water that generally is ignored or not fully integrated into water management.

According to the Oxford Dictionary, a determinant is defined as something that controls or affects what happens in a particular situation (Oxford Dictionary 2024). Determinants can be categorized into determinants that have a positive effect on a situation or a system or determinants that negatively impact the situation or system. When studying a complex system, it is key to identify the system structure that leads to challenges or issues that affect its adequate function and look for leverage points, which are elements that could lead to a large shift in the system in the wrong or the right direction depending on its application (Meadows 2008). The research aims to identify some of the common determinants that increase (leverage points for the right direction) or reduce (leverage points for the right direction) the water security of a city. Identifying increasers and reducers for water security can help to understand better the urban water system and how various factors interact with each other that can positively or negatively impact water security; it helps decision-makers to prioritize interventions by identifying the elements that, if intervened, will have the greatest benefit or the elements that if not properly addressed could have the more negative consequences; it stimulates sustainable and resilient planning by anticipating potential risks and vulnerabilities in the water system that can be integrated in future risk management plans, and finally it can help to increase awareness levels of the global water crisis and facilitates the adoption of more water wise consumption habits in communities.

To identify these key increasers and reducers in water security in cities, the research considers that an in-depth multiple case study approach is the best fit. Reviewing water security in multiple cities around the world provides a better and more complete understanding by presenting different approaches and perspectives on the matter. Data for each case study is collected from a literature review of key documents, informal interviews, and participatory observation. The selected cities are Mexico City, San Diego, Reggio Calabria, and Ruston. Mexico City is large metropolitan area with a global dimension that is a cultural and economic center for Mexico and the rest of Latin America. The city faces serious challenges regarding water security due to environmental, infrastructural, and institutional challenges. Currently, the city struggles to provide a continuous freshwater supply to all its inhabitants, this provokes considerable civil unrest and puts water security as one of the priority points of the development policy of the city and the region. San Diego is a metropolitan city of international dimension, home to one of the busiest border crossings between Mexico and the United States. The city faces serious challenges regarding water security due to the environmental conditions of the area aggravated by climate change. Since the 1990s, public authorities, in collaboration with the citizens, have combined efforts to cope with the issue. Currently, the city is in the vanguard regarding water culture, water planning, and water shortage management, with a clear reduction of water consumption in the last decades and the use of more innovative alternative water sources such as recycled water and desalinized water. Reggio Calabria is a medium-sized city of subnational dimension and legally classified as a metropolitan city. The city is located in one of the most challenging regions of the country and in an underdeveloped region inside the European Union, which requires special attention for its development at the national and European levels. Reggio Calabria is located in a vulnerable area to climate change that can affect the water supply and also faces water cuts because of infrastructural problems. Ruston is a small city, which can also be considered a town of local dimension Ruston's vulnerability to water-related risks is considered low, even though there are some water issues reported in recent times. The city and the state still do not have a comprehensive water management policy for cities at the local and state levels which can be considered a vulnerability in the case of water-related contingencies and is a step backward in the urban transition processes in the state. Considering all the previously reviewed aspects, the next research questions and their subsequent objectives emerge to structure the hypothesis and structure thesis.

II Main research question

What are the characteristics or actions of a city that could increase or reduce water security?

III Secondary research questions

1. What is the role of water in sustainable development and climate action?
2. What is the water crisis, and what are its dimensions?
3. Why water security framework is the best to address water-related issues?
4. How is water security evaluated at different levels?
5. Which is the best approach to evaluate water security in cities from a systemic approach?
6. How the social, economic, and political dimensions of cities interact with water security?

IV Main objective

Understand which characteristics or actions of a city could increase or reduce water security in cities.

V Secondary Objectives

1. Study the role of water in sustainable development and climate action.
2. Understand the water crisis and its multiple dimensions.
3. Study water security as the framework to address water related issues.
4. Study relevant evaluation frameworks for water security at different levels.
5. Develop an integral evaluation framework for water security in cities from a systemic approach.
6. Study how the social, economic, and political dimensions of cities interact with water security.

VI Proposed hypothesis

Identifying the possible main increasers or reducers of water security in cities could provide a better understanding of the urban water system, stimulate sustainable and resilient planning, contribute to the prioritization of decision-making, and increase the awareness of water security among citizens.

VII Significance of the study

Water security is an increasing problem in the world, with poorer communities being most badly affected (Food and Agriculture Organization of the United Nations, 2022). Around 4 billion people experience water scarcity, providing a dimension of the crisis that the global community is facing (UN-Water, 2023). The frequency and intensity of local water crises have been increasing, with serious implications for public health, environmental sustainability, food and energy security, and economic development. Cities continue to grow and bring more population in them, meaning that most of the world's population lives in cities (Organisation for Economic Co-Operation and Development, 2013). Demographics continue changing, and unsustainable economic practices are affecting the quantity and quality of the water at our disposal, making water an increasingly scarce and expensive resource. To advance towards water security and at the same time face global climate challenges, national and local governments, civil society, and the private sector must come together to develop plans, policies, and projects to transition to a more sustainable water management approach. The following research helps to reinforces the conceptual framework where water plays a central role in climate action and in the more general sustainable development strategy. It argues the value of the systemic approach of water security to unblock progress on the SDGs related to drinking water. It presents a new and innovative comprehensive water security assessment framework for cities from an exploratory sequential method that combines qualitative and quantitative approaches to obtain a clearer picture of the complex reality of water safety. This assessment framework can guide the future development strategy of cities, and identify priority areas, in addition to connecting land and water planning. By applying the proposed evaluation framework in diverse case studies, it allows the identification of the common elements that can increase or decrease the water security of cities. Through a relationship analysis it is possible to determine which are the key and nuclear elements that can initiate an effective water security strategy, which will be the aspects that strengthen the strategy and the aspects that consolidate it. Finally, the product of this research project contributes to the generation of knowledge about water safety in an area not yet developed to its maximum potential.

VIII Limitations of the study

The study's primary limitation can be the general lack of public data to review water security in cities from a systemic approach. Due to time constraints and available resources, there may also be a lack of a more comprehensive view of the water security challenge, with experiences only in Europe, North America, and Latin America. Finally, due to the relatively new development of the concept, the available literature regarding water security is still developing, leading to a small number of relevant sources regarding the subject.

IX General outline of the thesis

The thesis is divided into eleven chapters and four sections. Section 1 comprises the first four chapters, which set the theoretical background of the research. Chapter 1 explores the climate crisis to understand the current water crisis. Chapter 2 explores the water crisis because a secure and sustainable supply of water is key to the development of communities and how water is a key element in the most important international policies of the moment. Chapter 3 studies the concept of water security and why it is key to addressing the current water crisis. Chapter 4 studies different water security assessment frameworks, what their approaches are, what dimensions of water security they cover, and their level of action. Section 2 develops the methodological framework to build a comprehensive evaluation framework from a systemic approach. Chapter 5 presents the methodology of the comprehensive evaluation framework for water security composed of a qualitative and quantitative phase that will be applied to the selected case studies. The results obtained from the proposed evaluation framework will help identify the main determinants that increase or decrease the water security of cities. Section 3 tests the proposed evaluation framework into four selected cities for their different size, socioeconomic and territorial contexts, and normative and institutional frameworks (Chapter 6: Mexico City, Chapter 7: San Diego, Chapter 8: Reggio Calabria, and Chapter 9: Ruston). Section 4 presents the results of the case studies and the application of the proposed evaluation framework. Chapter 10 describes the results of the research by presenting the determinants that can increase or decrease the water security of cities in addition to categorizing the increasers of water security into three categories depending on their potential to trigger the development of the other increasers and be able to help decision makers structure their water safety strategy. Finally, Chapter 11 presents the discussion and conclusions of the thesis work.

Section 1

A literature review to understand water security and how it is evaluated

Port of Duluth. Armando Cepeda Guedea, 2023

Chapter 1

The global crisis of climate change to understand the freshwater crisis

Menta Dam. Armando Cepeda Guedea, 2024

1.1 A brief historical review of climate change

Climate change broadly refers to long-term shifts in temperatures and weather patterns, provoking glaciations, and warmer periods (United Nations Agency on International Development 2023). Throughout the earth's long history, different climatic changes have taken place. These changes are mainly attributed to minimal variations in Earth's orbit that change the amount of solar energy our planet receives, the sun's activity, or large volcanic eruptions (NASA-Science 2024a). In the last 800,000 years, there have been eight cycles of ice ages and warmer periods, with the end of the last ice age about 11,700 years ago marking the beginning of the modern climate era (NASA-Science 2024a). The evidence of these changes can be seen in tree rings, positions of glaciers, lake sediments, ice cores, ocean sediments, landforms, corals, and sedimentary rocks (NASA 2024).

The science that studies past climates is called paleoclimatology. This science tries to identify the causes of past climate changes to understand how they relate to the present and future climate changes on the planet.
The climate change that has taken place in the last 200 years for the first time can be mainly attributed to human activity due to the burning of fossil fuels, which generates greenhouse gas emissions, creating a dense layer in the atmosphere that traps the sun's heat and raises temperatures (Vigna, Friedrich, and Damassa 2024; Calvin et al. 2023). The consequences are intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms, and declining biodiversity (United Nations 2024e). This endangers the health, availability of food and water, and even the continuity of human communities worldwide. This makes climate change one of the most significant challenges global society faces in the 21st century. It calls for urgent actions to reduce or mitigate climate change and avoid potentially irreversible environmental damage (NASA-Science 2024b; Calvin et al. 2023). This requires advance towards sustainable development, which is defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

The research is limited to climate change linked to the human-driven increase in temperature in the last 200 years, which is a priority for the international community. Ambitious mitigation actions are indispensable to limit warming while achieving sustainable development and poverty eradication. To support this approach, the research uses the definition of climate change by the *United Nations Conference on Environment and Development* held in Rio de Janeiro in 1992, commonly known as the *Earth Summit* which defines climate change as "A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".

1.2 A brief historical review of climate change

It scientifically proved that human activities have unequivocally caused a global increase in temperatures, commonly known as global warming, principally through greenhouse gas emissions (Calvin et al. 2023). Greenhouse Gases (GHG) are composed of carbon dioxide (CO_2) 79.7%, methane (CH_4) 11.1%, nitrous oxide (N_2O) 6.1%, and fluorinated gases 3.1% (United States Environmental Protection Agency 2024b). Some studies use the emission of CO_2 as a proxy for GHG emissions since CO_2 is the main component (Vigna, Friedrich, and Damassa 2024). Observed increases in GHG concentrations have been evident since the second half of the XVIII century just when the industrial revolution sparked in Europe (Intergovernmental Panel on Climate Change 2007). Since the apparition of reliable data regarding carbon emissions and temperature in the late XIX century, there has been an increase in the global temperature of 1.2°C, by comparing the average temperature of the 2014–2023 decade with the 1850–1900 decade and the warmest multi-century period in more than 100,00 years (Intergovernmental Panel on Climate Change 2007; Vigna, Friedrich, and Damassa 2024). From the 1910s to the 1940s, there was an increase of 0.35 °C in the global temperature; meanwhile, since the 1970s to the 2000s, there has been a more substantial increase in temperature of 0.55 °C due to more significant emissions produced by newly industrialized countries such as China and India (Intergovernmental Panel on Climate Change 2007).

From 1850 to the mid-20th century, the world experienced near-constant growth in GHG emissions (Vigna, Friedrich, and Damassa 2024). This was due to industrialization and population growth mainly concentrated in the United States and Europe since the rest of the world was still pre-industrial and their emissions were relatively low. In this period, the United States became the top emitter of CO_2, followed by the United Kingdom and Germany. In the decades following World War II and until the 1980s, Russia became the second top emitter of CO_2 because of the heavy industrialization process of the Soviet Union. At the end of the XX century and due to globalization, Asian countries began to emerge as more significant contributors to GHG emissions, principally led by China, because of the rapid expansion of China's economy along with its bigger consumption of fossil fuels. China surpassed the U.S. as the world's top CO_2 emitter in 2005 (Vigna, Friedrich, and Damassa 2024). By 2022, the East Asia and the Pacific region were contributing 44% of global CO_2 emissions. The top emitters of GHG emissions may have changed, but a reduced group of 10 nations still contributes to 76% of global CO_2 emissions (Vigna, Friedrich, and Damassa 2024). Considering their responsibility for the rise of temperatures, these countries should step up their climate leadership by rapidly reducing emissions and supporting other nations in their transitions towards a lower-carbon economy, aiming to mitigate the impacts of climate change globally.

Scientists and governments worldwide agree that limiting global temperature rise to no more than 1.5°C of pre-industrial levels at the end of the XXI century would help to avoid the worst climate impacts and maintain a livable climate (IPCC 2022). This is reflected in the Paris Agreements signed in 2015 that pursue efforts to limit it to 1.5°C above pre-industrial levels, but that find acceptable an increase of 2°C (Raiser et al. 2020). Limiting global warming to 1.5°C instead of 2°C could result in around 485 million fewer people being exposed to frequent or exceptional extreme heatwaves, assuming constant vulnerability (IPCC 2022). Unfortunately, current predictions point to a 3°C temperature rise by the end of the century (see Figure 1), falling notary short on both pathways proposed in the Paris Agreements and increasing the uncertainty of the future impacts of climate change (United Nations 2023a). The World Economic Forum establishes that overpassing an increase of 3°C of pre-industrial times will potentially provoke irreversible and self-perpetuating changes to planet Earth and significantly endanger the continuity of many human communities worldwide (World Economic Forum 2024a).

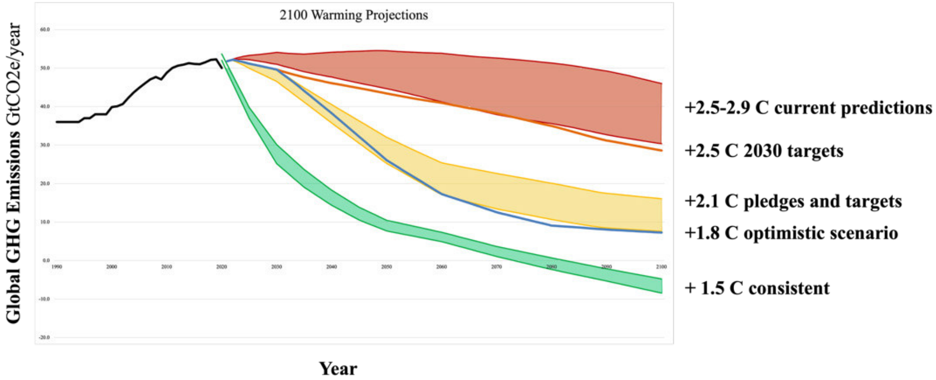


Fig. 1. Warming Projections for 2100 with the different scenarios. Source: Climate Action Tracker, 2023

1.2 Climate change a worldwide priority

The impacts of climate change are interrelated (National Oceanic and Atmospheric Administration 2021). Drought can harm food production and human health. Flooding can lead to disease spread and damage to ecosystems and infrastructure. Human health issues can increase mortality, impact food and water availability, and limit productivity. It is common to think about human-driven climate change as something that will happen in the future, but it is an ongoing process. The impacts of climate change are seen in every aspect of life on Earth, including humans. However, climate change impacts are uneven between different countries worldwide; even within a single community, climate change impacts can differ between neighborhoods or individuals. Long-standing socioeconomic inequities can make traditionally underserved groups, who often have the highest exposure to hazards and the fewest resources to respond, more vulnerable to climate change impacts. This section presents the main impacts of climate change at the global level; in subsequent parts of the research, more context-specific impacts will be reviewed. The research identifies nine main impacts of climate change based on the United Nations and the National Oceanic and Atmospheric Administration that pose considerable risks to the continuity of humans and other species on Earth (United Nations 2024a; National Oceanic and Atmospheric Administration 2021).

Higher temperatures: high concentrations of GHG have increased the global surface temperature. It was reported that the 2011-2020 decade (Calvin et al. 2023), was the warmest on record since the late XIX century when reliable information on global temperature emerged. Since the 1980s and due to the acceleration of industrialization processes and population growth worldwide, it has been reported that each decade has been warmer than the previous one. Nearly all countries are experiencing more and longer heat waves. Higher temperatures are increasing heat-related illnesses. Wildfires are spreading more quickly and easily due to hotter surface conditions. Temperatures in the North Pole have increased at least twice as fast as the global average, provoking the melting of glaciers, and increasing the sea levels.

More severe storms: the severity and frequency of destructive storms have increased in many regions. As temperatures rise, more moisture evaporates, intensifying extreme rainfalls and flooding, provoking more severe storms. The frequency of severe storms is conditioned by the warmer temperatures on the ocean’s surface. Such storms often cause deaths and huge economic losses.

Increased droughts: climate change is directly impacting water availability, causing water scarcity in more regions. Global warming aggravates water shortages in already water-stressed regions, increases the risk of agricultural droughts that affect crop production, and increases the overall vulnerability of ecosystems. Droughts increase the expansion rate of deserts, reducing land for growing food, and can also stir destructive sandstorms. Many communities around the world are not having enough water on a regular basis due to increasing droughts.

Sea level rise: The temperature of the oceans has been strongly increasing for the last two decades at an unexpected pace since the oceans are absorbing most of the heat from global warming. The sea levels are rising for two main reasons: with higher temperatures, the volume of the ocean increases since water expands as it gets warmer, and melting ice sheets also increase the levels of the oceans. Rising sea levels threaten the continuity of coastal and island communities. In addition, oceans absorb CO_2, keeping it from the atmosphere but making them more acidic, which endangers marine life and coral reefs.

Loss of species: climate change effects such as fires, extreme weather, deterioration of soil, change in the chemical composition of the oceans, droughts, and invasive pests and diseases are among the many threats that pose significant risks to the survival of land and water species. It is estimated that within the next few decades, one million species are at risk of becoming extinct due to climate-related impacts endangering these species' habitats. Some species can adapt and survive, but others will not and can provoke massive extinctions.

Food shortage: extreme weather events associated with climate change are among the reasons behind a rise in food shortages. Fisheries and other marine resources are at risk due to oceans becoming more acidic. Higher temperatures can diminish water and grasslands for grazing, causing declining crop yields and affecting livestock. All of this is affecting the capacity to feed billions of people causing a global rise in hunger, poor nutrition, and endangering the health of communities.

Health risks: It is estimated that every year, environmental factors related to climate change are taking the lives of around 13 million people. This makes climate change one of the biggest threats to the health of human populations. Climate change-related impacts are harming the health of human communities, through air pollution, extreme weather events, forced displacements, increased hunger and poor nutrition, and pressures on mental health. Changing weather patterns are expanding diseases, increasing deaths, and making it difficult for healthcare systems to keep up.

Poverty and displacement: climate change impacts are increasing the factors that put human communities in poverty and make them vulnerable to displacement of their homes provoking climate refugees. Floods may sweep away urban areas, destroying homes and livelihoods. Heat waves can make outdoor jobs difficult and affect workers' health and income. Water scarcity may affect food production and freshwater quantity and quality. In the (2010–2019) decade, weather-related events displaced approximately 23.1 million people each year, leaving more people vulnerable to poverty. Most climate refugees come from developing countries that are the most vulnerable and least ready to adapt to the impacts of climate change.

Vulnerability of Human Infrastructure: extreme weather events such as heavy rains, floods, storms, or temperature changes can stress and reduce the life of existing structures and facilities such as bridges, roads, ports, electrical grids, broadband internet, and communication systems. It is critical to design infrastructures with future climate changes in mind. Rising temperatures require more indoor cooling, which can stress the energy grid. Severe storms can lead to flooding that shuts down highways and major business areas affecting the development of communities.

Despite increasing awareness of climate change and its consequences, greenhouse gas emissions continue to increase. Countries can address climate change through two main avenues (NASA-Science 2024c).

Mitigation: reducing emissions and stabilizing the levels of greenhouse gases in the atmosphere, moving towards low-carbon societies, and reducing deforestation and forest degradation.

Adaptation: measures to adapt and adjust to future and current impacts of climate change by building resilience and financing new models for a green economy.

Climate change is one of the biggest challenges the global community has faced in the last decades, and it is striking harder than expected (World Economic Forum 2024a). It is considered a very complex issue since it involves multiple dimensions, such as science, economy, society, and politics, among others (Intergovernmental Panel on Climate Change 2007b; NASA-Science 2024c; IPCC 2022). Even though it is a global issue, it manifests differently depending on the region, country, province, and city (IPCC 2022). This calls for a wide range of mitigation and adaptation measures to face the issue effectively (see Figure 2). Mitigation measures involve reducing greenhouse gas emissions and limiting global warming to accepted levels (1.5 °C increase from preindustrial levels). Meanwhile, adaptation measures involve helping communities adjust to the current and future effects of climate change (NASA-Science 2024c; Intergovernmental Panel on Climate Change 2007b).

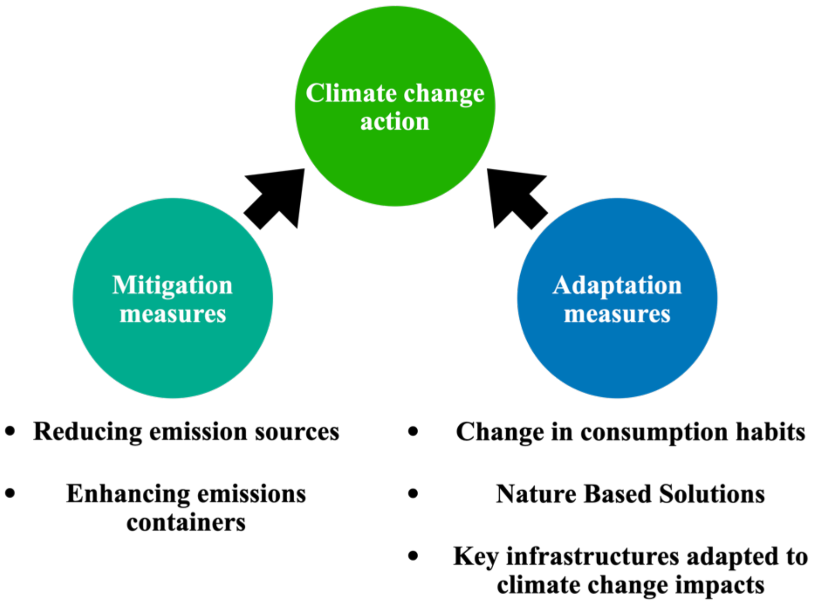


Fig. 2. Diagram of climate change action measures to be adopted. Source: Armando Cepeda Guedea, 2024

Mitigation centers on the root cause of climate change, which is the heat-trapping greenhouse gases that are adding to the atmosphere faster than the planet can absorb them. These can be addressed by reducing the sources of greenhouse gas emissions by human activity or enhancing new containers of greenhouse gases that remove them from the atmosphere (Intergovernmental Panel on Climate Change 2023; IPCC 2022; Calvin et al. 2023).

> Reducing emission sources: energy, industry, transport, buildings, agriculture, and land use are among the main sectors responsible for the emission of greenhouse gases, by burning large quantities of fossil fuels. Mitigation actions focus on replacing fossil fuels with more sustainable sources of energy, like renewable energies such as wind, solar, biomass, hydro, and nuclear power. Mitigation measures can also tackle other sources of greenhouse gases such as protecting the existing forests from being cut down or collecting methane from landfills.
>
> Enhancing emissions containers: growing new forests and developing air capture systems as mitigation measures work by taking greenhouse gases out of the atmosphere, commonly called "carbon removal." To make efficient emission containers they need to be implemented at a large scale and still require complementary mitigation measures to drastically reduce emissions, making challenging the adoption of this approach. Nevertheless, the IPCC and other organizations consider the adoption of carbon removal techniques to be valid and necessary to avoid the worst impacts of climate change.

Global warming is a reality. Even if emissions are reduced, and the increase in the global temperature is stabilized, the damage is already done, and the global population should assume that they live in a hotter world and should adapt to this new reality (IPCC 2022). Climate change impacts such as sea level rise may continue for hundreds of years after the Earth's temperature stabilizes (MIT Climate Portal 2023). There is no unique set of adaptation measures to climate change, and they will vary from place to place.

Adaptation measures involve building or retrofitting key infrastructures better adapted to climate change impacts, like the implementation of storm drain systems, to manage increased flooding. But adaption measures also include Nature Based Solutions (NBS), such as restoring wetlands to buffer hurricanes and contain floods, or behavior and policy changes, like growing new food crops that can better handle warmer seasons and droughts (MIT Climate Portal 2023; IPCC 2022; Calvin et al. 2023). Ideally, adaptation is proactive, meaning developing measures not only for current impacts but for future impacts. Territories and cities that don't take early steps will find themselves adapting reactively, meaning adapting after a climate-driven catastrophic event.

If mitigation measures for climate change are insufficient, adaptation will only become more important in future climate action. Policymakers focus mainly on mitigation rather than adaptation (MIT Climate Portal 2023). Most of the international funding for climate change has been spent on mitigation, with only a small share given to adaptation (MIT Climate Portal 2023; Calvin et al. 2023). Considering that the actions to mitigate the impacts of climate change worldwide are falling short, investing in adaptation measures will be critical in the future.

To effectively face climate change countries will need to adopt both mitigation and adaption measures. Without financial, capacity-building, and technological aid (see Figure 3), low- and middle-income countries are unlikely to adapt quickly enough to avoid serious hardship (MIT Climate Portal 2023). The Paris Agreement adopted in 2015 encourages wealthy developed nations to assist developing countries with the implementation of mitigation and adaptation actions, but so far, the efforts have fallen short, as reflected in the insufficient progress in achieving the 17 Sustainable Development Goals (SDG), more in specific the SDG 13 that is one focused in climate change (United Nations 2015; 2024b; United Nations Climate Change 2024).

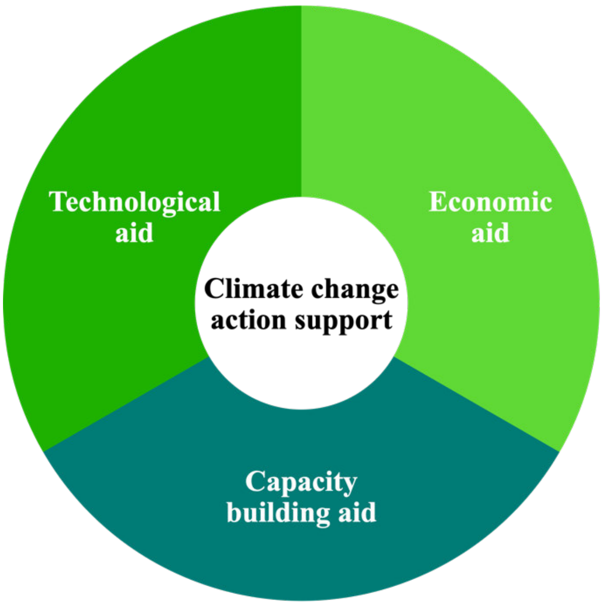


Fig. 3. Climate Change Action Support Framework from the Paris Agreement. Source: United Nations, 2015

Environmental risks related to climate change are one of the top priorities of the global community, according to the Global Risks Report 2024 of the World Economic Forum

(World Economic Forum 2024a). The report brings together 1,500 global leaders across academia, business, government, the international community, and civil society. It also gathers insights from over 200 thematic experts, including the risk specialists that form the Global Risks Report Advisory Board, Global Future Council on Complex Risks, and the Chief Risk Officers Community.

The report ranks the 34 main global risks identified by the World Economic Forum with the help of the 1,500 global leaders consulted worldwide. The risks are divided into five categories: economic, environmental, geopolitical, societal, and technological. In the form of synthesis, it presents the top 10 global risks for the short (2 years) and long (10 years) term (see Table 1). According to the report, environmental risks continue to dominate the risk landscape. Two environmental risks linked to climate change are present for the short-term global risks. For the long-term global risks, the predominance of environmental risks linked to climate change is more evident with five risks in the top 10 and four occupying the first positions. The top 10 global risks for the long and the short term are presented in the following table with a more specific description of the environmental risks of climate change.

Table 1: Top 10 risks for the long and short term according to the Global Risks Report 2024 of the World Economic Forum

Short term (2 years)	**Long term (10 years)**
1. Misinformation and disinformation	1. Extreme weather events: loss of human life, damage to ecosystems, destruction of property and/or financial loss due to extreme weather events such as wildfires, floods, storms, heatwaves including those exacerbated by climate change.
2. Extreme weather events: loss of human life, damage to ecosystems, destruction of property and/or financial loss due to extreme weather events such as wildfires, floods, storms, heatwaves including those exacerbated by climate change.	2. Critical change to Earth systems: Long-term, potentially irreversible, and self-perpetuating changes to planet Earth. This changes because of breaching a critical threshold (3°C over pre-industrial temperature), at a regional or global level, that have abrupt and severe impacts on planet health or human welfare.
3. Societal polarization	3. Biodiversity loss and ecosystem collapse: severe consequences for the environment due to the extinction or reduction of species both terrestrial and marine.
4. Cyber insecurity	4. Natural resource shortages: Supply shortages of food or water for human, or ecosystem use. Resulting in food and water insecurity at a local, regional, or global level as a result of human overexploitation and mismanagement of critical natural resources, climate change impacts, and/or a lack of suitable infrastructure.
5. Interstate armed conflict	5. Misinformation and disinformation
6. Lack of economic opportunity	6. Adverse outcomes of AI technologies
7. Inflation	7. Involuntary migration
8. Involuntary migration	8. Cyber insecurity
9. Economic downturn	9. Societal polarization
10. Pollution: Introduction of harmful materials into the air, water and soil	10. Pollution: Introduction of harmful materials into the air, water and soil

stemming from human activity, resulting in impacts to and loss of human life, financial loss and/or damage to ecosystems. Inclusive of household and industrial activities and accidents, oil spills and radioactive contamination.	stemming from human activity, resulting in impacts to and loss of human life, financial loss and/or damage to ecosystems. Inclusive of household and industrial activities and accidents, oil spills and radioactive contamination.

Two-thirds of the consulted experts for the report rank Extreme weather as the top risk on a global scale in 2024. It is also the top risk for the long-term horizon (10 years). It is also seen as the second-most severe risk over the short-term time frame (2 years): Nearly all environmental risks are among the top 10 over the longer term. A Critical change to Earth's systems poses one of the most severe risks the planet will face over the next decade. Human-driven climate change can push Earth past the tipping point, past a 3°C increase of pre-industrial levels to which society cannot adapt. Natural resource shortages are a global risk linked to climate change that is very relevant for the research since water shortage is inside this risk, confirming that global leaders consider water an essential resource for the global community and that it is in danger from the impacts of climate change. This means that international leaders can find valuable new knowledge that better seeks the water security of human communities.

Until the 1970s, environmental issues and climate change were not a major concern of the United Nations and the global community (Jackson 2007). The first acknowledgment of the need to preserve the environment and the potential effects of climate change was at the UN Scientific Conference of 1972, also known as the First Earth Summit, held in Stockholm (Jackson 2007). The results of the conference were a declaration that set out principles for the preservation and enhancement of the human environment, an action plan containing recommendations for international environmental action, and for the first time, a warning for Governments to be mindful of activities that could lead to climate change and evaluate the likelihood and magnitude of climatic effects.

Over the following years, there were efforts to reduce air pollution and limit the production and use of chlorofluorocarbons to protect the Ozone layer. This resulted in the creation in 1979 of the Earth Watch program, designed to monitor and evaluate the long-range transport of air pollutants, and the first international instrument on climate watch (C. E. Jensen and Brown 1981). This led to the adoption in 1985 of the Vienna Convention for the Protection of the Ozone Layer, which aimed at reducing sulfur emissions by 30 percent. This was to avoid the increasing damage that direct radiation was doing to planet Earth as the Ozone layer was diminishing (Sand 1985). From the late 1970s until the late 1980s, the efforts of the international community regarding climate were focused mainly on air pollution and did not fully acknowledge sustainable environmental development as a whole.

In 1987 when the United Nations adopted the Environmental Perspective to the Year 2000 and Beyond agenda. This document presents a framework to guide national action and international cooperation on policies and programs aimed at achieving environmentally sustainable development (Dabholkar 1989). It underlined the relationship between environment and development and, for the first time, introduced the notion of sustainable development, which today continues to be a key concept in the development of policies and actions by governments at different levels as well as civil associations. This long-term policy document recognized the need for clean air technologies and to control air pollution. Nevertheless, the document fell short of acknowledging climate change as a central issue but subsumed it under its policy directive related to energy. This document can be considered a transitional document that prepares the ground for subsequent documents that put climate change as a milestone for sustainable development.

The following year considering how global warming and the depletion of the ozone layer became increasingly prominent in the international public debate and political agenda the United Nations established in November 1988 the Intergovernmental Panel on Climate Change (IPCC) to provide governments at all levels with scientific reliable information such assessments, scientific publications, data and reports that they can use to develop climate policies (Intergovernmental Panel on Climate Change 2024). To date, IPCC reports are a key input into international climate change negotiations, and the adoption of policies and actions at different levels. The IPCC is an organization composed of 195 members of governments that are members of the United Nations or the World Meteorological Organization (WMO) (Intergovernmental Panel on Climate Change 2024). Thousands of experts collaborate for the development of the different documents, the IPCC produces. Each year the IPCC provides a comprehensive summary of what is known about the drivers of climate change, its impacts and future risks, and how adaptation and mitigation can reduce those risks.

As the urgency for more decisive international action on climate change, gained momentum. The United Nations held the Conference on Environment and Development (UNCED), also known as the 'Earth Summit' in Rio de Janeiro in 1992 (United Nations 1992). At this conference representatives from 179 countries designed a new blueprint for international action on environment and development issues that would help guide international cooperation and development policy for the XXI century (United Nations 1992). It was highlighted how social, economic, and environmental factors are interdependent and should evolve together to achieve a sound sustainable development of communities from an integral approach. One of the major results of the 1992 Rio Conference was Agenda 21, an ambitious plan of action that aimed to achieve overall sustainable development in the 21st century (Dahl 2014). Chapter 9 of the agenda dealt with the protection of the atmosphere and established the link between science, sustainable development, energy development and consumption, transportation, industrial development, stratospheric ozone depletion, and transboundary atmospheric pollution, reaffirming the complexity of current climate change and how is not an isolated phenomenon. The 1992 Earth Summit made climate change a top priority as is reflected in the establishment United Nations Framework Convention on Climate Change (UNFCCC) signed by 158 countries (Jackson 2007). The main objective of the convention was to stabilize greenhouse gas concentrations to avoid dangerous interferences to climate change and to allow ecosystems to adapt naturally to climate change. This is to ensure that food production and water availability are not threatened and to enable economic development to proceed sustainably.

Once climate change was established as a top priority in the Earth Summit of 1992, the next step was the 1997 Kyoto Protocol, a cornerstone of climate change action. It aimed to reduce the overall emissions of carbon dioxide and other greenhouse gases by at least 5% below the 1990 levels for the 2008-2012 period (Jackson 2007). The Kyoto

Protocol put special emphasis on GHG emissions reduction in developed industrialized countries that at that moment were the main emitters and responsible for the climate change crisis. In 2005 it was signed by over 160 countries.

The year 2015 was a landmark year for multilateralism and international policy shaping, with the adoption of several major agreements for sustainable development and addressing climate change. The outcomes of the agreements acquired in 2015 by the international community through the United Nations are still current. These agreements are reflected in the following documents: Sendai Framework for Disaster Risk Reduction (Mizutori 2020), the Paris Agreement on Climate Change (Carter and Ross 2016), and the 2030 Agenda for Sustainable Development with the 17 Sustainable Development Goals (SDGs) at its core (Boto-Álvarez and García-Fernández 2020).

A brief historical review of how the international community has addressed climate change helps to understand how the perception and acknowledgment of climate change and its impacts have evolved in the last fifty years and which strategies and agreements have emerged (see Figure 4). Also, it presents what previous agreements and documents support the current ones.

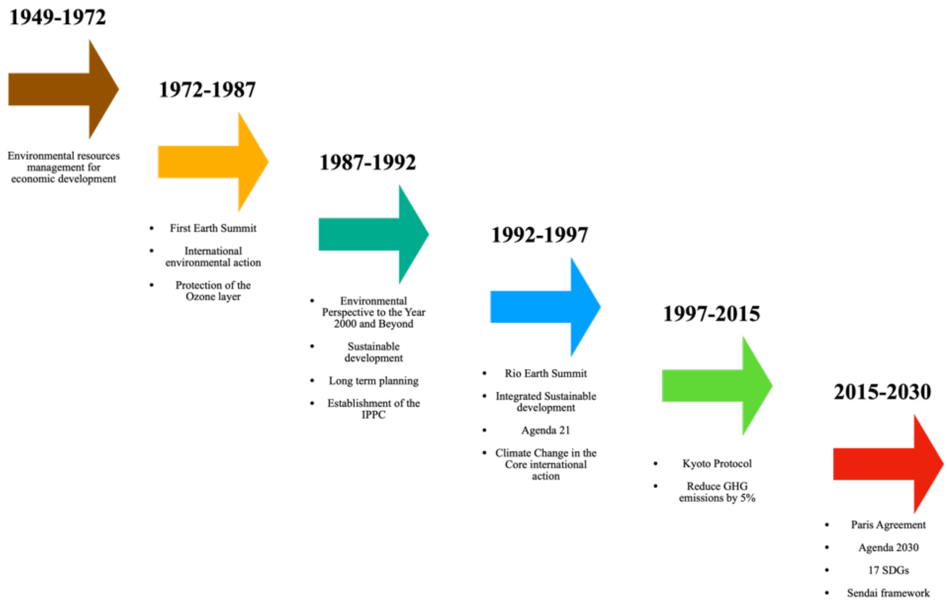


Fig. 4. Climate Change Action historical evolution. Source: Armando Cepeda Guedea. 2024

1.2.1 The Paris Agreement on climate change

The Paris Agreement is the first legally binding international treaty on climate change, representing a landmark on multilateral global action to face climate change. It was adopted at the UN Climate Change Conference (COP21) in Paris, France, in 2015 and signed by 196 parties (United Nations 2015; United Nations Climate Change 2024; Carter and Ross 2016). The main objective of the agreement is to hold an increase in the global average temperature below 2°C above pre-industrial levels and pursue efforts to limit this increase to 1.5°C, proposing two pathways that nations can follow (IPCC 2022; United Nations 2015). However, world leaders have stressed the need to limit global warming to 1.5°C by the end of the XXI century following the IPCC reports that indicate that crossing the 1.5°C threshold risks unleashing severe climate change impacts, including more frequent and severe droughts, heatwaves and alterations of rainfall cycles. To limit global warming to 1.5°C, greenhouse gas emissions must peak before 2025 at the latest and decline 43% by 2030 (IPCC 2022).

The implementation of the Paris Agreement requires a coordinated economic and social transformation. The Paris Agreement requires the signatory countries since 2020 to submit their national climate action plans, commonly known as Nationally Determined Contributions (NDC) (United Nations Climate Change 2024). Each successive NDC expects to reflect an increasingly higher degree of ambition compared to the previous versions. Each NDC communicates the actions each country will take to reduce their greenhouse gas emissions to reach the goals of the Paris Agreement, and the actions they will take to adapt to the impacts of climate change.

The Paris Agreement considers that developed countries and historically top emitters should take the leadership on climate actions since developing countries with minimal emissions are suffering the impacts of climate change, they did not provoke. The Paris Agreement provides a framework for financial, technical, and capacity-building support between countries (United Nations Climate Change 2024).

Climate finance: encouraging voluntary financial contributions of developed countries to developing countries more vulnerable to climate change. Climate finance is needed for mitigation since large investments at different levels are required to reduce emissions. Climate finance is also key for adaptation, as important financial resources are needed to adapt to the adverse effects of climate change and reduce its impacts.

Technology for climate response: encouraging technology development for reducing GHG emissions and increasing resilience to climate change to everyone, by creating a knowledge network between countries. The agreement establishes a technology framework to accelerate technology development and transfer through its policy and implementation arms.

Capacity building for climate change: the Paris Agreement puts great emphasis on capacity building for developing countries that do not have sufficient capacities to deal with many of the challenges brought by climate change and requests developed countries to support capacity-building actions for those developing countries.

Through the Enhanced Transparency Framework (ETF) established in 2024, participating countries will report transparently on actions taken in climate change mitigation, adaptation measures, and the support provided or received (United Nations Climate Change 2024). The information gathered through this framework will feed into the Global Stocktake which will assess the collective progress towards the long-term climate goals.

Since the publication of the Paris Agreement in 2015 and its implementation in 2016, significant results have emerged. More countries, regions, cities, and companies are establishing carbon neutrality targets, more noticeably in the power and transport sectors. It is expected that by 2030, zero-carbon solutions could be competitive in sectors that represent over 70% of global emissions (Carter and Ross 2016; United

Nations Climate Change 2024; IPCC 2022). Significantly reducing emissions and working towards the 1.5°C pathway the agreement proposes.

1.2.2 The 2030 Agenda for Sustainable Development and the 17 SDGs

The 2030 Agenda for Sustainable Development, adopted by all United Nations members in 2015, is currently the main document that guides sustainable development worldwide. The document provides a blueprint for peace and prosperity for, now and into the future. At the core of the agenda are the 17 Sustainable Development Goals (SDGs), which are a call for actions to reduce poverty and protect the planet from the impacts of climate change from an integrated approach since the agenda recognizes that action in one aspect will affect outcomes in others and that sustainable development must balance social, economic and environmental sustainability (see Table 2). The SDGs have a total of 17 goals, 169 targets, and 248 indicators, 92 of which are environment-related, confirming the critical role climate change plays in the agenda that is expected to be achieved by 2030 (UN Environment Program 2024; United Nations 2024b). The SDGs recognize that to achieve the proposed set of goals, they should go hand-in-hand with a wide range of strategies that improve health and education, reduce inequality, and spur economic growth, all while tackling climate change and working to preserve oceans and forests (UN Environment Program 2024; United Nations 2024b). The 17 SDGs are the following, with special emphasis on SDG 13, which is the one specifically designed to face climate change and its impacts. SDG 6, which is linked with sustainable water management, will be thoroughly reviewed in the following sections.

Table 2: Sustainable Development Goals

Sustainable Development Goal	Targets	Indicators
1. End poverty in all its forms everywhere	7	13
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	8	14
3. Ensure healthy lives and promote well-being for all at all ages	13	28
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	10	12
5. Achieve gender equality and empower all women and girls	9	14
6. Ensure availability and sustainable management of water and sanitation for all	8	11
7. Ensure access to affordable, reliable, sustainable and modern energy for all	5	6
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	12	16
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	8	12
10. Reduce inequality within and among countries	10	14
11. Make cities and human settlements inclusive, safe, resilient and sustainable	10	15
12. Ensure sustainable consumption and production patterns	11	13
13. Take urgent action to combat climate change and its impacts	5	8

14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	10	10
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	12	14
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	12	24
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	19	24

The Division for Sustainable Development Goals (DSDG) provides support and capacity-building for the SDGs and their related thematic issues such as water, energy, climate, oceans, urbanization, transport, science, and technology (United Nations 2024a). DSDG plays a key role in the evaluation and monitoring of the implementation of the 2030 Agenda and the 17 SDGs worldwide. To make the 2030 Agenda a reality, it should translate into a strong commitment by all stakeholders at different levels to implement the SDGs. The DSDG aims to help facilitate this engagement by providing expertise and guidance.

The Sustainable Development Report measures the total progress towards achieving all 17 SDGs for 193 countries and ranks them (Sustainable Development Report 2024). Each of the SDGs is classified into achieved, challenges remain, significant challenges remain, and major challenges remain. Also, the level of progress of each SDG and target is classified as on track or maintaining achievement, moderately improving, stagnating, and decreasing. The report provides a spillover score to measure the positive or negative effects on other countries in three dimensions: environmental and social impacts, economy & finance, and security. Finally, it describes the Policy efforts of each country to achieve the SDGs by evaluating the presence of voluntary national reviews, high-level statements, SDG action plans, SDGs in the national budget, National SDG monitoring, Designated lead unit, and Spillovers in the voluntary national reviews.

According to the Sustainable Development Report (Sustainable Development Report 2024), a country like Italy ranks 23, has an SDG progress of 79.29 and a Spillover Score of 69.58. Also, it meets all the policy efforts evaluated in the report. The result of the evaluation of Italy coincides with the expected progress of a developed country that belongs to the European Union. Even though there is plenty of work to do because none of the SDGs by 2023 are achieved. Four SDGs including SDG 13 which is focused on climate action are having major challenges and nine are still having significant challenges. The United States the historical top emitter of GHG ranks 46 has an SDG progress of 74.43 and a Spillover Score of 61.85. Unfortunately, the United States only partially covers one of the policy efforts (National SDG monitoring) through online reports on official SDG indicators. The results of the reports reflect the insufficient action the United States is taking on global sustainable development considering the country is the first global economy and has the historic responsibility as a top GHG emitter. Six SDGs including SDG 13 which is focused on climate action are having major challenges and eight are still having significant challenges. Finally, a developing country like Mexico ranks 80, has an SDG progress of 69.28 and a Spillover Score of 90.22, proving the global importance of the country as a regional center that connects Latin America with North America and the importance of stimulating the progress of the SDGs in the country since it will provide great benefits beyond its borders. Mexico lacks only two of the evaluated policy efforts which are High-level statements and Spillovers in voluntary national reviews. The result of the evaluation of Mexico coincides with a developing country, but the policy efforts show the commitment the country has to achieve the SDGs, Mexico's policy efforts are bigger than the United States, even with its limited resources. Ten SDGs including SDG 13 which is focused on climate action are having major challenges and the other seven are having significant challenges.

To evaluate and monitor the implementations of the SDGs every year, the United Nations presents an annual SDG Progress report, based on the global indicator framework and data produced by each national statistical system and information collected at the regional level. Since 2016 nine reports have been developed being the 2024 version the most updated version (United Nations 2024c). Additionally, a Global Sustainable Development Report is produced every four years to inform the quadrennial progress on the SDGs and it is written by an Independent Group of Scientists appointed by the UN Secretary-General. Only two reports have been published to date, the 2019 and the 2023 versions (United Nations 2023b). Nevertheless, the Global Sustainable Development Report provides greater analysis and diagnosis of the progress to achieve the SDGs, framing a future and pathways where achieving the SDGs and the Agenda 2030 is possible. The 2023 report is very relevant since it is at the halfway point of the Agenda, and it calls national and local governments, business leaders, and other actors to take action to prepare for and shape the future up to 2030 and beyond where sustainable development is possible.

Both the 2024 annual SDG Progress Report and the 2023 Global Sustainable Development Report confirm that the world is severely off-track to achieve the 2030 Agenda. The 2024 Annual SDG Progress Report shows that only 17% of the targets are on track, 48% exhibit moderate to severe deviation from the desired track, and 35% have stagnated or regressed below the 2015 baseline levels. More alarmingly none of the SDGs targets for SDG 13 and 6 are on track, due to the increasing impacts of climate change and the insufficient action of governments worldwide to mitigate and adapt to them. The 2023 Global Sustainable Development Report conducted an assessment of select targets with sufficient data, showing that most of the Sustainable Development Goals targets are far from being achieved, also shows a comparison of trends for each selected target, as assessed in 2020, with trends in 2023, this to understand if there is progress or regression from the objective.

The few targets that are close to being achieved and remain on track are access to mobile networks (9.c.1) and Internet access among individuals (17.8.1), closely linked with the advances and accessibility of technology in recent years. Meanwhile, targets that are close to being achieved but progress is stagnated are: Increase skilled birth attendance (3.1.2), Achieve full employment (8.5.2), Sustainable and inclusive industrialization (9.2.1). Most of them are linked to economic growth rather than climate change action.

Concerningly targets that are moving backward and continue to regress, are achieving food security (2.1.2), reducing global greenhouse gas emissions (13.2.2), and preventing the extinction of species (15.5.1). Food shortages (2.1.2) and loss of species (15.5.1) are direct consequences of climate change, meaning that those targets cannot be achieved if global greenhouse gas emissions are not reduced (13.2.2). Regarding SDG 6, which is linked to freshwater availability and the sustainable management of the resource, the only targets analyzed are Universal safe drinking water (6.1.1) and Universal safe sanitation and hygiene (6.1.2), which mainly focus only on the accessibility aspect of water rather than others equally relevant such as quality and availability. Still, these two targets are not progressing as expected and are moderately far from being achieved. This requires embracing transformations where governments and communities should take bold and unpreceded action, where small actions are not just enough considering the magnitude of the challenge. Initiatives must be broad-based and inclusive and should involve dynamic interactions between science, business, civil society, and government. Such action can be the adoption of zero-carbon technologies, techniques for the wise use of the available resources, and normative mechanisms to substantially reduce emissions, among others. Another important aspect that emerges from the report is the still limited data available to properly evaluate and monitor the progress toward achieving the SDGs this is reflected that only 36 targets were able to be analyzed. This requires an effort of national governments to produce and submit their key data to the United Nations. Developed countries should support countries that are not able to produce and process data relevant for the evaluation and monitoring of the SDGs with technological and financial support, following the same model of international cooperation model the Paris Agreement encourages.

The United Nations reports through the SDG Action Platform voluntary policies, commitments, multi-stakeholder partnerships, and other initiatives made by governments and other relevant stakeholders to support the acceleration of the UN Sustainable Development Goals. Currently, there are 8076 reported initiatives (United Nations 2024d). Each initiative may involve more than one SDG, contributing to an integrative approach to achieve the targets of the SDGs. Next it is presented a table ranking each SDG by the number of associated initiatives (see Table 3).

Table 3: Number of associated initiatives for each SDG

Sustainable Development Goal	Initiatives	Rank
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	2859	1
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	2201	2
13. Take urgent action to combat climate change and its impacts	2140	3
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	1929	4
6. Ensure availability and sustainable management of water and sanitation for all	1823	5
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	1822	6
5. Achieve gender equality and empower all women and girls	1655	7
12. Ensure sustainable consumption and production patterns	1620	8
1. End poverty in all its forms everywhere	1438	9
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	1372	10
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	1318	11

3. Ensure healthy lives and promote well-being for all at all ages	1289	12
11. Make cities and human settlements inclusive, safe, resilient and sustainable	1239	13
7. Ensure access to affordable, reliable, sustainable and modern energy for all	1048	14
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	1046	15
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	1038	16
10. Reduce inequality within and among countries	994	17

Nevertheless, SDG 13 occupies the third position of initiatives presented to the SDG Action Platform, this does not reflect in advances to achieve its targets as is reflected in the 2023 Global Sustainable Development Report where the target (13.2.2) reducing global greenhouse gas emissions is far from target and its progress is deteriorating. Regarding SDG 6 which is also in the top 5 in the number of presented initiatives is not reflecting significant progress in achieving its targets as reflected in the report. Nevertheless, it is highly valuable the considerable number of initiatives presented to face climate change, a reflection is required on how effective these initiatives are, if the number of initiatives is still low considering the dimension of the climate change crisis, or if a new approach to face climate change is required.

In the last five positions, it is surprising to find SDG 11 among them, considering that by 2050 it is expected that 70% of the global population will be living in cities, making cities a key element for sustainable development and requiring more interest and initiatives to create more sustainable, equitable and resilient cities for the future. Also, SDGs 7 and 11 are falling behind in the number of presented initiatives, considering that the full achievement of the targets of these objectives is critical to reducing GHG emissions. The SDG with less initiative is SDG 10 which is focused on reducing inequalities between countries. While the great inequalities between nations remain present, we must move towards a more sustainable future where the impacts of climate change are more manageable, and society better adapts to them.

To support the monitoring of the progress of the SDGs in a more graphic and approachable manner the Sustainable Development Solutions Network, which is a non-profit organization created by the United Nations presents the Sustainable Development Report (SDR) interactive map which provides the levels of progress to achieve the SDGs at the national level. The interactive map shows graphically the inequalities between countries in their progress to achieve the SDGs. Meanwhile, European Union countries have around 80% of achievement of their SDGs, and developing countries in Africa, Asia, and Latin America have less than 60% of achievement of the SDGs, reinforcing the statement that to reduce emissions and the impacts of climate change no country should be left behind in their road of sustainability. The improvement of the conditions of developing countries is also beneficiary for the well-being of developed countries since the planet Earth is an interconnected system where the actions in one place affect the other.

Sustainable Development Goal (SDG) 13 refers to "Climate Action" and is the one focused on facing climate change and its impacts (United Nations 2024a). The objective recognizes that climate change is a global challenge that requires urgent attention and combined efforts from governments at different levels, communities, and businesses worldwide. SDG 13 is composed of 5 targets and 8 indicators that are presented in the following table (see Table 4).

Table 4: Sustainable Development Goal 13: targets and indicators

Sustainable Development Goal 13: Take urgent action to combat climate change and its impacts	
Target	**Indicator**
Target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	**13.1.1:** Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population
	13.1.2: Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030
	13.1.3: Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies
Target 13.2: Integrate climate change measures into national policies, strategies and planning	**13.2.1:** Number of countries with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change
	13.2.2: Total greenhouse gas emissions per year
Target 13.3: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	**13.3.1:** Extent to which (i) global citizenship education and (ii) education for sustainable development are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment
Target 13.a: Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible	**13.a.1:** Amounts provided and mobilized in United States dollars per year in relation to the continued existing collective mobilization goal of the $100 billion commitment through to 2025
Target 13.b: Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities	**13.b.1:** Number of least developed countries and small island developing States with nationally determined contributions, long-term strategies, national adaptation plans and adaptation communications, as reported to the secretariat of the United Nations Framework Convention on Climate Change

The article "The central role of climate action in achieving the United Nations' Sustainable Development Goals" provides a good description of each target of SDG 13 that helps to understand better and provides a good base for further analysis (Filho et al. 2023). Target 13.1 focuses on strengthening the resilience and adaptive capacity to climate-related disasters that affect the livelihood of millions of people worldwide such as extreme flooding, droughts, heatwaves, wildfires, and other natural disasters. The aim is to ensure the development of disaster risk management skills at the national and local levels so that they may assist in the prevention and response to climate-related events. Target 13.2 pursues the effective integration of climate change measures and solutions into national and global policies. This target encourages governments to support policies, actions, strategies, and programs to be implemented regarding climate change which can increase the capacity of countries and communities to adapt to climate change and its impacts. Target 13.3 expects to improve education and awareness about climate change, increasing the acknowledgment of climate change impacts can increase the capacity building among people and institutions to address it, and also put pressure on local and national governments to adopt more ambitious measures on climate change. Targets 13.a and 13.b can be considered two subsets of a broader macro target that aims to reduce the inequalities between countries regarding climate change action. Target 13.a aims to ensure that international aid from developed countries in funding the operation of the Green Climate Fund to ensure the financing of adaptation and mitigation measures in developing countries. This helps to make developed countries who are the historical top emitters of GHG and the main responsibles for climate change accountable for their previous and current actions. Target 13.b involves raising the capacity of developing countries and vulnerable groups to implement effective climate change planning and management actions. This is facilitated by the Global Reporting Initiative (GRI) which allows countries to report their contributions and by doing so provides a base for further accountability,

SDG 13 plays a central role in the Agenda and is linked in different degrees to the other 16 SDGs since climate change is a milestone for sustainable development and a prerequisite for the well-being and continuity of human communities and requires urgent actions by the global community. Also, in the article "The central role of climate action in achieving the United Nations' Sustainable Development Goals" (Filho et al. 2023) explores the relationship between SDG 13 and its targets with the other SDGs and synthesized in a very clear figure (see Figure 5).

Target 13.1 is related to SDGs 1,2 and 11, which are related to building the resilience of vulnerable populations as a consequence of climate change. Target 13.3 relates to SDGs 4 and 8 since they are associated with the acquisition of knowledge and skills to promote sustainable development and efficient resource management. Targets 13.a and 13.b are related to the financial and capacity means to address climate change and require strong partnerships between countries and relevant stakeholders from an approach that not vulnerable countries and individuals are left behind. For that reason, Targets 13.a and 13.b are associated with SDGs 5,10,16 and 17.

The relationship with Target 13.2 helps to discover the SDGs that have a clear reference to climate change mitigations and adaptation efforts that can be translated into policies and planning instruments. Also contributing to the integral approach to climate change action requires, as mentioned before several aspects should be taken into consideration to effectively approach the challenge. The SDGs are 3,6,7,9,12,14 and 15 which are closely related to the key thematic aspects to approach climate change such as water, energy, climate, oceans, urbanization, transport, science, and technology. It is important to the research finding that policies and planning instruments related to SDG 6 which focuses on sustainable management and availability of water resources, are a key component to achieving Target 13.2 and as a consequence taking action against climate change.

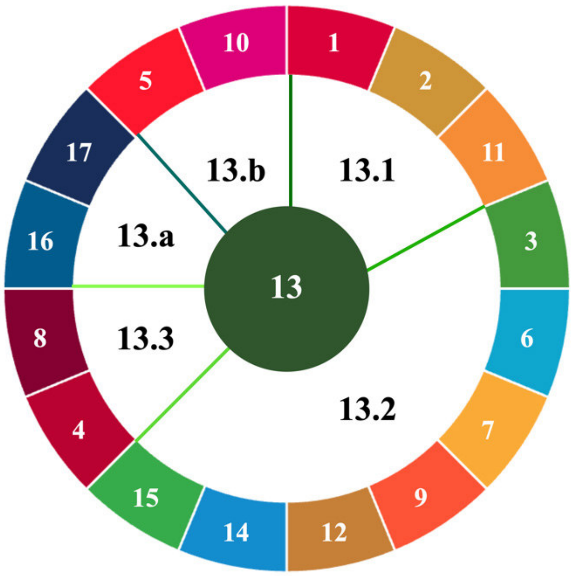


Fig. 5. Relationship between SDG 13 with the rest of the SDGs. Based on the work of (Filho et al. 2023)

The article "Connecting climate action with other Sustainable Development Goals" presents a deeper analysis of the relationship between climate change in the SDGs (Fuso Nerini et al. 2019). Firstly, it presents a figure that describes the targets with clear evidence that climate change impacts their achievement, of the 169 targets the study finds that 72 of them could be undermined by climate change. It is clear climate change can affect the achievability of SDGs relating to material and physical well-being such as prosperity and welfare, poverty eradication and employment, food, energy and water availability, and health. More specifically water shortages related to climate change can directly impact the health of individuals by reducing access to clean drinking water and sanitation for communities and cities worldwide as reflected in Targets 6.1, 6.2, and 6.4.

The article also presents a further analysis that identifies the synergies and tradeoffs to address whether climate change can reinforce or undermine other SDGs and vice versa. Effective climate action can enable the creation of prosperous, equal, sustainable, resilient, and peaceful societies. Firstly, it helps to decrease inequalities between countries if effective international cooperation is applied (10.1, 10.2, 10.7, 14.7, 15.6), contributes to the reduction of poverty, and increases the levels of welfare and job quality (1.1, 1.2, 1.4, 1.5, 1.a, 8.1, 8.2, 8.4, 8.5, 8.8, 8.9). It also helps to build strong, functioning, and capable institutions (17.1, 17.19). To have an efficient climate action it is required an integrated management approach of key resources such as water (6.1,6.6, 6.a), food (2.1–2.5, 2.a, 2.b), and electricity (7.2, 7.3). According to the article, there are clear synergies between climate action and the management and conservation of marine (14.1,14.5) and terrestrial (15.1,15.5, 15.8, 15.9) ecosystems.

Reducing GHG emissions can improve global health outcomes (3.3, 3.4, 3.9) by improving the air, soil and water quality. Finally, there is strong evidence that sustainable cities and human settlements will have to play a key role in both climate mitigation and adaptation efforts since it is where most of the world's population concentrates (11.1,11-6).

Regarding trade-offs, there are approximately four times fewer trade-offs than synergies between climate action and the achievement of the SDGs (34 targets across 12 SDGs). Nevertheless, those trade-offs can significantly block the progress of climate action by two main factors. Firstly, climate mitigation policies can be economically costly in the short term, especially for carbon-intensive and energy-exporting countries (8.1), and could hinder the productive activities of these countries (9.2) but with the potential to boost others in the medium and long term. Climate action could also adversely affect communities that rely on fossil fuel industries, if transition plans are not properly implemented those can increase the poverty and reduce the well-being of those communities. Secondly, climate policies, if not properly designed can be socially and economically regressive for vulnerable communities and developing countries, exacerbating inequality and poverty worldwide (1.1, 1.2). Certain climate policies that require considerable investments and the adoption of costly technologies can impact land and food prices (1.4, 2.3, 2.4), increasing the risk of leaving behind small food producers (2.3, 2.4). Unfortunately, some national climate adaptation programs have even resulted in violent conflicts, since they can endanger the economic livelihood of individuals or entire communities that depend on unsustainable activities, or forced displacement due to changes in land use regulations. In the energy sector, while climate action policies would underpin the adoption of efficient and renewable energy (7.2, 7.3) it might affect the delivery of affordable, reliable, and modern energy services (7.1) as fossil-fuel energy can be cheaper in certain developing areas and countries.

Climate change action confirms its complexity where one solution is not enough, and multiple coordinated actions are required to confront the phenomenon. The transition to a more sustainable and carbon-free society will not be easy, and there may be resistance to applying the necessary measures, so solutions should be adapted to each context where the benefits are greater than the losses. Furthermore, in the current context, achieving the targets of one SDG can hinder the achievement of others, as can be seen with SDG 13, which is the one linked to climate action. In this situation, decision-makers should prioritize their actions to ensure a future where climate change does not condition the survival of human communities since stabilizing the increase in temperatures and adapting to their impacts will eventually result in an improvement in the well-being of human communities which in the end is the main objective of the 2030 agenda.

1.2.3 Synergies between the 2030 Agenda and the Paris Agreement

The Paris Agreement and the 2030 Agenda with its 17 SDGs came almost simultaneously in 2015 as a response to the considerable economic, environmental, geopolitical, societal, and technological challenges the global community is facing. Aligning climate policies (Paris Agreement) and actions with the broader sustainable development objectives (SDGs) is imperative according to the United Nations (United Nations City 2019). Despite the growing recognition of the benefits of coordinating sustainable development and climate change agendas, many countries find it challenging to implement because each agenda has its own history, stakeholders, and political dynamics (Bodansky 2022; United Nations City 2019). This may be the result that even though both initiatives were presented in the same year, and pursued similar objectives they were presented separately, and no coordinating framework was developed to accompany them. Subsequently, the Global Conferences on Synergies between the 2030 Agenda and Paris Agreement, tried to cover this gap by delivering a set of concrete recommendations for strengthening the interlinkages between the SDGs and climate action, but it seems that their efforts continue to be insufficient in most of the cases (UN Department of Economic and Social Affairs 2019). National-level implementation of the 2030 Agenda and the Paris Agreement generally proceeds on different tracks with distinct institutional, policy, and monitoring frameworks for each. Commonly, environment ministries are the ones responsible for steering the climate change agenda and the Paris Agreement. Meanwhile, more central ministries such as the office of the president or prime minister or planning or finance ministries, are entrusted with coordinating SDG implementation. Limited coordination among the different ministries reduces the ability of decision-makers to identify linkages and opportunities to coordinately achieve climate action goals and sustainable development targets. A few countries such as Mexico, Kenya, Germany, and Indonesia, among others, are acknowledging the impacts of proposed climate policies on the SDGs in formulating their climate plans, by considering the benefits of the SDGs when selecting actions for its Nationally Determined Contributions (NDC) (United Nations City 2019). Some ministries have started to assess the alignment of national and sectoral development plans and budgets with both the NDC and the SDGs (United Nations City 2019). Updates of standard planning guidance can support local planners in identifying linkages and selecting priorities on the basis of benefits for the two agendas.

The World Resources Institute after reviewing the majority of NDCs in 2016 through the Climate Watch Platform discovered that they aligned with 154 out of the 169 targets of the SDGs and are currently updated until 2021 (Northrop et al. 2016). The study found that for 10 of the 17 SDGs, all their targets are addressed by at least one country's NDC. For the other seven Goals, at least two-thirds of their targets are addressed by at least one country's NDC. The analysis is global, which is why the coverage of the SDG targets by NDCs is so extensive. When analyzing each country individually the level of coverage significantly changes. For example, in countries like Mexico, 13 SDGs are addressed in its NDC, in the United States 10 SDGs, and in Australia 4 SDGs (Northrop et al. 2016).

1. Stimulate global digital transformation.
2. Increase the climate and mitigation actions in low and middle-income countries.
3. Invest in sustainable, smart, resilient, inclusive, and safe networks in all modes of transport.
4. Strengthen healthcare capacities around the world to overcome global pandemics and context-specific diseases that endanger people's health.
5. Invest in quality education and research to strengthen cooperation on research and innovation and include vulnerable groups in knowledge production.

Another example in a relevant policy area is the Water-Energy-Food-Ecosystem Nexus, which proposes the Nexus approach that understands the synergies of water, energy, and agricultural policies (Global Water Partnership 2024c). It also provides an informed and transparent framework for determining the proper trade-offs and synergies that maintain the integrity and sustainability of ecosystems. In a subsequent section of the research, this approach will be reviewed thoughtfully.

Regional groupings such as the European Union, do not fully engage in the Climate Watch Platform, since they have their own mechanisms to monitor and evaluate their progress in achieving the Paris Agreement objectives and the SDGs (Northrop et al. 2016). The European Union Green Deal is a roadmap to guide the sustainable growth of the union and the achievement of the Paris Agreements and the Agenda 2030 with their 17 SDGs (European Commission 2019; European Commission 2024e). The European Union even proposes 102 additional indicators to the SDGs adapted to the needs and objectives of the Union (Eurostat 2024). Understandably, a group of highly developed countries such as the European Union generate their own climate action and sustainable development objectives considering their specific conditions since the union may have greater ambitions than those established by the 2030 Agenda and the SDGs. But that should not mean that they disengage from coordinated efforts at a global level. In addition, it is important to mention the great responsibility that several countries in the European Union have for being historically large emitters of GHG and for the historic exploitation of natural resources in vulnerable countries. The work developed by the European Union can be a reference to good practices regarding climate action and sustainable development for developing countries.

1.3 The climate action and sustainable development of the European Union

The European Union (EU) is a political and economic partnership among 27 European sovereign countries that collaborate in multiple aspects for the common development of the region. Together they cover much of the European continent. The EU is home to around 447 million people, which is around 6 % of the world's population, and has the third largest economy (European Commission 2022).

As a global leader, the EU is engaging in international efforts to address environmental challenges and promote the implementation of ambitious climate, environment, and energy policies worldwide to transition towards more sustainable development pathways. The EU proposes 10 main policy areas to achieve that inside and outside the EU since the European Commission also finances projects for climate action and increases the overall sustainability of developing countries outside the EU (European Commission 2024c). The 10 main policy areas are the following: biodiversity and ecosystems, climate change, forests, nuclear safety, nutrition and food security, oceans, sustainable energy, sustainable food systems, transboundary water cooperation, and water-energy-food-ecosystem nexus. Each policy area has its own specific, policies and programs. For the climate change policy area, the European Union has the Global Gateway which is the European strategy to enhance sustainable development and climate actions across the world, and it is aligned with 2030 Agenda and the Paris Agreement. The Global Gateway aims to raise €300 billion in investments through the 'Team Europe approach', which will bring together the EU Member States and their financial and development institutions to mobilize the private sector to leverage investments for a transformational impact (European Commission 2024b). It is centered on 5 main objectives that can bring solutions to the various challenges in the current geopolitical context (European Commission 2024d).

The EU's 10 main policy areas are more focused on the international action of the Union with a special interest in developing countries. For the EU-specific context, the main climate action strategy is the European Green Deal, which is the main roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all. In 2019, the European Commission launched the Green Deal with four main objectives (European Commission 2019).

1. Make Europe carbon neutral by 2050,
2. Protect human life, animals, and plants, by cutting pollution,
3. Help companies become world leaders in clean products and technologies
4. Help ensure a just and inclusive transition where no one is left behind

The European Green Deal is the cornerstone where multiple legislations, policies, actions, and strategies at the European and national levels emerge. The key achievements of the European Green Deal by July 2024 are reflected in the following policies, legislation, programs, and investments (European Commission 2024a).

Walking towards a climate-neutral Europe by 2050

Being a climate-neutral continent by 2050 is at the core of the European Green Deal and was unanimously subscribed by the Member states and the European Parliament. Being climate-neutral does not mean eliminating all GHG emissions it means significantly reducing emissions while the remaining emissions will be captured by technology or in natural carbon sinks or containers, such as forests. To materialize this objective the European Parliament approved the EU Climate Law in 2021 making climate neutrality a binding commitment. It sets the ambitious target to reduce net emissions by at least 55% by 2030, in comparison to 1990 levels. To enable this objective the EU approved the following legislation commonly known as "fit for 55": EU Emissions Trading System (ETS) reform, New EU Emissions Trading System for building and road transport fuels, Social Climate Fund, Effort Sharing Regulation, Regulation on Land Use, Forestry and Agriculture, CO_2 emissions standards for cars and vans, Carbon Border Adjustment Mechanism, Renewable Energy Directive, Energy Efficiency Directive, Alternative Fuels Infrastructure Regulation, ReFuel EU Aviation Regulation, and the FuelEU Maritime Regulation. To reduce emissions, it is key to use a wide set of policies and regulations to obtain the goal.

Protecting vulnerable workers and societies

The transition toward a climate-neutral society requires that nobody is left behind. Transitions are costly and not every region can fully adopt the required measures fairly and socially conscious. To support European regions that are most affected by the socio-economic impact caused by the clean transition, the European Commission approved the Just Transition Fund (JTF) with a total allocation of €19.7 billion. The proposed fund directs investments into these regions to diversify economic activities towards cleaner industries and train workers for new sources of employment. Additionally, the Commission proposed a Social Climate Fund (SCF), which will be financed via a carbon pricing mechanism to support vulnerable groups by investing in energy efficiency, renovation of buildings to sustainability criteria, clean heating, and direct income support for households.

Supporting people and regions affected by increasingly frequent climate events

Climate change is striking harder than expected with unexpected damages in communities across the continent. To support communities the European Commission developed the EU Solidarity Fund (EUSF) which is the main solidarity instrument for climate-led disasters. Since 2019 it has provided €2.1 billion to 13 EU countries in the wake of disasters. To support disaster management the EU has the EU Civil Protection Mechanism (UCPM) that supports member and non-member countries when impacted by climate-related emergencies. Meanwhile, the Emergency Response Coordination Centre (ERCC) acts as a coordinator between Member States, the affected country, and local civil protection and humanitarian experts, enabling the necessary reactive support, but also in the forms of satellite mapping, modeling, and training. Finally, the program Next Generation EU, which is one the most ambitious recovery funds in recent times with an €806.9 billion investment to make Europe healthier, greener, and more digital, and address climate change mitigation after the COVID-19 pandemic.

Supporting farmers to withstand the consequences of climate change

Food security is one of the main challenges that the global community is facing, and the European Union is not exempt from this challenge. The European Commission has also taken important actions to increase the support to farmers and rural communities impacted by climate-related disasters. Farmers in 22 EU countries have received €330 million to cope with the impacts of climate events and higher input costs. To further support farmers, the Commission has given Member States the flexibility to complement EU financial support with national funds up to 200% to improve farmers' cash flow.

Financing green reforms and investments

Properly financing the Green Deal is key to climate action in Europe. The European Commission has set that one-third of the €1.8 trillion investment from the Next Generation EU and the EU's seven-year budget is used to finance the Green Deal. As mentioned before Next Generation EU is a key funding tool for the clean transition setting 37% of the funds invested on climate action, but it has been exceeded, reaching 42%, including €62 billion from the REPowerEU program which aims to contribute to affordable, secure and sustainable energy.

Cohesion Policy also plays a key role by securing €118 billion specifically for climate action ranging from infrastructure and sustainable urban mobility to energy efficiency and renewable energy. Additionally, the European Regional Development Fund (ERDF) coordinated with the Cohesion Fund have an ambitious target of investing at least 30% and 37% of their capacity respectively in climate action.

Furthermore, the Climate, Energy, and Environment Aid Guidelines adopted in 2022, have helped EU countries to reach the Green Deal objectives by providing public financing to ensure that private companies carry out the necessary investments at the least possible cost for taxpayers and without unduly distorting competition. Since

September 2019, the Commission has approved more than €400 billion in State aid for non-crisis related energy measures, including for renewables, energy storage and infrastructure.

Another effort is the adoption of the Temporary Crisis and Transition Framework in 2023 to support measures for the clean transition by financing clean-tech production with €13 billion. The Important Projects of Common European Interest (IPCEIs) are another key tool for innovation. In recent years, the European Commission has approved nine IPCEIs with the participation of 22 Member States, in the fields of batteries, microelectronics, hydrogen, and cloud computing with €35.3 billion of aid and an additional €59.5 billion in private investments.

Putting a price on carbon

The European Union has developed a world-leading carbon pricing mechanism named the EU Emissions Trading System (ETS) playing a key role in generating public revenue to be reinvested in climate action and social support. Since its implementation in 2005, the mechanism has collected over €180 billion in revenue for Member States and the EU budget. These funds are key to financing the Innovation Fund, the Modernization Fund, and the Social Climate Fund. The European Green Deal has added more sectors to be covered by the ETS, from industries and power plants to fuels for transport and buildings, thereby putting a price on more emissions. This program expects to shrink emissions, boost alternative energy sources, and finance more mitigation and adaptation measures.

Improving energy efficiency, energy security thanks to REPowerEU

To decrease the imports of fossil fuels from countries outside the union, the program REPowerEU drastically accelerated the permitting procedures for renewable energy projects. Since 2019, the amount of solar energy has doubled and in 2023, for the first time, more electricity from wind was produced than from gas. Increasing the share of renewable energies and reducing the overall energy demand contributes to reducing energy prices. The other pillar of the REPowerEU Plan is the diversification of supply, which cannot yet be covered by renewables and demand reduction and replacing non-reliable exterior suppliers with reliable ones such as Norway becoming the largest supplier of pipeline gas to the Union, and the United States providing the largest share of liquefied natural gas (LNG). The EU Energy Platform has allowed to pool of demand for gas from different European companies and launch competitive tenders on the international market to respond to the common demand of the resource. In 2023, the platform matched over 42 billion cubic meters of gas between European buyers and sellers, with over 180 companies across Europe and beyond participating.

Enhance the competitiveness of Europe's net-zero industry

The Green Deal pursues to make carbon neutrality not only good for the environment but also for economic development. To do so the European Commission launched the Green Deal Industrial Plan. The Plan aims to create conditions for the scaling up of net-zero industries, technologies, and products required to meet Europe's climate targets. Two key programs are the Critical Raw Materials Act (CRMA) and the Net-Zero Industry Act (NZIA), recently adopted in the first half of 2024. Both are expected to create a strong and clear regulatory environment by encouraging investments and the development of projects that are key to the European economy. The CRMA will help to ensure access to a secure, diversified, affordable, and sustainable supply of critical raw materials for European industries. The goal is to have the capacity to extract 10%, process 40%, and recycle 25% of its annual consumption of strategic raw materials by 2030. The NZIA is expected to boost the manufacturing of net-zero technologies in the EU and strengthen their resilience and competitiveness while creating a better regulatory environment to set up net-zero projects in Europe and attract investments.

Keeping the European green industry competitive and avoiding carbon leakage

The European Commission developed the world's first Carbon Border Adjustment Mechanism (CBAM) with its transitional phase starting in 2023 and entering into fully application by 2026. It encourages industries worldwide to embrace greener production methods and discourages companies from relocating production outside the EU to countries with lower environmental standards. CBAM in collaboration with the World Trade Organization developed a compliant tool to ensure that the EU's climate objectives are not undermined. Companies that import goods covered by CBAM will have to register with national authorities and buy CBAM certificates. These companies will then declare the emissions embedded in their imports and surrender the corresponding certificates. If they can prove that a carbon price has already been paid during the production of the goods, the corresponding amount will be deducted. CBAM is a turning point in the international carbon-neutral production of goods that enter the European Union. This also stimulates other countries outside the Union to adopt more sustainable and ethical ways of production.

Restoring the wealth of the European environment

Climate neutrality is reachable only if there is a good use of the available resources, addressing pollution, and recovering biodiversity. These actions are highly interconnected with each other, and one cannot be fully achieved if the others are not properly addressed. To better use scarce resources and reduce waste, the EU adopted measures to make products more sustainable, reducing the 2.2 billion tons of waste each year. Among these measures are facilitating repairing rather than disposal, reducing packaging waste, and banning the practice of destroying unsold products, such as textiles and footwear. This is supported by the New European Bauhaus (NEB), a program that aims to make the European Green Deal beautiful, sustainable, and inclusive. The initiative has over 600 official partner organizations ranging from EU-wide networks to local initiatives, with already six large-scale, replicable local transformations in product design.

The European Green Deal is helping to reduce pollution with the Zero Pollution Action Plan resulting in proposals for modernized standards on water quality, air quality, industrial emissions, and chemicals, accompanied by adequate financial instruments so pollution costs fall less on the taxpayer. These standards will continue to be improved in the coming decades, aiming to increase the overall health of Europeans. The Farm to Fork Strategy intends to increase the food security of the EU by making food supply systems fairer and healthier by rewarding farmers for providing environmental and climate-friendly services. Along the same line, the European Commission has proposed legally binding food waste reduction targets to be achieved by Member States by 2030, and new rules on the protection of animals during transport. Meanwhile, on international action, the EU is fully supporting and heading the Kunming-Montreal Global Biodiversity Framework, which sets global targets, such as restoring and protecting ecosystems and reducing pesticide risks by half by 2030. Finally, the Union leadership was also critical for a global deal on protecting biodiversity on the high seas with the UN High Seas Treaty concluded in 2023.

Listen to relevant stakeholders on the clean transition

The European Commission has launched a series of dialogues regarding clean transition with relevant stakeholders of key industrial sectors to overcome obstacles and share positive experiences and advice to ensure the European Green Deal. The relevant sectors where dialogues were held are hydrogen, energy-intensive industries, clean tech, energy infrastructure, critical raw materials, forest-based bioeconomy, cities, clean mobility, and steel. The Commission has also launched a Strategic Dialogue on the Future of Agriculture, bringing together farmers, local food store owners, retailers, consumer organizations, environmental groups, financial institutions, and academia to share ideas and find common solutions for the future of the agricultural sector in Europe.

The European Green Deal addresses the complexity of climate action by considering the multiple aspects that are required to make Europe a carbon-neutral continent and ensure its sustainable development by balancing mitigation and adaptation measures. Also, it shows how the different programs, policies, and legislations are interrelated. The European Green Deal is a step forward for climate action that can serve as a reference for countries outside the EU on their climate action plan.

1.3.1 The European Union and the SDGs

The Agenda 2030 and its 17 Sustainable Development Goals and objectives have been at the core of European policymaking since its publication in 2015. This is reflected in the six main ambitions of the political guidelines for the European Commission 2019-2024 mandate that are expected to continue beyond the 5 years mandate (Eurostat 2024).

1. European Green Deal
2. An economy that works for people
3. A Europe fit for the digital age
4. Protecting the European way of life
5. A stronger Europe in the world
6. A new push for European Democracy

Eurostat is responsible for monitoring and reporting the progress of Member states in achieving the 17 SDGs. They report on the 102 EU SDG indicators that are structured along the 17 SDGs and each goal has 6 indicators that are exclusively attributed to it, 34 of the 102 indicators are multipurpose, meaning they are used to monitor more than one SDG, they are designed to monitor the progress towards the goals in the context of long-term European Union policies, substituting the global set of indicators produced by the United Nations (Eurostat 2024). The progress of each indicator, depending on if it is qualitative or quantitative, is categorized as follows (see Table 5).

Table 5: EU SDG progress indicator

Quantitative indicator	Qualitative indicator
Significant progress	Significant progress
Moderate progress	Moderate progress
No applicable	No progress
Insufficient progress	Moderate movement away
Movement away	Significant movement away

The 2024 Sustainable Development in the European Union is a monitoring report which is a key tool for facilitating the coordination of SDG-related policies in EU countries by monitoring the progress in implementing the SDGs and helping to highlight the links between them (Eurostat 2024). The report in the introduction provides the relationship between the European Union's six main ambitions for the period 2019-2024 and the 17 SDGs in the following table (see Table 6).

Table 6: Synergies between EU priorities and SDGs

EU ambition /priority	Sustainable Development Goal
1. European Green Deal	2,3,6,7,8,9,10,11,12,13,14,15
2. An economy that works for people	1,3,4,5,8,9,10
3. A Europe fit for the digital age	4,9
4. Protecting the European way of life	3,4,10,16
5. A stronger Europe in the world	17
6. A new push for European Democracy	5,10,16

The 2024 Sustainable Development by Eurostat reported that SDG 10 and SDG 8 have made very significant progress. Significant progress has been made on SDG 1. Meanwhile, good achievements have been reported on SDG 2, SDG 9, SDG 12, SDG 14, SDG 4, and SDG 5. Moderate progress has been achieved on SDG 16, SDG 11, SDG 17 and SDG 13. The European Union unlike the rest of the world can report at least some progress on climate action, this progress can be sterile if the climate action is not done worldwide. SDG 6 progress is in a particular position since several indicators show positive developments, but others show no progress or even movement away. This represents a challenge in the achievement of the SDG. A slight setback was observed on SDG 7, SDG 3 was affected by setbacks, and finally SDG 15 moderately unfavorable assessment (see Figure 6).

The following table (see Table 7) shows the number of policies that address sustainable development at the Goal level for the period 2019-2024 (Know SDGs 2024a). SDG 16 is one with the highest number of associated initiatives with 3597, the second place is SDG 9 with 3403, the third position is occupied by SDG 8 with 3276 initiatives, the fourth position is SDG 3 with 3056 and the top 5 is completed with SDG 2 with 3001 initiatives.

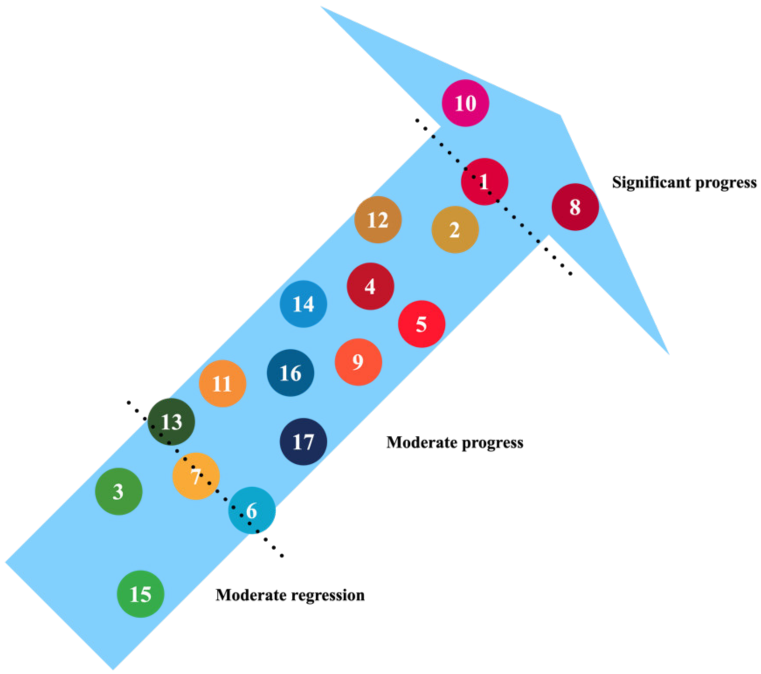


Fig. 6. EU Progress towards SDGs from the 2019-2024 period. Based on the work of (Eurostat 2024)

It is striking that SDG 13 the one directly linked to climate action is not even in the top five of presented initiatives in the union despite the great interest the EU has in becoming carbon neutral by 2050 through the European Green Deal. Even more striking is that SDG 6 occupies the last position with 864 initiatives despite that the progress toward achieving the goal is not even moderate progress, so there is a gap between the progress of the goal and the developed initiatives to face the challenge.

Table 7: EU SDG-associated initiatives

Sustainable Development Goal	Initiatives	Rank
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	3567	1
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	3403	2
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	3276	3

3. Ensure healthy lives and promote well-being for all at all ages	3056	4
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	3001	5
10. Reduce inequality within and among countries	2776	6
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	2336	7
1. End poverty in all its forms everywhere	2291	8
13. Take urgent action to combat climate change and its impacts	2159	9
12. Ensure sustainable consumption and production patterns	2030	10
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	1840	11
7. Ensure access to affordable, reliable, sustainable and modern energy for all	1833	12
11. Make cities and human settlements inclusive, safe, resilient and sustainable	1762	13
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	1714	14
5. Achieve gender equality and empower all women and girls	987	15
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	928	16
6. Ensure availability and sustainable management of water and sanitation for all	864	17

The following table (see Table 8) shows a comparison between the number of presented initiatives according to the European Union and the United Nations, this is a way to understand the different priorities regarding SDGs at the global level represented by the United Nations, and at the regional level represented by the European Union. Only SDGs 11 and 15 coincide in ranking and SDGs 1 and 8 only have a slight difference of 1. Significant differences are present in SDGs 16 and 14, with a difference of 15 places. This brief comparison exercise helps to understand how the priorities regarding sustainable development vary at the global and regional levels.

Table 8: Comparison between EU and UN ranks on associated initiatives

Sustainable Development Goal	EU rank	UN rank	Difference between EU and UN
1. End poverty in all its forms everywhere	8	9	**1**
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	5	10	**-5**
3. Ensure healthy lives and promote well-being for all at all ages	4	12	**-8**
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	14	6	**-8**
5. Achieve gender equality and empower all women and girls	15	7	**-8**
6. Ensure availability and sustainable management of water and sanitation for all	17	5	**-12**
7. Ensure access to affordable, reliable, sustainable and modern energy for all	12	14	**2**
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	3	4	**1**
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	2	15	**13**
10. Reduce inequality within and among countries	6	17	**11**
11. Make cities and human settlements inclusive, safe, resilient and sustainable	13	13	**0**
12. Ensure sustainable consumption and production patterns	10	8	**-2**
13. Take urgent action to combat climate change and its impacts	9	3	**-6**
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	16	1	**-15**

15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	11	11	**0**
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	1	16	**15**
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	7	2	**-5**

To increase the public knowledge of the SDGs progress and the key interlinkages between the goals the European Commission launched the "SDGs KNOW" platform (Know SDGs 2024b). It provides clear and synthetic information through interactive maps, diagrams, and figures. The SDGs KNOW platform, similar to the previously analyzed article "Connecting climate action with other Sustainable Development Goals" (Fuso Nerini et al. 2019), has an interlinkages visualization tool that graphically provides the synergies and trade-offs between the SDGs and also at the target level in the European Union. The SDGs KNOW platform goes a step ahead and provides a number of interlinked synergies and trade-offs. For example, SDG 13, which is the one focused on climate action, shows a total of 455 interlinkages composed of 296 synergies, 128 trade-offs, and 31 not specified (see Table 9).

Table 9: Synergies and Trade-offs between SDG 13 and the rest of SDGs

Sustainable Development Goal	**Synergies**	**Trade-offs**	**Not specified**
1. End poverty in all its forms everywhere	18	11	3
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	23	15	2
3. Ensure healthy lives and promote well-being for all at all ages	21	10	2
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	17	4	4
5. Achieve gender equality and empower all women and girls	12	5	1
6. Ensure availability and sustainable management of water and sanitation for all	26	11	4
7. Ensure access to affordable, reliable, sustainable and modern energy for all	26	9	2
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	18	9	0

9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	19	9	2
10. Reduce inequality within and among countries	13	7	0
11. Make cities and human settlements inclusive, safe, resilient and sustainable	22	8	1
12. Ensure sustainable consumption and production patterns	21	4	3
13. Take urgent action to combat climate change and its impacts			
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	19	7	1
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	22	13	3
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	9	2	2
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	10	4	1

One of the SDGs with more synergies with SGD 13 and consequently climate action, is SDG 6 "Ensure availability and sustainable management of water and sanitation for all" with 26 synergies. It can be interpreted that water security is closely linked to climate action since water is an element that intersects with the multiple aspects that intervene in climate action. The other SDG with 26 synergies is SDG 7 linked with sustainable energy, since the energy sector is critical to reduce. In second place is SDG 2 with 23 synergies since food security is also closely related to the impacts of climate change. To complete the top 3 SDGs with more synergies with SDG 13 are SDG 11 and SDG 15 with 22 each. Cities (SDG 11) and the surrounding environmental context (SDG 15) are also key elements for mitigation and adaptation measures to climate change.

Studying the relationship of the European Union (regional grouping) with the SDGs helps to understand that each region and country interacts differently with the SDGs and has its own priorities depending on the long-term policies each region and country has on their climate action and sustainable development.

1.4 Climate change a regional priority

Unfortunately, not every region worldwide has a strong regional grouping institutional framework, such as the European Union, to provide context-specific action to face climate change. Nevertheless, the IPCC fulfills its functions of producing reports and insights on climate change action by providing the key risks associated with climate change in different regions in its Climate Change 2023 Synthesis Report (Calvin et al. 2023). The confidence level should be at least medium to be included in the list. This list helps countries in each region prepare strategies to face their specific challenges (see Table 10).

Table 10. Climate Change challenges for each global region according to the IPCC (Calvin et al. 2023)

Region	Main risks
Small islands (southern, northern, and western Pacific Ocean, the central, eastern and western Indian Ocean, the Caribbean Sea, the eastern Atlantic off the coast of West Africa)	- Loss of terrestrial, marine and coastal biodiversity and ecosystem services - Loss of lives and assets, risk to food security and economic disruption due to destruction of settlements and infrastructure - Economic decline and livelihood failure of fisheries, agriculture, tourism and from biodiversity loss from traditional agroecosystems - Reduced habitability of reef and non-reef islands leading to increased displacement - - Risk to water security in almost every small island
North America (Canada, Mexico and the United States)	-Climate-sensitive mental health outcomes, human mortality and morbidity due to increasing average temperature, weather and climate extremes, and compound climate hazards - Risk of degradation of marine, coastal and terrestrial ecosystems, including loss of biodiversity, function, and protective services - Risk to freshwater resources with consequences for ecosystems, reduced surface water availability for irrigated agriculture, other human uses, and degraded water quality - Risk to food and nutritional security through changes in agriculture, livestock, hunting, fisheries, and aquaculture productivity and access - Risks to well-being, livelihoods and economic activities from cascading and compounding climate hazards, including risks to coastal cities, settlements and infrastructure from sea level rise
Europe	- Risks to people, economies and infrastructures due to coastal and inland flooding - Stress and mortality to people due to increasing temperatures and heat extremes - Marine and terrestrial ecosystems disruptions - Water scarcity to multiple interconnected sectors - Losses in crop production, due to compound heat and dry conditions, and extreme weather
Central and South America	-Risk to water security - Severe health effects due to increasing epidemics, in particular vector-borne diseases

	- Coral reef ecosystems degradation due to coral bleaching - Risk to food security due to frequent/extreme droughts - Damages to life and infrastructure due to floods, landslides, sea level rise, storm surges and coastal erosion
Australasia (Australia and New Zeland)	- Degradation of tropical shallow coral reefs and associated biodiversity and ecosystem service values - Loss of human and natural systems in low-lying coastal areas due to sea level rise - Impact on livelihoods and incomes due to decline in agricultural production - Increase in heat-related mortality and morbidity for people and wildlife - Loss of alpine biodiversity in Australia due to less snow
Asia	-Urban infrastructure damage and impacts on human well-being and health due to flooding, especially in coastal cities and settlements - Biodiversity loss and habitat shifts as well as associated disruptions in dependent human systems across freshwater, land, and ocean ecosystems - More frequent, extensive coral bleaching and subsequent coral mortality induced by ocean warming and acidification, sea level rise, marine heat waves and resource extraction - Decline in coastal fishery resources due to sea level rise, decrease in precipitation in some parts and increase in temperature - Risk to food and water security due to increased temperature extremes, rainfall variability and drought
Africa	- Species extinction and reduction or irreversible loss of ecosystems and their services, including freshwater, land and ocean ecosystems - Risk to food security, risk of malnutrition (micronutrient deficiency), and loss of livelihood due to reduced food production from crops, livestock and fisheries - Risks to marine ecosystem health and to livelihoods in coastal communities - Increased human mortality and morbidity due to increased heat and infectious diseases (including vector-borne and diarrhoeal diseases) - Reduced economic output and growth, and increased inequality and poverty rates - Increased risk to water and energy security due to drought and heat

The risks associated with climate change manifest differently depending on each region and require coordinated action at different government levels with solid interactions between mitigation and adaptation measures to ensure the sustainable development of communities.

Among the different risks regions around the world face as a consequence of climate change, one that remains constant is the risk of water security. Of course, this risk manifests in a different degree depending on the particular context. Nevertheless, it means that ensuring a safe and reliable supply of freshwater is becoming more difficult due to the impacts of climate change and an increasing demand for the resource. This calls for coordinated actions by different government levels and relevant stakeholders, where water should be a central axis for climate action.

Chapter 2

Understanding the water crisis

Venice Lagoon:
Armando Cepeda
Guedea. 2024

2.1 Water a connector of the leading global agreements of climate action and sustainable development

Water is a unique resource critical to sustaining life on Earth. Water is a finite resource dynamically stocked through solid, liquid, and gaseous phases (Conca & Weinthal, 2016). About 71% of the Earth's surface is covered with water (United States Geological Survey, 2019). Water can be divided into salt water and fresh water (World Wildlife Foundation , 2023). Saltwater represents 97% of all Earth's water and is found mostly in oceans and seas. The remaining 3% is defined as fresh water and is found in glaciers, lakes, reservoirs, ponds, rivers, streams, wetlands, and aquifers. Freshwater is the only one suitable for human consumption (World Wildlife Foundation , 2023). The small quantity of available freshwater is shared among 7.7 billion human beings and ecosystems that rely on this valuable resource (Dumont-Bergeron & Gramlich, 2021). Unfortunately, the quantity of available freshwater suitable for human consumption continuously decreases due to multiple factors such as droughts and changes in precipitation cycles mainly driven by climate change, pollution of the sources mainly by human action, and overexploitation of the resource that doesn't allow the natural regeneration of the resource (Pereira, Cordery, & Iacovides, 2009).

The world population in the year 2000 consumed 8.4% of available water resources and is estimated that by 2025 the consumption will reach 12.2% (Alsharhan and Rizk 2020). The annual renewable global water resources are 42,750 km3. The distribution of this water among the continents varies in time and space. Asia (13,500 km3) and South America (12,000 km3) receive the largest share of Earth's water, while Europe (2900 km3) and Australia (2400 km3) receive the lowest share (Alsharhan and Rizk 2020). The variation in the continental water budget of annual renewable water ranges from 15% to 25% of their average values. The rapid increase of population between 1970 and 1994 lowered the per capita water share from 12,900 m3 in 1970 to 7600 m3 in 1994 (Alsharhan and Rizk 2020). The largest water shortage was in Africa, followed by Asia and South America, while in Europe, the water shortage due to population growth did not exceed 16% (Alsharhan and Rizk 2020).

Freshwater resources can be globally organized in basins (Food and Agriculture Organization 2022). A basin is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel (United States Geological Survey 2019). These water systems consist of surface water, lakes, streams, reservoirs, wetlands and all the underlying groundwater (United States Geological Survey 2019). Generally, they occupy a big portion of land and can cross several countries. Larger basins contain many smaller watersheds known as sub-basins (United States Geological Survey 2019). They can be critical units for understanding and addressing water-related challenges, such as water scarcity, pollution, and climate change impacts. The United Nations through FAO recognizes the importance of basins as a framework for water governance encourages countries to adopt basin-level approaches in their water management policies and supports initiatives that promote cooperation, information sharing, and decision-making among stakeholders (Food and agriculture organization 2023). FAO define 230 major hydrological basins worldwide and 7611 sub-basins, this provides an understanding of the available freshwater distribution in the world, and how complex the water systems are (Food and Agriculture Organization of the United Nations 2022).

At the local level, regions and cities are divided into watersheds. It is an area of land determined by its topography that drains precipitation and other runoff of a small stream or tributary that is part of a larger river network's watershed (minor basin and major basins). Cities can be composed of multiple watersheds depending on their characteristics.

Regarding planning, a major basin is generally addressed at the national and international levels. Some major basins cover areas that involve more than one country. Planning at major basin levels is generally included in national or international comprehensive plans. A minor basin is usually addressed at the regional or inter-regional since its areas can cover an entire region or more than one. Planning at minor basin levels is generally included in regional or inter-regional comprehensive plans. Finally, watersheds are generally addressed at the regional and city levels. Watersheds cover areas of a city but also go beyond its limits and include several municipalities. All this is determined by the geographical conditions of the territory. In other words, a major basin is composed of multiple regions, a minor basin is composed of multiple cities, and a watershed is composed of multiple neighborhoods and districts (see Figure 7).

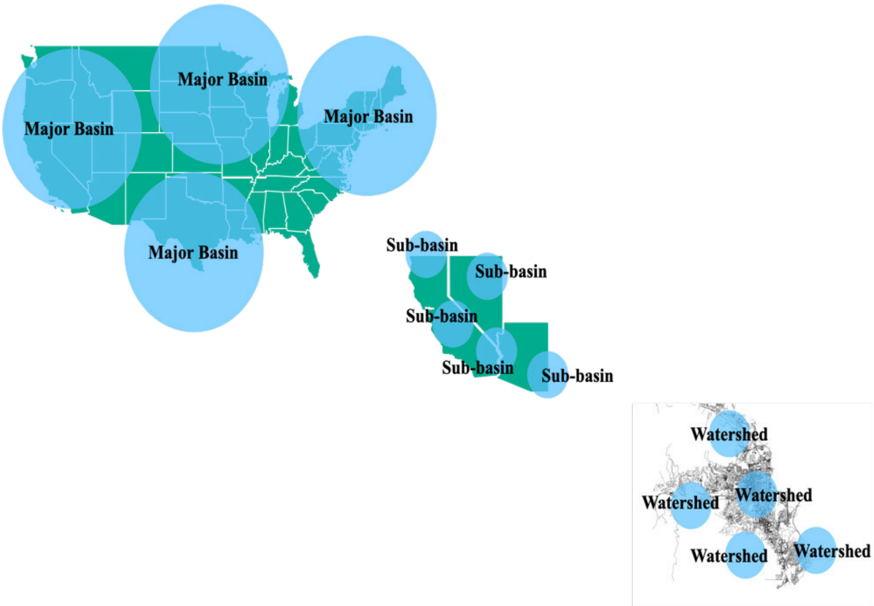


Fig.7. Freshwater organization at different levels. Source: Armando Cepeda Guedea. 2024

Freshwater availability has determined the rise and fall of cities since the origins of human civilization, determining settlement patterns and social structures (Buerkert, Ganeshaiah, and Siebert 2021). Water plays a key role in supporting cities and human settlements in general. Without a safe water supply, there would be no economic activity, industry, or public services. An array of pipes, canals, and pumping stations managed by public or private water systems are needed to provide a reliable supply of water to people all around the world (United States Environmental Protection Agency 2023).

The United Nations divides the uses of water into three categories: municipal, industrial, and agricultural, around 70% of the water resources go directly to agriculture being the rest divided between municipal (urban use) and industrial (United Nations 2023). The US CDC defines water use into five categories: drinking and household needs, recreation, industry, and commerce, agriculture, and thermoelectricity/energy (United States Centers for Disease Control and Prevention 2023). This classification provides a wider range of categories to better understand the uses of water in human society. Meanwhile, some academics divide the uses of freshwater in human society into two main categories which are direct and indirect. While most people are aware of their direct water consumption that is the one directly used when faucets or hoses are opened. The latter is defined as the water that is required to produce the goods and services humans consume. The "water footprint" is the total amount of freshwater used by an individual or community to cover their needs (Vanham, Gawlik, and Bidoglio 2019).

Population growth, urbanization, and socioeconomic development are expected to increase urban, industrial, and domestic water demand by 50–80% over the next three decades (Flörke, Schneider and McDonald 2018) making the current water system extremely vulnerable. Also, climate change is expected to affect water's availability spatial distribution and timing (He, et al. 2021). According to the United Nations, global water use has been increasing by roughly 1% per year over the last 40 years (United Nations 2023). Most of this increase is concentrated in emerging economies. Future trends estimate that overall global demand for water will continue to increase at an annual rate of about 1%, resulting in an increase of between 20 to 30% by 2050 (United Nations 2023).

According to United Nations, currently there are 2.3 billion people living in water-stressed countries, of which 733 million live in high and critically water-stressed countries and about 4 billion people, representing half of the global population, experience severe water scarcity during at least one month of the year (UN-Water 2023). This gives a dimension to the crisis of water shortage at the global level. When a territory withdraws 25% or more of its renewable freshwater resources it is said to be water-stressed. The global water stress level is approximately 18.6% (United Nations 2019), which is below the line of water stress. Nevertheless, three out of the eight SDG (Sustainable Development Goals) regions have water stress values above 25% (UN - Water 2021) like Western Asia, Northern Africa and Central and Southern Asia. Freshwater is not fairly distributed around the world due to geographical, consumption habits, pollution, or population density factors (Dumont-Bergeron and Gramlich 2021), where some regions suffer more from water scarcity than others. Therefore, while it is a global problem, it is simultaneously a local problem that requires local solutions.

The rapid urbanization processes after the second half of the XX century resulted in a range of socioeconomic changes in addition to the movement of people from rural contexts to cities (Molden 2007). An increase in the urban population increases the demand for drinking and industrial water in urban centers. Modern city inhabitants eat more animal products and vegetables. Meat and milk products require much more water than cereal grains, especially when cereal grains are used as cattle feed (Molden

2007). Vegetables typically require some sort of irrigation and a high degree of water control. The implication is that more water will be needed in agriculture indirectly provoked by the population growth in cities. To meet this demand, cities actively search for other sources of water outside their original already insufficient to meet their current demand, leading to the construction of new hydraulic works (Molden 2007). But in many basins, there is simply not enough water to meet the demands of cities regarding technological advances (Molden 2007). These basins are said to be closed to further development. Irrigation and damming have caused fragmentations of river basins drastically reducing the downstream freshwater availability and alarmingly threatening aquatic and terrestrial ecosystems (Koehler 2008). Inappropriate water resource management and changing the natural course of the water resources endangering the ecological functions and biodiversity provoking a disturbance in the natural water cycle and desiccation of rivers, streams, and land. Aggravating the situation climate change is expected to intensify the water crisis by changing rainfall patterns and inducing elevated evaporation and dramatic droughts in many regions of the world: around 20% of the increase in water shortage in the coming decades will be caused by climate change according to estimates by the United Nations (United Nations 2006).

The fragmentation of water resources also affects water security. There are 276 transboundary basins, shared by 148 countries, which account for 60% of the global freshwater. Also, 300 aquifers systems are transboundary in nature, with 2.5 billion people worldwide dependent on groundwater (The World Bank 2022). The challenges of fragmentation between countries and at the subnational level, this needs the cooperation of governments at different levels to achieve optimal water resources management and development solutions. To deal with these complex water challenges, countries will need to improve the way they manage their water resources and associated services.

2.1.2 The link between climate change and the water

Climate change is closely related to the water crisis. Climate change affects where, when, and how much water is available due to worsening floods, rising sea levels, shrinking ice fields, wildfires, and droughts (United States Environmental Protection Agency 2024a). However, water is a key element to fight climate change since sustainable water management is central to building the resilience of human communities and ecosystems and to reducing carbon emissions (UN Water 2024). Climate change impacts have the potential to disrupt the stability of water resources at different levels from the global level to the local level. The United Nations identifies four key impacts of climate change to water (UN Water 2024).

> Flooding and rising sea levels can contaminate land and water resources with saltwater or other pollutants, and cause damage to freshwater water supply and sanitation infrastructure, such as waterpoints, wells, toilets and wastewater treatment facilities.

Glaciers, ice caps and snow fields are rapidly shrinking and disappearing. Volatility in the cryosphere can affect the regulation of freshwater resources for vast territories since meltwater feeds many of the great river systems.

Droughts and wildfires are destabilizing water supplies for communities worldwide. Destruction of large tree areas exacerbates soil erosion and reduces groundwater recharge, increasing water scarcity and food insecurity.

Growing demand for water increases the need for energy-intensive water pumping, transportation, and treatment, and has contributed to the degradation of critical water-dependent carbon sinks. Water-intensive activities such as agriculture for food production, can further exacerbate water scarcity.

Decision makers should put water at the core of their climate action plans. Sustainable water management contributes adapting to climate change by building resilience, protecting health and saving lives. It also directly contributes with mitigation actions by protecting ecosystems and reducing carbon emissions from water and sanitation transportation and treatment. International cooperation is key to balance the water needs of communities, industry, agriculture and ecosystems. Also, innovative financing for water resource management is critical to attract investment, create jobs, and support governments in fulfilling their water and climate goals to achieve water security. The main solutions to face the water crisis linked as part of the wider climate action framework based on the work of United Nations and the United States Environmental Protection Agency are the following (United States Environmental Protection Agency 2024a; UN Water 2024).

Improving carbon storage wetlands: store at least twice as much carbon as forests. For example, mangrove soils can sequester up to three or four times more carbon than terrestrial soils. Protecting and expanding wetlands can have considerable benefits to mitigate climate change action.

Protecting natural buffers: besides its carbon sequestration benefits coastal mangroves and wetlands are effective and inexpensive natural barriers to flooding, extreme weather events and erosion, as the vegetation helps to regulate unexpected water flows and consolidates the soil in flood plains, riverbanks and coastlines.

Rainwater harvesting: harvesting rainwater is particularly useful practice to ensure water supply for dry periods or irregular rainfall periods. Rainwater harvesting techniques include rooftop capture for small-scale use in cities and surface dams to slow run-off to reduce soil erosion and increase aquifer recharge.

Adopting climate-smart agriculture: since agriculture is the sector that consumes more water it is critical to adopt techniques to reduce the impacts of agricultural activities. Such as the use of organic matter to increase soil moisture retention; drip irrigation; reducing post-harvest losses and food waste; and transforming waste into a source of nutrients or biofuels/biogas.

Reusing wastewater: water wise techniques require the use of unconventional water resources, such as recycled wastewater, that can be used for irrigation and industrial and municipal purposes. Safely managed wastewater is an affordable and sustainable source of water, energy, nutrients and other recoverable materials.

Protecting groundwater sources: due to overexploitation groundwater is becoming scarce and polluted. Protecting and sustainably using groundwater is central to adapting to climate change and meeting the needs of a growing population.

Create resilient and sustainable water operators: cities and communities through their operators by renewing aging water systems and operate more efficiently the water supply and sanitation with planning tools, financing help, and new technologies. Also, it is important to increase the resilience of water operators by increasing their capacities to assess climate risks to their systems and increase resilience.

2.1.2 Water a connector of the leading global agreements

As environmental issues related to water began to cross borders and became more complex, aggravated by climate change and urbanization a new phase of international initiatives encouraged by the United Nations emerged, which incorporated environmental objectives with other water-related ones (Neto, 2023). In 1977 the first United Nations conference specifically devoted to water was held in the city of Mar del Plata in Argentina. The main resolution of this conference was to get for the first time a clear statement regarding the right for all people to have access to drinking water which is essential both for life and the full development of human beings.

The next big step regarding water management at the global level was fifteen years after, in 1992, the United Nations organized the International Conference on Water and the Environment in Dublin, Ireland. In this conference it was stated that there had been a qualitative deterioration in freshwater in recent decades, it was suggested that governments, civil society, and international organizations implemented pacts that guaranteed the adoption of water resources management (Neto, 2023). The conference proposed a program known as the "Water and Sustainable Development" and at the same time, it was encouraged a very important change in the paradigm regarding water, that is, fresh water as a finite and vulnerable resource that is essential to guarantee life, development, and the environment (Neto, 2023). Also, in the same year, the United Nations Conference on the Environment and Development took place in June in Rio de Janeiro, Brazil. This conference produced important high-level commitments, including some conventions, and development of the Agenda 21, an important "booklet" of consensual international proposals proposing integration between humans and nature where water security continued to be a relevant topic as reflected in chapter 18 of the agenda.

During the United Nations Millennium Assembly in 2000 held in New York, the Millennium Development Goals were presented. One hundred ninety-one member states agreed to reduce poverty by 2015 (Neto, 2023). Regarding the supply of fresh water and sanitation, the pledge was expressed as halving the percentage of people without access to drinking water. An important milestone was reached in 2010 when the United Nations recognized safe, reliable, and universal access to fresh water and sanitation as a human right (UN-Water, 2023). This brief complementary historical review put the foundation for the role of water and its role of connector for the three main international agreements for climate action and sustainable development for the 2015-2030 term, which are the 2030 Agenda and its 17 SDGs, the Paris Agreement on climate change, and the Sendai Framework on disaster risk reduction (see Figure 8).

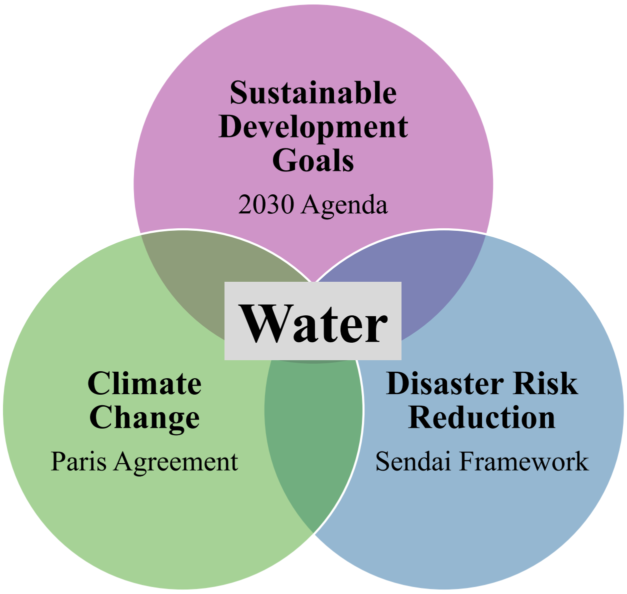


Fig. 8. Water as a connector of the three main international agreements on climate action and sustainable development encouraged by the United Nations. Based on the work of (UN-Water 2019)

The Climate Change and Water UN-Water Policy Brief proposes water as a connector of the three main international agreements on climate action and sustainable development encouraged by the United Nations (UN-Water 2019). The 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) are closely interlinked and intended to support one another. For instance, SDG 6 "Ensure availability and sustainable management of water and sanitation for all" focused on water is key to supporting the attainment of the other 16 SDGs. The achievement of SDG 6 is essential for society's health and well-being, improving nutrition, ending hunger, ensuring peace and stability, preserving ecosystems and biodiversity, and achieving energy and food security.

The Sendai Framework for Disaster Risk Reduction 2015–2030 was adopted in Sendai, Japan, in 2015. This framework for disaster risk management aims to prevent new and reduce existing disaster risk. It includes seven targets and four priorities for action to reduce the occurrence and impact of disasters resulting from natural hazards. Among those priorities, the Sendai Framework calls for the strengthening and implementation of global mechanisms on hydrometeorological issues. The Sendai framework expects to raise awareness and improve the understanding of water-related disaster risks and their impact on society, as well as advance strategies for risk reduction at different levels.

Although water is not explicitly mentioned in the Paris Agreement. Effective climate action requires adequate water resources. Adaptation initiatives related to safe and reliable freshwater water supply and coastal water are included as a top priority in many nationally determined contributions (NDCs). Despite this, governance mechanisms and methods for integrating water and climate remain largely absent in many countries. NDCs, together with other key national and multisectoral strategies such as national adaptation plans, are a powerful framework for laying out national priorities for national climate action, with the potential to guide priorities such as building water climate resilience and fostering integrated management of natural resources. They can also provide a basis for investment plans that integrate climate vulnerability and resilience building integrating the SDGs and the Sendai Framework.

2.2 SDGs Indicators and goals to address water challenges

Among the 17 SDGs water plays a key role as is reflected in the SDG 6 "Ensure availability and sustainable management of water and sanitation for all". This SDG is composed by eight targets and eleven indicators. As reflected in the following table (see Table 11).

Table 11: Sustainable Development Goal 6: targets and indicators

Sustainable Development Goal 6: Ensure availability and sustainable management of water and sanitation for all	
Target	**Indicator**
6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all	**6.1.1** Proportion of population using safely managed drinking water services
6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	**6.2.1** Proportion of population using (a) safely managed sanitation services and (b) a hand-washing facility with soap and water
6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	**6.3.1** Proportion of domestic and industrial wastewater flows safely treated
	6.3.2 Proportion of bodies of water with good ambient water quality
6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	**6.4.1** Change in water-use efficiency over time
	6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
6.5 By 2030, implement integrated water resources management at all levels, including	**6.5.1** Degree of integrated water resources management

through transboundary cooperation as appropriate	**6.5.2** Proportion of transboundary basin area with an operational arrangement for water cooperation
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	**6.6.1** Change in the extent of water-related ecosystems over time
6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programs, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies	**6.a.1** Amount of water- and sanitation-related official development assistance that is part of a government-coordinated spending plan
6.b Support and strengthen the participation of local communities in improving water and sanitation management	**6.b.1** Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management

Target 6.1aims to achieve universal and equitable access to safe and affordable drinking water for all by 2030. This target focuses on ensuring access to a safe and reliable water supply in urban and rural contexts worldwide, this involves an infrastructure of good quality, stable freshwater sources and the affordability of the service. Target 6.2 focuses on achieve access to adequate and equitable sanitation and hygiene for all. Good sanitation is key to safeguard the health of people and the environment and requires quality infrastructure. Target 6.3 focuses on improving water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally. Water quality is a key element for water security and reducing water risks. This target has two main dimension the territorial one focused on the sources and the urban one focused on the treatment and recycling of water. Target 6.4 aims to substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity. Water wise techniques are key to achieve the target since the resource is becoming more scares by a growing demand and the impacts of climate change. Target 6.5 is linked to policy making since it focuses to implement integrated water resources management at all levels. Integrated Water Resources Management can be defined as a process which promotes the coordinated development and management of water, land, and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of the ecosystems (Ojha, et al. 2017). Targets 6.1,6.2,6.3,6.4 and 6.5 should be achieved from an Integrated Water Resources Management approach. Target 6.6 focuses on protecting and restoring water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes. This target is closely related to environmental protection and preservation, which is also a key element for the SDGs, as reflected in SDGs 15 and 14. Target 6.a aims to expand international cooperation and capacity-building support to developing countries in water and sanitation related activities and programs. The water challenges are global and require international cooperation to help more vulnerable countries since the welfare of one country impacts positively the others. Target 6.b

focuses on the governance of water by supporting and strengthening the participation of local communities in improving water and sanitation management. Civil society should be fully incorporated in the decision-making processes regarding water since this resource is key for the health, livelihood, and development of people.

In the Sustainable Development Report regarding SDG 6 progress (Sustainable Development Report 2024), only three countries have achieved all SDG targets (Belarus, Monaco, and Andorra). Most countries are facing challenges to achieve SDG 6. Twenty countries, including the United States, France, Australia, and Brazil, are facing challenges. Countries such as Italy, Canada, China, India, Argentina, and Russia are having significant challenges. Finally, countries such as Mexico, the United Arab Emirates, Pakistan, Libya, and most of sub-Saharan Africa are facing severe challenges in achieving SDG 6. The three selected countries for the research will be used as examples to review the progress toward achieving the SDG 6 indicators at the country level (see Table 12). The United States is a country with remaining challenges, although the service coverage of fresh water and sanitation is almost fully covered. The country has challenges regarding freshwater withdrawals and significant challenges in water scarcity. In the case of Italy, with significant challenges to achieving SDG 6, only there is positive advance regarding access to water and sanitation associated with adequate infrastructure as expected in a first-world country, but there are challenges in freshwater withdrawals and considerable challenges regarding water scarcity. In the case of Mexico, a developing country with significant major challenges in achieving SDG 6, only the target associated with access to drinking water is achieved. The rest of the indicators are facing considerable challenges, with special consideration on access to safely managed sanitation and water services.

Table 12: Sustainable Development Goal 6 indicators progress at the country level according to the Sustainable Development Report

SDG 6 indicator	Italy (Significant challenges remain)	United States (Challenges remain)	Mexico (Major challenges remain)
Population using at least drinking water services	1	1	1
Population using at least basic sanitation services	1	1	2
Freshwater withdrawal	2	2	2
Anthropogenic wastewater that receives treatment	1	1	3
Scarce water consumption embodied in imports	3	3	2
Population using safely managed water services	2	1	4
Population using safely managed sanitation services	2	1	4

1. Achieved	2. Challenges remain	3. Significant challenges remain	4. Major challenges remain

The United Nations, through the Economic and Social Commission for Asia and the Pacific presents a clear diagram (see Figure 9) establishing the relationship between SDG 6 and the other 16 SDGs since SDG 6 is key to support the attainment of the other 16 SDGs (United Nations Economic and Social Commission for Asia and the Pacific 2017).

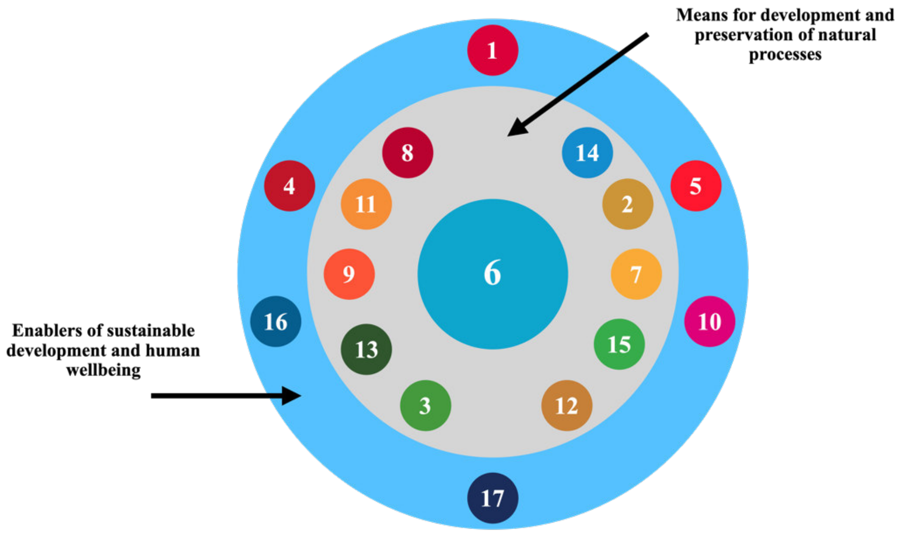


Fig. 9. Interlinkages between SDG6 and the rest of SDGs. Based on the work of (UN ESCAP 2017)

The UN ESCAP diagram (United Nations Economic and Social Commission for Asia and the Pacific 2017) proposes two types of relationships between SDG 6 and the rest of the 16 SDGs. The first one is the SDGs that provide the means for the development and preservation of natural processes related to water that involves most of the SDGs; 10 of them (8, 11, 9, 13, 3, 14, 2, 7, 15, and 12). The second kind of relationship are the six SDGs that enable sustainable development and human wellbeing (1, 5, 10, 17, 16, and 4).

Unfortunately, as mentioned in a previous section, most SDGs, including SDG 6, are facing considerable setbacks in order to be achieved. In this context, UN-Water presented in 2020 the SDG 6 Global Acceleration Framework, which aims to deliver faster results at an increased scale as part of the Decade of Action to deliver the SDGs by 2030 with the intention to achieve this SDG critical for sustainable development (UN-Water 2020). This framework is expected to be a catalyst for more ambitious actions from governments at different levels and relevant stakeholders to achieve SDG 6 on water and sanitation through four action pillars (see Figure 10).

Engage: enable a better engagement with all relevant stakeholders and push for coordinated action for the required transformation to achieve SDG 6.
Align: reduce fragmentation of actions through aligning financial strategies, policies, legislations, operations, and approaches worldwide to ensure the availability and sustainable management of water and sanitation.

Accelerate: enable countries and relevant stakeholders to improve their progress to achieve SDG 6 through financing, capacity building, data and information, innovation, and governance.
Account: promotes shared accountability among governments and relevant actors by reviewing, monitoring, and evaluating transparently the progress on SDG6 and learning together.

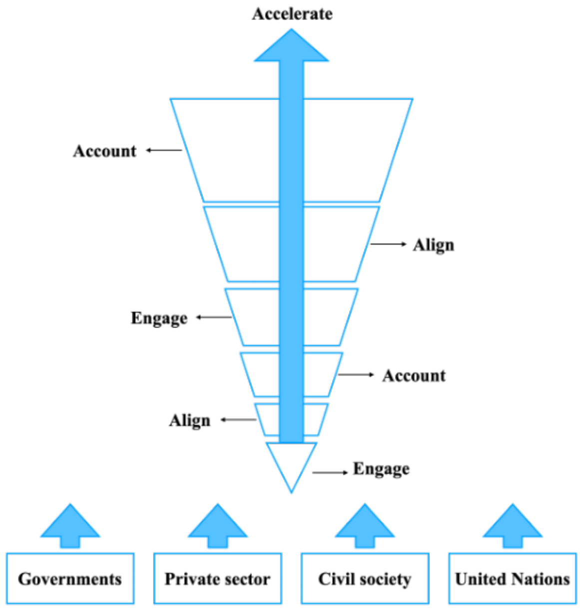


Fig.10. Visualization of the SDG 6 Global Acceleration Framework action pillars. Based on the work of (UN-Water 2020)

The SDG 6 Global Acceleration Framework is based on the following guiding principles: inclusivity, prioritizing the vulnerable, conflict sensibility, unleashing female and youth potential and reaching gender equality, planning for resilience/sustainability, and making scientific evidence a prerequisite. Both the 2024 annual SDG Progress Report and the 2023 Global Sustainable Development Report confirm that SDG 6 is still severely off-track to be achieved. This means that the SDG 6 Global Acceleration Framework need to be better reinforced in order to be achieved by 2030.

2.3 EU Water Framework Directive

To understand the water crisis from a regional perspective and study the good practices of one of the most solid regional groping for water action, the research finds it pertinent to present the case of the European Union as it was previously done with the broader climate action in the past chapter. The European Union presents the EU Water Framework Directive (WFD) that establishes a legal framework to protect and restore clean water in the EU and to ensure its long-term sustainable use (European Parliment 2023). It is complemented by more specific legislation, such as the Drinking Water Directive, the Bathing Water Directive, the Floods Directive and the Marine Strategy Framework Directive, as well as by international agreements between member states.

The EU Water Framework Directive establishes a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater. It aims to prevent and reduce pollution, promote sustainable water use, protect and improve the aquatic environment and mitigate the effects of floods and droughts. The overall objective is to achieve good environmental status for all waters (European Parliament 2023). Member States are therefore requested to draw up so-called river basin management plans based on natural geographical river basins, as well as specific programs of measures to achieve the objectives (European Parliament 2023). In the European Union's Water Framework Directive, it is stated that all the 160 river basins in Europe should be managed using a River Basin Management Plan. The Member States shall ensure that a river basin management plan is produced for each river basin district lying entirely within their territory and the river basin management (European Environment Agency 2023).

The revised Drinking Water Directive of 2020 defines essential quality standards for water intended for human consumption (European Parliament 2023). It requires Member States to regularly monitor the quality of water intended for human consumption by using a 'sampling points' method. Member States can include additional requirements specific to their territory but only if this leads to setting higher standards. The directive also requires the provision of regular information to consumers.

Among the 10 main policy areas of the European Union to address environmental challenges, there is the Water-Energy-Food-Ecosystem Nexus approach that highlights the interdependence of water, energy, and food security in collaboration with the United Nations (see Figure 11). The Nexus approach identifies mutually beneficial responses that are based on understanding the synergies of water, energy, and agricultural policies. It also provides an informed and transparent framework for determining the proper trade-offs and synergies that maintain the integrity and sustainability of ecosystems.

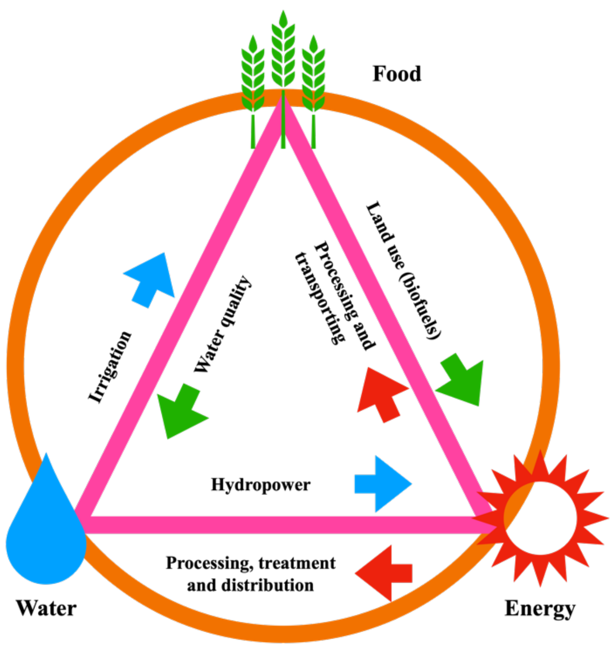


Fig.11. Water-Energy-Food-Ecosystem Nexus framework interlinkages. Based on the work of (UNECE 2020)

The Nexus approach helps to understand the complexity of water since different aspects impact the resource. Water through irrigation is critical for agricultural activities and represents around 70% of water consumption worldwide. Meanwhile, sustainable agriculture is key to ensuring water quality since fertilizers and pesticides can severely affect water quality when they recharge aquifers or are reused in other activities. Regarding energy, water is crucial for energy production since hydropower is a renewable source of energy that generates power by using a dam or diversion structure to alter the natural flow of a water body. On the other hand, energy is required to process, treat, and distribute fresh water to cities and industries.

The European Union, to support its particular objectives as reflected in the European Green Deal and other complementary projects, presents an additional set of indicators for SDG 6 through Eurostat (see Table 13).

Table 13: Sustainable Development Goal 6 European Union Indicators

Sustainable Development Goal 6: Ensure availability and sustainable management of water and sanitation for all
EU_06_10. Population having neither a bath, nor a shower, nor indoor flushing toilet in their household.
EU_06_20. Population connected to at least secondary wastewater treatment.
EU_06_30. Biochemical oxygen demand in rivers.
EU_06_40. Nitrate in groundwater.
EU_06_50. Phosphate in rivers.
EU_06_60. Water exploitation index plus (WEI+).
EU_14_10. Bathing sites with excellent water quality.

The progress on SDG 6, according to its own indicators, paints mixed progress for the European Union according to its 2024 report (Eurostat 2024). On the positive side, the share of people with adequate sanitation facilities has been steadily increasing. The percentage of connectivity to at least secondary wastewater treatment has been improving slowly. However, trends regarding water quality are less favorable than expected. While the biochemical oxygen demand in rivers and the nitrate concentrations in groundwater bodies have decreased since 2016, phosphate concentrations in rivers have risen strongly. Water scarcity is one of the major concerns in the EU, with the water exploitation index showing a slightly increasing trend in recent years. Also, a new indicator of the impacts of drought on ecosystems shows that the number of EU areas affected by drought has increased strongly since 2017. Additionally, the complementary EU indicator shared with SDG 14 regarding the share of inland bathing sites with excellent water quality has been falling since 2017. Water scarcity and the impacts of droughts are major concerns for the European Union that require creative and proactive solutions.

The European Commission with the “SDGs KNOW” platform (Know SDGs 2024b) same as SDG 13 it provides a number of interlinked synergies and trade-offs for SDG 6, which is the one focused on water, shows a total of 594 interlinkages composed of 400 synergies, 139 trade-offs, and 55 not specified (see Table 14).

Table 14: Synergies and Trade-offs between SDG 6 and the rest of SDGs

Sustainable Development Goal	Synergies	Trade-offs	Not specified
1. End poverty in all its forms everywhere	30	10	4
2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture	38	18	5
3. Ensure healthy lives and promote well-being for all at all ages	32	8	6
4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	21	2	3
5. Achieve gender equality and empower all women and girls	21	5	4
6. Ensure availability and sustainable management of water and sanitation for all			
7. Ensure access to affordable, reliable, sustainable and modern energy for all	30	21	3
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	26	11	4
9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	24	8	5
10. Reduce inequality within and among countries	21	6	2
11. Make cities and human settlements inclusive, safe, resilient and sustainable	25	8	4
12. Ensure sustainable consumption and production patterns	24	10	1
13. Take urgent action to combat climate change and its impacts	24	7	3
14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development	22	6	2
15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	27	10	4
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	19	6	3
17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development	16	3	2

The SDG with more synergies with SDG 6 is SDG 2, which is related to food security in clear syntony with the Nexus approach previously mentioned. The second SDG with more synergies is SDG 3 since quality drinking water and sanitation are critical for the health of communities. Completing the top 3 there are SDG 1 and SDG 7 with 30 synergies each. SDG 7 completes the Nexus approach since energy is the third component in the relationship water, food and energy. Finally quality water and sanitation services are crucial for good levels of welfare and reduce poverty which is the main aim of SDG 1.

Chapter 3

Water security: an integral approach to face water challenges

Charles River Boston. Armando Cepeda Guedea, 2023

3.1 Water Security

Water security is a relatively new term that can be broadly defined as the availability of an adequate quantity and quality of water to sustain livelihoods, socio-economic development, health, and ecosystems (Tortajada and Fernandez 2018). The concept of 'water security' was first introduced in the Second World Water Forum in the Hague in 2000. To achieve water security a declaration that emerged from the forum stated: that water resources and related ecosystems need protection and improvement, sustainable development and political stability are to be promoted, every person needs access to enough safe water at an affordable cost and the vulnerable are protected from water-related hazards. The United Nations in 2013 defined water security as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UN Water 2013).

It is estimated that over 40% of the world's population lives in water-scarce areas, and provoking that approximately 25% of the world's GDP is exposed to this situation. Water security can be considered a major challenge for many countries in recent times and is estimated that this threat will grow in the future if proper measures are not enforced. The drivers that can endanger water security can be categorized into climatic and non-climatic ones.

Climatic drivers

Climate change refers to the change in the state of the climate it can be due to natural internal processes (solar cycles, volcanic eruptions) and anthropogenic activities that change the composition of the atmosphere. Climate change can be statistically identified through the changes in the mean of its properties and persists for extended periods, usually decades or longer. Water security in recent decades has been endangered due to climate change with the following main impacts.

Changes in precipitation patterns: the timing, amount, intensity, and quality of precipitation, and in atmospheric evaporative demand (the potential loss of water from the Earth's surface, driven by atmospheric factors), will alter the availability of surface and groundwater sources.

Increase in temperatures: decreasing ice volumes and increasing evaporation rates from lakes, reservoirs, and aquifers will decrease the quantity of freshwater available. In addition, increased temperatures will increase the water demand.

Shifts in the timing of river flow: the change in precipitation patterns and more frequent and intense droughts will affect the normal seasonal flow of rivers, increasing the need for artificial water storage.

Higher water temperatures: Increased algal blooms and natural organic material will lead to additional or new treatment processes for drinking water, making potabilization processes more expensive.

Drier conditions: increasing and more severe droughts will threaten surface and groundwater supplies that are already of low quality by affecting their replenishment rates.

- Increased stormwater run-off: increased stormwater run-off will increase loads of pathogens, nutrients, and suspended sediment.
- Sea-level rise: increased sea-level rises will increase the salinity of coastal aquifers, particularly when groundwater recharge is predicted to decrease.

Climate change is an ongoing reality set to continue, this creates uncertainty on how the water cycle will evolve and adapt to this new reality. Uncertainty is particularly high regarding future precipitation patterns, that can induce wet and dry periods in the same location. Overall, however, it is expected a higher frequency and intensity of floods. It is also expected because warmer temperatures increase evaporation and allow the atmosphere to hold greater volumes of water vapor.

Non-climatic drivers

Other factors not directly linked to climate change that seriously endanger water security include rapid population growth and urbanization, unsustainable economic growth and rising income levels, and increased demand for energy and food, which are impacting the availability of good quality water of sufficient quantity.

- Rapid population growth: the world's population is likely to grow by 30 percent between 2000 and 2025 and as much as 50 percent between 2000 and 2050. The available amount of freshwater is globally shared among 8 billion people and natural ecosystems (United Nations 2022). Despite this knowledge, water is largely taken for granted, at the national and international levels (Dumont-Bergeron and Gramlich 2021). Many countries and regions do not have accessible water supply to support this population growth.
- Urbanization: urbanization processes integrate the rural population that comes to the city for better opportunities and quality of life, provoking an increase in the existing urban population, sometimes surpassing the capacity of cities to absorb this new population (UN Habitat 2020). To carry on the sustenance of this new excess of population it is required the construction of more roads, houses, and commercial and industrial buildings is necessary. This additional development unfortunately has its own impact on the urban ecosystem directly impacting the accessibility, quality, and availability of the water resources (Majumder 2015). The decrease of accessibility of water as the amount of surface runoff also increases due to the reduction of filterable area. In addition to this, overgrowth in the density of population and change in land use and land cover are two other relevant impacts of urbanization. Both changes could eventually increase the stress on the natural resources of the region and will also change the nature of the surrounding areas of the city. As the population increases so will be the demand for water (Majumder 2015). One of the damaging effects of increasing concentration of industries is the toxic discharges from them which will pollute the surface water and eventually the groundwater.
- Rapid economic growth: economic growth is generally accompanied by an increase in water demand. By 2050, it is estimated that the world's economy will grow to four times its current size requiring 55% more water to support this growth. According to the United Nations, global water use has been increasing by roughly 1% per year over the last 40 years (United Nations 2023). Most of this increase is concentrated in emerging economies. Future trends estimate that overall global demand for water will continue to increase at an

annual rate of about 1%, resulting in an increase of between 20 to 30% by 2050 (United Nations 2023). It is estimated that 3 billion people, approximately 40% of the world's current population, will join the middle classes by 2050. As a result, emerging markets will comprise almost two-thirds of global consumption by 2050, compared to one-third today, impacting global water consumption patterns.

Increased demand for energy: according to the United Nations water is at the core of sustainable development and is critical for energy and food production, healthy ecosystems, and socioeconomic development (United Nations 2023). The International Energy Agency (IEA) estimates that global freshwater withdrawals for energy production in 2010 were around 583 billion cubic meters, approximately 15% of the world's total water withdrawals. By 2040 the IEA projects global energy demand to increase by 37 percent. Because thermal power generation and hydropower, which account for 80 and 15 percent of global electricity generation, are water-intensive, it would translate into a 20 percent increase in freshwater withdrawals.

Increased demand for food: agriculture represents approximately 70% of the global water withdrawals. By 2050, the world will require 60% more food to maintain current consumption patterns. Intensive agricultural production, that aims to satisfy the increasing demands of foods has a negative side, it changes the physical properties of soils reducing water infiltration rates and increasing run-off leading to lower groundwater recharge rates, soil erosion, loss of soil nutrients, and increased contamination of waterways. Additionally, increased demand for limited water places pressure on water-intensive food producers to seek alternative supplies, often leading to inter-sectoral competition for limited water resources.

As the global population continues to grow and cities become bigger and more complex water security becomes a critical factor to ensure the survival and development of cities (Fitzhugh and Richter 2004). Climate change impacts are directly affecting the availability of freshwater by increasing droughts, reducing rain seasons, and groundwater recharge (McDonald, et al. 2011). Human activity also directly damages the available freshwater sources by polluting the sources and overexploiting the water mantles. Water shortage risk also affects directly the economic development of cities, costing up to 6% of their GDP (Dumont-Bergeron and Gramlich 2021). Water insecurity and access problems are not confined to the global South or developing countries. Some research reports problems of insecure water access, quality, affordability, and trust experienced by households in developed countries such as Canada and the United States (Meehana, et al. 2020), despite the presence of water governance systems and a general assumption of universal network coverage. Societies can achieve water security when they: successfully manage their water resources and services to satisfy the water and sanitation needs in all communities; support productive economies in agriculture, industry, and energy; develop sustainable and livable cities and towns; restore healthy rivers and ecosystems; and build resilient communities that can adapt to change. Five critical dimensions should be considered to achieve water security (Brears 2021) (see Figure 12).

Economic Water Security: Water is used for multiple interlinked economic activities such as agriculture, industry, and the energy sector. The water–energy–food nexus approach helps to raise awareness of the critical role of water in supporting economic activities. Economic water security focuses on measuring the productive use of water to sustain economic growth in the food production, industry, and energy sectors.

Household Water Security: The core of water security is providing safe water and sanitation services to all people. Household water security is key to eradicating poverty and supporting economic development.

Urban Water Security: The world is rapidly urbanizing (it is estimated that by 2050, 70% of the world's population will be urban), and cities are becoming the drivers of the global economy. As such, urban water security is achieved through better water management and services in support of livable water-secure cities.

Environmental Water Security: Traditionally, regions and countries worldwide have prioritized economic growth over ecological objectives. In recent times, there has been a shift toward green growth that focuses on sustainable development. Environmental water security is achieved through the restoration of rivers and ecosystems on the regional, national, and provincial levels. The sustainability and development of communities and cities depend on these natural resources.

Resilience to Water-Related Disasters: Building resilient communities that can adapt and reduce the risk from natural water-related disasters. Innovative approaches should be implemented to minimize the impact of future disasters.

Fig. 12. Water Security dimensions. Based on the work of (Brears, 2021)

3.1.1 Economic Water Security

Water as an economic asset has been at the center of the debate, and its complexities and many dimensions have been long recognized since water can be a public good, a common pool resource, and a private good (Hanemann 2006). A safe, sustainable, and reliable water supply and sanitation system is critical to ensure the survival and suitability of communities (Garrick and Hahn 2021).

Achieving water security requires matching uncertain water supplies with multiple demands, including both consumptive and non-consumptive uses of water. Economists have long focused on the market and institutional failures that contribute to water management problems (Hanemann 2006; Garrick and Hahn 2021). These problems emerge from prevalent externalities across the water cycle, including the negative externalities associated with water extraction and pollution and the positive externalities associated with developing and maintaining capital-intensive, long-lived water supply infrastructure (Damania 2020). Thus, addressing and balancing the multiple objectives associated with water security requires addressing multiple sources of market and institutional failure. An economic perspective on water security can help to both define water management problems and determine the costs and benefits to consider when comparing potential solutions. Addressing water security challenges from the economic perspective should be viewed from three main aspects: inadequate water infrastructure, misallocation, and water risk. Economic efficiency on water security should aim to maximize the sum of producer and consumer surplus.

Inadequate Water Infrastructure: Water security requires different infrastructures to ensure access, storage, distribution, and conservation of freshwater. This infrastructure includes dams and hydropower, water supply and sanitation pipelines, irrigation, and green capital (Garrick and Hahn 2021; Grigg 2019). Water insecurity can emerge from underinvestment in infrastructure that generates a public benefit, such as water supply networks, and overinvestment in infrastructure whose negative externalities have not been accounted for, like hydropower dams and irrigation systems.
Water misallocation: Advancing towards water security involves adequate water allocation across competing users, sectors, and demands (domestic, industrial, energy, and agriculture). This is translated into who gets water, how, and how much. Water misallocation happens when there is a lack of allocative efficiency and water management patterns that fail to maximize the net benefits across competing demands (Pujol, Raggi, and Viaggi 2006). Water is a dynamic resource that is constantly moving, which complicates efforts to develop, monitor, and enforce rules limiting access to shared aquifers and river basins. Efforts to regulate water extractions can be undermined by new surface water diversions or groundwater pumping activity that intercept previously claimed and used water. Political resistance from existing water users has made the introduction of new metering technologies and property rights reforms contentious, even when the benefits far outweigh the costs of doing so (Garrick and Hahn 2021). In this situation, if water is not properly allocated, vulnerable populations can suffer water scarcity.
Water risks: Achieving water security has become increasingly associated with managing and mitigating water risks since the climate change crisis has aggravated the impacts and frequency of weather-related shocks such as droughts, storms, or floods. These impacts can provoke water shortages, affect public health, and cause environmental pollution. All of them have economic impacts on buildings, livelihoods, and economic activities, among others. From a risk management perspective, water security can be defined as a "tolerable level of water-related risk to society." The uneven distribution of water risks across territories, gender, and socioeconomic characteristics

contributes to poverty and inequality, which requires coordinating water operators and institutions to address water security in the context of development policies (Tallman and Cuervo-Cazurra 2021). These three main challenges should be addressed by institutions, including (1) assigning governance tasks at the right levels of decision-making and managing the degree of centralization or decentralization of resource management; (2) distributing and coordinating tasks between the private and public sector and across different levels; and (3) capacity building for monitoring, enforcement, and conflict resolution between water users and sectors.

3.1.2 Household Water Security

Household water security encompasses water-related factors that pose threats to public health at the household level. Household water security covers access to an adequate volume of potable water and sanitation to meet basic needs, as well as other water-related factors that may threaten the health and livelihood of household dwellers (Akinyemi, Afolabi, and Aluko 2022). The main components of household water security are water quality perceived by users, per capita water consumption in households, access to the service, reliability, resilience in case of variations of the supply or water supplies, and affordability of the service (Akinyemi, Afolabi, and Aluko 2022; O. Jensen and Wu 2018). Household water security and urban water security are closely related. Meanwhile, urban water security focuses on how safe and reliable water supply and sanitation services arrive at households in the cities. Household water security focuses on the social factors of how users interact with the water service.

3.1.3 Urban Water Security

As mentioned before, urban water security is one of the five main dimensions of territorial water security. Urban water security can be defined as the capacity of a city to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability. In this dimension, water operators play a critical role since they are responsible for providing the water supply and sanitation service and managing the runoff water, preferably from an integrated urban water management approach.

Urban Water security has received greater consideration over the past decades, being the central element in several studies and debates, and has become a critical topic among researchers, policymakers and interested stakeholders focused on adding value to urban water management and ensuring the sustainability of the water system. Urban water security is a complex concept, with different definitions, interpretations, and assessments used across different disciplines. Water security is also typically a primary goal of water management.

The book "Urban Water Security" (Brears, 2017) proposes eight main elements to achieve urban water security (see Figure 13).

1. Access to safe and sufficient drinking water at an affordable cost in order to meet basic needs including sanitation and hygiene and safeguarding of health and well-being.

2. Protection of livelihoods, human rights, and cultural and recreational values

3. Preservation and protection of ecosystems in water allocation and management systems to maintain their health and sustain the functioning of ecosystem services.

4. Stable water supplies for socioeconomic development and activities (energy, transport, industry, and tourism)

5. Collection and treatment of used water to protect human life and nature from pollution

6. Collaborative approaches to transboundary water resource management within and between countries to promote freshwater sustainability and cooperation

7. The ability to cope with uncertainties and risk of water-related hazards, for example, floods, droughts, and pollution of sources

8. Good governance and accountability and the consideration of the interests of all stakeholders through effective legal regimes; transparent, participatory, and accountable institutions; properly planned, operated, and maintained infrastructure; and capacity development.

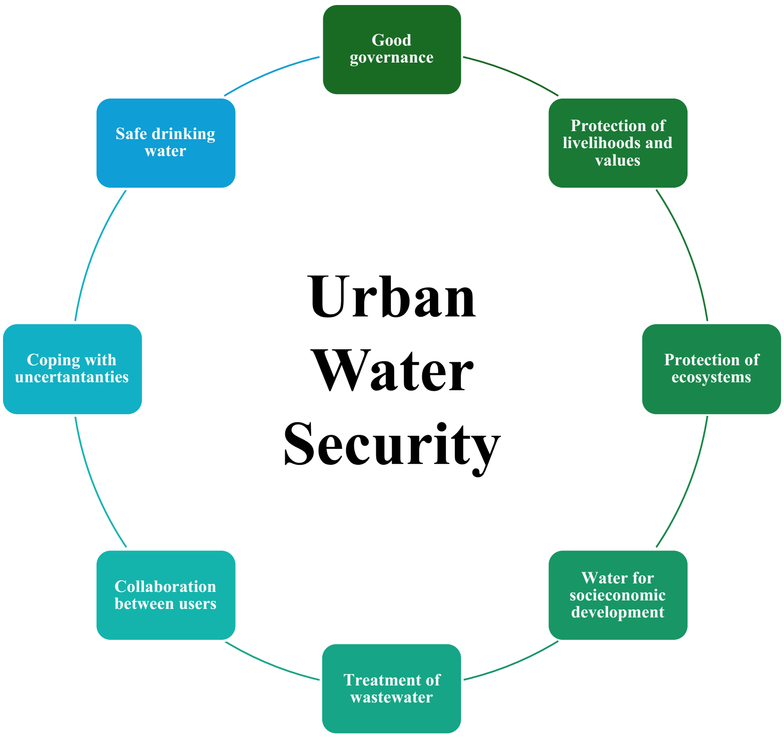


Fig.13. Urban Water Security dimensions. Based on the work of (Brears, 2017)

Achieving water security is not an easy task and cities around the world face several challenges such as a lack of economic resources, inefficient water service, insufficient institutional response, unsatisfactory planning documents, depletion of traditional water sources, and polluting activities (Talat 2021; Tekile and Legesse 2023). Water security represents an important challenge; nevertheless, it is not yet a lost cause. It represents an opportunity to create multidisciplinary knowledge, improve or generate tools, innovate technology and infrastructures, and most importantly help investors and companies toward sustainable decision-making (Dumont-Bergeron and Gramlich 2021).

Water is an essential resource for cities to continue to thrive and contribute to the social and economic development of the national and global economies (Organization for Economic Co-Operation and Development 2015). It is estimated that around 25% of large cities are experiencing some levels of water stress (Josefine Lund Schlamovitza 2021). Sustainable and safe water supply is at the core of urban transition, a global trend built around clean energy and innovative net-zero carbon solutions.

Stable and safe distribution systems to guarantee the water supply have been a central aspect of the development of cities around the world (Organization for Economic Co-Operation and Development 2015). The capacity to safeguard sustainable access to adequate quantities of and acceptable quality water is defined as water security (Tortajada and Fernandez 2018). Water is a prerequisite for human security and subsistence. Its scarcity has impacts at all levels of society, often exacerbating poverty and holding back socioeconomic development (Conca y Weinthal 2016). Cities in the XXI have generally achieved an acceptable level of water security through a combination of technical and institutional features that emerged in the late XIX century in the developed world and in the mid to late XX century in the developing world (Organization for Economic Co-Operation and Development 2015).

Today, cities face three sets of challenges regarding water management: water-related risks, ageing infrastructures, and trends in institutional reforms (Organization for Economic Co-Operation and Development 2015). This situation requires a change of the current water management system, from a transformative approach. Transiting to a more sustainable and efficient urban water management must combine technical and non-technical approaches. Innovation and community involvement are key to enhance water security and lower the costs (Organization for Economic Co-Operation and Development 2015). Cities around the world are acknowledging the need to change the current system. In line with these challenges, academics and international institutions consider that there is an urgent need to support the transitions of urban water systems towards more sustainable configurations that can cope with the current water challenges (Daniell, et al. 2015).

The increasing complexity of water management challenges requires moving towards a more inclusive bottom-up approach which fosters and increases the involvement of local inhabitants, organized civil society and the private sector to build bridges between government leaders and citizenry (Monyai, et al. 2022). A community-based approach is critical for addressing barriers to water management by recognizing and incorporating the knowledge, skills, and experiences of local people combined with the expertise of technicians and academics. Engaging local communities as key stakeholders in water management can help improve the local water supply services and prepare communities better in case of water shortage.

Drinking water distribution systems in cities connect water treatment plants or water sources (in the absence of treatment facilities) to different types of users via a network of pipes, storage facilities, valves, and pumps (United States Environmental Protection Agency, 2023). In addition to providing water for household use, distribution systems may supply water for fire protection, agricultural, and commercial uses. Public water systems agencies are responsible for operating and maintaining their distribution systems, which extend from the designated entry point to the service connection, after which is the property owner's responsibility (United States Environmental Protection Agency, 2023).

Distribution systems represent most of the physical infrastructure for water systems and serve as the final barrier against contamination of the resource. Is critical for distribution systems to be properly operated and maintained to reduce the risk of contamination from external sources or internal sources within the system that can have negative impacts on the health of the users (United States Environmental Protection Agency, 2023) (see Figure 14).

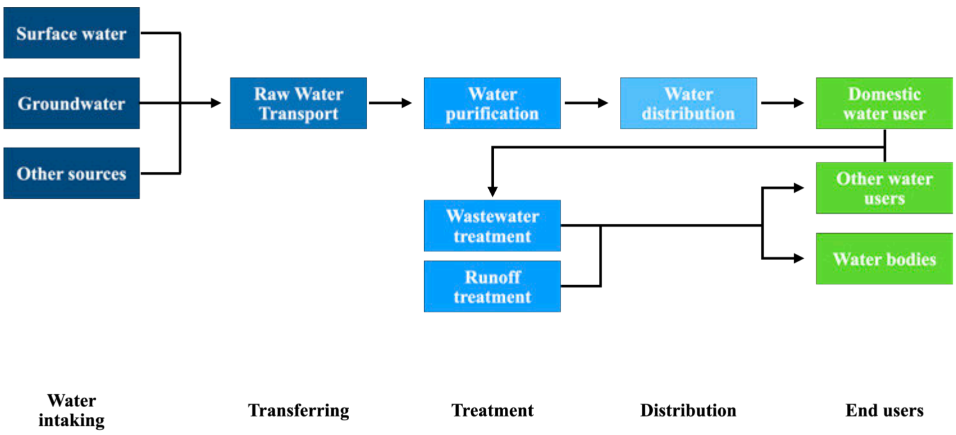


Fig.14. The Urban Water Supply System. Based on the work of (Liu et al. 2018)

As urban populations continue to expand in different regions around the world, the demand for the delivery of safe and clean freshwater will also increase (Lee & Schwab, 2005). In most larger cities, governments or privately contracted companies have constructed the necessary infrastructure to provide potable water to all residents. Due to climate change reducing the quality and quantity of available fresh water and the rapid urbanization processes increasing the demand for the resource, the current model is becoming unsustainable (Organization for Economic Co-Operation and Development, 2015). For that reason, is required to transition from the grey infrastructure model of the XX century to a greener and more sustainable model to ensure the supply of the resource. According to the OECD, these are the main challenges water systems are facing to provide sustainable and quality service to their citizens (Organization for Economic Co-Operation and Development, 2015).

- Infrastructures, that transport the freshwater to citizens, generally are ageing and require upgrading. The prevailing business models for urban water management fail to attract needed financial sources.
- Urban water management faces emerging pressures, such as more stringent health and environmental standards, diffuse pollution, increasing competition to access the resource, increased intensity, and frequency of extreme weather and more generally, higher uncertainty about the future of freshwater security.
- Cities are locked in technical trajectories, and retrofitting existing infrastructure is particularly challenging.
- Water governance in cities is affected by several gaps, such as data asymmetries, sectoral fragmentation, and limited capacities. Moreover, institutional structures are constantly changing, driven by regulations, territorial reforms, decentralization, and the reallocation of competencies across jurisdictions. These changes may affect the capacity of cities and other actors to manage water at the appropriate scale.

There are four major factors in evaluating the water systems such as water quality, water quantity, guaranteed probability of water source and convenience of water acquisition (Song, et al., 2020).

- Water quality: a water source with good water quality and easy to protect is ideal for a sustainable water system. In general, the water quality of a surface water source should meet national and international requirements.
- Water quantity: a water source with abundant water should be selected to meet the current and future needs. To avoid environmental problems, it is needed to not arrive at an overexploitation status.
- Guarantee probability of the water source: ensure the supply not only in high-flow periods but also in low-flow and dry periods.
- Water source and convenience: to reduce the economic costs, the water sources and water plants should be as close as possible to the major water users and be easy to construct.

3.1.4 Environmental Water Security

As mentioned in previous chapters, environmental and water security are closely linked. The current climate change crisis directly impacts the water cycle and endangers water security for territories and cities. Climate change affects where, when, and how much water is available due to worsening floods, rising sea levels, shrinking ice fields, wildfires, and droughts (United States Environmental Protection Agency 2024a). The quantity of available freshwater continuously decreases due to multiple climate factors such as droughts and changes in precipitation cycles, pollution of the sources mainly by human action, and overexploitation of the resource that doesn't allow the natural regeneration of the resource (Pereira, Cordery, & Iacovides, 2009).

Water ecosystems such as rivers, lakes, groundwater, coastal waters, and seas support the delivery of crucial ecosystem services, such as fish production, water provisioning, and recreation. Ecosystemic services are defined as the benefits that communities obtain from ecosystems, such as clean air and purified water (Grizzetti et al. 2016;

Brears 2017a). Key ecosystem services are also connected to the hydrological cycle in water basins. Water purification, water retention, and climate regulation are some of the key aspects. Environmental water security aims to protect the integrity of natural water ecosystems necessary for human survival through the restoration of rivers, lakes, aquifers, and other water bodies on the regional, national, and provincial levels (Brears 2017a; 2021). The sustainability and development of communities and cities depend on these natural resources.

3.1.5 Resilience to Water-Related Disasters

The term risk is used and defined by different disciplines such as finance, industry, mathematics, environmental sciences, and social sciences. Within the broad field of risk research, two main approaches regarding risk can be found (Birkmann, Risk 2013). The first one views risk as a product of the interaction of a hazard and the vulnerability of a system or exposed element, which is widely represented by the work of the United Nations (United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction 2004). In contrast, the second school of thought views risk primarily within the broader context of the decision and game theory. Consequently, the risk is seen as closely linked to decisions that could lead to loss or damage, in the light of a hazard.

The Oxford Dictionary defines environmental risk as any source of harm or danger in the environment from natural hazards, pollution, or depletion of natural resources (Oxford Dictionary, 2023). Other more precise definition are the risks that arise in the natural environment or are transmitted through water, air, soil, or biological food chains (Whyte & Burton, 1980). Environmental risks can be divided into two main typologies the first one human-driven through the introduction of a new technology, product or chemical that can damage the environment (Whyte & Burton, 1980). The second typology of environmental risks comes from natural processes which interact with human settlements such as floodings, fires, landslides, among others (Whyte & Burton, 1980). Another categorization for environmental risks is if they can be anticipated or are wholly unsuspected (Whyte & Burton, 1980). Regarding the first category decision-makers and civil society can develop preparedness strategies to cope with the damage, meanwhile with the second category, response, mitigation and reconstruction strategies must be used to deal with the challenge. Environmental risks share a common feature which is that they cause harm to populations who have not voluntarily or specifically chosen to suffer their consequences, and thus they require regulations and policies to protect them at the international, national, and local level. Water risks are among the different environmental risks that endanger the continuity of communities.

Considering a risk-based approach to water security, a risk is considered acceptable if the likelihood of a given hazard is low and the impact of that hazard is low. In such cases, there is no pressure to reduce acceptable risks further, unless more cost-effective measures become available. The acceptability and tolerability judgement process enables policymakers to prioritize risk management decisions when risks exceed acceptable levels (Organization for Economic Co-operation and Development 2013). The OECD proposes four water risks.

1. Risk of shortage (including droughts): Lack of sufficient water to meet demand (in both the short- and long-run) for beneficial uses by all water users (households, businesses and the environment).

2. Risk of inadequate quality: Lack of water of suitable quality for a particular purpose or use.

3. Risk of excess (including floods): Overflow of the normal confines of a water system (natural or built) or the destructive accumulation of water over areas that are not normally submerged.

4. Risk of undermining the resilience of freshwater systems: Exceeding the coping capacity of the surface and groundwater bodies and their interactions (the "system"); possibly crossing tipping points and causing irreversible damage to the system's hydraulic and biological functions.

All four risks must be assessed at the same time as they can impact each other given the nature of water as a hydrologically interconnected resource. Indeed, these risks are interrelated; for instance, the risks of shortage, inadequate quality and excess may all increase the risk of undermining the resilience of freshwater systems. Managing all of these water risks is central to achieving the objective of water security.

Water shortage which can be referred to as water scarcity has different definitions. According to the Ecology Dictionary (Majumder, 2015) water shortage is defined as the situation within all or part of an area where the available water is insufficient to meet the present and anticipated needs of the system, or when conditions are such as to require a temporary reduction in total use within a particular area to protect water resources from serious harm. According to RWL (Majumder, 2015), water shortage can be defined as a condition in which people lack sufficient water or else do not have access to safe water supplies. A simpler definition for water shortage can be the lack of sufficient available water resources to meet the demands of water usage of a population. Water shortage affects the water security of human communities and has been addressed for decades by international organizations like United Nations (United Nations, 2022) and the OECD (Organisation for Economic Co-Operation and Development, 2023). Water shortage may be attributed to four main drivers (Majumder, 2015).

1. Urbanization

2. Water Pollution

3. Climate Change

4. Mismanagement of Available Water Resources

Urbanization

Urbanization processes integrate the rural population that comes to the city for better opportunities and quality of life, provoking an increase in the existing urban population, sometimes surpassing the capacity of cities to absorb this new population (UN Habitat, 2020). To carry on the sustenance of this new excess of population it is required the construction of more roads, houses, and commercial and industrial buildings is necessary. This additional development unfortunately has its own impact on the urban ecosystem directly impacting the accessibility, quality, and availability of the water resources (Majumder, 2015). The decrease of accessibility of water as the amount of surface runoff also increases due to the reduction of filterable area. In addition to this, overgrowth in the density of population and change in land use and land cover are two other relevant impacts of urbanization. Both changes could eventually increase the stress on the natural resources of the region and will also change the nature of the surrounding areas of the city. As the population increases so will be the demand for water (Majumder, 2015). One of the damaging effects of increasing concentration of industries is the toxic discharges from them which will pollute the surface water and eventually the groundwater.

The urbanization impacts on water availability can be grouped into the following four classes.

1. Population Overgrowth

2. Land use Change

3. Stress on available Resources

4. Change in the surrounding nature

Water Pollution

It is not uncommon that water bodies near urban areas are highly polluted. This is the result of both garbage dumped by individuals and dangerous chemicals legally or illegally dumped by the industrial or commercial sectors (Majumder, 2015) (World Economic Forum, 2022). The effects of water pollution depend on what kind of chemicals are dumped and in which locations. The causes of water pollution can be contributed by:

1. Increase in Concentration of Industries

2. Increase in Agriculture Activities

3. Increase in Amount of Urban Domestic Waste

4. Increase in Power Plants

5. Water and Energy Demand

Climate Change

Climate change is hitting harder than expected with unprecedented results in the development of cities and communities (World Economic Forum, 2022). The uncontrolled extraction of natural resources, the exponential growth of non-sustainable industrial activities, and the destruction of natural reserves and water bodies followed by the rising demand for water and energy from an ever-growing global population have increased the stress on water resources of most countries in the World (Majumder, 2015). The use of fossil fuels has also increased in the last decades and as a result amount of greenhouse gas in the atmosphere has increased. The major impact of climate change can be considered:

1. Rise in average temperature

2. Increase in the number of Extreme Events such as heat waves

3. Increase in Occurrence of Floods and Droughts

4. Stress on Water Resources

5. Early Onset of Seasons

Mismanagement of Available Water Resources

While the amount of freshwater on the planet has remained constant over time recently it has to be shared among a bigger population and increasing industrial activities. This means that the competition for a clean and safe freshwater supply intensifies. Freshwater makes up a very small fraction of all water on the planet representing around 2.5% of the available water (World Wildlife Foundation , 2023). Even then, just 1 % of the world's freshwater is easily accessible, with much of it trapped in glaciers and snowfields. In summary, only 0.007 % of the planet's water is available to around 7 billion people. One of the biggest challenges for the future decades will be to provide enough water to the predicted 9 billion people by 2050 (Majumder, 2015).

Unfortunately, the available freshwater in many countries is non-optimally utilized. There are no specific methods for the allocation of the available water resources to different kinds of consumers. Monetary and political gains are still considered a priority before allocation of the scarce water resources (Majumder, 2015). Thus, due to the non-optimal allocation of water resources, a considerable amount of available water could also be wasted. The reason for this situation is:

1. Non-Optimal Allocation of Water Resources

2. Drawback with the Indicators

3.2 The Integrated Water Resources Management (IWRM) approach

Water management can be defined as the control and movement of water resources to maximize efficient beneficial use and minimize damage to life and property. Good water management reduces the risk of harm due to flooding and reduces the impacts of water shortage (United States Department of Agriculture, 2023). In the context of multiple challenges countries and cities are facing around the world the future and present of water management must be sustainable. Sustainable water management means meeting the need the water requirements of the present generation without hampering the ability of future generations to meet their own needs. It also describes how resilient the water system is in the face of change. Various factors must be taken into consideration to achieve sustainability in water management which can be classified into economic, environmental, ecological, physical, and social. A water system can be called sustainable if it meets the present and future needs of its community along with maintaining its ecological, environmental, and hydrological integrity. The challenges of the water system should be analyzed to improve the actions and methods of planning, developing, managing, and maintaining to achieve the sustainability of the system. Sustainable water resource management is a complex process that incorporates various steps and sub-processes that must be taken into consideration.

Integrated Water Resources Management (IWRM) is a framework that promotes the coordinated development and management of water, land, and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment (Global Water Partnership 2024b; Savenije and Van der Zaag 2008). The IWRM approach originates from the Dublin-Rio Principles, adopted at the 1992 Dublin Conference on Water and endorsed at the Rio de Janeiro Summit on Sustainable Development (Global Water Partnership 2024a; Brears 2017a). IWRM is strongly aligned with the principles and ambitions set by Agenda 2030 and is an integral part of SDG 6 as it is reflected in Target 6.5, specifically on the implementation of Integrated Water Resources Management (Taka et al. 2021).

IWRM offers a comprehensive framework for achieving water security (Global Water Partnership 2024b). The integrated approach seeks to identify effective water investments to increase economic development that contributes to overall socio-economic well-being and ecological sustainability. By aligning and integrating policies, legislations, and actions that are traditionally seen as unrelated or that, despite clear interrelationships, are not coordinated, IWRM can foster a more efficient and sustainable use of water resources to achieve sustainable development by promoting a way of thinking that enhances the capacity to tackle multi-objective, multi-sectoral development planning. The transformative potential of IWRM extends well beyond water from a sectoral perspective; it is a framework designed to contribute to achieving overall sustainable human development. IWRM effectively aligns the five main water security dimensions with sustainable development's main aspects: social equity, economic efficiency, and environmental sustainability (see Figure 15). Water should be put at the core of development strategies and a connector between different sustainable development approaches to ensure the well-being and continuity of human communities.

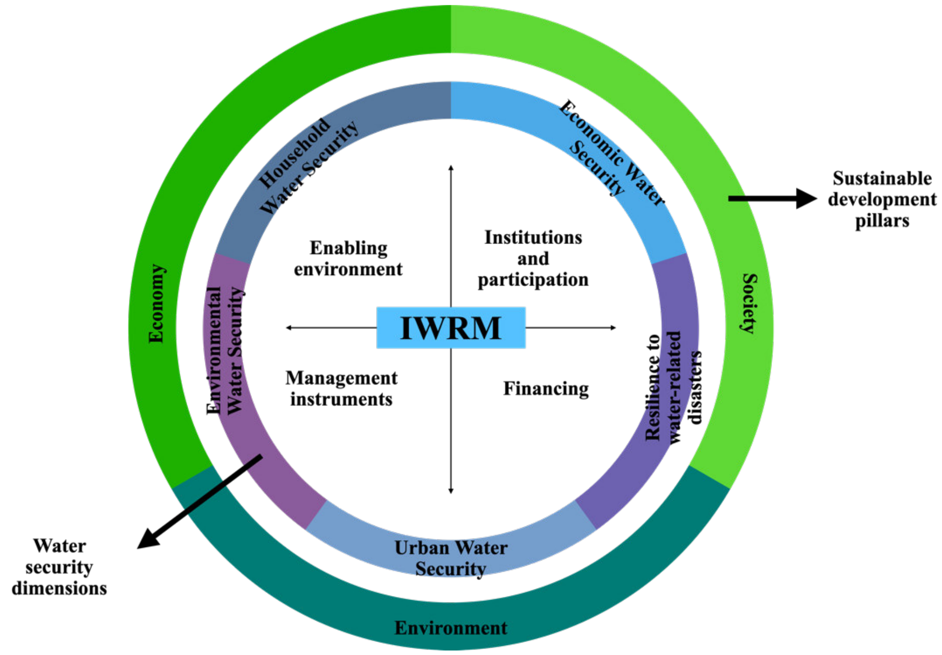


Fig.15. IWRM Water Security Framework. Based on the work of (Global Water Partnership, 2024)

3.2.1 Integrated Urban Water Management (IUWM)

IWRM has a subset known as Integrated Urban Water Management (IUWM), which calls for aligning urban development and basin management to achieve sustainable economic, social, and environmental goals in cities (Global Water Partnership 2013). IUMW can be considered the vehicle for achieving urban water security. It brings together water supply, sanitation, storm- and wastewater management and integrates these with land use planning and economic development. An IUWM approach aims to integrate planning for the water sector with other urban sectors, such as land, housing, energy, and transport, to avoid fragmentation and duplication in policy and decision-making (see Figure 16). The main IUWM principles are the following according to the Global Water Partnership (Global Water Partnership 2013).

1. Integrate alternative water sources.
2. Match water quality with water use.
3. Integrate water storage, distribution, treatment, recycling, and disposal.
4. Protect and conserve water sources.
5. Plan for non-urban users.
6. Recognize and seek to align formal and informal institutions and practices.
7. Recognize relationships among water, land use, and energy (Water-Energy-Food-Ecosystem Nexus framework).
8. Pursue efficiency, equity, and sustainability in water service.
9. Encourage participation by all stakeholders.

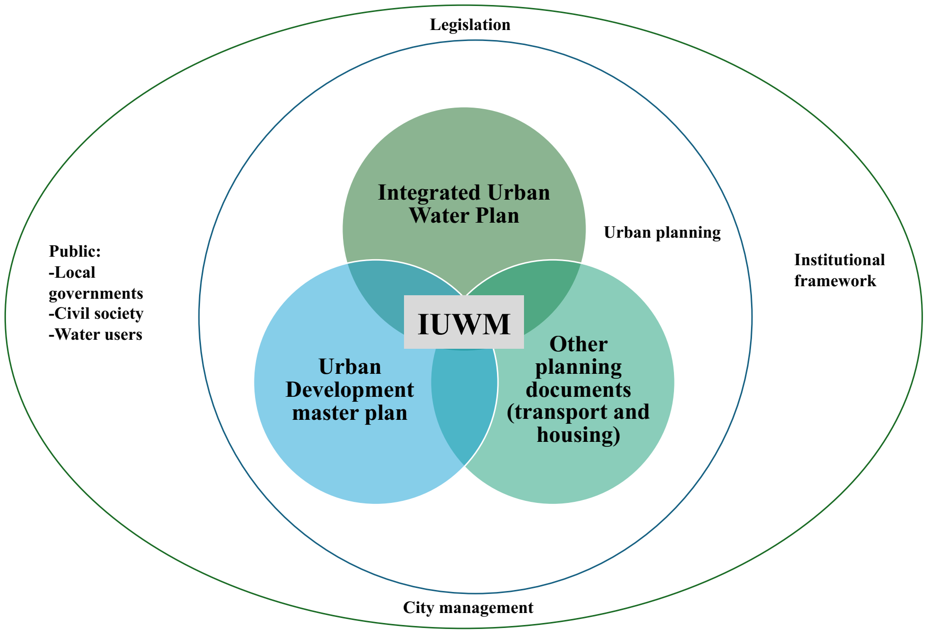


Fig. 16. IUWM Framework. Based on the work of (Global Water Partnership, 2013)

3.3 IWRM as a vehicle to advance towards Water Security

The multidimensionality of the water security approach helps address the water-related challenges that cities face in the context of the climate change crisis and rapid population growth. This is by addressing the complexity of water supply and management in cities comprehensively, not separately, as has been done in traditional water management approaches. In addition to highlighting how the different dimensions are connected, and that advances towards water security cannot be made without at least the five main dimensions being adequately developed. Once it is clear that Water Security is the appropriate approach to address current challenges, the following question arises: What is the vehicle that can concretize the concepts and approaches that the Water Security advocates and translate them into policies, regulations, actions, and projects to improve people's lives?

The research finds that the IWRM is the most appropriate management model to advance toward water security. In other words, IWRM can be considered the most appropriate vehicle to advance towards Water Security for the present and future water security. IWRM aligns and integrates policies, legislations, and strategies to foster more efficient and sustainable use of water resources to achieve sustainable development by promoting a way of thinking that enhances the capacity to tackle multi-objective, multi-sectoral development planning, which is much needed to face the current water-related challenges that cities are facing. IWRM also contributes to enhancing the economic potential of water sustainably by identifying effective water investments. As mentioned before, IWRM effectively aligns with the five main water security dimensions by acknowledging the multidimensionality of water and stating that resource management should be coordinated considering the interlinkages and complexities of water and be reflected in the integrated approach that IWRM proposes. This represents a complete change compared with the traditional water management approach, which tends to compartmentalize the different aspects of water and see them as separate elements. This can be observed when the environmental strategy is not aligned with the operational objectives of the urban water manager, for example. The research project believes that the IWRM is the fundamental basis for the development of actions that enhance water security in cities since they provide the framework for a more fluid implementation of the necessary policies.

When talking about water security in cities, it is important to see the city not as an isolated entity but as an element strongly linked to its environment. That is why research when evaluating water security proposes to do so also considering the surrounding territory where the main water sources generally come from and where wastewater is also discharged; in that sense, the IWRM provides this comprehensive approach that integrates the urban and not urban elements but at the same time gives the IUWM that is the subset specifically focused on the urban context and is intrinsically linked to the Urban Water Security dimension. Although Urban Water Security is the central element of this research, the rest of the dimensions should be considered and integrated into the proposed evaluation framework and its expected results to provide a more integral guidelines.

Chapter 4

Frameworks to evaluate water security

Vatican City, Armando Cepeda Guedea, 2023.

4.1 Categorizing and evaluating evaluation frameworks

When measuring water security, one of the main challenges is to fuse the different dimensions of water security into a comprehensive framework because of the difficulty of integrating different competing indicators (Garrick and Hahn 2021; Octavianti and Staddon 2021). This requires a systemic approach to understanding water security by analyzing complex phenomena and studying the interrelations between various dimensions. In the last decades, multiple frameworks to measure water security have emerged from academia, civil society, governments, and international organizations. Acknowledging the complexity of water security, some frameworks focus on one or more dimensions of water security without approaching it as a whole. This can be explained by the simplicity of elaborating the set of indicators, the data availability, and the needs of the framework developer.

There are two dominant types of frameworks when measuring water security: experiential scale-based metrics and resource-based metrics. The experimental-based one mainly focuses on measuring the water experiences of households and their impact on human well-being, while the resourced-based one assesses freshwater availability or water resources security at the city, provincial, and basin levels (Octavianti and Staddon 2021). The experimental-based one mainly focuses on measuring the water experiences of households and their impact on human well-being, while the resourced-based one assesses freshwater availability or water resources security at the city, provincial, and basin levels (table 15).

Table 16: A summary of different characteristics of experiential scale-based and resource-based metrics according to (Octavianti and Staddon 2021)

Aspect	Experiential scale-based metrics	Resource-based metrics
Disciplines	Social science	Engineering and natural science
Spatial scale	Household, individual	Municipality, city, province, basin, country, region, global
Temporal scale	Snapshot data (present data) Recall period in the survey: 1 week, 1 month, 4 months	Past annual data to measure water status (some publications use the data to predict water status in the future)
Purpose	Capturing water insecurity experiences Identifying vulnerable, water insecure groups Evaluating water interventions	Improving water security Identifying mitigation targets Allocation of funding Raise awareness (benchmarking)
Water domain/focus	Water supply and hygiene; and human well-being	Mainly freshwater resources, but some with broad focus

	Water insecurity (what we are trying to fight)	Water insecurity (what we are trying to achieve)
Data collection	Household surveys, preceded by formative survey and validation of questions (some studies)	Mainly secondary data from governmental agencies
Vision for universal application	Yes (some metrics)	Yes (some metrics), but generally only used locally
Weighting	Not applicable (basic arithmetic)	Vary (fixed weights, equal weights, up to local judgments)

Using the synthesis of Octavianti and Staddon (Octavianti and Staddon 2021)the research proposes an evaluation framework of the water security evaluation framework by adding the dimension of typology of water security evaluation framework, water security aspect covered and the associated SDGs indicators (see Table 16).

Table x: Main aspects for reviewing water security evaluation frameworks

Aspect
1. Disciplines
2. Spatial scale
3. Temporal scale
4. Purpose
5. Water domain/focus
6. Data collection
7. Vision for universal application
8. Weighting
9. Type of framework
10. Water security dimensions covered
11. Associated SDG indicators

4.2 Global Water Security 2023 Assessment (UNU INWEH)

The United Nations University Institute for Water Environment and Health (UNU INWEH) is a United Nations think tank on water. The UNU INWEH released its Global Water Security 2023 Assessment that evaluates the state of water security for 7.78 billion people living in 186 countries. The report identifies 10 main elements of water security at country level regardless of size, population, or geography from an inclusive approach to ensure a maximum number of countries are represented and compared globally by their assessed national water security levels (see Table 17).

Table 17: The main elements for Water Security according to UNU INWEH (2023)

The main elements for Water Security
1. Drinking Water
2. Sanitation

3.	Good Health
4.	Water Quality
5.	Water Availability
6.	Water Value
7.	Water Governance
8.	Human Safety
9.	Economic Safety
10.	Water Resource Stability

The identified components are assessed and mapped at a national level using indicators with clear metrics and publicly available data that are linked to SDGs. Each component is measured by at least one indicator (see Table 18). As the frameworks develop in future reports and better-quality data become available, additional SDG-related indicators can be introduced. However, the simplicity and flexibility of the overall structure should remain to be easily implemented in developing countries. Each water security element is assessed in each country and receives a score out of 10 with an equal weighting with a maximum score of 100. National scores are classified as water 'secure' (75 and above), 'moderately secure' (65–74), 'insecure' (41-64), or 'critically insecure' (40 or less).

Table 18: Water security components, indicators, and Associated SDGs according to UNU INWEH (2023)

Factor	Indicators	Associated SDG indicator
Drinking water	• Proportion of the population using basic to safely managed drinking water (%)	6.1.1: Proportion of the population using safely managed drinking water services
Sanitation	• Proportion of the population using basic to safely managed sanitation (%)	6.1.2: Proportion of the population using safely managed sanitation services
Good health	• Mortality rate attributed to exposure to unsafe Water Sanitation and Hygiene (WASH) (deaths per 100,000 population)	3.9.2: Mortality rate attributed to unsafe water, unsafe sanitation, and lack of hygiene (exposure to unsafe Water, Sanitation, and Hygiene for All (WASH) services)
Water quality	• Proportion of household wastewater treatment (%)	6.3.1: Proportion of domestic and industrial wastewater flows safely treated
Water availability	• Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (%)	6.4.2: Level of water stress: freshwater withdrawal as a proportion of available freshwater resources
Water value	• Water Use Efficiency (USD/m3)	6.4.1 Change in Water Use Efficiency over time
Water governance	• Degree of Integrated Water Resource Management (%)	6.5.1 Degree of Integrated Water Resource Management (%)

Human safety	• Mortality due to water-disasters (deaths per 100,000 population)	1.5.1, 11.5.1, 13.1.1 Number of deaths, missing persons, and directly affected persons attributed to disasters per 100,000 population
Economic safety	• Modelled economic impact of floods (% of national GDP) • Modelled drought risk (non-dimensional integer)	1.5.2, 11.5.2: Direct economic losses attributed to disasters in relation to global gross domestic product (GDP)
Water resource stability	• Interannual variability (non-dimensional integer) • Large dam storage /capita (m3 /capita)	None

The key findings that emerge from this report are the following:

1. Most of the world's population lives in water-insecure countries today

2. There is a clear disparity in water security across global regions and between countries

3. Least Developed Countries face critical levels of water security

4. Globally, all regions face a trajectory of low levels of water security

5. Access to safely managed drinking water and sanitation is still challenging for more than half the global population

6. Globally, significantly more people die from a lack of safe drinking water, sanitation, and basic hygiene services than as a result of water disaster

7. Comprehensive and accurate water quality assessment at the national level remains a challenge despite a dedicated SDG 6 target

8. Abundant natural water availability does not necessarily ensure water security

9. High water values ('Water Use Efficiency') do not always translate into water security

10. The influence of climate change on water security is not well addressed by the water-related SDGs

11. Prosperity is not the main driver of water security

12. Water security assessment provides, at best, coarse national-level estimates that mask water security variability at finer scales

Finally, the proposed reviewing framework for the water security indicators framework is applied (see Figure 19). This framework can be considered from the resource-based type at the country level with secondary from 2020 to track the progress towards a water-secure world and identify development opportunities, funding allocation, and policy development opportunities. This evaluation framework covers several SDGs reaffirming the required holistic approach to water security. Also, it covers three water security dimensions, missing the urban and household ones, since this report is designed at the country level due to data availability.

Table 19: Review of the UNU INWEH Global Water Security 2023

Aspect	
1. Disciplines	Social science
2. Spatial scale	Country
3. Temporal scale	2020
4. Purpose	Improving water security Identifying mitigation targets Allocation of funding Raise awareness (benchmarking)
5. Water domain/focus	Water insecurity (what we are trying to achieve)
6. Data collection	Mainly secondary data from governmental agencies
7. Vision for universal application	Yes
8. Weighting	Scale 1 to 10 each factor has the same weight
9. Type of framework	Resource-based metrics
10. Water security dimensions covered	3/5 economic water security, environmental water security, resilience to water-related disasters
11. Associated SDG indicators	SDG 6, 3, 1, 11, and 13 6.1.1, 6.2.1, 3.9.2, 6.3.1, 6.4.2, 6.4.1, 6.5.1, 1.5.1, 11.5.1, 13.1.1, 1.5.2, 11.5.2

4.3 The World Resources Institute Aqueduct 4.0 Water Risk Atlas

The World Resources Institute (WRI) is a non-profit global organization founded in 1982 that uses a research-based approach to protect and restore nature, stabilize the climate change impacts, build resilient communities, and meet people's essential needs. Fundamentally, the WRI aims to transform the way the world produces and uses food, energy, and other natural resources and design a better future for all (World Resources Institute 2024). The WRI has offices in Brazil, China, Colombia, India, Indonesia, Mexico, and the United States, as well as regional offices in Africa and Europe.

To contribute to face water security, the World Resources Institute presented in 2013 the Aqueduct framework. Aqueduct present a set of tools that help companies, governments, and civil society to understand and respond to water risks such as water stress, variability from season to season, pollution, and water access. Aqueduct maps and data are used directly by hundreds of companies and are cited in many publications. Inside the Aqueduct framework exists the Water Risk Atlas, which is an evaluation framework designed to translate complex hydrological data into an intuitive set of indicators of water-related risks (Hofste et al. 2019). The WRI proposes 13 water risk indicators spanning quantity, quality, and reputational concerns into a comprehensive framework (Kuzma et al. 2023). The data for each indicator is sourced from open-source, peer-reviewed data and then transformed to a normalized risk score based on the severity of the water challenge. The normalized indicator score is subsequently aggregated by category (quantity, quality, reputational, and overall) into composite risk scores using sector-specific weighting schemes (default, agriculture, energy, semiconductor, oil and gas, and chemical). The index provides a score in the basin and sub-basin levels that can be aggregated into country and provincial administrative boundaries. Regarding temporality, the Water Risk Atlas provides projections for 2030, 2050, and 2080 in pessimistic, business-as-usual and optimistic scenarios. Currently, the Water Risk Atlas is in its fourth edition, presented in 2024. The following table presents the 13 proposed indicators of water risk and the default weighting schemes (see Table 20).

Table 20: Water Risk Atlas 4.0 (WRI 2024)

Factor	Indicator	Weight	Final weight
Physical Risk Quantity	Baseline water stress	0.1632	0.694
	Base water depletion	0.1632	
	Interannual variability	0.0204	
	Seasonal variability	0.0204	
	Groundwater table decline	0.1632	
	Riverine flood risk	0.0408	
	Coastal flood risk	0.0408	
	Drought risk	0.0816	
Physical Risk Quality	Untreated Connected Wastewater	0.0816	0.122
	Coastal Eutrophication Potential	0.0408	
Regulatory and Reputational Risk	Unimproved/No Drinking Water	0.0816	0.184
	Unimproved/No Drinking Sanitation	0.0816	

	Peak Rep Risk country ESG risk Index	0.0204	

The proposed reviewing framework for the water security indicators framework is applied (see Figure 21). This framework can be considered from the resource-based type at the country level, with secondary data from 2023. WRI Aqueduct information platform aims to provide reliable information to companies, governments, and nongovernmental organizations about water-related risks. The data have been updated regularly, making them comparable on global, country, and provincial levels and accessible to decision-makers worldwide. This evaluation framework has only three SDGs, more specifically, SDGs 6, 14, and 17. It covers only two water security dimensions (environmental water security and resilience to water-related disasters) since the Water Risk Atlas is focused on water risks. It is an example of a framework designed for specific aspects of water security and does not approach the whole phenomenon.

Table 21: Review of the Water Risk Atlas 4.0

Aspect	
1. Disciplines	Social and natural science
2. Spatial scale	Country and province
3. Temporal scale	2023
4. Purpose	Improving water security Identifying mitigation targets Raise awareness (benchmarking)
5. Water domain/focus	Water insecurity (what we are trying to achieve) Freshwater resources, but some with broad focus
6. Data collection	Mainly secondary data from governmental agencies
7. Vision for universal application	Yes
8. Weighting	Scale 1 to 5 each factor has an specific weight
9. Type of framework	Resource-based metrics
10. Water security dimensions covered	2/5 environmental water security and resilience to water-related disasters
11. Associated SDG indicators	SDG 6, 14 and 17 6.1.1, 6.2.1, 6.3.1, 6.4.1, 6.4.2, 6.6.1, 14.1, 17.14.1

4.4 Key Performance Indicators framework to evaluate the water security of urban water systems

Performance evaluation of urban water systems and their operators using a Performance Indicators Methodology have been used as valid management tools since the 1990s because it requires less sophisticated data, facilitates comparisons and benchmarking, enhances water services quality, assists in assessing the performance of urban water systems and their operators with reduced costs, and builds a foundation in developing and implementing future public water policies (Pokhrel et al. 2023; Alegre et al. 2016). This has produced a considerable pool of performance indicators (PIs) since different governments, associations, and researchers have developed their own PIs frameworks to measure the performance of urban water systems or specific aspects of them. Key Performance Indicators (KPIs) are the set of PIs that are more important to follow a specific objective, in the case of this research urban water security of urban water systems (Pokhrel et al. 2023). Considering the data, the research could access, it identifies four relevant performance indicator frameworks to evaluate the performance of urban water systems and their operators.

When developing policies and plans to address water security in cities and territories, one of the main challenges is the integration of water planning and land planning. Meaning, that the water security goals and strategies developed by water planners and operators do not transfer properly into the main planning documents such as comprehensive plans, sustainability plans, and zoning plans (Nolon 2018). Water and land use planners are usually disconnected from what they do, and the tools at their disposal. Water planning is usually done by local or regional water operators, or basin regional authorities who are subject to a differing array of national, regional, and local water planning and regulatory requirements (Nolon 2018). The land use planning that drives future water demand, and allocation of water resources, however, is done predominantly at the local level by regions and cities. To achieve water security in cities water and land use planning must be connected effectively. Water providers need to understand the growth and development patterns anticipated by land use planners and consider that information when projecting water demands and be prepared, and land use planners need to understand how development patterns affect water use and water loss and consider what rate and style of growth is possible given water-supply availability.

4.4.1 IWA Performance Indicators for Water Supply Services (2017)

IWA (International Water Association) is an international nonprofit organization based in London with members in over 140 countries. It is considered a knowledge hub for the water sector bringing together water and wastewater operators, scientists, technology companies, and stakeholders related to water management. Their publications and reports are widely used by decision-makers worldwide when developing plans and policies regarding water management and related good practices. One of the most popular and accepted manuals on performance indicators for urban water systems is the "Performance Indicators for Water Supply Services" published in 2000 and currently in its third edition from 2017 (Alegre et al. 2016). The manual proposes a set of 135 indicators and 34 sub-indicators divided into six main categories: water resources, personnel, physical, operational, quality of the service, and economics and finance. The main six categories are structured into 43 subcategories (see Table 24).

Table 24: IWA Performance Indicator Framework (2017)

Factor	Levels	Indicators	Sub indicators
Water resources	1	3	1
Personnel	7	20	6
Physical	6	15	0
Operational	10	32	11
Quality of service	6	24	10
Economic and finance	13	41	6
Total	**43**	**135**	**34**

4.4.2 AWWA 2022 Utility Benchmarking Performance Indicators (2023)

The American Water Works Association (AWWA) is an international, nonprofit association dedicated to providing solutions for effective water management. Currently, 4,300 water operators in the US are members of the association representing roughly 80% of the nation's drinking water and almost half of the nation's wastewater (American Water Works Association 2020). This makes AWWA a reference for water management in the US. AWWA membership is diverse, integrating public water and wastewater operators, environmental advocates, academicians, and interested individuals. Originally from the United States, AWWA has expanded its network into countries such as Canada, Mexico, and even India. The AWWA utility benchmarking program expects to provide water operators the possibility to self-evaluate their performance by producing objective performance measures for decision-makers. The most recent document is the 2022 AWWA Utility Benchmarking Performance Indicators composed of 63 indicators, 79 sub-indicators, and 7 third-level indicators divided into five categories: organizational development, business operations, customer relations, water operations, and wastewater operations (American Water Works Association 2022) (see Table 25). AWWA constantly updates and adds indicators according to the needs of the member water operators.

Table 25: AWWA Performance Indicator Framework (2022)

Factor	Indicators	Sub indicators	III Level indicators
Organizational Development	12	2	0
Business Operations	14	15	0
Customer Relations	19	30	7
Water Operations	9	18	0
Waster Water Operations	9	14	0
Total	**63**	**79**	**7**

4.4.3 2023 Key Performance Indicators Frameworks in WAREG member countries

The European Water Regulators Association (WAREG) is an association of public authorities with economic responsibilities in the drinking water and wastewater sector. It was established in 2014 in alignment with the European Water Framework Directive. WAREG is based in Milan and Brussels and hosted by the Italian Regulatory Authority for Energy Networks and Environment (ARERA) and the Brussels Energy Regulatory Commission (BRUGEL) (European Water Regulators 2023). The association encompasses 24 Members and 10 Observers from EU and non-EU countries, allowing public water operators in countries such as the United Kingdom to participate as observers or Georgia as a full member. Following the 2022 proposal for a recast of Wastewater Directive 91/271/EEC, which presents a change of consideration of the water and sanitation sector in EU legislation. Authorities responsible for water and sanitation regulation and water and their operators in EU member states are facing new requirements for allowing public access to information for the sector, as well as presenting an evaluation of the performance of water systems (European Water Regulators 2023). The implementation of performance indicators is expected to be introduced allowing a more standardized approach for the assessment of directives implementation and performance monitoring. In 2024 WAREG published the Key Performance Indicators Frameworks in WAREG Member Countries. The document analyses the performance indicators frameworks of 19 WAREG members who submitted their information to the association to develop the document. Italy is included among the members that submitted its 13 KPIs. WAREG organizes the 425 indicators into five categories: service coverage, service quality, environment, asset efficiency, and economic efficiency. The five main categories are structured into 23 subcategories to organize the 425 Key Performance Indicators (European Water Regulators 2023). It is important to point out that WAREG does not filter the submitted indicators by its members and limits to just organizing them, meaning that in the same category, PIs may repeat or have a very close meaning. Each category and subcategory has an assigned share, representing the number of indicators associated with them.

Economic efficiency has the biggest share with 29.6% followed closely by Asset efficiency and Service Quality with 27.8% and 23.3% respectively (see Table 26). A bigger share of indicators can be interpreted as the priority water operators give to that specific aspect of water management and an initial step to propose a weighing of the indicators.

Table 26: WAREG Performance Indicator Framework (2023)

Factors	Levels	Indicators	Share
Service coverage 11.5%	Water coverage	19	4.5%
	Sewer coverage	17	4.0%
	WW treatment coverage	6	1.4%
	New connections	7	1.6%
Service quality 23.3%	Water quality	23	5.4%
	Water continuity and bursts	29	6.8%
	Water pressure	2	0.5%
	Sewerage flooding and bursts	20	4.7%
	Complaints and communication	25	5.9%
Environment 7.8%	WW quality	21	4.9%
	WW discharge	4	0.9%
	Sludge	8	1.9%
Asset efficiency 27.8%	Asset Management	33	7.8%
	Asset capacity	24	5.6%
	Electricity	31	7.3%
	Non-Revenue Water	30	7.1%
Economic efficiency 29.6%	Meters and reading	12	2.8%
	Billing and consumption	9	2.1%
	Debt collection	11	2.6%
	Affordability	4	0.9%
	Cost unit/covereage/efficency	45	10.6%
	Personnel	39	9.2%
	Revenue and profit	6	1.4%

4.4.4 IMTA 2018 Key Performance Indicators for Water Operators

The Mexican Institute of Water Technology (IMTA) is dependent on the Mexican Ministry of Environment and Natural Resources and is responsible for carrying the Program of Management Indicators of Operating Organizations (PIGOO) that since 2005 evaluates the performance of the public water operators in Mexican cities starting with 12 indicators. Currently, with the 2018 itineration, 36 indicators, and 30 sub-indicators (see Table 27). PIs are organized into five categories: operations, service quality, commercial management, population, and financial (Programa de Indicadores de Gestión de Organismos Operadores 2020). PIGOO framework has a considerable level of comparability with AWWA benchmarking, using the 2017 AWWA Utility Benchmarking manual as a reference. Currently, 346 Mexican cities participate in PIGOO, representing approximately 62% of the Mexican population (Programa de Indicadores de Gestión de Organismos Operadores 2020). The data provided by water operators to PIGOO is classified into three categories: highly reliable sources, reliable sources, and not-reliable sources. IMTA has an active public website where citizens can view the result of the evaluation of the performance of its water operator, representing a good practice in transparency. The PIGOO framework provides insight into how developing countries evaluate their water operators.

Table 27: IMTA Performance Indicator Framework (2018)

Factor	Indicators	Sub indicators
Operations	7	14
Service quality	7	5
Commercial management	9	4
Financial	7	7
Population	6	0
Total	**36**	**30**

Although the presented frameworks are developed by different organizations and adapted for their respective contexts, they share common features: they aim to measure the performance of water operators, they are based on secondary data provided by local governments or the water operator, they are predominantly urban, they do not weight their indicators, and builds a foundation in developing and implementing future public water policies.

The proposed reviewing framework for the Key Performance Indicators frameworks is applied (see Figure 28). This framework can be considered from the resources-based type at the urban/city level, with secondary from governmental agencies and water operators. These evaluation frameworks, due to the multiple aspects they have to cover to evaluate urban water systems, have five associated SDGs, more specifically, SDGs 1, 3, 6, 10, and 11. It covers three water security dimensions (economic water security, household water security, and urban water security) since it focuses on the urban level and its surrounding territories.

Table 28: Review of Key Performance Indicators frameworks for water operators (2017, 2022, 2023 and 2018)

Aspect	

1.	Disciplines	Social and Engineering
2.	Spatial scale	City
3.	Temporal scale	Past annual data to measure water status
4.	Purpose	Improving water security Identifying mitigation targets Allocation of funding Raise awareness (benchmarking)
5.	Water domain/focus	Water insecurity (what we are trying to achieve) Freshwater resources, but some with broad focus Water supply and hygiene; and human well-being
6.	Data collection	Mainly secondary data from governmental agencies
7.	Vision for universal application	Yes
8.	Weighting	No
9.	Type of framework	Resource-based metrics
10.	Water security dimensions covered	3/5 urban water security, household water security and economic water security
11.	Associated SDG indicators	SDG 1, 3, 6, 10, and 11 1.2.1,1.4.1,1.5.4,3.9.2,6.1.1,6.2.1,6.3.1,6.3.2,6.4.1,6.4.2,6.5.1,6.5.2,6.6.1,6.a.1,6.b.1,10.1.1, 11.1.1,11.3.2,11.4.1,11.5.2,.11.5.3, and 11.7.1

Section 2

Evaluating water security in cities from a systemic approach

Tiber River. Armando Cepeda Guedea, 2024

Chapter 5

Building an integral framework to Evaluate Water Security in cities (Methodology)

Leuven Botanic Garden. Armando Cepeda Guedea, 2024

5.1 A Systemic approach to build an indicator framework for Water Security

A systemic approach is a holistic and interdisciplinary method of understanding and solving complex problems (Guarnieri and Garbolino 2019; Durand 2006). It views the world as a collection of interconnected and interdependent elements and emphasizes the relationships and interactions between them. A systemic approach has the potential to drive greater efficiency and a better understanding of threats and opportunities for water security. This approach contributes to the improvement of systems by identifying the right problem to solve, creating a range of possible solutions, and refining the best of these to deliver appropriate outcomes (see Table 29).

A system can be defined as a set of units in mutual interaction, a set of elements in dynamic interaction organized around a goal, or a global unit made up of interrelationships between elements, actions or individuals (Durand 2006). The better fit to understand water security from a systemic approach is a set of different dimensions in dynamic interactions organized around a goal, which is water security. There are four main components that characterize the systemic approach: interaction, comprehensiveness, organization, and complexity (Guarnieri and Garbolino 2019; Durand 2006).

Interaction: elements in a system interact, and they perform actions on other elements, and they are subjected to actions by other elements. If one element does not interact with any others, it can be considered external to the system. The systemic approach offers the advantage of diagnosing existing relationships that describe an element's reflexivity. The action of one element on another element affects the nature or intensity of the actions between them.

Comprehensiveness: the different elements that compose a system cannot be reduced to the sum of its parts in a systemic approach. A system's irreducible properties change depending on the degree of aggregation of the elements or eventual subsets. The hierarchy of the aggregate elements reflects their qualitative or quantitative properties.

Organization: The arrangement of the system components is critical to ensuring its functions and processes. The functions and processes of the system should be differentiated in a way that the elements that make them effective constitute the actual structure of the system. The structure and operation of a system should be organized in a common goal or set of goals.

Complexity: the term should be distinguished from the term complicated; sometimes, they are referred to as the same. A complicated system refers to the multiple relationships of different elements that are difficult to understand. Generally, this kind of system has linear causalities and little interactive causality. The results of the analysis of a complicated system may be simple, stable, or repetitive. The analytical approach is the best fit for understanding complicated systems. Complex systems have particular characteristics, such as: self-organization is the capacity to change its organization without any causal influence from its environment, the emergence of new and dynamic properties in the system, and the system's sensitivity to conditions or constraints and its adaptability. Complexity suggests that it is difficult to predict the dynamics or evolution of a system and can be viewed as uncertainty.

Uncertainty can be reduced by taking into account those elements that were initially excluded from the system but which are subsequently found to have strong relationships with the original main elements of the system. Another aspect of uncertainty difficult to reduce, relates to the system's temporal dynamics. Certain temporal phenomena (dependent on the system's spatial complexity) produce events that can create ramifications in the system dynamics.

Table 29: Systemic approach main characteristics (Guarnieri and Garbolino, 2019)

Systemic approach
Unifies
Effects of interactions
Global perception
Groups of variables
Duration and irreversibility of phenomena Global templates
Validation through modelling and simulation
Global templates
An efficient way to handle nonlinear and strong interactions
Multidisciplinary education
Action through objectives
Knowledge of goals

Cities are complex systems composed of other complex systems and subsystems (see Figure 17): city operation system (how cities are governed and comply with provincial and national governance), city user system (businesses and citizens), and city infrastructure (energy, water, communications, and transport) (Dodgson and Gann 2011). All of the mentioned systems and subsystems should work and connect adequately since if one aspect of the city system is not functioning correctly; it can affect the performance of the other aspects and the overall function of cities.

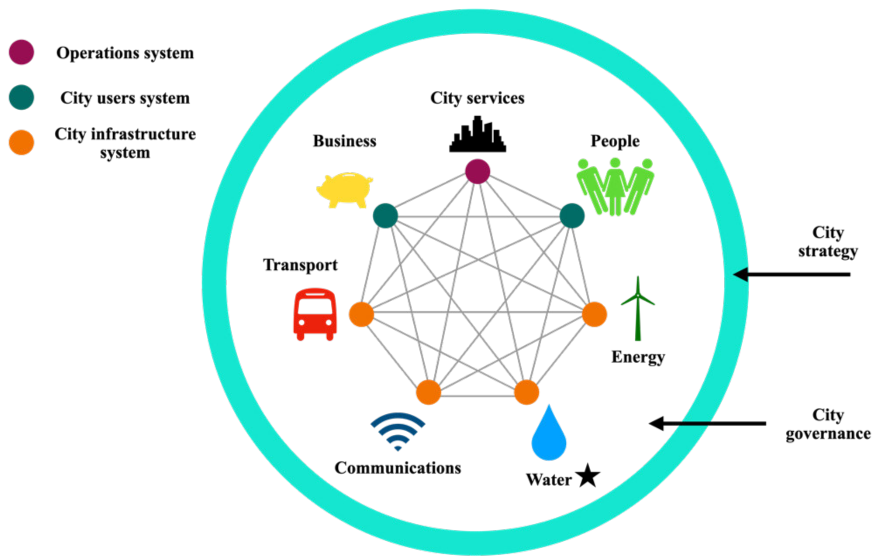


Fig. 17. Model of the city as a system of systems based on the work of (Dirks and Keeling, 2009)

The complex city system interacts with its surrounding territory, which provides key ecosystemic services such as water, energy, food, and natural conservation areas for the city (see Figure 18). When addressing cities from a systemic approach, it is important to integrate with its surrounding territory as one key aspect of the city system.

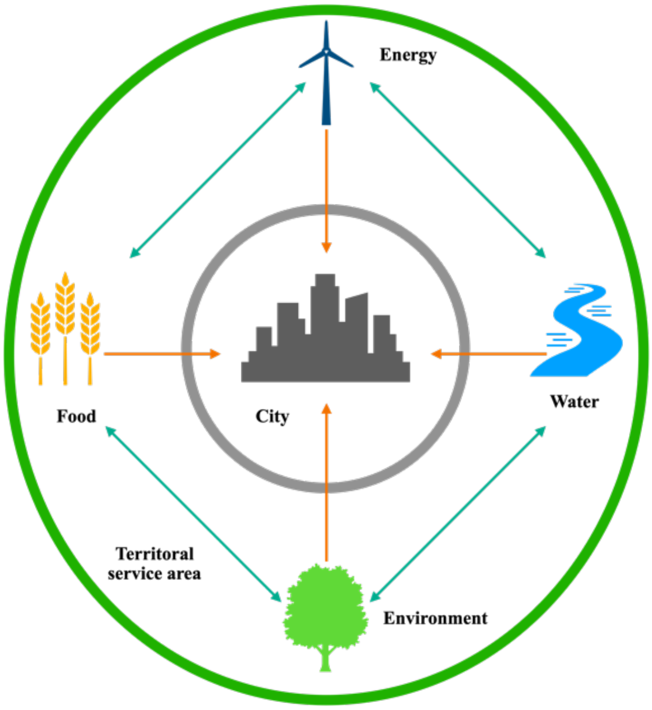


Fig. 18. Model of the city interaction with its surrounding territory. Source: Armando Cepeda Guedea, 2024

The conventional urban water supply system (Liu et al. 2018) needs to consider multiple aspects from a systemic approach. The research proposes, based on the reviewed literature of previous chapters and the works of (Tekile and Legesse 2023; Talat 2021), a model of the water system in cities from a systemic approach that considers six aspects (environment, infrastructure, operations, finance, governance and quality of the service) that interact with three dimensions (drinking water, wastewater, and runoff water) (see Figure 19).

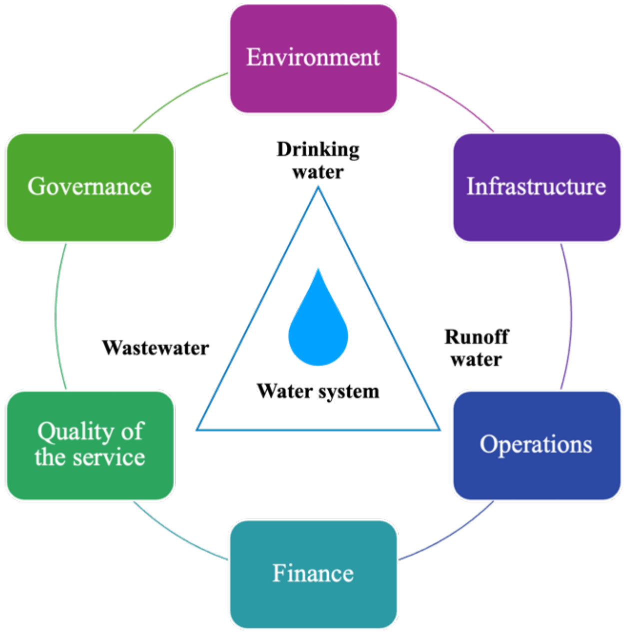


Fig. 19. Model of the urban water system. Source: Armando Cepeda Guedea, 2024

City systems and the water system are complex entities that also face complex challenges such as lack of economic resources, inefficient water service, insufficient institutional response, unsatisfactory planning documents, depletion of traditional water sources, water-related risks, and polluting activities. Water security is a systemic framework to face water challenges in cities and their surrounding territories or service areas. Water security is the condition cities and territories should aim for. Achieving water security ensures the urban water system's sustainability and guarantees the cities' overall sustainable development. Water security should be approached from a systemic approach since it is a complex object of study that interacts with different aspects of the city and its surrounding territory, has five irreducible dimensions, and shares a common goal. The vehicle to advance towards water security is the Integrated Water Resources Management.

5.2 Methodological approach for water security in cities

When developing research, it is critical to define the research paradigm in which the project will be conducted (B. Johnson and Christensen 2017). The research paradigm is a perspective about how research is done, and that is based on a set of shared assumptions, concepts, values, and practices. In other words, it is an approach to thinking about and doing research. There are three main research paradigms or approaches widely accepted by the scientific community: quantitative research, qualitative research, and mixed research. Quantitative research relies on the collection of numerical data. The research tests hypotheses and theories with data, following confirmatory or "top-down" rationale. Qualitative research relies on the collection of nonnumerical data such as interviews, observations, fieldwork, and pictures to generate knowledge, hypotheses, and grounded theories following a "bottom-up" approach. Mixed research involves the mixing of quantitative and qualitative methods. The exact mixture depends on the research questions and the conditions in which the research is conducted. In other words, it can be mixed with an emphasis on qualitative, mixed with an emphasis on quantitative, or mixed with an equal emphasis on qualitative and quantitative.

Mixed research approaches see positive value in both the quantitative and the qualitative sides of a phenomenon. Only using quantitative or qualitative approaches may become limiting and incomplete for many research problems. Considering the complexity of urban water security the research finds pertinent to adopt a mixed approach (see Figure 20). Among the different typologies of mixed approaches, the more suitable is the exploratory sequential method. The exploratory sequential method is based on the idea that qualitative and quantitative approaches are sequential and complementary (Creswell and Creswell 2018). The qualitative phase provides a foundation for the quantitative phase, and its findings influence the design of the next phase. The qualitative phase relies on literature reviews, participatory observations, interviews, and focus groups. Qualitative data is collected and analyzed to identify emerging themes, patterns, or trends useful for the quantitative phase. The quantitative phase deepens the results obtained in the previous phase. The obtained qualitative data are interpreted and used to design the quantitative phase. It helps to determine which variables will be measured and select the appropriate data collection method, such as surveys, tests, or existing databases. The quantitative phase uses appropriate statistical techniques aiming to find relationships, associations, or patterns in the studied data to expand and explain the qualitative phase results. To integrate the qualitative and quantitative findings a joint interpretation of the results is sought to get a holistic picture of the studied phenomenon.

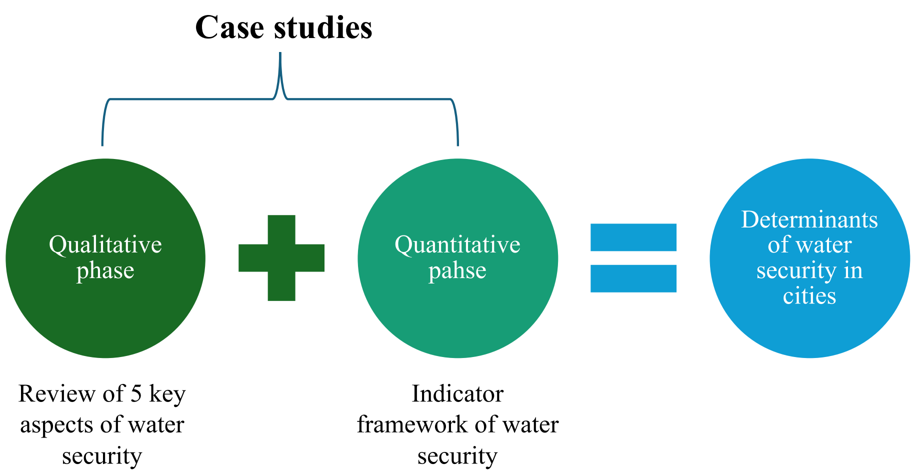


Fig. 20. Diagram of the proposed approach to obtain the main determinants of water security in cities. Source: Armando Cepeda Guedea, 2024

5.2.1 Qualitative exploratory phase of water security in the city

The initial qualitative phase of the evaluation framework proposes to review 5 key aspects, taking as reference the case study review structure of the books "Urban Water Security" and "Regional Water Security" partially (Brears 2021; 2017a). The selected 5 aspects are the following: Context analysis, which includes the identification of insecurity drivers from context analysis; the strategic vision for sustainable development and climate action; description of the water system of the city, which includes consumption patterns and pricing of the service; regulatory instruments for water insecurity, which include water operator and management approach, innovation practices for water security, and communication strategies to raise awareness on water security; and water-related risks with respect to the basin and urban link. The following table deepens into the 5 proposed key aspects to qualitatively review water security in cities from a systemic approach (see Table 30).

Table 30: Review of the proposed key aspects to review water security

Aspect	Description	Relevant areas to cover
1. Context analysis	Provides the context to understand the basic characteristics of the city to start the water security approach Identification of the main water insecurity drivers because of the context analysis	National context Population Income Territorial characteristics Weather Topography Major basin, Sub-Basin, and local watersheds
2. Strategic vision for sustainable development and climate action	Review the Development Plan of the city or similar documents to understand the climate and water action link	Review of the planning system Climate action policies Water security policies in the document
3. Water system of the city	Describe the main water infrastructure, how water arrives to the city, the pricing of the service and consumption patterns	Water sources Water lines Water treatment characteristics Sanitation and runoff infrastructure Water consumption per capita Water culture in the city Affordability of the service in relation with the monthly income
4. Regulatory instruments for water security	Present the main legislation,	National water laws and policies

	regulation and policies for water in the city Present the water operator of the city and how they manage the water resources Identify relevant innovative practices to achieve water security Present how cities communicate and involves citizen to achieve water security	Provincial/regional water laws and policies Local water laws and policies Description of the water operator and its attributions Innovative practices on water management Practices and instruments to raise awareness on water security
5. Water-related risks with respect to basin and urban link	Present the main water related risks the city is vulnerable Understand the relationship between basin and urban planning and identify if there is a gap	Water related risks and its impacts to the city Basin planning at different levels

5.2.2 Indicator Framework for Water Security (Quantitative phase)

The quantitative phase to represent water security from a systemic approach comes as the result of the synthesis of the reviewed evaluation frameworks in Chapter 4 and key indicators the research finds pertinent to add after the literature review conducted in the previous chapters. This creates a synthetic set of indicators that aims to approach water security more systematically and cover its main dimensions (see Figure 21). Also, it expects to fill the gap of existing quantitative evaluation frameworks that may fail to cover the multidimensionality of water security. The use of this framework can contribute to better understand which characteristics or actions of a city could increase or reduce water security, as will be addressed in following chapters.

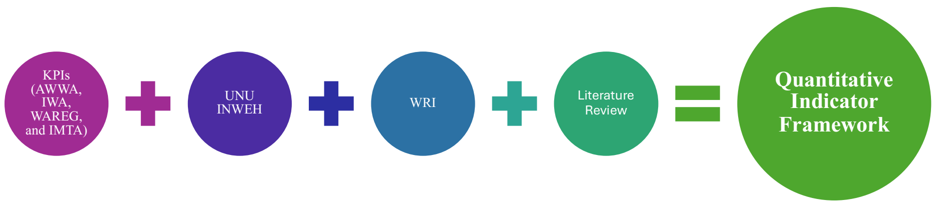


Fig. 21. Diagram that describes the building of the quantitative phase. Source: Armando Cepeda Guedea, 2024

After reviewing 659 indicators, 143 sub-indicators, and 7 third-level indicators, the research synthesized them into 49 indicators and 20 sub-indicators (see Table 31). It is essential to point out that some proposed indicators emerge from the literature review to fill the gaps the reviewed indicators may have in approaching water security. This evaluation framework proposes a set of indicators that aims to comprehensively cover the five main dimensions of water security, making it possible to use just one framework instead of different ones to obtain a similar result, making assessment processes more effective.

Table 31: The proposed set of indicators to evaluate water security quantitatively

Proposed Indicator	Source	Proposed Indicator	Source
Cost efficency of the service	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Green house emissions**	WAREG (2023)
Non revenue economic water losses	IWA (2017), IMTA (2018)	**Rainwater collector units**	Literature review
Investments	IWA (2017), IMTA (2018)	**Power failures**	IWA (2017)
Payment collections efectiviness	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Water quality**	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018), UNU INWEH (2023), WRI (2024)
Operating expense ratio	AWWA (2022), IMTA (2018), WAREG (2023)	**Water demand and supply ratio**	AWWA (2022), WAREG (2023)
Debt ratio	AWWA (2022), WAREG (2023), IWA (2017)	**Average age of the pipelines**	WAREG (2023)
Freshwater consumption	AWWA (2022), WAREG (2023), IMTA (2018)	**Data availability**	Literature review
Water quality reports	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Maintenance**	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)
Bulk water delivery	WAREG (2023), IWA (2017), IMTA (2018)	**Water losses**	IWA (2017), IMTA (2018)
Interruptions to the service	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Staff levels**	AWWA (2022)
Metering efficency	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Diversity of the sources in local supply system**	Literature review
Service coverage	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018), UNU INWEH (2023)	**Recycled water use**	IWA (2017)
Service complaints	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Stakeholder participation**	UNU INWEH (2023)
Service efficiency	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Integrated Water Management plan**	UNU INWEH (2023)
Billing issues	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Quality level of wastewater discharge to the environment**	WAREG (2023)
System failures	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Storm water discharge**	AWWA (2022), WAREG (2023)
Water pressure	IWA (2017), WAREG (2023)	**Sludge management**	WAREG (2023)
Affordability of the service	AWWA (2022), WAREG (2023)	**Green areas**	Literature review
Low-income billing assistance offered	AWWA (2022)	**Blue areas**	Literature review
Water Metering Coverage	AWWA (2022), WAREG (2023), IWA (2017), IMTA (2018)	**Quality of available surface freshwater**	WRI (2024), UNU INWEH (2023)
Network size	IMTA (2018)	**Sustainability planning**	UNU INWEH (2023)
Water Treatment Capacity	WAREG (2023), IWA (2017), IMTA (2018), UNU INWEH (2023)	**Basin planning instrument**	UNU INWEH (2023)
Water storage	WAREG (2023), IWA (2017)	**Overall Water Risks**	WRI (2024)
Energy consumption	AWWA (2022), WAREG (2023), IWA (2017)	**Risk assessment and response preparedness**	WRI (2024)
Renewable energy use	WAREG (2023), IWA (2017)		

The proposed set of indicators is divided into the five main dimensions of Water Security proposed by Brears (Brears 2021). Economic Water Security has 6 associated indicators, Household Water Security has 13 associated indicators, Urban Water Security has 20 associated indicators, Environmental Water Security has 8 associated indicators, and Resilience to water-related disasters has 2 associated indicators. For the six aspects of the urban water systems, Finance has 6 associated indicators, Quality of service 12 associated indicators, Infrastructure 8 associated indicators, Operations 10 associated indicators, Environment 7 associated indicators, and Governance 5 associated indicators. With the support of Rstudio software, the following Sankey diagrams show graphically how the proposed indicators interact with the main dimensions of water security and the main aspects of the urban water system.

Table 32: Proposed set of Indicators with its interlinkages with Household Water Security

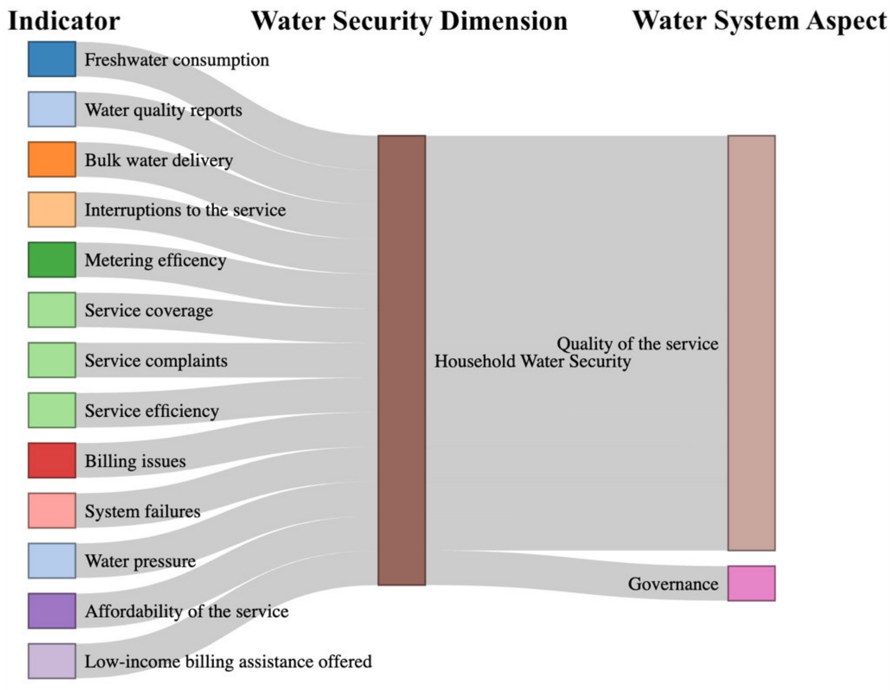


Table 33: Proposed set of Indicators with its interlinkages with Urban Water Security

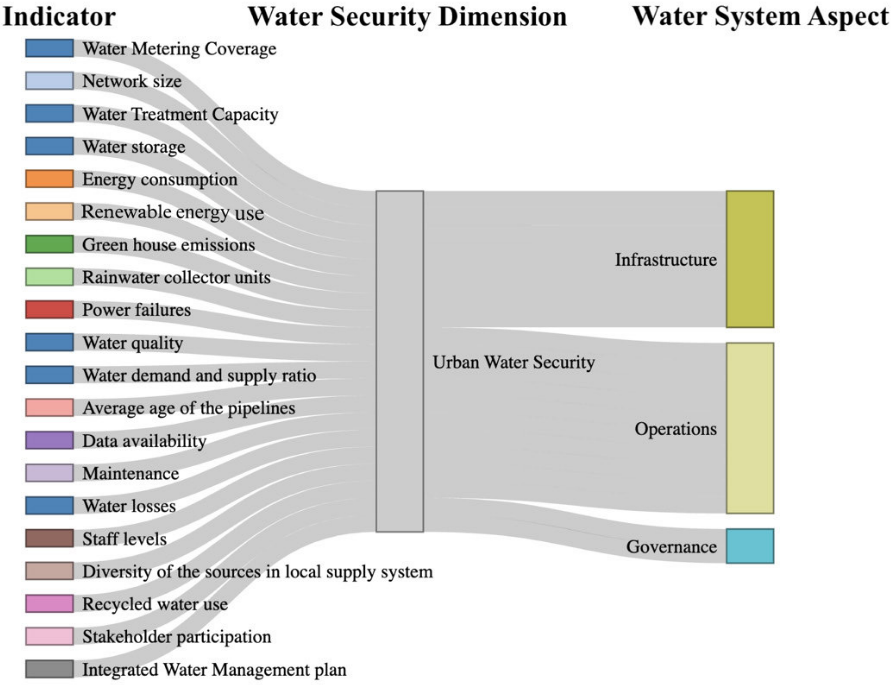


Table 34: Proposed set of Indicators with its interlinkages with Environmental Water Security

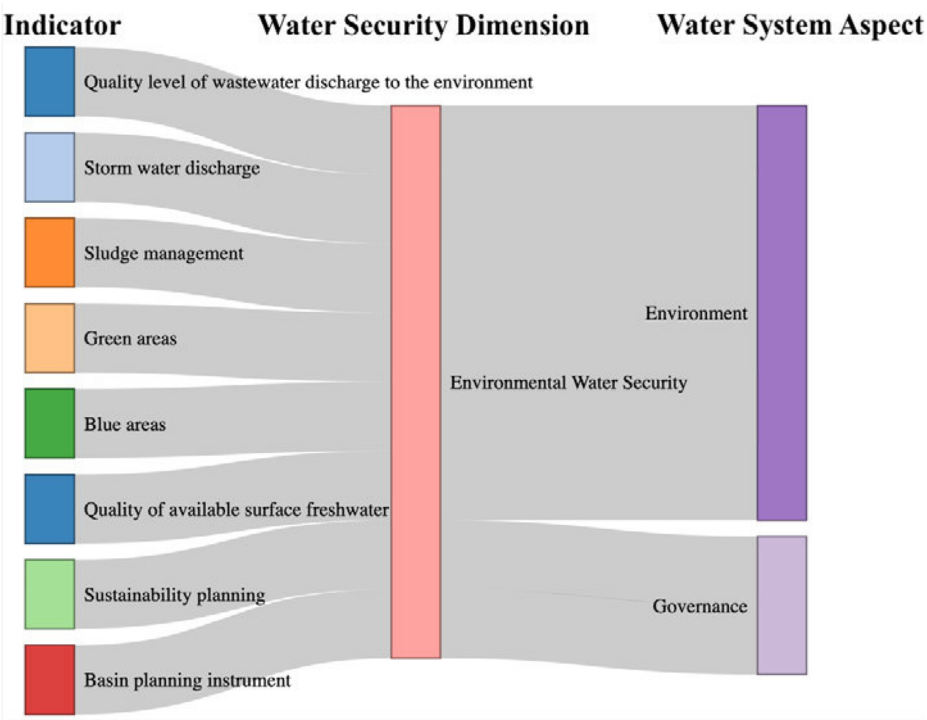


Table 35: Proposed set of Indicators with its interlinkages with Resileince to Water Related Disasters

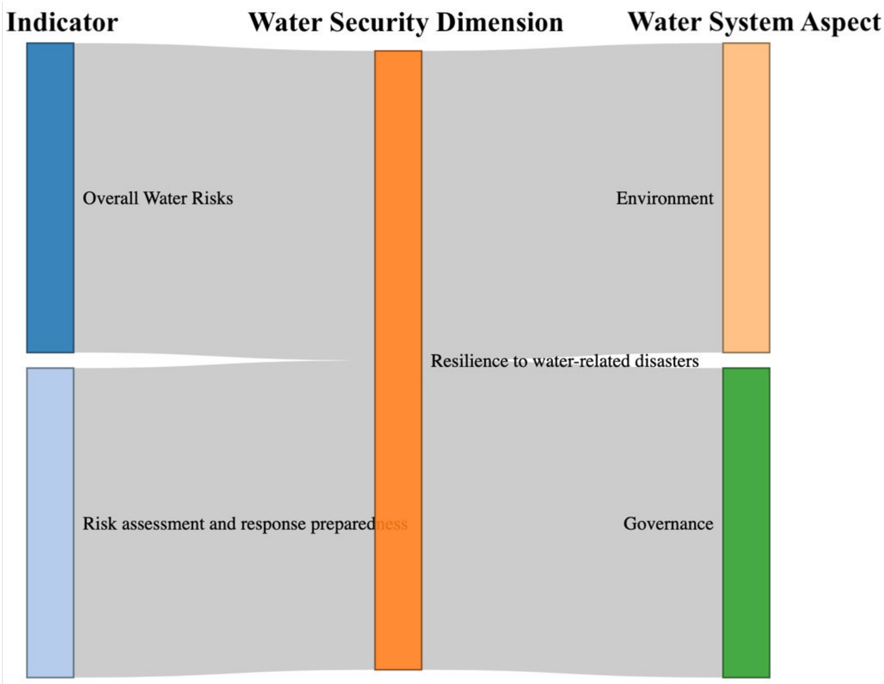
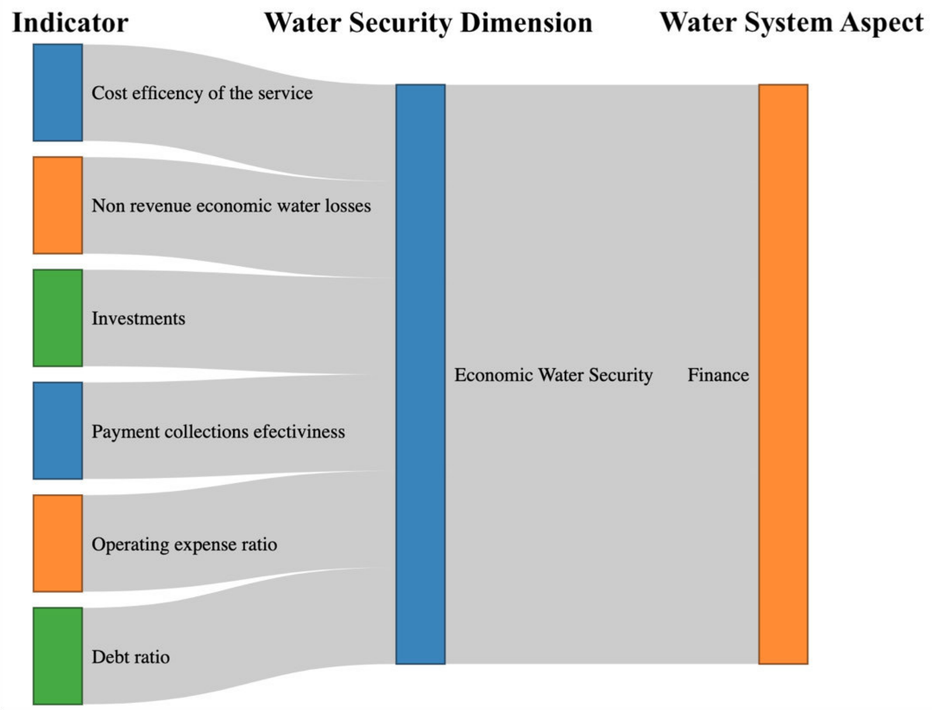


Table 36: Proposed set of Indicators with its interlinkages with Economic Water Security



To enrich the framework, it also presents the interlinkages with the SDGs as a way to link local strategy with the global agreements and objectives (see Table 32). The proposed indicator framework aims to better understand the complexity of water security, identify mitigation and adaptation targets, collaborate in decision-making process on funding allocations and raise awareness on the importance of water security. The graphic representation of this interlinkages through a Sankey diagram that allows a clear visualization of the flow was possible using Rstudio software. Regarding the relationship between the proposed indicator framework for water security and the SDGs (Sustainable Development Goals), shows a clear effort to face the complexity of water security by involving 9 SDGs (1, 3, 6, 7, 8, 10, 11, 13, 14, 15 and 16) and 32 indicators. This indicator framework provides a wider understanding of the relevance of water for sustainable development of cities and territories, since it has more involved SDGs than the reviewed existing indicators frameworks in Chapter 4.

Table 36: Proposed set of Indicators with its interlinkages with the SDGs (part 1)

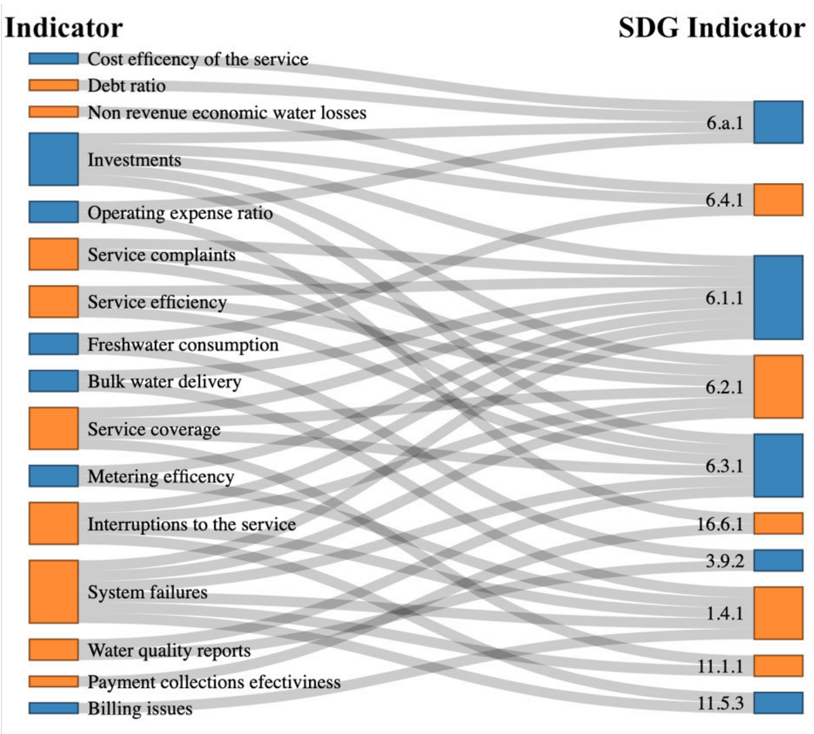


Table 37: Proposed set of Indicators with its interlinkages with the SDGs (part 2)

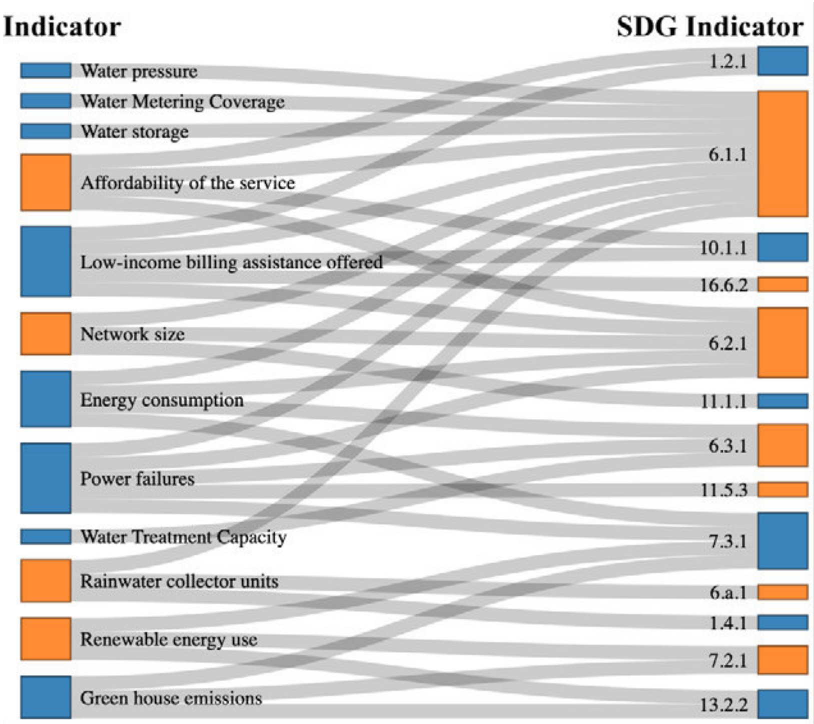


Table 38: Proposed set of Indicators with its interlinkages with the SDGs (part 3)

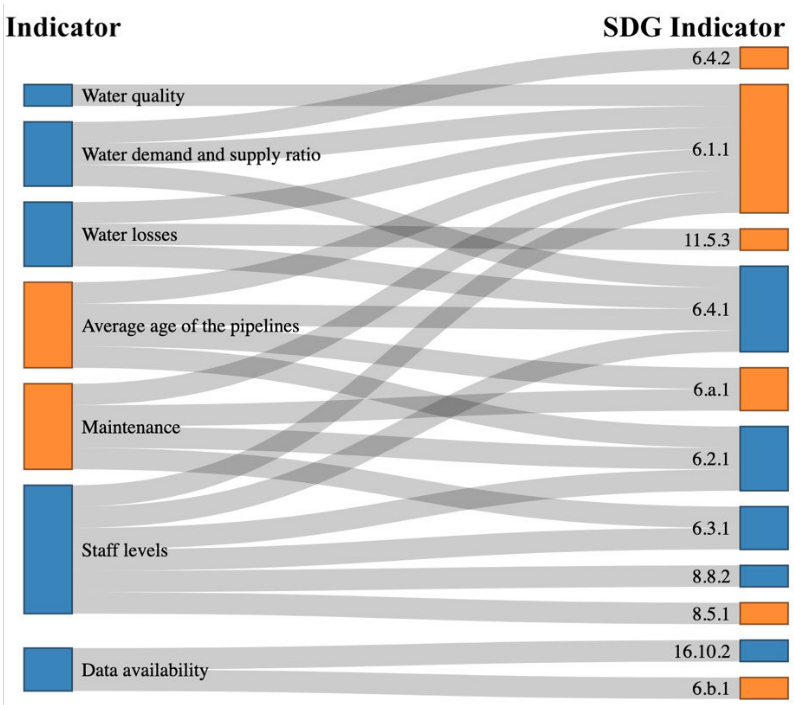


Table 39: Proposed set of Indicators with its interlinkages with the SDGs (part 4)

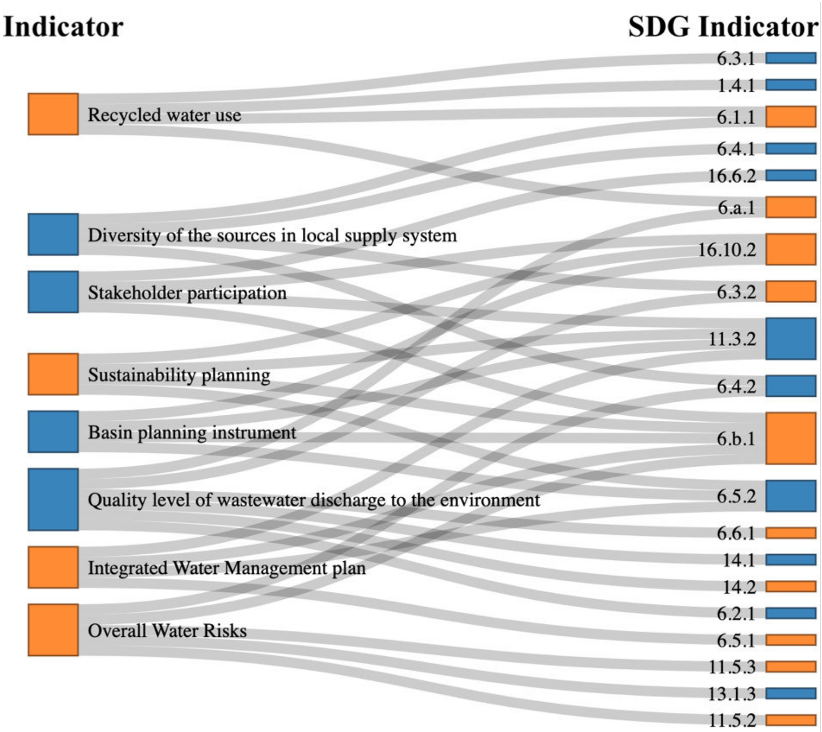
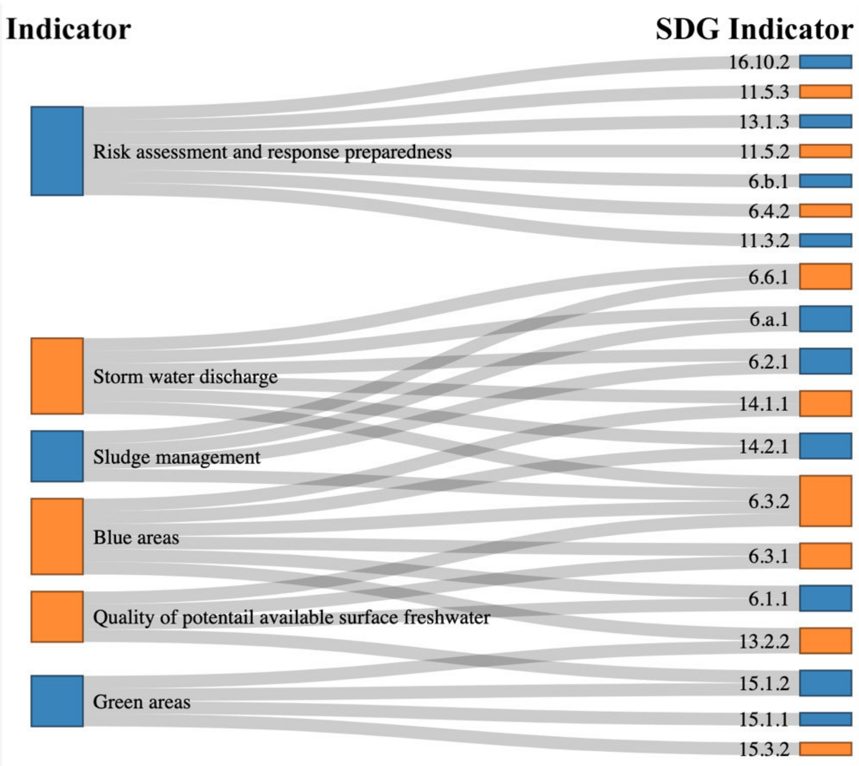


Table 40: Proposed set of Indicators with its interlinkages with the SDGs (part 5)



To better understand the water security situation in each city, it is proposed to implement a range scale with values from 1 to 5 in the evaluation framework, where 1 is the most desirable score, and 5 is the least desirable for water security (see Table 41). Based on 56 sources, the research proposes a scale of values for each of the selected indicators and sub-indicators that are subsequently standardized to the proposed 1 to 5 scale (see Table 42). In this way, each proposed indicator can be uniformly evaluated, and observe how the evaluation framework behaves in different cities.

Table 41: Description of the proposed ranges for the water security indicator framework

Ranges of the indicator framework
1. Very low concern: desirable value that aims to fully achieve water security, preventive measure might be in order to sustain the desirable condition.
2. Low concern: value that reflects an acceptable condition that do not endangers the water security of the city but is improvable and might become a bigger issue if measures are not enforced.
3. Moderate concern: value that indicates an ongoing issue that affects the water security of the city. This value stands on the threshold of functionality of the aspect and might not be sustainable in the short term. Corrective measures may be required and should be reflected in the land and water planning documents.
4. High concern: value that reflects risk of collapse and reflects a water insecurity scenario. It requires urgent actions to stabilize the situation. It should be a top priority in planning documents.
5. Very high concern: value that reflects an unsustainable situation and very high risk of collapse of the system. In some indicators should be managed in an emergency context.

Table 42: Proposed sets of indicators for water security and its ranges

Economic Water security		**Units**	**Ranges**					**Description**	**Sources**
Indicator	**Subindicator**		**1**	**2**	**3**	**4**	**5**		
Cost efficency of the service		%	> 30%	20%-30%	20%-10%	10%-0%	<0%	Pre Tax Operating profit	NYU (2024), CCW (2017)
Non revenue economic water losses		USD/m3	0-0.1	0.1-0.5	0.5-1	1.0-2.0	> 2.0	Cost of NRW per m3 of water	European Comission (2015), IWA (2018)
Investments		USD	>250	250-150	150-100	100-50	<50	Annual average expenditure per inhabitant	OECD (2023)
Payment collections efectiviness		%	> 95%	90%-95%	70%-90%	60%-70%	<60%	Colection efficency for the domestic sector	World Bank (2014)
Operating expense ratio		%	>60%	60%-70%	75%-70%	75%-80%	<80%	Operating expense ratio of the supplier	CED (2015)
Debt ratio		Unit	>2.0	1.5-2.0	1.5-1.2	1.2-1.0	<1.0	Debt service coverage ratio	World Bank (2014), City of Austin (ND)

Urban Water security		Units	Ranges					Description	Sources
Indicator	Subindicator		1	2	3	4	5		
Water Metering Coverage		%	100%-95%	95%-80%	80%-60%	60%-40%	<40%	% of consumers covered by smart (electronic) meters	Europen Union (2024), OFWAT (2020)
Network size	Freshwater	Meters of pipeline/inhabitant	>10	10.0-6.0	6.0-4.0	4.0-2.0	<2.0	meters of pipelines per inhabitant	European Union (2017), Review
	Wastewater	Meters of pipeline/inhabitant	>8.5	8.5-5.1	5.1-3.4	3.4-1.7	<1.7	meters of pipelines per inhabitant	European Union (2017), Review
	Stormwater	Meters of pipeline/inhabitant	>4	4.0-3.2	3.2-2.4	2.4-0.8	<0.8	meters of pipelines per inhabitant	European Union (2017), Review
Water Treatment Capacity	Freshwater	%	100%	96%-99%	96%-90%	90%-80%	<80%	% of freshwater treated before supply	United Nations (2022)
	Wasterwater	%	100%-97%	97%-95%	95%-85%	85%-70%	<70%	% of treated wastewater	EEA (2021),
Water storage		Days	> 1 week	5 days-7 days	3 days-5 days	1 day-3 days	< 1 day	freshwater storage capacity in days (considering per capita consumption)	(HJ Jongen, 2022), (Bevilacqua and Cepeda-Guedea, 2023)
Energy consumption		%	<10%	20%-10%	20%-30%	30%-40%	>40%	% of enery consumed by the city	EPA (2017), OSPAR (2023), European Union (2019)
Renewable energy use		%	>50%	30%-50%	10%-30%	5%-10%	<5%	% of renewable energies used in the system or city	EEA (2024)
Green house emissions		GHE per capita	<3	3.0-6.0	6.0-9.0	9.0-12.0	>15.0	GHE per capita	C40 (2012)
Rainwater collector units		Number of units	1.0-0.8	0.8-0.6	0.6-0.4	0.4-0.2	<0.2	Number of public rainwater collector units per household	Field study (2022-2024)
Power failures		Hours	0	0-2.0	2.0-6.0	6.0-10.0	>10	Hours of power outages in a year	World Bank (2019)
Water quality		%	100%	97%-99.9%	97%-94%	94%-90%	<90%	% of samples of treated water that comply with national water quality standards	World Bank (2018)
Water demand and supply ratio		units	>1	0.9-1.0	0.6-0.9	0.6-0.3	<0.3	% of water water supply that covers the water demands	Huang and Ying (2017)
Average age of the pipelines	Freshwater	years	<35 years	35-40 years	40-45 years	45-50 years	>50 years	average age of the pipelines	EPA (2022)
	Wastewater	years	<35 years	35-40 years	40-45 years	45-50 years	>50 years	average age of the pipelines	EPA (2022)
Data availability		units	Extensive	High	Moderate	Minimal	Scarse	degree of public data availability to evaluate the system	IWA (2023)
Maintenance		%	>5%	4%-5%	3%-2%	2%-1%	< 1%	% of budget on repairs and maintainance	US Water corporation (2024), State of California (2024)
Water losses		%	<15%	15%-25%	25%-35%	35%-50%	>50%	% of water loss in the system	Rupper (2022), EPA (2013)
Staff levels		Number of employees/ 1000 connections	2.0-2.5	2.5-3.0	1.5-2.0/3.0-3.5	0.5-1.5/3.5-5.0	<0.5/>5.0	Staff per 1000 connections	WAREG (2017), World Bank (2014)
Diversity of the sources in local supply system		%	>60%	60%-45%	45%-30%	30%-15%	<15%	% of sources different from the main one	Boryczko and Rak (2020)
Recycled water use		%	>10%	6%-10%	4%-6%	2%-4%	< 2%	% of recycled water used in the system	European Union (2024), State of California (2020)
Stakeholder participation		Unit	Empowerment	Collaboration	Involvment	Consulting	Information	Level of involvment of stakeholders in decision making	Borrini (2013)
Integrated Water Management plan		Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Presence of a full Integrated Water Management plan	United Nations (2015), Global Water Partnership (2013)

Resilience to water-related disasters		Units	Ranges					Description	Sources
Indicator	Subindicator		1	2	3	4	5		
Overall Water Risks	Physical Risks Quantity	Unit	Low	Low-Medium	Medium-High	High	Extremenly High	Physical risks quantity measures risk related to too little or too much water	WRI Aqueduct 4.0 (2024)
	Physical Risks Quality	Unit	Low	Low-Medium	Medium-High	High	Extremenly High	Physical risks quality measures risk related to water that is unfit for use	WRI Aqueduct 4.0 (2024)
	Regulatory and Reputational Risk	Unit	Low	Low-Medium	Medium-High	High	Extremenly High	Measures risk related to uncertainty in regulatory change, as well as conflicts	WRI Aqueduct 4.0 (2024)
Risk assessment and response preparedness	Risk assessment and response preparedness	Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Level of prescense of Risk Assessment for the local water supply system	Brears (2017)
	Water shortage planning	Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Level of prescense of Risk Assessment for the local water supply system	California Government (2023)

Household Water security		Units	Ranges					Description	Sources
Indicator	Subindicator		1	2	3	4	5		
Freshwater consumption		liters	150 L-200 L	>200 L	100 L-150 L	50 L-100 L	<50 L	liters consumed daily per inhabitant (domestic)	United Nations (2015) Mexico City (2022)
Water quality reports		number of reports /1000 inhabitants	< 1	1.0-2.0	2.0-5.0	5.0-10.0	> 10.0	Number of water quality reports per 1000 inhabitants in one year	City of Albuquerque (2019), City of Fort Collins (2021)
Bulk water delivery		%	0%	1%-25%	25%-50%	50%-75%	75%-100%	Bulk water delivery coverage	Mexico City (2022)
Interruptions to the service		outages/1000 inhabitants outages/reductions/year	0-5 days/0	6-15 days/0.0-1.0	16-30 days/1.0-3.0	31-60 days/3.0-5.0	>60 days/>5.0	Days with outages or reduction of the supply	ISTAT (2020), Yorkshire (2019), Mexico City (2022)
Metering efficency		% of unmetered water	0%-0.5%	0.5%-2.0%	2.0%-5.0%	5.0%-10.0%	>10%	% of unmetered water in a year	European Comission (2015)
Service coverage	Freshwater	%	100%	93%-99%	87%-93%	87%-81%	<81%	% of coverage of the service	United Nations (2022)
	Wastewater	%	100%	91%-99%	85%-91%	85%-79%	<79%	% of coverage of the service	United Nations (2022)
Service complaints		number of reports /1000 inhabitants	0-5	6 to 10	11 to 20	21 to 30	> 30	Number of water service complaints in one year	Field study (2022-2024)
Service efficiency		%	100%	99%-95%	95%-90%	90%-85%	> 85%	% of satisfactory resolved complaints in the year	Field study (2022-2024)
Billing issues		%	0%	0.1%-1.5%	1.5%-3%	3%-5%	> 5%	% of total water service bills with complaints	Field study (2022-2024)
System failures	Reported leaks	number of reports /1000 inhabitants	0.0-2.0	2.0-5.0	5.0-10.0	10.0-20.0	>20.0	Number of water quality reports per 1000 inhabitants in one year	European Comission (2015)
	Reported sewerage fails	number of reports /1000 inhabitants	0.0-0.5	0.5-1.0	1.5-2.0	2.0-2.5	> 2.5	Number of sewerage reports per 1000 inhabitants in one year	Queensland (2022), CCW (2023)
	Reported stormwater overflows	number of reports /1000 inhabitants	0.0-0.5	0.5-1.0	1.5-2.0	2.0-2.5	> 2.5	Number of stormwater overflows reports per 1000 inhabitants in one year	Queensland (2022), CCW (2023)
Water pressure		psi	60-80	40-60	40-35	35-20	>20	Pressure in the domestic distribution line	EPA (2023), Louisiana Health Department (2014)
Affordability of the service		%	<1.5%	3%-1.5%	3%-5%	5%-10%	> 10%	% of the montly income dedicated to pay the water bill	United Nations (2011), PPCI (2021)
Low-income billing assistance offered		Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Presence of a Low-income billing assistance	US Government (2022)

Environmental Water Security		Units	Ranges					Description	Sources
Indicator	Subindicator		1	2	3	4	5		
Quality level of wastewater discharge to the environment		%	>90%	70%-90%	70%-50%	50%-30%	<30%	% of discharged water with Tertiary treatment	OSPAR (2023), EEA (2020)
Storm water discharge		%	>85%	60%-85%	40%-60%	20%-40%	<20%	% of treated stormwater runoff	EPA (2011)
Sludge management		%	100%	99%-95%	95%-90%	90%-85%	<80%	% of Sludge disposed properly	EEA (2021)
Green areas		%	>30%	15%-30%	10%-15%	10%-5%	<5%	% of green areas in the city	Reu Junqueira, Serrao-Neumann and White (2022), EEA (2022)
Blue areas		%	>15%	15%-10%	10%-5%	5%-2%	<2%	% of blue areas in the city	EEA (2022)
Quality of available surface freshwater		%	100%	97%-99.9%	97%-94%	94%-90%	<90%	% of samples that comply with national water quality standards	World Bank (2018)
Sustainability planning	Habitat/watershed protection goals	Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Watershed planning objectives	EPA (2008)
	Green infrastructure planning	Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Level of implementation of Green Infrastructures in planning	McDonald et al. (2005)
	Energy optimization planning	Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Evaluation of energy optimization planning	EPA (2013)
Basin planning instrument		Unit	Very high implementation	High implementation	Moderate implementation	Low implementation	Very low implementation	Presence of a full basin planning instrument	Global Water Partnership (2024)

The framework can be considered from the resources-based type mainly at the city level and its surrounding territory that should be carried on with secondary from governmental agencies and water operators. It aims to cover the five water security dimensions (economic water security, household water security, environmental water security, resilience to water-related disasters and urban water security) since it focuses on the urban level and its surrounding territories (see Table 43).

Table 43: Review of the proposed indicator framework for water security (2024)

Aspect	
1. Disciplines	Social
2. Spatial scale	City and territorial
3. Temporal scale	Past annual data to measure water status
4. Purpose	Better understand of the complexity of water security Identify mitigation and adaptation targets Collaborate in decision-making process on funding allocation Raise awareness on the importance of water security
5. Water domain/focus	Water insecurity (what we are trying to achieve) Freshwater resources, but some with broad focus Water supply and hygiene; and human well-being
6. Data collection	Mainly secondary data from governmental agencies

7. Vision for universal application	Yes
8. Weighting	No
9. Type of framework	Resource-based metrics
10. Water security dimensions covered	5/5 economic water security, household water security, environmental water security, resilience to water-related disasters and urban water security
11. Associated SDG indicators	SDG 1, 3, 6, 7, 8, 10, 11, 13, 14, 15 and 16 32 indicators

5.2.3 Selection of case studies: context analysis and evaluation framework

To test the proposed indicator framework the research proposes to apply it on four selected case studies using a multiple case studies rationale (Yin 2018). Considering the data, interviews, and field studies the research can access, four cities where selected: Mexico City (Mexico), San Diego (United States), Reggio Calabria (Italy), and Ruston (United States). These cities have different sizes, socio-economic contexts, institutional frameworks, and surrounding natural environments (see Table 44). The diversity of the city's characteristics can help to enrich the testing of the proposed evaluation framework since it is possible to observe how it interacts in different contexts. The main criterion considered for selecting the cities for the testing phase is the diversity of city size, this to understand how cities of different sizes face water insecurity. The proposed classification model is the one developed by OECD in collaboration with the European Union (Dijkstra and Poelman 2011). Combining the qualitative case study analysis and the quantitative evaluation framework for water security will help to understand which characteristics or actions of a city could increase or reduce water security.

Mexico City (Mexico): Large metropolitan area with a global dimension (Sassen 2007). A cultural and economic center for Mexico and the rest of Latin America. The population is around 9 million inhabitants and approximately 22 million considering the metropolitan area (Mexican Federal Government 2024). The city faces serious challenges regarding water security due to environmental, infrastructural, and institutional challenges. Currently, the city struggles to provide a continuous freshwater supply to all its inhabitants. This provokes considerable civil unrest and puts water security as one of the priority points of the development policy of the city and the region.

San Diego (United States): Metropolitan area of international dimension, home to one of the busiest border crossings between Mexico and the United States. The City of San Diego’s population stands at approximately 1.4 million inhabitants, and 3.2 million inhabitants considering its metropolitan area (US Census Bureau 2024c). The city faces serious challenges regarding water security due to the environmental conditions of the area aggravated by climate change. Since the 1990s, public authorities in collaboration with the citizens have combined efforts to cope with the issue. Currently, the city is in the vanguard regarding water culture, water planning, and water shortage management with a clear reduction of water consumption in the last decades, and the use of more innovative alternative water sources such as recycled water and desalinized water.

Reggio Calabria (Italy-European Union): Medium-sized city of subnational dimension (considering the metropolitan city). The city is located in one of the most challenging regions of the country and in an underdeveloped region inside the European Union, which requires special attention for its development at the national and European levels (European Union 2022). The population of the municipality where the main core of the city is located is 169,795 in an administratively defined metropolitan city of 522,177 (the Metropolitan city of Reggio Calabria is not an urban continuous and is composed of detached urban nucleus) (ISTAT 2020a; 2023c). Reggio Calabria is located in a vulnerable area to climate change that can affect the water supply and also faces water cuts because of infrastructural problems.

Ruston (United States): A small city, which can also be considered a town of local dimension. The city has a population of 22,295 in a micropolitan area of 48,129 (US Census Bureau 2024b) (still below the threshold of 50,000 to be considered a city according to OECD criteria). Ruston's vulnerability to water-related risks is considered low, even though there are some water issues reported in recent times. The city and the state still do not have a comprehensive water management policy for cities at the local and state levels which can be considered a vulnerability in the case of water-related contingencies and is a step backward in the urban transition processes in the state.

Table 44: Main characteristics of the selected cities

	Mexico City (entity)	**City of San Diego**	**Municipality of Reggio Calabria**	**City of Ruston**
Population	9,209,944 (2020)	1,381,162 (2022)	169,795 (2024)	22,295 (2022)
Classification OECD/ European Union	Global City	Metropolitan area	Medium City	Not a city
Median Household income	USD 3,761 (2024)	USD 74,326 (2023)	USD 22,848 (2021)	USD 21,292 (2022)
Climatic area (KOPPEN)	Template with dry winters (Cwb)	Dry (BSk) and Mediterranean (Csa)	Mediterranean (Csa)	Continental Template (Cfa)
Institutional context	Special Entity with degree of autonomy like a state	City	Core municipality of metropolitan city	City
Water operator	SACMEX: public operator for the whole entity	San Diego Water Utilities: local autonomous water operator	Sorical: regional operator with a local branch that covers multiple municipalities	Ruston Water Utilities: local autonomous water operator

5.3 Translating the results of the case studies into the increasers and reducers of water security

After testing the proposed evaluation framework in the selected case studies, the next step is to transform the obtained information into the possible determinants that increase or reduce of water security in cities. The research will propose a set of practices that were identified during the testing process that, according to the author, can increase or reduce water security in cities. In the form of two tables (one for increasers and another for the reducers) the research will explain from which city or cities the practice emerged or partially emerged (see Tables 45 and 46). Each identified practice will be described and categorized into one of the main dimensions of water security as an increaser or a reducer (Economic Water Security, Household Water Security, Urban Water Security, Environmental Water Security, and Resilience to Water Related disasters).

Table 45: Proposed scheme to identify practices that can increase Water Security in cities

Presence of the practice	Description
Identified	The practice is clearly enforced by the city and with positive results in increasing the water security of the city.
Partially identified	The practice can be partially applied, recently applied and still with not clear results, or just in sections of the city
Not identified	The practice is not present in the city

Table 46: Proposed scheme to identify practices that can decrease Water Security in cities

Presence of the practice	Description
Identified	The practice is clearly reducing the water security in the city and has been having a negative impact
Partially identified	Some aspects of the practice may be impacting the city or is just present in specific areas
Not identified	The practice is not present in the city and in not negatively impacting

Aiming to contribute to informed decision-making for local authorities, the research finds it relevant to organize and categorize the identified practices that can increase water security to facilitate the decision-making process for a solid water security strategy. The research proposes three categories to organize the identified determinants.

Nuclear determinants: they are the practices that lay the foundation for a solid policy to advance water security, since they are the ones that allow other practices to be developed.

Development determinants: the next level is practices that reinforce nuclear practices and develop secondary aspects that are still key to a solid strategy that can involve more than one dimension of water safety.

Consolidation determinants: the last level proposed and are those practices that consolidate the water security strategy and contribute to the specific development of a dimension of water security.

The proposed methodology to organize the determinants in the proposed categories is by their level of relationship. By mapping the relationships between determinants, those with the strongest connections (highest relationship levels) can emerge as nuclear to the strategy. These determinants often have a cascading effect, meaning that improving them can positively impact multiple other areas of water security. Following the World Economic Forum in the Global Risks Report 2024 (World Economic Forum 2024b) model to represent the relationships between the different risks, four levels of relationship were established with a specific weight: no relationship, light relationship, moderate relationship, and strong relationship (see table 47).

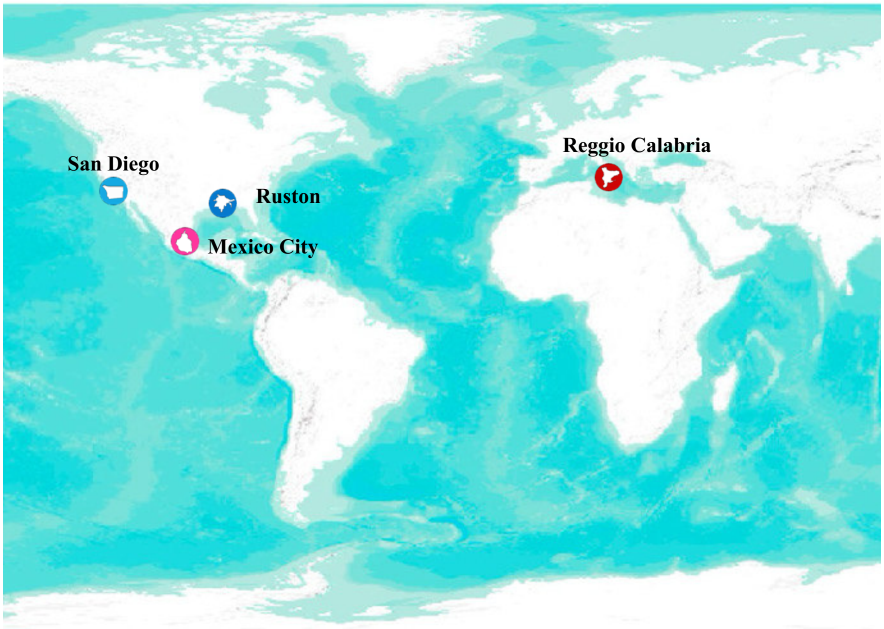
Table 47: Relationship levels between determinants

Relationship level	Description	Value
No relationship	The determinant has no relationship with the achievement of the other determinant.	**0**
Light relationship	The determinant has a light impact into the achievement of the other one. It can be a support element or indirectly influence.	**1**
Moderate relationship	The determinant has a moderate relationship, it means that is important for the achievement of the other one but not critical. In the literature can be named as an element key for the achievement of the other determinant or a direct result of its application.	**2**
Strong relationship	The determinant is key for the achievement of the other one. This means that without this determinant the other determinant cannot be implemented or not in an optimal way. They are deeply connected between each other and can be inserted in a same strategy.	**3**

In this way, the determinants with the higher score will emerge as the nuclear ones to increase the water security in cities, followed by the development determinants with an intermediate score that are enablers for more than one water security dimension, and the determinants with the lower relationship score mean that they can be considered as consolidation ones and that are designed for the improvement of a specific dimension of water security.

Section 3

Urban Water Security: Case study analysis and evaluation



Location of the case studies: Armando Cepeda Guedea, 2024.

Chapter 6

Mexico City

Mexico City: Armando Cepeda Guedea, 2024.

6.1 Context analysis

Mexico is a Latin American country and is the eleventh most populous nation in the world after countries such as China, India, and the United States of America. It ranks 15th in gross domestic product globally (Mexican Ministry of Foreign Affairs 2024). Mexico is a federal republic organized into 32 entities with high levels of autonomy. Mexico City, its capital, is the sixth biggest city after cities such as Tokyo and Mumbai (see Figure 22). Mexico faces significant water challenges like many other countries around the world (Cortés, Pérez, and Mogollón 2012).

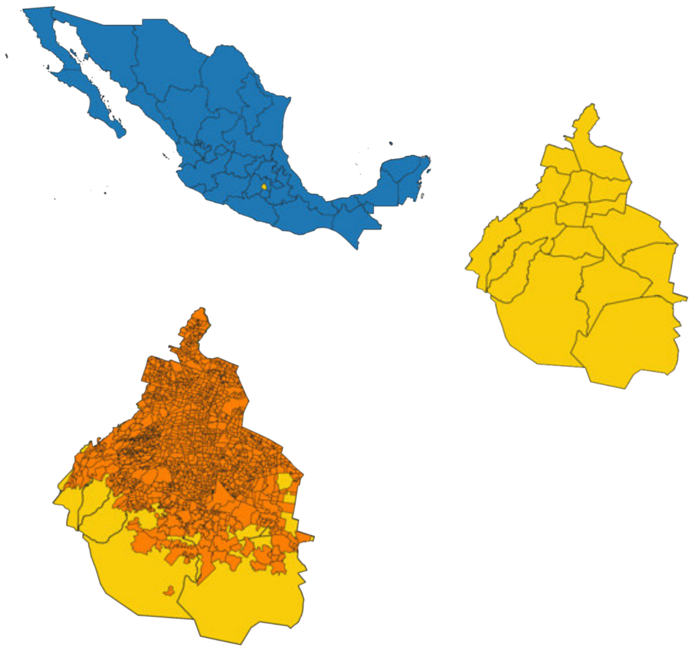


Fig. 22. Context of Mexico City. Source: Armando Cepeda Guedea, 2024

Mexico is a federal republic composed of 32 political entities and is institutionally organized into three government levels. The three levels of government are federal, state, and municipal. It is important to point out that Mexico, as a federal republic, each state has high levels of autonomy with the capacity to set their regulations, policies, and guidelines. Municipalities also have a high level of autonomy inside their states, as established in Article 115 of the Mexican constitution, as they can regulate and manage their resources autonomously. The current political and institutional organization of Mexico City is the result of the 2016 reform, in which Mexico City passed from being a federal district, which had limited autonomy, to a political entity equivalent to the other 31 states of the Mexican Federation. This allows Mexico City to manage its resources more efficiently and autonomously. Nevertheless, some particularities remain that differentiate Mexico City from the rest of the states. Mexico City, as an entity, has its public services centralized, such as public security and water management, reducing the autonomy of its boroughs in comparison with that of its municipal counterparts in the rest of the states. This means that Mexico City should be studied and analyzed considering its institutional particularities.

Mexico City is one of the 32 political entities in Mexico, and it's the core of the Mexico City Metropolitan Area. Mexico City's metropolitan area, commonly known as the "Valley of Mexico Area" (see Figure 23), has an estimated population of 21,804,515, comprising three entities (State of Mexico, State of Hidalgo and Mexico City), sixty municipalities (59 municipalities of the State of Mexico and one from the State of Hidalgo), and the16 boroughs of Mexico City (equivalent to municipalities), which in turn are divided into neighborhoods (INEGI 2020).

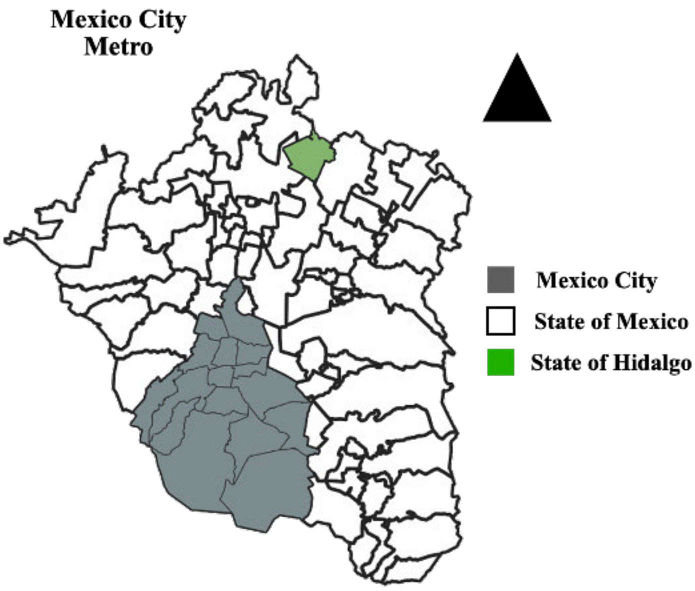


Fig. 23. Mexico City Metro. Source: Armando Cepeda Guedea, 2024

The estimated population of the city is 9,209,944 (INEGI 2020), and it is one of the most important cities in Latin America because of its economic and political relevance. It is estimated that in 2030, it will be the 8th most populated city in the world. In this context, according to Globalization and World Cities Research Network (GaWC), based on the theories of Peter Hall and Saskia Sassen, Mexico City is considered an Alpha City, which means that the city has a global influence (GaWC 2020). Officially, Mexico City is divided into 1812 neighborhoods (Mexico City government 2024b). In many cases, this delimitation can be insufficient due to the changing dynamics in the city where the traditional limits of the neighborhood are overpassed, and it can happen that a group of different neighborhoods share the same identity, socioeconomic characteristics, services, infrastructure, and geographical conditions that make to identify as one neighborhood (Hurtado Cano and Aguirre Aguilar 2017).

Mexico City is in the Valley of Mexico. Its territory is 1,486.45 km2, which only represents 0.08% of the country's total surface. The average altitude is 2,240 meters above sea level. Mexico City has two predominant types of land use: urban covers 45%

of the entity's territory towards the center-north. The rural area covers approximately 55% of the territory, including forestry, livestock, agricultural areas, and ecological reserves. Considering the high altitude where the city lies, the city has four main climates: Subhumid template (Cw), Subhumid semi-cold (CEw), Wet semi-cold (CEm), and Temperate semi-dry (BS1k) (Procuraduría Ambiental y del Ordenamiento Territorial de la CDMX 2024). Mexico City is vulnerable to several climate-related impacts, such as flooding, an increase in the urban heat island effect, losses in productive sectors, and negative impacts on health (SEDEMA 2022).

Regarding hydrology, Mexico City Metro lies at the intersection of three major basins (Lerma, Balsas, and Rio Verde). Mexico City lies mainly on the Rio Verde major basin that occupies the eastern part of the country (Kuzma et al. 2023). The Sub-basin that occupies most of Mexico City is the Moctezuma one (see Figure 24). Mexico City government proposes 66 watersheds that cover most of the nonurbanized areas of the city (CONAGUA 2012). The strong urbanization levels of the city disappeared from the previously existing watersheds of the urban area of Mexico City (see Figure 25).

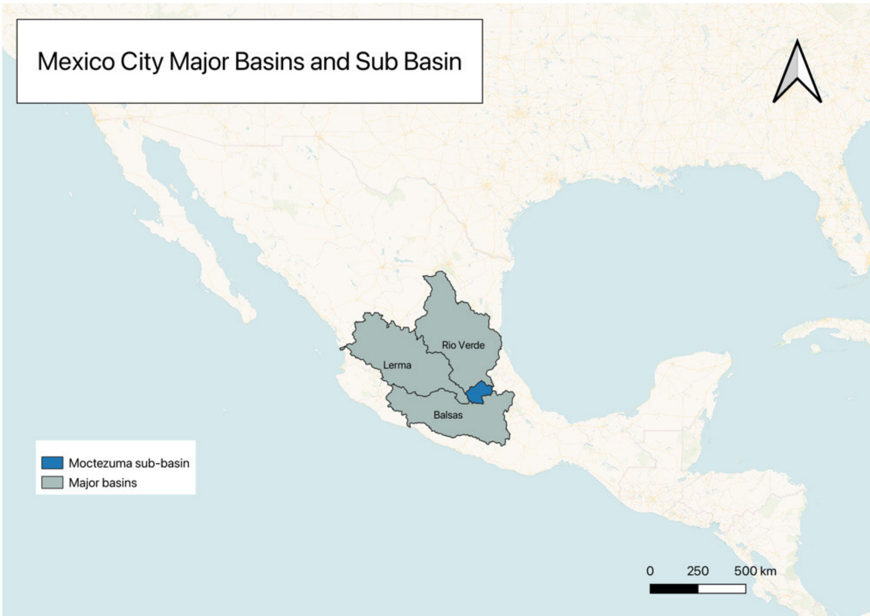


Fig. 24. Major basin and sub-basin for Mexico City. Source: Armando Cepeda Guedea, 2024

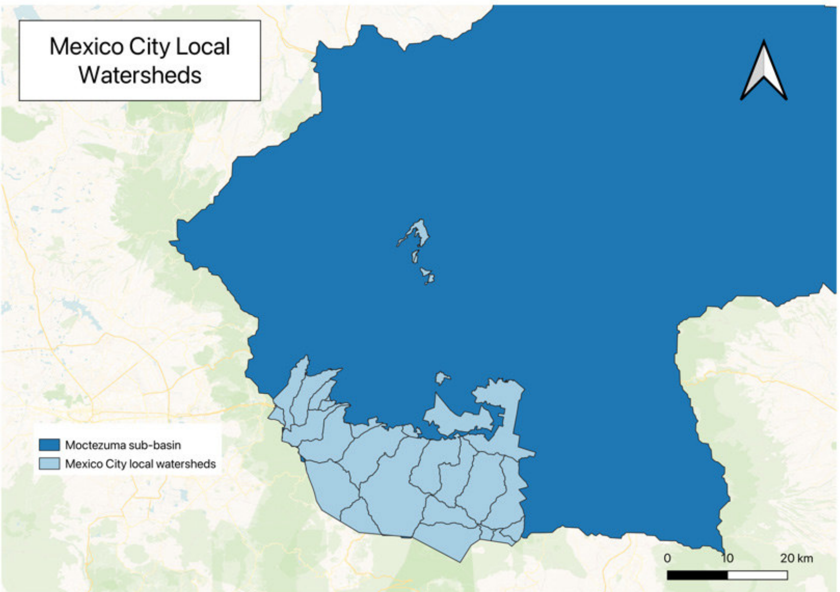


Fig. 25. Mexico City Metro. Source: Armando Cepeda Guedea, 2024

6.1.1 Water insecurity drivers from context analysis

Mexico City is a complex city that faces several challenges that can endanger the safe and sustainable water service in the city. The identified drivers of Mexico City for achieving water security after a literature review of government documents, field studies, and informal interviews include: vulnerability of the water cycle, vulnerability of the infrastructure, ensure water quality, institutional factors, high vulnerability to water-related disasters, water scarcity, climate change, and increasing demand (see Figure 26).

Fig. 26. Main water insecurity drivers for Mexico City. Source: Armando Cepeda Guedea, 2024

Vulnerability of the water cycle: the high levels of pollution in Mexico City have affected the quality of rainwater, high levels of urbanization have severely affected the infiltration capacity of Mexico City, the high levels of extraction have reduced the recharge capacity and the low treatment capacity of discharge waters that affect the quality of water bodies (Garcia Martinez 2018; Escolero, Herrera-Toledo, and Pedrozo-Acuña 2021). All of the abovementioned factors affect the adequate flow of the water cycle and endanger the water security of the city.

Vulnerability of the infrastructure: The infrastructure that requires to extract, transfer, treat, and distribute water to Mexico City is complex and vulnerable. A failure in any of the phases can affect the correct function of the service. The main sources of freshwater such as the Cutzamala sytem comes from other regions outside Mexico City and hundreds of kilometers away. Repairs or failures in any of the kilometers of transportation lines may leave several areas of Mexico City without water. The local water distribution infrastructure is old with an average age of 50 years of the pipeline, way over the concealed age of less than 35 years (José Fernando Mercado Guaida 2022). Also, the treatment capacity is insufficient, with approximately 18% of the treated water with tertiary treatment before discharge. Mexico City government recognizes the vulnerability of their water infrastructure as reflected in the objective 3.5 of the 2020-2040 development plan.

Ensure water quality: water quality is big issue, since most of the tap water is not suitable for human consumption. Several local sources are contaminated, and also several neighborhoods report low quality in their water. Currently Mexico City does not provide public reports of the overall quality of the water, only at the neighborhood level (Mexico City government 2024a). Quality is a key aspect for water security and the health of citizens.

Institutional factors: the institutional framework to ensure water supply to Mexico City has become increasingly complex since it involves water agencies at the federal and state level, state governments, and several municipalities. The instruments to fully integrate and coordinate all the involved actors is still developing. Good governance increases the efficacy of the service.

High vulnerability to water-related disasters: in 2019, the Mexico City government reported 1168 water-related events such as hailstorms, flooding, heavy rains, fogs and strong winds, leaving 25 injured citizens. Also, it is important to add one social risk, which is the interruption of vital services with 761 reported events, 47 injured citizens, and 36 deaths; this risk includes the water supply and sanitation services (Mexico City Government 2019). Also, Mexico City is located in a high seismic region that can affect the water supply service in case of a severe earthquake (Mexico City Government 2019).

Water scarcity: Mexico City has a Relative Water Stress Index of 140.4% making it one of the regions with the greatest pressure on its water resources in the country (Revollo-Fernández, Rodríguez-Tapia, and Morales-Novelo 2020). According to the World Resources Institute, Mexico City has an overall High-Water Risk, but a Very High-water stress levels (Kuzma et al. 2023). Mexico City is not autonomous with its water resources meaning that the federal government has to intervene to provide water to the city. Unfortunately, the local and out-of-state resources are becoming increasingly scarce. Currently, 18% of the population does not receive water every day, and 32% does not receive enough water to meet their needs and require the support of bulk water delivery and buying water in jugs (SACEMX and Mexico City Parliament 2017). Relying in bulk water delivery puts in great vulnerability the population of Mexico City.

Climate change: climate change impacts directly affect the availability of water in Mexico City. It has been reported that in 2021, the water levels of the Cutzamala system (one of the main providers of water to the city) will be at their lowest in the last 25 years. This situation is associated with a drought of categories D2 and D3 (The scale goes from D0 to D5 and considers D2 and D3 categories as severe and extreme drought) derived from climate change in the supply basins for the system (Santos Téllez, Medina Mendoza, and Rodríguez Varela 2021). The local water bodies that can serve as an alternative to guarantee the water supply have reported high levels of contamination and exploitation (José Fernando Mercado Guaida 2022).

Increasing demand: Mexico City's water demand is expected to increase at least until 2053 steadily. Currently, in 2024, there is a demand of 76.45 m3/s, but there is only availability of 64.50 m3/s, leaving a deficit of 11.95 m3/s (CONAGUA 2022). This increases the scarcity of resources and water cuts all over the city. A deficit of such dimension greatly endangers the water security of the city. Ambitious strategies are required to reduce the deficit and ensure the sustainability of the city.

6.2 Strategic vision for sustainable development

The 2020-2040 General Development Plan for Mexico City is the city's main planning document (Mexico City Government 2020). The vision of Mexico City for 2040 is guided by innovation to close territorial, social, and gender inequality gaps and the development of citizen and government capacities for the effective and progressive fulfillment of human rights aligned with the Sustainable Development Goals (see Figure 27). The Plan is structured into six development goals: city of well-being and equality; prosperous, dynamic and innovative city; sustainable and resilient city; city with balance and territorial organization and management; city in peace and with justice; and city of honest government, close to citizenship and good administration. Each development goals has its own objectives, policies and indicators to evaluate and monitor the progress.

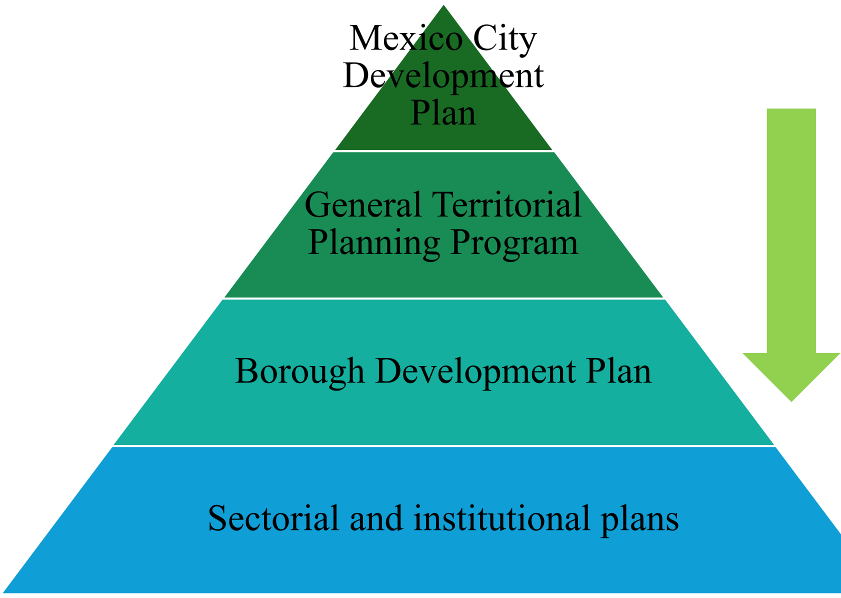


Fig. 27. Planning framework of Mexico City. Source: Armando Cepeda Guedea, 2024

Development goal 1. City of Well-being and Equality: This development goal is structured into 4 main objectives, 16 policies, and 76 programs. It covers issues related to poverty, food, public health and free access to health care services and medicines, right to education, equality, equity and non-discrimination. The 4 main objectives are reducing poverty, solid health system for well-being, right to education, and equality and equity between citizens.

Development goal 2. Prosperous, dynamic, and innovative city: This development goal is structured into 4 main objectives, 13 policies, and 52 programs. It covers, topics related to economic activities, whose purposes are to promote the industry and specialized services, promote the use of scientific and technological innovations that contribute to the increase in productivity and the creation of better-paid jobs, and improve the public services provided to citizens; In addition, develop sustainable activities (circular economy). The 4 main objectives are economic transformation and social well-being, innovation and economic development, innovation in public services, and sustainability of productive activities. The objective "innovation in public services" has a relevant set of indicators related to water security (see Table 48).

Table 48: Indicator for Objective 2.3

Indicator	Unit	Baseline		Goals		Tendence	Source
		Value	**Year**	**2030**	**2040**		
Score of the basic public services	Average	5.9	2019	8.6	10.0	Increasing	INEGI
Score of the procedures	Average	7.8	2019	8.9	9.9	Increasing	INEGI

Development goal 3. City with balance and territorial organization and management: This development goal is structured into 5 main objectives, 17 policies, and 77 programs. This goal focuses on topics such as ecological balance and preservation of the conservation soil, improving the air quality, reduction of GHG emissions, safeguarding the water cycle, sustainable treatment and use of solid waste, and comprehensive risk management and civil protection. This development goal is critical for Mexico City's climate action and sustainable water management. The 5 main objectives are ecological balance and conservation of soil, actions to counteract climate change, safeguarding the water cycle, sustainable solid waste treatment, comprehensive risk management and civil protection. Due to the importance of this development goal, a further analysis of three of the five development objectives is important.

Objective 3.2 focuses on actions to counteract climate change and aims to improve the city's air quality and reduce greenhouse gas emissions that provoke climate change. Three main policy lines are implemented to achieve the objective, which are green infrastructure implementation integral program, policy for the promotion and use of renewable and sustainable energies, and policies to reduce emissions of polluting gases and greenhouse gases. The following table presents the indicators for the objective (see Table 49).

Table 49: Indicator for Objective 3.2

Indicator	**Unit**	**Baseline**		**Goals**		**Tendence**	**Source**
		Value	**Year**	**2030**	**2040**		
Percentage of clear days	Days	39.6	2021	54.8	73.8	Increasing	SEDEMA
Green House Gas emissions	Millions of tons of CO_2	1.4	2017	0.7	0.1	Decreasing	SEDEMA

Objective 3.3 focuses on safeguarding the water cycle by reducing soil deterioration. Further analysis of the policies related to water management in the city is developed in the following section. Five main policy lines are implemented to achieve the objective, which are sustainable groundwater recharge use and extraction policy, sustainable management policy for watersheds, sustainable water management policy to rescue rivers and bodies of water, water wise policy for households, and water infrastructure development policy. The following table presents the indicators for the objective (see Table 50).

Table 50: Indicator for Objective 3.3

Indicator	Unit	Baseline	Goals	Tendence	Source

		Value	Year	2030	2040		
Average annual availability of groundwater	Millions of m3	-507.23	2020	-306.3	-185	Increasing	CONAGUA
Annual renewable water per capita	Sqm2 per inhabitant	70	2020	77	85	Increasing	CONAGUA

Objective 3.5 focuses on comprehensive risk management and civil protection by promoting comprehensive risk management and civil protection to address and control the effects of

natural, health, chemical, or social disasters. Five main policy lines are implemented to achieve the objective, which are early warning policy and comprehensive risk management with resilience associated with different situations of vulnerability, vulnerability reduction policy in the City's hydraulic infrastructure, public-private partnership policies for risk reduction and resilience strengthening projects, professionalization and risk study policy, and comprehensive policy for the dissemination and understanding of disaster risk and a culture of prevention. The following table presents the indicators for the objective (see Table 51).

Table 51: Indicator for Objective 3.5

Indicator	Unit	Baseline		Goals		Tendence	Source
		Value	**Year**	**2030**	**2040**		
Number of climate related accidents	Number	508	2020	385	293	Decreasing	INEGI
Number of annual flooding recorded	Number	282	2019	142	67	Decreasing	SEGIRPC

All of the abovementioned shows how Mexico City prioritizes overall climate action and puts value on water resources since they are in crisis. They are key to the city's sustainable development and ensure its inhabitants' health.

Development goal 4. City with balance and territorial organization and management: This development goal is structured into 9 main objectives, 20 policies, and 76 programs. This development goal addresses issues concerning territorial planning and management, promotion of a smaller ecological footprint and comprehensive management of the territory, reduction of irregular human settlements, reinforcement of existing centralities and generation of new centralities, promotion of urban regeneration practices, adequate and inclusive housing promotion, strengthening of equitable coverage of services, physical infrastructure, public spaces, sustainable mobility and urban accessibility, metropolitan coordination and identity of Indigenous peoples and resident Indigenous communities. The 9 main objectives are efficient use of land based on its primary zoning, sustainable urban expansion, polycentric city, urban regeneration and appropriate and inclusive housing, equitable coverage of urban services and infrastructure, quality public spaces for inclusive, safe education, culture, leisure and recreation, sustainable mobility, sustainable metropolitan coordination, strengthen neighborhoods and resident indigenous communities. The objective “are efficient use of land based on its primary zoning” has a relevant set of indicators related to water security (see Table 52). Also, objective "equitable coverage of urban services and infrastructure" has a relevant set of indicators related to water security (see Table 53).

Table 52: Indicator for Objective 4.1

Indicator	Unit	Baseline		Goals		Tendence	Source
		Value	**Year**	**2030**	**2040**		
Surface of natural protected areas in Mexico City	Ha	26,047	2020	28,000	30,000	Increasing	SEDEMA
Restored natural surface	Ha	260	2019	390	585	Decreasing	SEMARNAT CONAFOR

Table 53: Indicator for Objective 4.5

Indicator	Unit	Baseline		Goals		Tendence	Source
		Value	**Year**	**2030**	**2040**		
Percentage of households with adequate freshwater supply service	%	75.9	2020	100.0	100.0	Increasing	INEGI
Percentage of households with adequate sanitation service	%	94.5	2020	100.0	100.0	Increasing	INEGI
Percentage of households with trash collection service	%	93.1	2020	100.0	100.0	Increasing	INEGI
Percentage of households with adequate electricity service	%	99.8	2020	100.0	100.0	Increasing	INEGI
Number of clinics	Clinics	529	2021	600	700	Increasing	SEDESA

Development goal 5. City in peace and with justice: This development goal is structured into 4 main objectives, 12 policies, and 49 programs. In this development goal, topics of crime prevention, a professional police system close to citizens, scientific research, technological support, and inter-institutional coordination, effective access to justice, and impartiality in the application of the law are developed. The 4 main objectives are efficient are crime prevention, a professional police system and close to citizens, scientific research, technological support and inter-institutional coordination, and access to justice, equality and impartiality in the application of the law.

Development goal 6. City of honest government, close to citizenship and good administration: This development goal is structured into 5 main objectives, 13 policies, and 45 programs. This development goal addresses issues related to honest and competent government, austerity, innovative public administration, efficient public spending and sustainable public income. The five main objectives are honest, competent and austere government, modern and efficient public administration, efficient public spending, sustainable public income, and global city.

Following the synthetic review of the 2020-2040 General Development Plan for Mexico City, the next step is to explore how some of the plan's proposed indicators interact with the five dimensions of water security (see Table 54).

Table 54: Relationship between the 2020-2040 General Development Plan for Mexico City and Water Security Dimensions

Indicator	Water security dimension
Average annual availability of groundwater	Resilience to water-related disasters
Annual renewable water per capita	Resilience to water-related disasters
Number of annual flooding recorded	Resilience to water-related disasters
Score of the basic public services	Household Water Security
Surface of natural protected areas in Mexico City	Environmental Water Security
Percentage of households with adequate freshwater supply service	Household Water Security
Percentage of households with adequate sanitation service	Household Water Security

The 2020-2040 General Development Plan for Mexico City, with its indicators, is related to three dimensions of water security: Household Water Security, Environmental Water Security, and Resilience to water-related disasters. The two missing dimensions (Economic Water Security and Urban Water Security) are delegated to the local water operator. This put in evidence the gap between land planning and water planning.

6.3 Water system of the city

To have a safe and reliable freshwater supply for one of the most populated urban areas in the world is a considerable challenge for the government at different levels. Currently, it is estimated that 56% of the water resources come from outside the entity and 44% from inside the entity mainly from wells and springs (SACMEX 2023) (see Figure 28). This means that Mexico City is not autonomous with its water resources meaning that the federal government has to intervene to provide water to the city. Unfortunately, the local and out-of-state resources are becoming increasingly scarce. Currently, 18% of the population does not receive water every day, and 32% does not receive enough water to meet their needs and require the support of bulk water delivery and buying water in jugs (SACEMX and Mexico City Parliament 2017). Relying in bulk water delivery puts in great vulnerability the population of Mexico City. Water losses is also a great vulnerability of Mexico City’s water system. It is estimated that the system will experience an average of 42% water losses (CONAGUA, SACMEX, and EDOMEX 2019). This means that only 58% of the extracted water arrives at the final user. In the context of considerable water stress, Mexico City should not be able to afford such considerable losses. This requires an upgrade and constant maintenance of the complex water network.

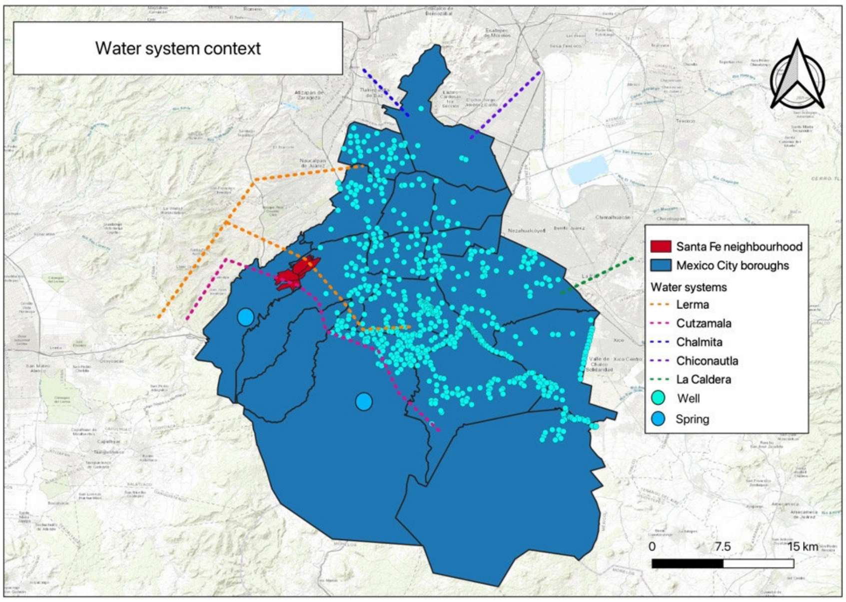


Fig. 28. Water system of Mexico City. Source: Armando Cepeda Guedea, 2024

The Cutzamala system is one of the main providers of potable water for the Mexico City metropolitan area and the VMB with approximately 26% of the water supply for the region (Santos Téllez, Medina Mendoza, and Rodríguez Varela 2021). The system is composed of 322.32 km of main pipelines and seven main dams involving two states (the State of Mexico and Michoacan) and Mexico City (see Figure 29). It is estimated that the system provides 20 m³/s of potable water. In recent times, the loss of capacity of water collection of the basins that supply the dams that compose the system has put at great risk the supply of potable water in Mexico City Metro. It has been reported that in 2021 the water levels of the Cutzamala system are at their lowest in the last 25 years (Santos Téllez, Medina Mendoza, and Rodríguez Varela 2021). This situation is associated with a drought of categories D2 and D3 (The United States Drought Monitor considers D2 and D3 categories as severe and extreme drought) derived from climate change in the supply basins for the system (National Drought Mitigation Center, United States Department of Agriculture, and National Oceanic and Atmospheric Administration 2024). The local water bodies that can serve as an alternative to guarantee the water supply have reported high levels of contamination and exploitation (Bevilacqua and Cepeda Guedea 2023). The VMB contains seven aquifers, 70% of which are being overexploited. The vast majority of the economic activities in the region extract the water they need from the following seven water bodies: 1) Mexico City Metropolitan Zone (overexploited), 2) Cuautitán-Pachuca (overexploited), 3) Texcoco (overexploited), 4) Chalco- Amecameca (overexploited), 5) Tecocomulco (underexploited), 6) Apan (underexploited) and 7) Soltepec (underexploited). It is also important to mention that the majority of inhabitants and, thus, most of the economic activities are located in regions with overexploited aquifers (Revollo-Fernández, Rodríguez-Tapia, and Morales-Novelo 2020).

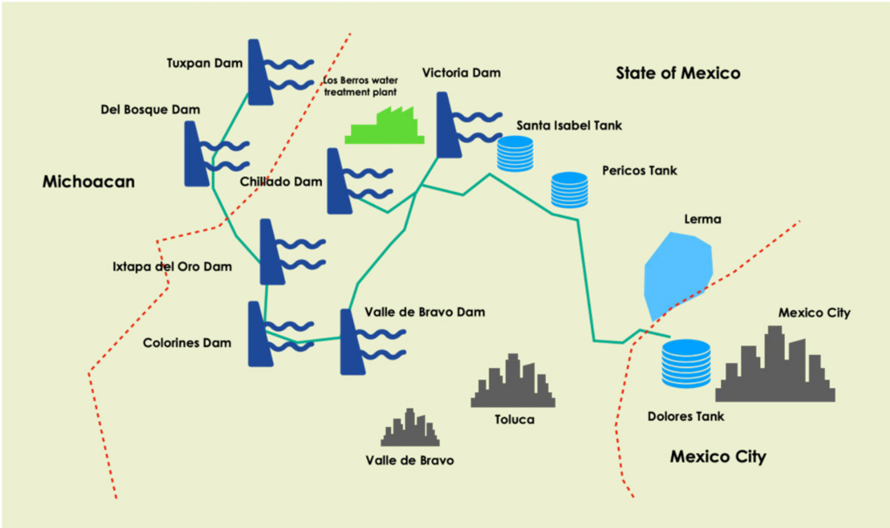


Fig. 29. Schematics of the Cutzamala system. Source: Armando Cepeda Guedea, 2024

Mexico City's water demand is expected to increase at least until 2053 steadily. Currently, in 2024, there is a demand of 76.45 m3/s, but there is only availability of 64.50 m3/s, leaving a deficit of 11.95 m3/s (CONAGUA 2022). This increases the scarcity of resources and water cuts all over the city. A deficit of such dimension greatly endangers the water security of the city. Ambitious strategies are required to reduce the deficit and ensure the sustainability of the city. The average provision of drinking water by SACMEX is 150 liters per inhabitant per day. Despite this, each person consumes an average of 380 liters (SACMEX 2021). Meanwhile, PIGOO presents a more optimistic scenario regarding water consumption in Mexico City, which is 183 liters (Programa de Indicadores de Gestión de Organismos Operadores 2020). This situation aggravates the water shortage in the city. In this context, it is required a strategy for a better water-wise use of the resource.

Water is a human right, so the Mexico City Government tries to make access as universal as possible with a billing assistance program based on income. In Mexico City, the price of water is linked to the city's development index for each block (Mexico City Government 2023). This means that the water price is higher in areas of higher income and high levels of development, meanwhile the water price is lower in areas of low income and low levels of development. Mexico City government proposes four tiers to charge water services: popular, low income, medium income and high income. Depending on the consumption of water each bimester SACMEX charges the users (Mexico City Government 2023). Take, for example, a medium-income block with an ideal consumption of (150 liters per day) per individual in an average household with four inhabitants makes 36,000 liters each bimester. This makes a bill of 905.88 pesos (approximately 45.29 USD) for every two months. Considering the average household income in 2022 for a bimester is 59,541.8 pesos (Mexico City Government 2022)(approximately 2977.09 USD). The water bill will represent 1.52% of the household income, just slightly above the optimal threshold of water affordability of 1.5% of the household income (Chappelle and Hanak 2021), but it is still in the range of good affordability, below 3% for water service and 5% for the combined water and sanitation service (UN-Water Decade 2015).

6.4 Regulatory instruments for water security

The current water management framework comes from the 1992 Law of National Waters with many innovative concepts such as sustainable management and integral planning; social participation in hydraulic planning, in the water market and in concessions; public information in terms of water quality, availability and use; and the Basin Councils (Guerrero García Rojas 2019).

The Mexican National Water Commission (CONAGUA) which is the national operator and regulator presents the National Water Plan 2020-2024 which is a governing document for the water policy at the national level (CONAGUA 2020). This plan derives from the National Development Plan (PND) 2019-2024 and aligned to the Environment and Natural Resources Program (PROMARNAT) 2020-2024 and was published in 2020; It includes 5 objectives, 20 strategies and 87 specific actions. The 5 main objectives are progressively to guarantee the human right to water and sanitation, especially for the most vulnerable populations, and more efficient use of water resources to contribute to the sustainable development of productive sectors, reduce the vulnerability of the population to floods and droughts, with emphasis on traditionally vulnerable populations, preserve the integrity of the natural water cycle to guarantee the water supply in basins and aquifers, and improve the conditions for water governance to strengthen decision-making process and reduce corruption.

In 2022 it was presented the Comprehensive Plan to Access the Human Right to Water for the Valley of Mexico 2019-2030 (CONAGUA et al. 2022). In 2022 the plan had already advanced by approximately 40%. This plan can be summarized in three points: make the current water supply systems more efficient, recycle rainwater and water from the Valley of Mexico and at the same time recover the environmental services of the basin. This plan involves the three states that make the Mexico City Metropolitan Area (Mexico City, State of Mexico, and Hidalgo) representing a relevant advance in the metropolitan governance of the area. This plan functions as a regional water shortage management plan and can be a useful framework for the implementation of neighborhood-level water shortage management plans.

The complex water challenges that Mexico City faces made it critical to update the previous 2003 Water Law. In 2017 it was approved the Mexico City Water Sustainability Law that aims to ensure a safe and reliable freshwater supply to the inhabitants of the city by recovering water sources, reducing losses, using them more efficiently, adopting new technologies, and increasing water governance (SACEMX and Mexico City Parliament 2017). The development and implementation of this law are possible thanks to the new attribution Mexico City received after becoming a federal entity in 2016. The Law provides more autonomy to the water operator and regulator SACMEX becoming a decentralized institution dethatched from the direct administration of the local government with legal personality and own assets. The law also contemplates the creation of an Advisory Council, as a consultation body, made up of representatives of the academia, non-governmental organizations, the private sector, and civil society, which will increase the participation of citizens and specialists in the decision-making process of water management. Finally, the law considers raising the social and institutional impact indicators to legal status to make the public water supply service more efficient, both in quality and availability. The law expects to establish the conditions for sustainable planning and management in water matters through a long-term program, with the objective that all inhabitants of Mexico City have quality water and drainage service.

Mexico City's water operator alongside the local government launched in 2020 the "Strategic program to guarantee the right to water 2020-2024 (SACMEX and Mexico City government 2020). This is a key strategic plan for a better, more suitable, and more efficient use of water resources. This plan is divided into four main lines of action which are:

- Macro measurements and telemetry: Monitor Mexico City's drinking water system in real-time, on a single data reception and processing platform, to support daily operation and planning. Supported with new technologies SACMEX and the local government intend to provide a better water service, identify more efficiently possible issues, and overall move towards equitable distribution of available water.
- Improve the distribution of freshwater: Divide the network into 830 hydraulic sectors by 2024 with a single entry, and with measurement, to compare supply with consumption and achieve water recovery with adequate pressure management and leak repair by establishing appropriate strategies. Hydraulic sectors are an innovative solution to manage water resources from a local perspective and focus efforts on specific areas that may suffer from water issues and respond more efficiently in case of leaks.
- Recovery and improvement of supply sources: Ensure the production of safe a reliable freshwater through the different sources of supply to our city. This is done by recovering and improving local water sources like wells and surface water like Madin Dam and the wells of the Lerma system.
- Improving the water quality: Mexico's city suffers from bad quality water, not allowing its inhabitants to drink tap water without a series of filtration systems. Mexico City's government aims to improve the operation and efficiency of water treatment plants, optimizing processes, to guarantee that the effluent water is suitable for consumption and use in the daily activities of the population.

6.4.1 Water operator and management approach

To enforce the National Law the National Water Commission (CONAGUA) was created as a decentralized administrative institution part of the Secretary of Environment and Natural Resources (SEMARNAT) with attribution to regulate and operate the federal water resources and infrastructures. Mexico City's water resources since 2003 are managed by the Mexico City Water System (SACMEX), by merging the then General Directorate of Construction and Hydraulic Operation (DGCOH) and the Federal District Water Commission (CADF) (SACMEX 2024a). This intends to create more appropriate mechanisms to provide the means to achieve an efficient distribution of hydraulic services in Mexico City, as well as the modernization of the systems for their operation, avoiding the duplication of functions at the time of exercising the actions in this matter. Mexico's City Water System functions are to provide a safe freshwater supply, drainage, sewerage, water treatment and wastewater reuse (SACMEX 2024a). It is important to mention that the particular institutional reality of Mexico City centralizes water management into the entity water regulator operator and regulator which is SACMEX. This leaves boroughs with no contributions and capacity to manage the water resources and infrastructures in their territories, being one of the main differences between Mexico City's boroughs with the municipalities in the rest of the country that have the attribution to regulate and operate their water resources.

6.4.2 Innovation practices for water security

Rainwater harvesting is considered an innovative practice that has been stimulated in Mexico City as reflected on the Comprehensive Plan to Access the Human Right to Water for the Valley of Mexico 2019-2030 and the 2020-2040 General Development Plan for Mexico City. Up to 2022, more than 70,000 public-funded rainwater harvesting units have been installed in 11 Mexico City boroughs (SACMEX 2022). It is important to invest in a more diffused use of rainwater harvesting units in the other boroughs, regardless of income. Until now, only low-income households have benefited from the program, but it is important to extend the program to all households in the city to increase their water resilience.

The use of recycled water is starting to increase in Mexico City as a good practice to use water resources more wisely. Approximately 5% of the treated water is recycled in the city; due to economic and technological barriers, the use is not as widespread as expected, considering the dire water crisis in the city (Centro Mario Molina 2011).

6.4.3 Communication strategies to raise awareness of water security

The Program of Management Indicators of Operating Organizations (PIGOO) was developed by IMTA in 2005, and it evaluates the performance of the public water operators in Mexican cities starting with 12 indicators. Currently, with the 2018 itineration, 36 indicators, and 30 sub-indicators, IMTA has an active public website where citizens can view the results of the evaluation of the performance of its water operator, representing good practice in transparency. Mexico City, through SACMEX, participates in the PIGOO framework so that citizens of the city can review the progress of their water operators in terms of water security. At the local level, SACMEX has a website to review and study how water arrives in neighborhoods, schedule water cuts, and make recommendations on how to use water wisely. This is a solid instrument to raise awareness of water security (SACMEX 2024b).

6.5 Water-related risks with respect to basin and urban link

In 2019, the Mexico City government reported 1168 water-related events such as hailstorms, flooding, heavy rains, fogs and strong winds, leaving 25 injured citizens. Also, it is important to add one social risk, which is the interruption of vital services with 761 reported events, 47 injured citizens, and 36 deaths; this risk includes the water supply and sanitation services (Mexico City Government 2019). The Water Risk Atlas by the World Resources Institute established Extremely High levels of water stress, low levels of riverine flood risk, medium risk levels of droughts, and low, medium levels of Coastal eutrophication potential (Kuzma et al. 2023).

CONAGUA currently has a national plan against droughts (PRONACOSE), which proposes a series of actions that would be applied before, during and after possible situations of temporary water shortage due to drought or even from conditions before it, aiming to minimize environmental, economic, and social impacts (Mexican Government 2022). These actions seek to guarantee the availability of water required to ensure the health and life of the population, prioritizing the supply of public-urban and domestic use, both in urban and rural environments.

Among the different initiatives and programs inside PRONACOSE the Preventive Measures and Drought Mitigation Programs (PMPMS) are a key and a step in the right direction for better water shortage management in cities and metropolitan areas (Mexican Government 2024b). The program aims to have advanced guidelines and actions that would be applied in possible situations of water shortages to minimize environmental, economic, and social impacts. The plan seeks to guarantee the availability of water required to ensure the health and life of the population: public, domestic, urban, and rural supply, avoid or minimize the negative effects of drought on the environment, and minimize the negative effects on economic activities. Thus, the PMPMS prioritize preparation and mitigation actions, defines proactive mitigation and planning measures, risk management, public dissemination and resource management, and coordinates drought programs and response activities efficiently and effectively, focusing on user needs. PRONACOSE and their different initiatives can be considered a positive policy but there is still important room for improvement because these plans need to emphasize more the multifactoriality of water shortage and go beyond the simple risk of drought.

The River Basin Councils were created to promote the participation of water users and local authorities. For the first time, the environment is considered a non-consumptive water user, and environmental flow is described as the part of river flow that must be maintained to conserve freshwater ecosystems (Arias-Rojo and Salmón-Castelo 2019). The integrated river basin management approach is one of the strategies in the application of water policies by CONAGUA, the water authority. In 1997 the decentralization continued by empowering the 13 Hydrologic Administrative Regions, now called River Basin Organizations to manage the water resources from a regional and local perspective and present more efficient solutions. In 2004 the law was amended by adding clarifications to the old version (Arias-Rojo and Salmón-Castelo 2019). For example, the constituency of the River Basin Councils is clearer. One of the biggest challenges in Mexico's water management is the difficulty in fully implementing the Law of National Waters in all the territory, due to a lack of resources and political willingness (Arias-Rojo and Salmón-Castelo 2019).

Mexico City is located in the XIII Hydrologic Administrative Region, the Valley of Mexico Basin (VMB) (SEMARNAT 2015). The VMB is Mexico's smallest and most densely populated region, with more than 22 million inhabitants (54.6% in the State of Mexico, 40.9% in Mexico City, and the rest in other states), and approximately 2234 inhabitants per km2, making this one of the densest populations in the world. While it occupies less than 1% of the national territory, 20% of the country's total population inhabits the region, generating approximately 31.3% of the national GDP (Revollo-Fernández, Rodríguez-Tapia, and Morales-Novelo 2020). The VMB has a Relative Water Stress Index of 140.4% making it one of the regions with the greatest pressure on its water resources (Revollo-Fernández, Rodríguez-Tapia, and Morales-Novelo 2020).

6.6 Indicator Framework to Evaluate Water Security

Table 55: Water Security evaluation for Mexico City

Economic Water security		**Units**	**Ranges**					**Sources**
Indicator	**Subindicator**		**1**	**2**	**3**	**4**	**5**	
Cost efficency of the service		%					0	SACMEX (2024)
Non revenue economic water losses		USD/m3					4.29	SACMEX (2019)
Investments		USD				67.69		SACMEX (2024)
Payment collections efectiviness		%			71%			PIGOO (2017)
Operating expense ratio		%					100%	SACMEX (2024)
Debt ratio		Unit	0% debt					SACMEX (2024)

Household Water security		**Units**	**Ranges**					**Description**
Indicator	**Subindicator**		**1**	**2**	**3**	**4**	**5**	
Freshwater consumption		liters	183					PIGOO (2017)
Water quality reports		number of reports /1000 inhabitants	0.2					SACMEX (2022)
Bulk water delivery		%			27%			PIGOO (2017)
Interruptions to the service		outages/1000 inhabitants outages/reductions/year					9.1	SACMEX (2022)
Metering efficency		% of unmetered water					12.6%	SACMEX (2012)
Service coverage	Freshwater	%		98%				PIGOO (2018)
	Wastewater	%		93%				PIGOO (2018)
Service complaints		number of reports /1000 inhabitants			16.6			SACMEX (2022)
Service efficiency		%					84%	SACMEX (2023)
Billing issues		%		0.50%				SACMEX (2013)
System failures	Reported leaks	number of reports /1000 inhabitants			7.27			SACMEX (2022)
	Reported sewerage fails	number of reports /1000 inhabitants		0.81				SACMEX (2022)
	Reported stormwater overflows	number of reports /1000 inhabitants	0.03					SACMEX (2022)
Water pressure		psi					13	SACMEX (2017)
Affordability of the service		%		1.52%				SACMEX (2023)
Low-income billing assistance offered		units		High implementation				

Urban Water security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Water Metering Coverage		%					24%	SACMEX (2019)
Network size	Freshwater	Meters of pipeline/inhabitant					1.43	SACMEX (2013)
	Wastewater	Meters of pipeline/inhabitant					1.51	SACMEX (2013)
	Stormwater	Meters of pipeline/inhabitant					ND	PIGOO (2018)
Water Treatment Capacity	Freshwater	%	100%					IMT (2021)
	Wasterwater	%					58%	Escolero, Herrera, and Pedrozo (2021)
Water storage		Days					0.47 days	SACMEX (2013) (2019)
Energy consumption		%		16%				Centro Mario Molina (2011)
Renewable energy use		%					ND	ND
Green house emissions		GHE per capita		4.25				Moran (2018)
Rainwater collector units		Number of units				0.34		Mexico City Government (2022)
Power failures		Hours					66	SACMEX (2022)
Water quality		%					63%	SACMEX (2023)
Water demand and supply ratio		units			0.8185			SACMEX (2023)
Average age of the pipelines	Freshwater	years				50		SACMEX (2019)
	Wastewater	years				50		SACMEX (2019)
Data availability		units		High				High
Maintenance		%			2.53%			SACMEX (2024)
Water losses		%				42%		SACMEX (2019)
Staff levels		Number of employees/ 1000 connections					5	PIGOO (2019)
Diversity of the sources in local supply system		%		46%				SACMEX (2019)
Recycled water use		%			5.40%			Centro Mario Molina (2011)
Stakeholder participation		Unit				Consulting		
Integrated Water Management plan		Unit		High implementation				

Resilience to water-related disasters		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Overall Water Risks	Physical Risks Quantity	Unit					Extremely high	WRI Aqueduct 4.0 (2024)
	Physical Risks Quality	Unit		Low Medium				WRI Aqueduct 4.0 (2024)
	Regulatory and Reputational Risk	Unit		Low Medium				WRI Aqueduct 4.0 (2024)
Risk assessment and response preparedness	Risk assessment and response preparedness	Unit				Low implementation		Literature Review
	Water shortage planning	Unit				Low implementation		Literature Review

Environmental Water Security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Quality level of wastewater discharge to the environment		%					18%	PIGOO (2017); Escolero, Herrera, and Pedrozo (2021)
Storm water discharge		%					0%	PIGOO (2017); Escolero, Herrera, and Pedrozo (2021)
Sludge management		%		98%				Castrejon et al. (2002)
Green areas		%					4.50%	Mexico City Government (2015)
Blue areas		%					1.25%	Mexico City Government (2015,2023)
Quality of potentail available surface freshwater		%					50%	CONAGUA (2024)
Sustainability planning	Habitat/watershed protection goals	Unit		High implementation				Literature Review
	Green infrastructure planning	Unit		High implementation				Literature Review
	Energy optimization planning	Unit				Low implementation		Literature Review
Basin planning instrument		Unit		High implementation				Literature Review

6.7 Performance per dimension of water security

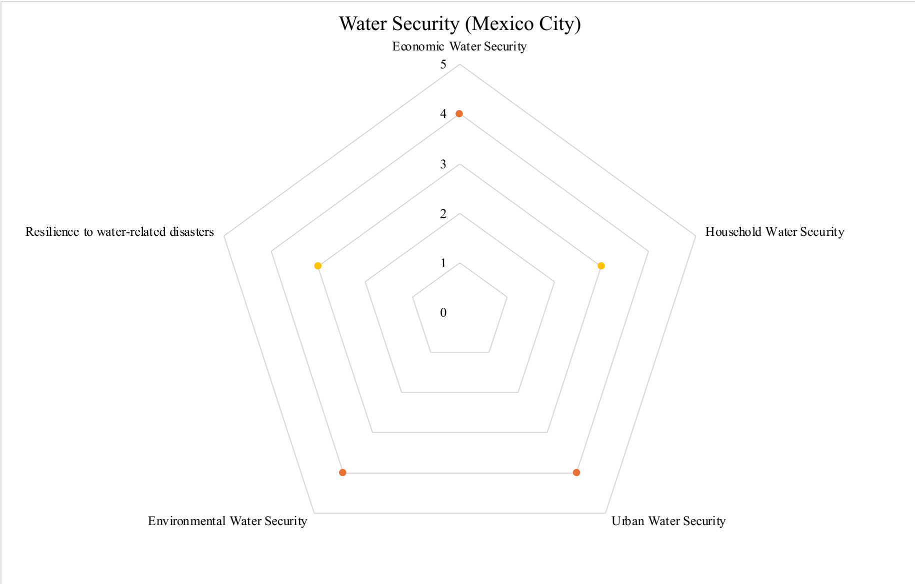


Fig. 30. Water security performance by dimension in Mexico City. Source: Armando Cepeda Guedea, 2024

The indicator framework for water security shows concerning results in the case of Mexico City. Three out of the five water security dimensions indicate a high risk (Economic Water Security, Urban Water Security, and Environmental Water Security) (see Figure 30). This reflects a serious risk of the collapse of the city's water system that considerably endangers water security. The result of the evaluation framework is consistent with the current reality of the city since, in early 2024, Mexico City had an imminent risk of arriving at "day zero" and running out of water in the next months (Paddison, Guy, and Gutierrez 2024). Fortunately, the situation has momentarily stabilized due to the increase of precipitations and replenishment of the water bodies in August and September 2024 and good water management techniques in the Cutzamala System by federal and local authorities (CONAGUA 2024). Despite the stabilization of the system, the risk of running out of water in the city is constant, and urgent measures are required. Due to technological progress and the implementation of good management practices, household water security remains within the threshold of functionality, but considerable action should be implemented to have sustainable and durable household water security. Due to adequate risk management planning practices, Mexico City's resilience to water-related disasters remains moderate despite the fact of high overall physical water risk.

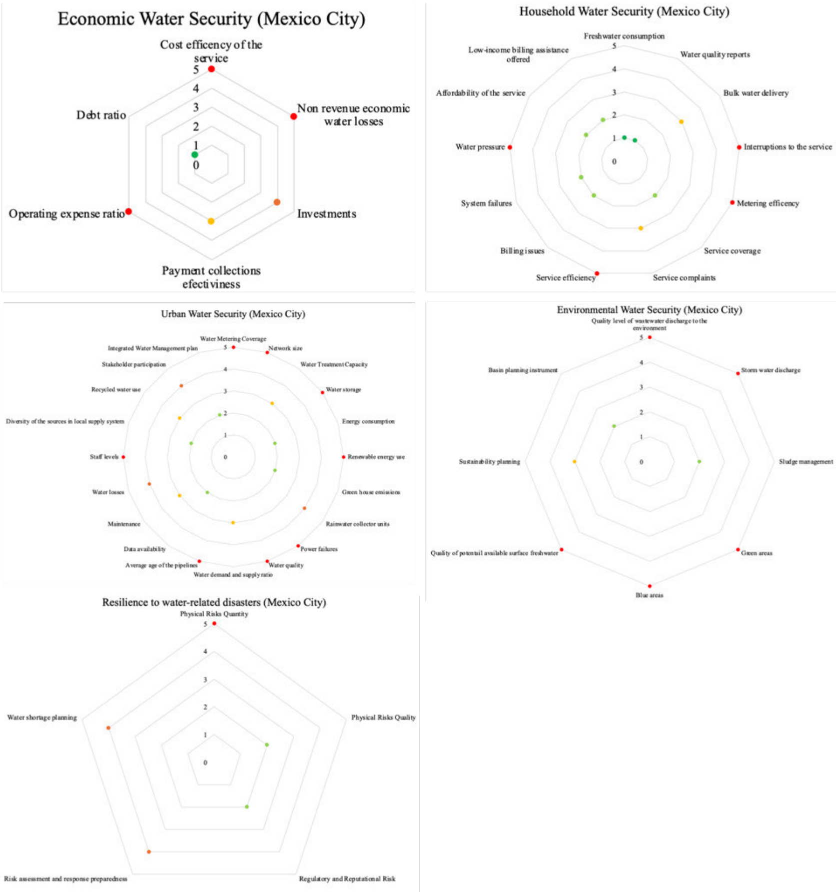


Fig. 31. Water security performance by indicator in Mexico City. Source: Armando Cepeda Guedea, 2024

Economic water security: Mexico City only performs well in debt ratio since the SACMEX does not report direct debt and is completely financed by the Mexico City government. Payment Collection effectiveness is a moderate concern since the city has some difficulty in fully collecting the bills from all the water users. Investments by the water operator are a high concern since there are not enough investments to meet the growing and complex needs of the water system in the city. Finally, there is a high risk in the cost efficiency of the service, non-revenue water losses, and operating expense ratio. These three indicators show the fragility of the economic water security system.

Household Water Security: This is one of the dimensions that better perform in the city due to the advance in the quality of the service by SACMEX. Despite the progress, it is shadowed by concerning issues such as constant interruptions of the water service, low water pressure, low service, and service efficiency, due to that considerable portions of the population lives in vulnerable areas that do not have full access to full water service and rely on improvised water infrastructure.

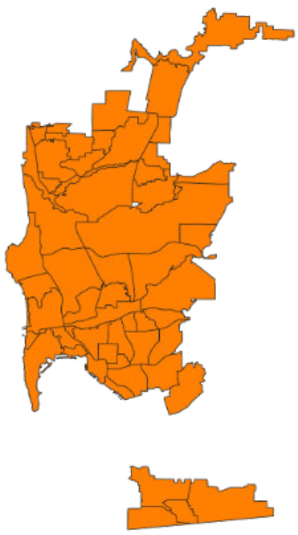
Urban Water Security: one of the most important dimensions when studying water security in a city. In Mexico City Urban Water security has considerable concerns on water quality, age of the pipelines, network size, power failures, water metering coverage, staff levels, and renewable energy use. Other concerns include water losses, little stakeholder participation, and the low presence of rainwater collector units. In this dimension, there are no indicators optimally performing, just adequately performing (maintain, GHG emissions, diversity of water sources, recycled water use, data availability, and energy consumption).

Environmental Water Security: the environmental water security in Mexico City is also greatly endangered due to low quality of water discharges, lack of run-off water discharge management, low quality of the surface water, and low permeability in the city due to high levels of urbanization in the territory. Only sludge management and basin planning have adequate levels.

Resilience to water-related disasters: Mexico City lies in an area with severe water stress levels due to climate change and overexploitation of the available resources. The moderate score on this dimension comes because of acceptable levels of physical quality and reputational risks. It is also combined with adequate risk management planning documents to face the water-related risks the city faces. Despite this, Mexico City should take urgent action to face the extreme water stress levels.

Chapter 7

San Diego



City of San Diego: Armando Cepeda Guedea, 2024.

7.1 Context analysis

The United States is a North American country with approximately 335,000 million inhabitants (US Census Bureau 2024c) and is among the most powerful countries in the world in the economic and political aspects. The country is a federal republic composed of 50 states with their particular legislation (United States Government 2024). The United States is organized into four levels which are: federal, state, county, and city. Depending on the state counties may have a relevant or a small role in planning. As a federal republic, the states that compose the federation have plenty of autonomy in their internal affairs.

California is a state located on the west coast of the United States bordering the south with Mexico, (more specifically the Mexican state of Baja California), Nevada and Arizona to the east, and Oregon to the north. If it were an independent country the state of California would be the fifth largest economy in the world, and closely to become the fourth largest by-passing Germany (Los Angeles Area Chamber of Commerce 2023). The state leads the U.S. economy in a wide array of sectors such as industrial, agricultural, technological and services. The success of the state can be attributed to an exceptional higher education system, its advantageous geographic location, and a diverse skillful workforce. The current population of California is approximately 39,000,000 inhabitants (US Census Bureau 2024a). Nevertheless, the state is facing an evident depopulation that can affect the economic development of the territory and reducing its political power in the federation by losing a congressional seat. California lost 433,000 people between July 2020 and July 2023 (H. Johnson, Cuellar Mejia, and McGhee 2024). Most of the loss occurred during the first year of the pandemic and was driven by a sharp rise in residents moving to other states due to the rising prices of housing and high cost of life. But fewer births, higher deaths, and lower international migration also played a relevant role.

San Diego is a city in southern California (see Figure 32) next to the border with the Mexican city of Tijuana that together make an international urban continuous of more than 5 million inhabitants (US Census Bureau 2024b; Mexican Government 2024a). The city is one of the most populated cities in California and the United States with 1,381,162 inhabitants and is the seat of San Diego County and the core of the San Diego metropolitan area with a population of approximately 3.2 million inhabitants (US Census Bureau 2024b). Like the rest of California, the city is experiencing a decrease in its population with a decrease of 0.4% of the total population in the period 2020-2022 (US Census Bureau 2024b).

The city of San Diego is divided into 52 communities each of them supported with a local community plan and committee (City of San Diego 2024a). The plans and committees are the results of the civil participatory process and local governance to estimate community development. The plan establishes the guidelines on how the individual community will be planned over the next 30 years. This includes policies on land use, mobility, urban design, public facilities and services, natural resources, historic and cultural resources, and economic development. The city can be considered a good example of local empowerment and bottom-up approaches in planning and policymaking.

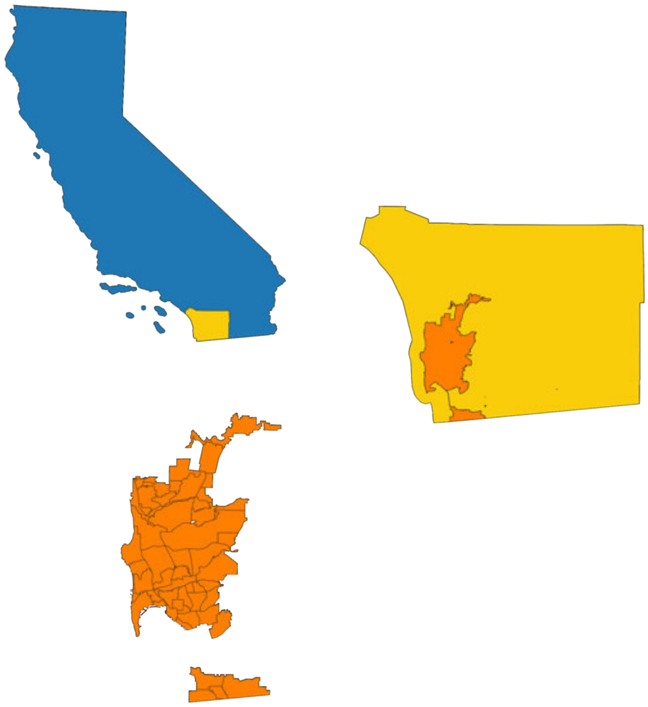


Fig. 32. San Diego's general context. Source: Armando Cepeda Guedea, 2024

The City of San Diego covers 887.07 km2 and stretches nearly 65 km from north to south. There are approximately 150 km of shoreline, including bays, lagoons, and the Pacific Ocean. The topography is mainly composed of mesas intersected by canyons with elevations ranging from sea level to approximately 183 meters (City of San Diego 2011). The city of San Diego features a Mediterranean climate according to the Köppen climate classification (Csa) and receives just over 250 mm of precipitation a year. While the annual mean temperature is around 17°C, the city can still be subject to extreme heat events with temperatures exceeding 40°C), particularly in late summer (NASA DEVELOP National Program 2021).

Regarding hydrology, San Diego lies in the major California basin, although the WRI divides the California Basin into California and Baja California (Kuzma et al. 2023). San Diego and Tijuana are the two Sub-basins occupying the City of San Diego (see Figure 33). San Diego County proposes 11 watersheds that cover its territory (see Figure 34). According to the World Resources Institute San Diego has a very high-water risk index, due to the severe droughts and water stress the region faces (Kuzma et al. 2023). The critical situation the city faces requires immediate and efficient measures to first reduce the impacts of the contingency to subsequently regenerate the area and reduce the water risk.

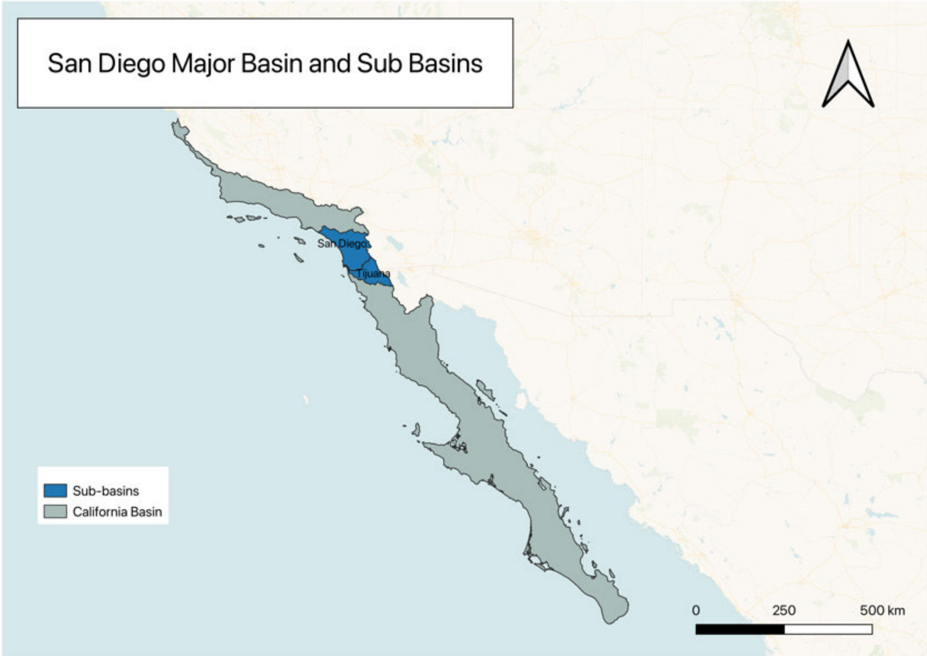


Fig. 33. Major basin and sub-basins for San Diego. Source: Armando Cepeda Guedea, 2024

Fig. 34. Watersheds in San Diego County. Source: San Diego Coastkeeper (2018)

7.1.1 Water insecurity drivers from context analysis

San Diego is located in a heavily populated region with high freshwater demands and limited local water supply. The region is also affected by long periods of droughts aggravated by climate change leading to uncertainty about freshwater accessibility. Since the 1990s the city has turned to a variety of means to meet its freshwater needs.

Currently, San Diego imports roughly 80 percent of its freshwater supply from other regions. This has made San Diego's water among the expensive in the United Sates costing about 26% more at the wholesale level in 2021 than Los Angeles area. In face of these challenges after a literature review the research identifies seven main drivers to pursue water security in the City of San Diego: vulnerability of the infrastructure, high vulnerability to natural disasters, increasing prices to ensure water supply, misallocation of water resources, climate change, low water autonomy of the city, and restore habitat and natural water flows (see Figure 35).

Fig. 35. Main water insecurity drivers for San Diego Source: Armando Cepeda Guedea, 2024

Vulnerability of the infrastructure: San Diego purchases approximately 85% to 90% of its water, which is imported mainly from Northern California and the Colorado River (City of San Diego 2024d). This means that the City of San Diego requires a big infrastructure to transport the water from long distances, and it should be maintained and updated to ensure a safe and reliable water supply. Despite this, key portions of the regional water system are outdated and crumbling (Californians for Water Security 2024). This increases the possibility of collapse in case of an earthquake or natural disaster, cutting off water supplies in the San Diego region. This water delivery system needs to be modernized to better prepare for climate change impacts such as extreme droughts, severe floods, and increasing salinity in the Delta caused by rising sea levels.

High vulnerability to natural disasters: The region and climate of San Diego make the City susceptible to natural disasters such as earthquakes, wildfires, and flooding, which might result in the interruption of critical services such as power, water, and communications (City of San Diego 2024b). Considering the large water infrastructure and the high reliance on water sources outside the city and county, one failure associated with a natural disaster can severely affect the water supply in the city.

Increasing prices to ensure water supply: ensuring the water supply from sources outside the city and the county represents a considerable economic burden on the water bills of the citizens. San Diego County’s water is among the most expensive in the United States, costing about 26% more at the wholesale level in 2021 than the water in Los Angeles County (Naishadham 2022). The high costs of water alongside water-sensitive practices such as more efficient showers, toilets and taps, rebates to tear out grass and the use of recycled water have significantly reduced the consumption of water in the city.

Misallocation of water resources: water is a seriously undervalued resource. Its price does not reflect the true total cost of service, from its transport via infrastructure to its treatment and disposal (World Resources Institute 2017). This has led to the misallocation of water and a need for investments in infrastructure and new water technologies that use water more efficiently. Water misallocation is a big issue in San Diego and most of southern California as the result of an outdated pricing structure for water. The solution is to update the pricing structure (UCSD Water Economics 2017). The current misallocation is not a short-term problem; rather, the stress on California's water resources will likely be indefinite due to constant drought that will likely be aggravated due to climate change.

Climate change: San Diego lies in a region particularly vulnerable to the impacts of climate change. The main vulnerabilities are the following changes in the frequency and severity of wildfires, sea level rise, and related coastal hazards, changes in precipitation patterns, including heavy rains and severe droughts, and more frequent extreme heat events (ICF and City of San Diego 2020).

Low water autonomy of the city: the complex challenge is to provide safe and reliable fresh to the citizens of San Diego in a context of very high water risk and stress. The city of San Diego purchases approximately 85% to 90% of its water, which is imported mainly from Northern California and the Colorado River (City of San Diego 2024c). Even though most of the water comes from outside the city and the county (the County estimates 80% of its water comes outside the county), San Diego tries to have their water supply from multiple sources (San Diego County Water Authority 2020a). This creates a great vulnerability making the city not water autonomously and rely upon complex water systems that can fail and severely damage the supply in the city.

Restore habitat and natural water flows: Due to the impacts of urbanizations natural habitats and the flows of water bodies have been altered (Californians for Water Security 2024). It is important to restore habitats and more natural water flows in rivers and streams in order to reduce impacts on endangered fish and other wildlife.

7.2 Strategic vision for sustainable development and climate action

Blueprint SD is the main planning document for the City of San Diego to guide the efforts to create equitable and sustainable growth and advance toward climate action for the city. Blueprint SD identifies areas for more homes and jobs that are connected to convenient and affordable options to walk, bike, and ride transit to meet daily needs, such as going to work, school, or the grocery store. The plan is structured into ten main elements (see Table 56).

Table 56: Blueprint SD main elements

Element	Brief description
Land Use and Community Planning	Guide future growth and development into a sustainable citywide development pattern, while enhancing the quality of life in communities.
Mobility	Improve urban mobility through the development and operation of a balanced, well- connected, safe, sustainable, and equitable multimodal transportation system for people to safely, conveniently, and enjoyably move around.
Urban Design	Guide the physical development consistent with the social, economic, aesthetic and equity values of the San Diego.
Economic Prosperity	Increase wealth and the standard of living of all people with policies that support a diverse, innovative, competitive, entrepreneurial, and sustainable local economy.
Public Facilities, Services and Safety	Provide the public facilities and services needed to serve the inhabitants of San Diego.
Recreation	Preserve, protect, acquire, develop, operate, maintain and enhance public recreation opportunities and facilities throughout the city.
Conservation	To become an international model of sustainable development. Provide for the long-term conservation and sustainable management of the natural resources that help to define the city identity, contribute to economic growth and improve the overall quality of life.
Noise	To protect people living and working in the City of San Diego from excessive noise.
Historic Preservation	Guide the preservation, protection, restoration, and rehabilitation of historical and cultural resources. To improve the quality of the built environment, encourage

	appreciation for the City's history and culture, maintain the character and identity of communities, and contribute to the City's economic vitality through historic preservation.
Environmental Justice	To identify and reduce unique and compounded health risks, increase community assets and improve overall health.

Inside the Public Facilities, Services, and Safety elements are the wastewater, stormwater infrastructure, and water infrastructure components, which are critical for an integrated water resources management approach. The following table shows the main policies for each component (see Table 57).

Table 57: Public Facilities, Services, and Safety Main Policies for Integrated Water Management

Wastewater	Storm Water	Freshwater
1.Meet or exceed federal and state regulatory mandates cost effectively. 2. Produce quality reclaimed water 3.Minimize sewer spills by best practice infrastructure asset management practices. 4.Maintain conveyance and treatment capacity. 5.Construct and maintain facilities to accommodate regional growth projections that are consistent with sustainable development policies. 6.Coordinate land use planning and wastewater infrastructure planning to provide for future development and maintain adequate service levels. 7.Ensure facilities meet business, safety, and life-cycle cost concerns.	1.Ensure that all storm water conveyance systems, structures, and maintenance practices are consistent with the federal Clean Water Act and California Regional Water Quality Control Board NPDES Permit standards. 2.Install infrastructure that includes components to capture, minimize, and/ or prevent pollutants in urban runoff from reaching receiving waters and potable water supplies. 3.Meet and preferably exceed regulatory mandates to protect water quality in a cost-effective manner monitored through performance measures. 4.Develop and employ a strategic plan for the City's watersheds to foster a comprehensive approach to storm water infrastructure improvements.	1. Optimize the use of imported supplies and improve reliability by increasing alternative water sources to: provide adequate water supplies for present uses, accommodate future growth, attract and support commercial and industrial development, and supply local agriculture. a. Prepare, implement, and maintain, long-term, comprehensive water supply plans and options in cooperation with the appropriate state and federal agencies, regional authorities, water utilities, and local governments. b. Develop, coordinate, facilitate, and implement water conservation plans and projects that are sustainable in reducing water demands. c. Develop potential groundwater resources and storage capacity, combined with management of surface

8.Manage infrastructure assets optimally through efficient repair and replacement. 9.Support informed and timely resource allocation decisions. 10.Develop and execute a financing plan to satisfy requirements validated through the public participation process. 11.Explore entrepreneurial and environmental initiatives (such as the cogeneration of power) and pursue as appropriate. 12.Maximize the beneficial use of sludge. 13.Maintain a cost-effective system of meeting or, preferably, exceeding regulatory standards related to wastewater collection and treatment and storm water pollution prevention. 14.Incorporate new technologies and scientific advancements in the optimal provision of wastewater services.	5.Identify and implement BMPs for projects that repair, replace, extend or otherwise affect the storm water conveyance system. These projects should also include design considerations for maintenance, inspection, and, as applicable, water quality monitoring. 6.Identify partnerships and collaborative efforts to sponsor and coordinate pollution prevention BMPs that benefit storm water infrastructure maintenance and improvements.	water in groundwater basins to meet overall water supply and resource management objectives. d. Participate in advanced water treatment processes and non-traditional water production techniques such as brackish groundwater and seawater desalination programs. e. Continue to develop the recycled water customer base, and expand the distribution system to meet current and future demands. f. Consider and evaluate water transfers. g. Optimize storage, treatment and distribution capacity of potable water systems. 2. Provide and maintain essential water storage, treatment, supply facilities and infrastructure to serve existing and future development. 3.Coordinate land use planning and water infrastructure planning with local, state, and regional agencies to provide for future development, maintain adequate service levels, and develop water supply options during emergency situations. a. Plan for a water supply and emergency reserves to meet peak load demand during a natural disaster such as a fire or earthquake.

		b. Plan for water supply and emergency reserves recognizing anticipated climate change impacts. c. Recognize the water/energy nexus. Plan and implement water projects after consideration of their energy demands in coordination with energy suppliers to minimize and optimize the energy impact of projects.

Inside the conservation element, water also plays a key role, as reflected in the Water Resource Management component, which aims to effectively long-term management of water resources so that demand is in balance with efficient, sustainable supplies and a safe and adequate water supply that effectively meets the demand for the existing and future population through water efficiency and reclamation programs (see Table 58). Also, the conservation element considers Urban Runoff Management to protect and restore water bodies, including reservoirs, coastal waters, creeks, bays, and wetlands and preserve the natural attributes of both the floodplain and floodway without endangering human lives and property (see Table 59).

Table 58: Conservation Policies for Water Resources Management

Water Resource Management
1. Implement a balanced, water conservation strategy as an effective way to manage demand by: reducing dependence on imported water supplies; maximizing the efficiency of existing urban water and agricultural supplies through conservation measures/programs; and developing alternative, reliable sources to sustain present and future water needs. a. Integrate watershed planning with water supply and land use studies to achieve an integrated approach to ensure that the city can provide adequate water supplies for present uses, accommodate future growth, attract and support commercial and industrial development, and supply local agriculture. b. Manage groundwater and surface water resources and capacity through an integrated approach to meet overall water supply and resource management objectives c. Participate in advanced water treatment processes such as brackish groundwater and seawater desalination programs. d. Emphasize and refine recycled water programs to help meet non-potable irrigation demands. e. Develop and expand water-efficient landscaping to include urban forestry, urban plants, and demonstration projects. f. Support regional efforts towards ensuring that imported water is reliable, cost-effective, and is of high quality. g. Maintain existing and future water supply, storage, treatment and distribution facilities with minimal or no impact to the environment.

h. Implement conservation incentive programs that increase water-use efficiency and reduce urban runoff. i. Develop a response plan to assist community members in reducing water use during periods of water shortages and emergencies. j. Encourage local water agencies to use state-mandated powers to enforce conservation measures that eliminate or penalize wasteful uses of water. k. Explore alternative conservation measures and technology as they become available. l. Review/update the City's landscaping regulations as needed to ensure they effectively address the efficient use of water in landscaping. m. Educate the public on wise water use. n. Diversify the City's water supply sources and reduce dependence on imported water. 2. Protect drinking water resources by implementing guidelines for future development that may affect water supply watersheds, reservoirs and groundwater aquifers. The guidelines should address site design, Best Management Practices (BMPs) and storm water treatment measures. a. Collaborate with other jurisdictions to reduce the potential for polluted runoff to water supply reservoirs. b. Enter into cooperative, voluntary agreements with other jurisdictions to enable the City to provide advisory review of development projects outside of the city's boundaries that may impact watersheds and reservoirs. 3. Continue to participate in the development and implementation of watershed management plans. a. Control water discharge in a manner that does not reduce reasonable use by others, damage important native habitats and historic resources, or create hazardous conditions (e.g., erosion, sedimentation, flooding and subsidence). b. Protect reservoir capacity from sedimentation. c. Improve and maintain drinking water quality and urban runoff water quality through implementation of Source Water Protection Guidelines for New Development. d. Improve and maintain urban runoff water quality through implementation of storm water protection measures. e. Encourage proper sustainable agricultural practices (if applicable) such as tillage, use of grass filter strips, runoff detention basins, and organic farming. 4. Coordinate local land use planning with state and regional water resource planning to help ensure that the community members of San Diego have a safe and adequate water supply that meets existing needs and accommodates future needs. a. Consider and evaluate water transfers and other cost-effective ways to increase reliable supplies with minimal environmental effects, where it benefits the city, to help achieve a balanced and integrated water conservation strategy. 5. Integrate water and land use planning into local decision-making, including using water supply and land use studies in the development review process.

Table 59: Conservation Policies for Urban Runoff Management

Urban Runoff Management
1. Continue to develop and implement public education programs.

a. Involve the public in addressing runoff problems associated with development and raising awareness of how an individual's activities contribute to runoff pollution.
b. Work with local businesses and developers to provide information and incentives for the implementation of Best Management Practices for pollution prevention and control.
c. Implement watershed awareness and water quality educational programs for City staff, community planning groups, the general public, and other appropriate groups.

2. Apply water quality protection measures to land development projects early in the process- during project design, permitting, construction, and operations-in order to minimize the quantity of runoff generated on-site, the disruption of natural water flows and the contamination of storm water runoff.
a. Increase on-site infiltration, and preserve, restore or incorporate natural drainage systems into site design.
b. Direct concentrated drainage flows away from open space areas. If not possible, drainage should be directed into sedimentation basins, grassy swales or mechanical trapping devices prior to draining into open space areas.
c. Reduce the amount of impervious surfaces through selection of materials, site planning, and street design where possible.
d. Increase permeable areas for new trees and restore spaces that have been paved, focused in areas with the greatest needs.
e. Increase the use of plants in drainage design.
f. Maintain landscape design standards that minimize the use of pesticides and herbicides.
g. Avoid development of areas particularly susceptible to erosion and sediment loss (e.g., steep slopes) and, where impacts are unavoidable, enforce regulations that minimize their impacts.
h. Apply land use, site development, and zoning regulations that limit impacts on, and protect the natural integrity of topography, drainage systems, and water bodies.
i. Enforce maintenance requirements in development permit conditions.
j. Increase the use of green infrastructure, both at watershed scale and site-specific locations.

3.Require contractors to comply with accepted storm water pollution prevention planning practices for all projects.
a. Minimize the amount of graded land surface exposed to erosion and enforce erosion control ordinances.
b. Continue routine inspection practices to check for proper erosion control methods and housekeeping practices during construction.

4.Continue to participate in the development and implementation of Water Quality Improvement Plans for water quality and habitat protection.

5. Assure that City departments continue to use "Best Practice" procedures so that water quality objectives are routinely implemented.
a. Incorporate water quality objectives into existing regular safety inspections.
b. Follow Best Management Practices and hold training sessions to ensure that employees are familiar with those practices.
c. Educate City employees on sources and impacts of pollutants on urban runoff and actions that can be taken to reduce these sources.
d. Ensure that contractors used by the City are aware of and implement urban runoff control programs.

e. Serve as an example to the community-at-large.

6. Continue to encourage "Pollution Control" measures to promote the proper collection and disposal of pollutants at the source, rather than allowing them to enter the storm drain system.
a. Promote the provision of used oil recycling and/or hazardous waste recycling facilities and drop-off locations.
b. Review plans for new development and redevelopment for connections to the storm drain system.
c. Follow up on complaints of illegal discharges and accidental spills to storm drains, waterways, and canyons.

7. Manage floodplains to address their multi-purpose use, including natural drainage, habitat preservation, and open space and passive recreation, while also protecting public health and safety.

Blueprint SD can be considered a good example of a development plan that tackles the complexity of the city system of San Diego since it thoroughly covers the different aspects to achieve sustainable development and provides a wide set of flexible solutions.

7.3 Water system in the city

The city of San Diego purchases approximately 85% to 90% of its water, which is imported mainly from Northern California and the Colorado River (City of San Diego 2024d) (see Figure 36). Even though most of the water comes from outside the city and the county (the County estimates 80% of its water comes outside the county), San Diego tries to have their water supply from multiple sources (San Diego County Water Authority 2020a). This creates a great vulnerability making the city not water autonomously and rely upon complex water systems that can fail and severely damage the supply in the city.

The California Department of Water Resources which is also the water regulator of the state is responsible for the operation of the water system at the state level which includes the State Water Project (SWP), the nation's largest state-built water conveyance program. The SWP supplies water to almost 27 million Californians and 750,000 acres of farmland. The system spans more than 700 miles from Northern California to Southern California and includes 36 storage facilities, 21 pumping plants, 26 dams, 5 hydroelectric power plants, 4 pumping-generating plants, and approximately 700 miles of canals, tunnels, and pipelines. In addition to supplying high-quality water for California's cities, industries, and farms, the SWP also provides flood control, hydroelectric power generation, recreational opportunities, and ecosystem enhancements to protect fish and wildlife habitats (California Department of Water Resources 2024a). The regional contractor in Southern California of the State Water Project is the Metropolitan Water District of Southern California (MWDSC). It serves 26 public water agencies which include cities, municipal water districts and one county water authority. MWDSC delivers freshwater directly or indirectly to 19 million people in Los Angeles, Orange, Riverside, San Bernardino, San Diego, and Ventura counties. Its main attribution is to operate the Colorado River Aqueduct and work in stretch collaboration with the SWP and the local agencies.

To ensure a steady supply of freshwater the city had to adapt and transform their water culture and management. In 1990 the city experienced its last big water cut as a result of a severe drought season reducing up to 31% of its water supply, being a 20% reduction for urban water uses and 50% for agricultural uses (The San Diego County Water Authority 2023). This event was the spark that caused the transformation in the way the local government managed water and the consumption habits of its inhabitants (Naishadham 2022; The San Diego County Water Authority 2023). The main challenge was to ensure a safe and reliable freshwater supply. In 2003, the local county water authority cut a deal to get water from the single largest user of the Colorado River, the Imperial Irrigation District (a neighboring county east of San Diego) (The San Diego County Water Authority 2023). San Diego County funded repairs to leaky canals belonging to Imperial County and signed a historic water transfer deal. Currently, San Diego receives about 35% of its total supply from the Imperial Irrigation District as part of the deal (San Diego County Water Authority 2020a). In 2012, San Diego County signed a deal to get 10% of its water supply from the Carlsbad Desalination Plant.

Diversification of supply makes the water supply more resilient. In 2020 the water supply of San Diego County can be broken as follows: 35% of the Imperial Water District, 15% from Canal Lining, 11% from the Metropolitan Water District from Southern California, 10% from Local Surface Water, 10% from Seawater Desalination, 8% from recycled water, 6% from local groundwater, 3% from San Luis Rey water and 3% from potable water reuse (San Diego County Water Authority 2020a). The water system in San Diego can be considered diversified since no one water source represents more than 60% of the total water supply (Boryczko and Rak 2020). The only vulnerability is that the city relies heavily on sources outside their territory making it not fully autonomous in the administration of their water resources and relying only upon the signed agreements with other entities and their capacity to pay for the resource.

Fig. 36. Water system of San Diego. Source: Armando Cepeda Guedea, 2024

By 2020 San Diegans used 30% less water than in 1990 (Naishadham 2022). At the county level, the reduction is more evident at the county level where per capita water has declined 49% since 1990 (San Diego County Water Authority 2023). In 2022 the average residential consumption was 64 gallons (242.26 liters) per day per capita and 104 gallons (393.68 liters) per capita systemwide (Pacific Institute 2022). It is important to remark how still in 2024 San Diego local authorities still use the year 1990 as a reference to how they have progressed accentuating the impact of the 1990 drought in San Diegan's psyche.

Ensuring the water supply from sources outside the city and the county represents a considerable economic burden on the water bills of the citizens. San Diego County's water is among the most expensive in the United States, costing about 26% more at the wholesale level in 2021 than the water in Los Angeles County (Naishadham 2022). The base fee in the City of San Diego is 24.11 US Dollars per month (City of San Diego Public Utilities 2023). For billing purposes, the Public Utilities Department measures water used by hundred cubic feet (HCF), the price of each HBC is not fixed and varies on the number of units consumed. Putting as an example an average household in San Diego inhabited by 3 persons (the average number of persons per household according to the US census in the city of San Diego is 2.59 (US Census Bureau 2024b)) and the average residential consumption is 64 gallons per day per capita (Pacific Institute 2022). This means 5760 gallons per month and 7.70 HCFs. This falls in the range of 6 - 11 HCFs used and is billed at $6.89 per HCF. It is estimated that an average household in the city of San Diego will pay 77.16 USD per month in their water bill in 2024. The high costs of water alongside water-sensitive practices such as more efficient showers, toilets and taps, rebates to tear out grass and the use of recycled water have significantly reduced the consumption of water in the city.

7.4 Regulatory instruments for water security

The United States as a federal republic provides broad autonomy to the states in various aspects including water management (Berman 2020). Nevertheless, states must follow some guidelines and standards established by federal laws and enforced by federal agencies such as EPA (United States Environmental Protection Agency) (EPA 2023). The main federal law for water management in the US is the Safe Drinking Water Act (SDWA) a law that was originally passed by Congress in 1974 to protect public health by regulating the nation's public drinking water supply and was amended in 1986 and 1996. SDWA authorizes EPA to set national health-based standards for drinking water to protect against both naturally occurring and man-made contaminants that may be found in drinking water. EPA, states, and water systems work together to make sure that these standards are met. It is important to note that the last amendment of the law was in 1996 which can be considered outdated and not fitted with the current water needs. The EWG asserts that the federal government's legal limits may not be health protective, as some standards have not been updated for almost 20 years, and others are more than 40 years old (EWG 2021).

EPA also establishes The National Primary Drinking Water Regulations (NPDWR) which are legally enforceable primary standards and treatment techniques that apply to public water systems (EPA 2024b). Primary standards and treatment techniques protect public health by limiting the levels of contaminants in drinking water. From the primary drinking water regulations emerge the Secondary Drinking Water Regulations are guidelines to help public water systems manage their drinking water for issues not related to health, such as taste, color, and smell. Although some contaminants may not be harmful to public health, if they are in the water at levels above the standards, they can cause the water to look cloudy or colored, or to taste or smell bad.

The state-level policy for water management depending on the state can be just following the federal guidelines and recommendations or going further and developing their water policy framework adapted to the needs and objectives of the state to use more efficiently and their water resources. The state of California government is aware of the challenges they face to ensure a safe and reliable freshwater supply in the context of severe droughts and a considerable reduction of precipitation mainly in the Southern Coast hydrological region where the cities of San Diego and Los Angeles are located, two of the main cities of the state (California Department of Water Resources 2023).

State water laws play a prominent role in both statewide and regional water allocations and usage. The California Water Code is the main legal framework in the state of California for water management (California State Legislature 2024). The Code covers a wide range of topics related to water management in the state divided into 35 divisions. The code regulates the state's powers over water, water management institutions at the sub-state level, water quality, water sources preservation and use, flood protection, sustainable use of water, water planning requirements and guidelines, financial criteria, and water shortage management. The California Code is a step forward in law-making for a sustainable regional water system in a context where environmental challenges threaten the water availability in the state. The code stimulates a change in the water culture by aiming to reduce water consumption, use innovative technologies to ensure the supply and develop instruments to be better prepared and more resilient in case of water shortages, severe droughts, and floods among other events that can affect the normal water supply.

The state of California has long been at the forefront of water conservation at the national and international levels, becoming the first state to adopt urban water use efficiency targets in 2009. The Water Conservation Act of 2009 aimed to achieve a 20 percent reduction in urban per capita water use by 2020 (California Department of Water Resources 2018). However, the effects of climate change are hitting harder than expected in an already vulnerable state to climate change with longer droughts, destructive wildfires, more intense floods, reduction of precipitation and shrinking snowpack (World Economic Forum 2022). With the passing of the years, it became clear to decision-makers and civil society that California needed to do more to make our water go as far as possible. In 2018, new landmark water conservation legislation was signed into law with the new 2018 California Water Conservation Act which lays out a new long-term water conservation framework for California (California Department of Water Resources 2018). This law proposes a new far-reaching framework for both the urban and agricultural sectors and represents a major shift in water management in the state. Programs and initiatives are organized around four primary goals which are: to use water more wisely, eliminate water waste, strengthen local drought resilience, and improve agricultural water use efficiency and drought planning. This legislation provides a road map to ensure the water supply now and, in the years, ahead. Planning for the long term but still in a flexible and adaptive way is key for the future of water management.

Required by the Water Code the state has to present a strategic plan for sustainably managing and developing water resources for current and future generations. This plan should be renewed every 5 years with the intention to have an updated document that can effectively respond to the water management in California (California Department of Water Resources 2023). The plan presents the status and trends of California's water-dependent natural resources; water supplies; and agricultural, urban, and environmental water demands for a range of plausible future scenarios. The document provides an instrument for the different stake holders to collaborate on findings and recommendations and make informed decisions regarding California's water future. The current version was presented in 2023 and is expected to be renewed in 2028.

Arriving at the county level is when urban water management gains priority. San Diego County has its own Urban Water Management Plan in concordance with the state regulations and policies. The current plan was published in 2021 by the San Diego County Water Authority and serves as a long-term planning document that helps to ensure a reliable water supply for the county and its cities (San Diego County Water Authority 2021a). The document first introduces the context of the county and some basic characteristics of the water system. Secondly, it explains the water demand for the county and the projections for the future. The next section presents the water demand management with the intention manage most efficiently the water resources of the county by promoting water-use efficiency programs and increasing the reliability of the San Diego region's water supply through diversifying its water supply portfolio, all of this from a long-term perspective. The fourth section describes the water system supplies, the ones managed directly by the San Diego County Water Authority, the ones managed at the state levels, and the ones locally managed by the city's local water agencies. The next section describes the monitoring criteria for water quality.

An important part of the plan is the Integrated Regional Water Management (IRWM) planning which involves coordinating and integrating water planning activities in the region to improve and maintain the water supply reliability and water quality. IRWM planning recognizes that water supplies, water quality and natural resources are connected, and as such, focuses on projects that produce multiple benefits in those areas. Intending to ensure the reliability of the freshwater resources in the county the plan presents reliability assessments considering a series of scenarios from 2025 through 2045. Each assessment compares the total projected water supply and demands over the next 20 years in five-year increments under the following scenarios: normal water year, single dry-year and multiple dry-year. The plan also considers how to manage uncertainty in water management and incorporates a traditional scenario-based planning process. This process assesses potential risks associated with the implementation of projected resource mixes and identifies management strategies to help address potential uncertainty. Critical uncertainties surrounding the implementation of the mix were identified and evaluated.

The Water Authority's five potential scenarios are developed based on supply uncertainties as listed: climate change, demographic shift, drought, drought with further limitations on metropolitan supplies, and drought with limited metropolitan supplies and member agency local supplies. The scenario planning process includes the establishment of key tracking criteria to evaluate the status of water supply sources in the projected resource mix. These metrics are used to determine whether adaptive management strategies are required to ensure continued reliability. Finally, the plan considers potential actions the Water Authority could take to address water supply shortages due to a catastrophe, drought, or other factors. It also highlights elements of the Water Shortage Contingency Plan (WSCP) at the county level, including actions to be taken in response to various water shortage levels and the process to perform an annual water supply and demand assessment. The WSCP serves as San Diego County's guiding shortage management document and includes information on the context in drought planning documents, the process to prepare an annual water supply and demand assessment, the shortage supply matrix and response level triggers, the supply allocation methodology, and the model drought response ordinance.

The California Water Code establishes that local urban water suppliers should prepare, adopt, and submit an Urban Water Management Plan (UWMP). The UWMP of the city of San Diego must describe the water supplier's service area, water demands and supplies, water conservation activities, and assess the reliability of water sources over a 20-year planning time frame. The current 2020 plan emphasizes a cross-functional approach that is intended to better guide and integrate any subsequent water resources studies, facilities master planning, and various regulatory reporting and assessment activities at the city, regional and state levels going beyond a basic profiling of the City's water system (City of San Diego Public Utilities 2021). The city developed the 2020 version of the plan with the following implementation goals. The first one is to develop a credible and balanced 20-year projection of water demand supported by the latest geographic information system and land use data sets. The second one is to update and improve the water demand forecast in the plan with a better statistical Water Use Factor data set and improve geospatial water use profiles and projections in the city. The third one is to adopt and integrate a Water Shortage Contingency Plan (WSCP) which provides a consecutive five-year Drought Risk Assessment of water reliability and includes a framework to support the development of new requirements for Annual Water Supply and Demand Assessments, this aspect is very relevant for the research purposes because it considers water shortage management at the city level. Finally, the fourth one is to utilize and build on the city's sustainability department's climate action plan. Considering water management inside a bigger climate strategy is key to affront the climate emergency in a more effective way. Also putting on light the critical role of water in the sustainable development of cities.

7.4.1 Water operator and management approach

The United States Environmental Protection Agency (EPA) is the federal agency that regulates the nation's public drinking water supply, as the enforcer of the Safe Drinking Water Act (SDWA). EPA was established in 1970 to merge key anti-pollution programs into an environmental protection administration as a new independent agency of the executive branch of the US government (EPA 2024a). EPA sets the national standards for drinking water. In addition to the establishment of drinking water standards, EPA regulations identify methods and schedules by which contaminants must be analyzed and tested. As long as state standards are at least as stringent as federal standards, states can promulgate their drinking water regulations. EPA also provides a series of studies, reports guidelines and good practices on water management that institutions at the local and the state level can use as reference.

In the state of California, the main water regulator responsible for enforcing the state water code is the Department of Water Resources (DWR), established in 1956 after being approved by the California State Legislature. Its main functions are to protect, conserve, develop, and manage much of California's water supply (California Department of Water Resources 2024a). The department's main functions are: overseeing the statewide process of developing and updating the California Water Plan, planning, designing, constructing, operating, and maintaining the state water infrastructure, regulating dams, providing flood protection, and assisting in emergency management, working to preserve the natural environment and wildlife, educating the public about the importance of water, water conservation, and water safety, providing grants and technical assistance to service local water needs, and collecting, analyzing, and reporting data useful to manage and protect California's water resources. DWR has a double function to regulate and operate the water resources in the state.

The San Diego County Water Authority (SCWA) founded in 1944 is the public entity responsible for delivering a safe and reliable freshwater supply to the 23 local water agencies, including cities, special districts and a military base (San Diego County Water Authority 2020b). The state of California delegates the SCWA to administer the region's water rights and import water from other counties, regions and water systems to fulfil the local demand for water. SWA plans and works from a long-term approach by constantly diversifying its water supply sources, promoting fiscal and environmental responsibility, major infrastructure investments and adopting innovative technologies. These strategies aim to enhance the reliability of the region's water supply for decades to come in a context of uncertainty due to the climate change emergency and urbanization processes in the county.

The city of San Diego is the biggest local water agency in the county serving approximately 1.3 million people. The City's Public Utilities Department is the local regulator and the direct provider of freshwater to the city inhabitants. The department is the one that directly bills and regulate the price of water to citizens (City of San Diego 2024c). The department with the objective to provide a better and more reliable freshwater supply collaborates with other agencies and regional partners and maximizes the potential of the local sources. The City of San Diego owns, manages and regulates nine surface water reservoirs. The reservoirs capture local runoff from rainfall and store purchased imported water that is sent to the City's three water treatment plants for treatment and distribution. Every year the Public Utilities Department publish its annual water report provides information on drinking water and how it compares to state standards.

7.4.2 Innovation practices for water security

In 2012, San Diego County signed a deal to get 10% of its water supply from the Carlsbad Desalination Plant for the next 30 years, which is the largest, most technologically advanced and energy-efficient seawater desalination plant in the United States, considered an innovative approach to face water shortage (Carlsbad Desalination Project 2024). The plant produces 50 million gallons of drinkable water every day enough for about 400,000 people and is by far the region's most expensive water source (Carlsbad Desalination Project 2024; Naishadham 2022).

7.4.3 Communication strategies to raise awareness of water security

To ensure a steady supply of freshwater the city had to adapt and transform their water culture and management. In 1990 the city experienced its last big water cut as a result of a severe drought season reducing up to 31% of its water supply, being a 20% reduction for urban water uses and 50% for agricultural uses (The San Diego County Water Authority 2023). This event was the spark that caused the transformation in the way the local government managed water and the consumption habits of its inhabitants (Naishadham 2022; The San Diego County Water Authority 2023). Water-sensitive practices such as more efficient showers, toilets and taps, rebates to tear out grass and the use of recycled water have significantly reduced the consumption of water in the city.

7.5 Water-related risks with respect to basin and urban link

According to the 2020 San Diego Climate Change Vulnerability Assessment, there are two main water related risks that affect the city, coastal hazards and change in the precipitation patterns (ICF and City of San Diego 2020). The 150 km of shoreline is critical to San Diego's economy, industry, and tourism. Coastal hazards wich includes coastal flooding and erosion are one of the most climate-related concerns for San Diego. Sea levels rose 21 cm in San Diego during the 20th century. San Diego could experience another 24 cm of sea level rise by 2030, 0.49 m to 0.73 m by 2050, and 1.09 to 3.10 meters by 2100, depending on the rate of climate change and how the world's oceans and glaciers respond. Rising seas levels boost the occurrence of severe floods. Elevating storm tides and rising sea levels makes it easier for waves to overtop natural barriers, increasing the relative frequency of flooding along the Pacific coast in cities such as San Diego. Coastal erosion has long been an issue in San Diego, affecting cliff areas in the city, as well as beaches. Ongoing erosion has required beach nourishment at certain locations to maintain beach width. Sea level rise and changes in storms are expected to increase coastal erosion in the city. Precipitation-driven hazards have been a historical concern for the San Diego region. Projections expect more variability in rainfall from year to year and more intense transitions between droughts and deluges. Some areas of San Diego already suffer from severe floodings when there are heavy rainfall events. This requires better run off management to adapt to this new reality.

In an interesting overlap between the county and state level comes the Regional Water Management Group (RWMG) formed by The San Diego County Water Authority, the City of San Diego, and the San Diego County but which also includes and collaborates with the neighboring regions of Upper Santa Margarita, and South Orange County, forming the San Diego Funding Area (San Diego Integrated Regional Water Management 2024). The RWMG funds, guides, and manages the development of the different water resources in the area through its main instrument called the Integrated Regional Water Management Plan (IRWMP) which is a document result of a collaborative effort aimed at developing long-term water supply reliability, improving water quality, and protecting natural resources. The Statewide IRWM Program is supported by bond funding provided by the California Department of Water Resources (DWR) to fund competitive grants for projects that improve water resources management. IRWMP is collaboratively developed by water retailers, wastewater agencies, stormwater and flood managers, watershed groups, the business community, tribes, agriculture, and non-profit stakeholders to fund and develop high-priority water management projects. The San Diego IRWM Program began in 2005 and until 2022 has received approximately 132 million USD, which has funded 84 projects (San Diego Integrated Regional Water Management 2024). The current 2019 plan provides a mechanism for 1) coordinating, refining and integrating existing planning efforts within a comprehensive, regional context; 2) identifying specific regional and watershed-based priorities for implementation projects; and 3) providing funding support for the plans, programs, projects and priorities of existing agencies and stakeholders. This document is key for regional development considering that water resources are beyond administrative limits and effective water management has to aim to collaborate with the neighboring regions to ensure a safe and reliable supply (San Diego Integrated Regional Water Management 2019).

7.6 Indicator Framework to Evaluate Water Security

Table 60: Water Security evaluation for San Diego

Economic Water security		Units	Ranges					Sources
Indicator	Subindicator		1	2	3	4	5	
Cost efficency of the service		%	44%					San Diego Public Utilities (2024)
Non revenue economic water losses		USD/m3	0.07					San Diego Public Utilities (2024)
Investments		USD				126.67		San Diego Public Utilities (2024)
Payment collections efectiviness		%		94.90%				San Diego Public Utilities (2024)
Operating expense ratio		%		69%				San Diego Public Utilities (2024)
Debt ratio		Unit			1.47			San Diego Public Utilities (2024)

Environmental Water Security		Units	Ranges					Description
Indicator	**Subindicator**		1	2	3	4	5	
Quality level of wastewater discharge to the environment		%		80%				San Diego Public Utilities (2017)
Storm water discharge		%	85%					San Diego Public Utilities (2015)
Sludge management		%	100%					California Water Boards (2024)
Green areas		%				8.38%		City of San Diego (2024)
Blue areas		%			13.57%			San Diego Public Utilities (2024)
Quality of potentail available surface freshwater		%	100%					California Water Boards (2024)
Sustainability planning	Habitat/watershed protection goals	Unit		High implementation				San Diego Integrated Regional Water Management (2024)
	Green infrastructure planning	Unit		High implementation				San Diego Public Utilities (2024)
	Energy optimization planning	Unit	Very High implementation					San Diego Public Utilities (2024)
Basin planning instrument		Unit		High implementation				San Diego Integrated Regional Water Management (2024)

Resilience to water-related disasters		Units	Ranges					Description
Indicator	**Subindicator**		1	2	3	4	5	
Overall Water Risks	Physical Risks Quantity	Unit					Extremely high	WRI Aqueduct 4.0 (2024)
	Physical Risks Quality	Unit		Low Medium				WRI Aqueduct 4.0 (2024)
	Regulatory and Reputational Risk	Unit	Low					WRI Aqueduct 4.0 (2024)
Risk assessment and response preparedness	Risk assessment and response preparedness	Unit	Very High implementation					Literature Review
	Water shortage planning	Unit	Very High implementation					Literature Review

Urban Water security		Units	Ranges					Description
Indicator	**Subindicator**		**1**	**2**	**3**	**4**	**5**	
Water Metering Coverage		%	100%					San Diego Public Utilities (2024)
Network size	Freshwater	Meters of pipeline/inhabitant				3.82		San Diego Public Utilities (2022)
	Wastewater	Meters of pipeline/inhabitant			3.48			San Diego Public Utilities (2022)
	Stormwater	Meters of pipeline/inhabitant				1.28		ThinkBlue (2024)
Water Treatment Capacity	Freshwater	%	100%					San Diego Public Utilities (2022)
	Wasterwater	%	100%					San Diego Public Utilities (2022)
Water storage		Days					0.39 days	San Diego Public Utilities (2021)
Energy consumption		%	6.90%					San Diego Public Utilities (2024)
Renewable energy use		%		36%				City of San Diego (2022)
Green house emissions		GHE per capita			7.4			City of San Diego (2022)
Rainwater collector units		Number of units					ND	
Power failures		Hours	0					City of San Diego (2024)
Water quality		%	100%					San Diego Public Utilities (2022)
Water demand and supply ratio		units	1					San Diego Public Utilities (2022)
Average age of the pipelines	Freshwater	years		39				San Diego Public Utilities (2024)
	Wastewater	years		39				San Diego Public Utilities (2024)
Data availability		units		High				Literature Review
Maintenance		%				1.68%		San Diego Public Utilities (2022)
Water losses		%	7.40%					City of San Diego (2020)
Staff levels		Number of employees/ 1000 connections				0.57		San Diego Public Utilities (2024)
Diversity of the sources in local supply system		%					14.90%	City of San Diego (2022)
Recycled water use		%		8%				San Diego County Water Authority (2020)
Stakeholder participation		Unit		High implementation				Literature Review
Integrated Water Management plan		Unit	Very High implementation					Literature Review

Household Water security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Freshwater consumption		liters		241.92				Pacific Institute (2022)
Water quality reports		number of reports /1000 inhabitants	0*					City of San Diego (2022)
Bulk water delivery		%	0%					San Diego Public Utilities (2024)
Interruptions to the service		outages/1000 inhabitants outages/reductions/year	0					San Diego Public Utilities (2024)
Metering efficency		% of unmetered water			2.44%			City of San Diego (2011)
Service coverage	Freshwater	%	100%					San Diego Public Utilities (2024)
	Wastewater	%	100%					San Diego Public Utilities (2024)
Service complaints		number of reports /1000 inhabitants	4.07					City of San Diego (2022)
Service efficiency		%					79%	City of San Diego (2022)
Billing issues		%			2%			City of San Diego (2022)
System failures	Reported leaks	number of reports /1000 inhabitants	0.02					City of San Diego (2020)
	Reported sewerage fails	number of reports /1000 inhabitants	0.089					City of San Diego (2020)
	Reported stormwater overflows	number of reports /1000 inhabitants					3.73	City of San Diego (2022)
Water pressure		psi	80					San Diego Public Utilities (2024)
Affordability of the service		%	1.14%					San Diego Public Utilities (2024)
Low-income billing assistance offered		units					Very low implementation	San Diego Public Utilities (2024)

7.7 Performance per dimension of water security

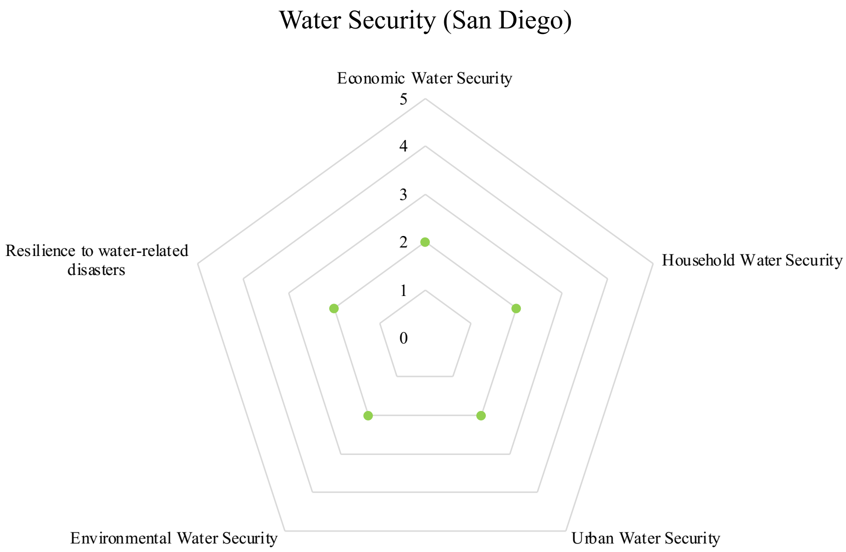


Fig. 37. Water security performance by dimension in San Diego. Source: Armando Cepeda Guedea, 2024

The indicator framework for water security shows overall stable levels regarding water security in San Diego since every dimension shows low concern levels (see Figure 37). The extreme weather conditions that the city experiences could represent a big challenge for water security, but thanks to vanguard water culture, water planning, and water shortage management with a clear reduction of water consumption in the last decades, and the use of more innovative alternative water sources such as recycled water and desalinized water the potential risk of water collapse in the city has been correctly stabilized allowing the city to thrive. San Diego represents an example of how cities can adapt to the climate and water crisis. Nevertheless, all these actions have represented high economic costs reflected in a high-water bill that cannot be easily assumed by vulnerable populations.

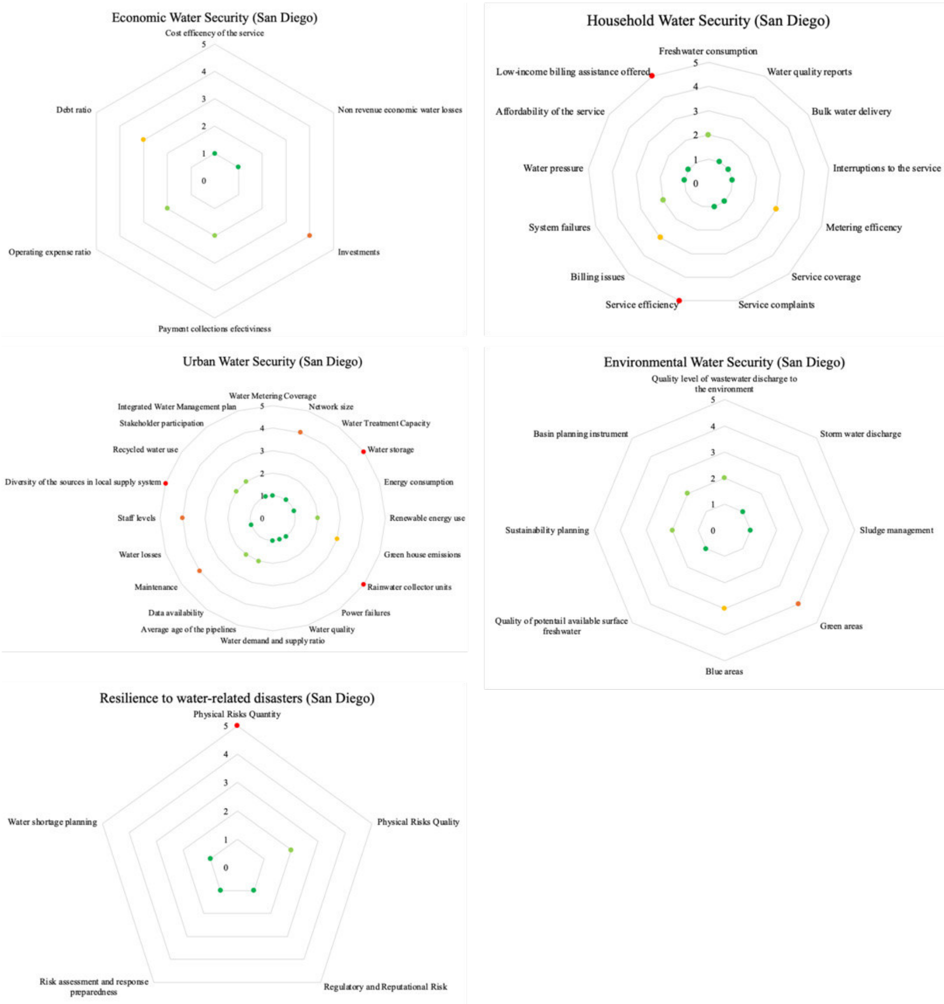


Fig. 38. Water security performance by indicator in San Diego. Source: Armando Cepeda Guedea, 2024

Economic water security: San Diego optimally performs on the cost efficiency of the service and non-revenue economic water losses. Regarding operating expense ratio and payment collection effectiveness, it performs adequately. Having indicators performing optimally or adequately reflects an overall good financial management of the water operator in the city. This overall good economic performance has as counterpart moderately concerning levels of debt. Finally, the levels of investments are concerningly low compared to the needs of the city; this may require more state and federal funding since continuing to increase the water bills is not sustainable for the long term.

Household Water Security: Household water performance reflects mostly optimal values, such as a good quality of water service and high levels of welfare in the city. Since the end of the low-income assistance program to cover the high costs of water bills in 2024, the vulnerable populations may struggle to cover the water bills, and their quality of life can be reduced. Also, the service efficiency, meaning the response time to resolve water service-related issues, is considerably inefficient; this requires more staff and more efficient customer service. Related to customer service, billing issues represent a moderate concern accompanied by metering efficiency.

Urban Water Security: San Diego has, in general, good or optimal levels of urban water security as a result of more than 30 years of an ambitious, coordinated policy to achieve water security. The main concerns regarding water security in San Diego are the low levels of already treated water storage, public-funded rainwater collection units, and low levels of water source autonomy. Also, important concerns are the low staff levels and maintenance very linked to low levels of investment and customer service efficiency.

Environmental Water Security: San Diego has overall well handled the environmental dimension of water security, only falling low in the levels of permeable green and blue areas. This again reflects the efforts of the city to provide sustainable environmental-wise water service.

Resilience to water-related disasters: San Diego is located in a region with extreme high levels of water stress that directly affects the physical availability of the resource which requires considerable efforts to bring water from outside the city to satisfy the needs of its inhabitants. To compensate for this vulnerability, the city makes considerable efforts on quality and regularity risk reductions accompanied by a ambitus policy framework that addresses the multiple dimensions of water security, including water shortage management plans.

Chapter 8

Reggio Calabria

Reggio Calabria: Armando Cepeda Guedea, 2024.

8.1. Context analysis

Italy is a southern European country with High income that, since 1958, has been a member of the European Union. Italy is a unitary parliamentary republic divided into 20 regions (European Union 2024). The estimated population in 2023 is 58,851,000 and is on a decreasing trend being 3% lower than in the previous year. This decrease is more evident in the southern regions of the country like Calabria with more than 7% of the population loss respect from the previous year (ISTAT 2023b). Population decrease is one of the biggest challenges for Italy and the European Union. The GDP of the country is 2.04 billion USD and 34,776.4 GDP per capita (World Bank 2022). This makes Italy a very high-income country and is considered a first-world country. Italy is organized into four levels which are: national, regional, provincial/metropolitan city, and municipality.

The Calabria region is one of the 20 Italian regions and is located in southern Italy, extending for about 250 km with the Tyrrhenian and Ionian seas to the west and east, respectively (Zema, Nicotra, and Zimbone 2018). The population in the Calabria region in 2019 was 1,947,131 people representing 3.2% of the total population in Italy. The region is divided into 5 provinces with Catanzaro as the capital of the region. Approximately 31.7% of the population resides in the five provincial capitals and in the municipalities of Corigliano-Rossano, Lamezia Terme and Rende (ISTAT 2020). The median income per inhabitant in Calabria is 14,973 Euro which is far below the Italian average 25,272 Euro (ISTAT 2020). The Calabrian region is generally considered an underdeveloped region in the Italian context and also among the other southern Italian regions.

Reggio Calabria is a city in southern Calabria region and is the capital of the Metropolitan City of Reggio Calabria (previously the province of Reggio Calabria) (see Figure 39). The city lies in the Strait of Messina which separates the Italian peninsula from Sicily by approximately 3 km. The municipality of Reggio Calabria has a population of 180,369 inhabitants and 522,127 in its metropolitan area (Istituto Nazionale di Stastica ISTAT, 2019). Reggio Calabria can be considered a metropolitan area using OECD standards (OECD 2013). The city median household income per capita is USD 12,456 for the Reggio Calabria municipality and USD 10,367 for the metropolitan city (ISTAT 2023a). The city before was divided into 15 constituencies which were sub-city entities composed of several neighborhoods to better manage city services. Currently, the local government is pushing to recover this figure.

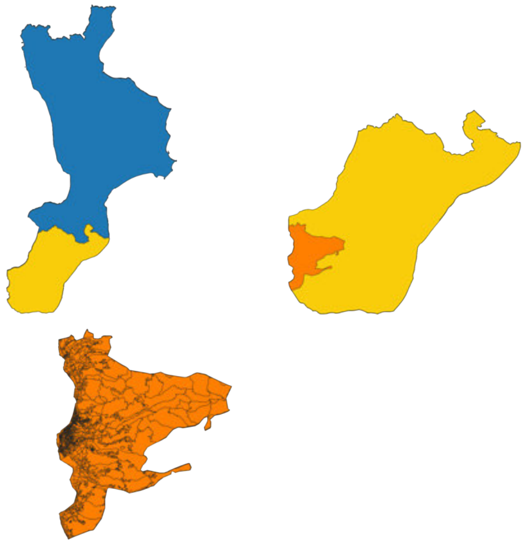


Fig. 39. Reggio Calabria's Context. Source: Armando Cepeda Guedea, 2024

The Calabria region is considered one of the most mountainous in Italy. Around 42% of the land is mountainous (elevation greater than 500 m), 49% is classified as hilly (elevation between 50 and 500 m), and only 9% has an elevation lower than 50 m (Caloiero et al. 2015). The municipality of Reggio Calabria has a territorial extension of 236.02 km2. It has an average altitude of 31 m due to its condition of coastal city (Comune di Reggio Calabria 2008). Reggio Calabria has a Mediterranean climate having a Csa Koopen climate classification similar to the one in San Diego (Beck et al. 2018).

Reggio Calabria is located in the Italy West Coast major basin and the Crati minor basin (Kuzma et al. 2023); due to the geographical conditions of Reggio and Italy, there is no intersection between major or sub-basins, making basin planning and management easier for the city (see Figure 40). The city of Reggio Calabria proposes seven watersheds (Comune di Reggio Calabria 2008) (Catona, Gallico, Torbido, Annunziata, Calopinace, Sant'Agata, and Valanidi) associated with the traditional torrents of the city (see Figure 41).

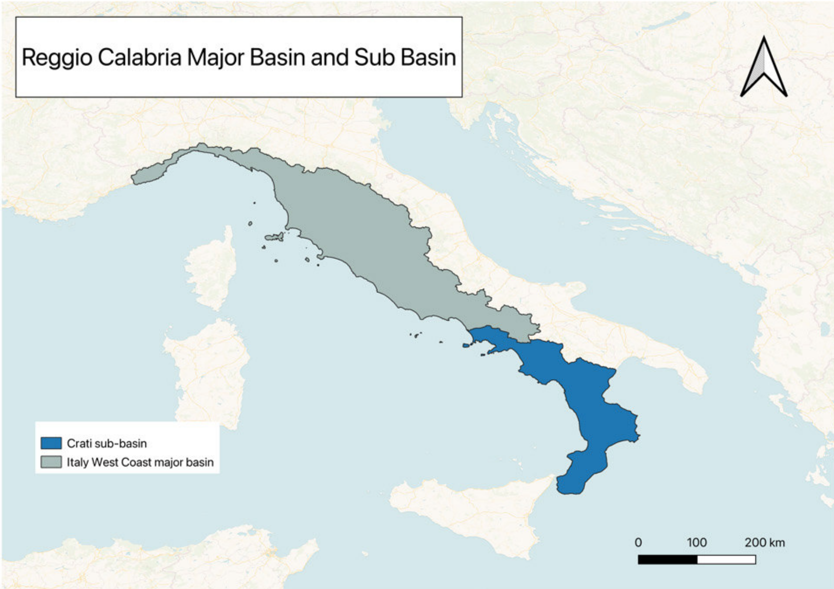


Fig. 40. Major basin and sub-basins for Reggio Calabria: Armando Cepeda Guedea, 2024

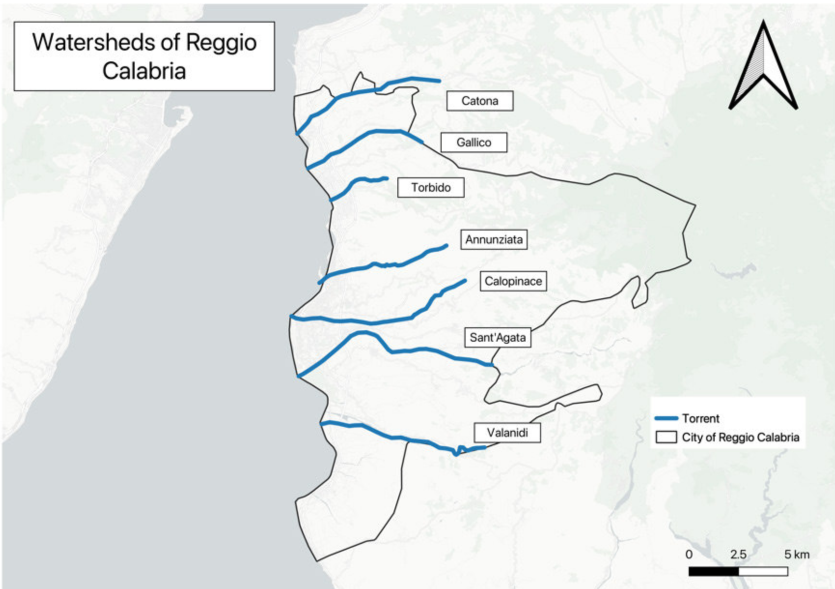


Fig. 41. Watersheds of Reggio Calabria. Source: Armando Cepeda Guedea, 2024

8.1.1 Water insecurity drivers from context analysis

The city of Reggio Calabria aims to become a modern, competitive city committed to the urban transition to a carbon-neutral city. As reflected in Development and Cohesion

Plan of the Metropolitan City of Reggio Calabria and the PON METRO funded projects in the city (PON METRO Reggio Calabria 2018; Città Metropolitana di Reggio Calabria 2021). Water security is an important issue for the city since Reggio Calabria is among the Italian cities that reduced or restricted the supply of fresh water to its inhabitants. The city lies in a region with extreme levels of water stress, although not fully acknowledged by local authorities, since there is still a perception of Reggio Calabria as a water-rich city. Water infrastructure vulnerability is also a big issue in the city since multiple leaks are reported during the year, the tap water in several districts of the city is not drinkable, water treatment capacity is not adequate, effluent quality still faces challenges, and there are not enough wells to provide water in some parts of the city. Climate change impacts and natural disasters such as earthquakes can affect the city's water supply. After a literature review and an active observation process, the research identifies six main drivers for the pursuit of water security in the City of Reggio Calabria: vulnerability of the infrastructure, high vulnerability to natural disasters, water scarcity, climate change, ensuring water quality, and institutional factors (see Figure 42).

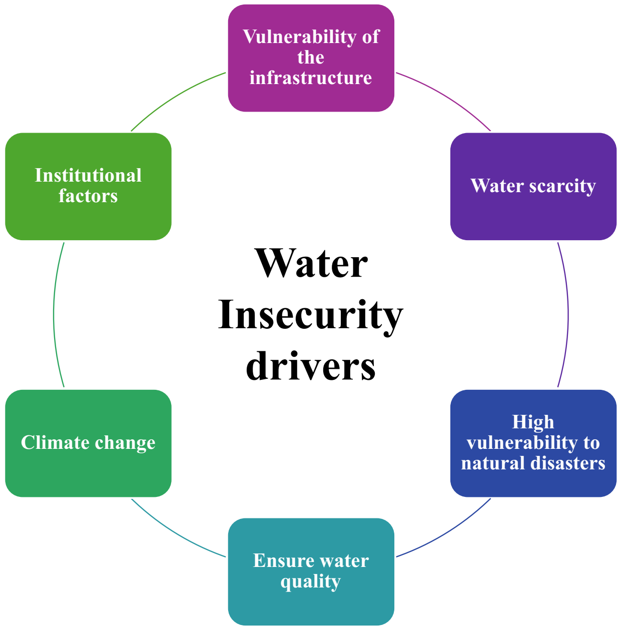


Fig. 42. Main water insecurity drivers for Reggio Calabria: Armando Cepeda Guedea, 2024

Vulnerability of the infrastructure: in the Calabrian region, 28.9% of the population is unsatisfied with the water service provided by the local governments (ISTAT 2022b). The platform "Segnaliamo Reggio Calabria" shows multiple reports regarding water leaks, low water quality, and problems with the sanitation network, among others (Comune di Reggio Calabria 2024). The current state of the water infrastructure endangers the safe and reliable water service in the city. Also, natural disasters such as earthquakes (Reggio Calabria lies in a high seismic area) can impact the regional water lines.

High vulnerability to natural disasters: Reggio Calabria is located in an area with very high seismic risk, which increases the possibility of collapse in case of an earthquake, cutting off water supplies in the region. Other natural disasters that the city is vulnerable to and can affect the water security in the city are landslides, floods, fires, tsunamis, and others (Comune di Reggio Calabria 2008).

Water scarcity: According to a report done by ISTAT Reggio Calabria in 2020 was among the Italian cities that reduced or restricted the supply of fresh water to its inhabitants, in the Calabrian context 28.9% of the population is unsatisfied with the water service provided by the local governments (ISTAT 2022). The report indicates that the city of Reggio Calabria reduced or restricted its water supply for 77 days in 2020 (ISTAT 2022). This means that for approximately 21% of the year 2020, the city of Reggio Calabria suffered from water shortages.

Climate change: The main source of fresh water in Calabria is groundwater, mainly coastal aquifers. The aquifers in the region are subject to risks of qualitative degradation, due to the effects of marine water intrusion and the pollution of the sources as a result of human activities, and to risks of quantitative degradation associated with the growing and often unsatisfied demand for water, which leads to the overexploitation of underground water resources, and also the impacts of climate change that is affecting the recharging of the aquifers due to the reduction of precipitations (Dramis and Mottana 2013).

Ensuring water quality: water quality is a relevant issue since multiple reports in the city point to issues with the water that arrives at households (Comune di Reggio Calabria 2024). In several districts of the city the tap water is not drinkable, and citizens have to rely on filters or bottled water (Naso, 2022; Loria, 2021; Iannello, 2022; Giusi, 2022). Lack of trust in the quality of water supply service in the city is considerable.

Institutional factors: the water system management in Reggio Calabria is complex since there are two main bodies that coordinate the integrated water service in the city (water operator and regulator). A water regulator prepares the regional water plan, collaborates in land planning, prepares the water tariff, elaborates the management agreement between the water operator and regulator, and updates the economic-financial plan, among other attributions. The water operator Sorical is a company controlled by the Calabria Region, which has been entrusted with the management, completion, modernization, and expansion of large-scale adduction, accumulation, and potable water schemes (Società Risorse Idriche Calabresi 2024b). Until 2022, it was composed of public-private capital; currently it is composed completely public by public capital. This means that the relevant decisions regarding the water service are taken in the regional capital of Catanzaro rather than in the city of Reggio Calabria. In countries such as Mexico and the United States, water regulators and operators are merged into one entity at the city level, making local water management easier and decision-making more straightforward. Increasing the challenges is the water institutional instability in the region, since 2017 the water regulator has changed twice, first in 2017 it was established the Calabrian Water Authority by regional law and then in late 2022 Arrical (Autorità Rifiuti e Risorse Idriche Calabria) replaced the Calabrian Water Authority and is currently the new regional governing body for the waste and water sector in the Calabria Region.

Despite the fact that the current regional water plan for the Calabria region was developed by the Calabrian Water Authority with a time horizon of 2033. Constant institutional changes don't allow medium and long-term planning, and the transition periods can provoke the loss of important resources and time to face water security challenges in the city.

8.2 Strategic vision for sustainable development and climate action

In 2021, the Development and Cohesion Plan of the Metropolitan City of Reggio Calabria was approved after an investment of 136 million euros from the Development and Cohesion Fund 2014-2020 for South Italy (Città Metropolitana di Reggio Calabria 2021). The plan aims to articulate the metropolitan territory, protect the environment, stimulate productive sectors, reduce inequalities, and help to reduce the gap between northern and southern cities. The plan is articulated in nine thematic areas (see Table 61). It is important to point out that the plan was designed at the metropolitan level not at the city level. This means that some of the specific needs of the city of Reggio Calabria might be lost. In the future a Development Plan at the city level may be pertinent since it provides a guiding instrument for the climate actions and sustainable development of the city.

Table 61: Cohesion Plan of the Metropolitan City of Reggio Calabria thematic areas

Thematic area	Description
Business Competitiveness	Interventions to support structures, investments and services for the competitiveness of businesses in all sectors, including the sectors of agriculture, tourism and cultural and creative businesses
Energy	Interventions aimed at increasing energy efficiency, also through the diffusion of renewable energy production systems and smart grids, networks and storage points equipped with intelligent technologies
Environmental and natural resources	Interventions aimed at protecting biodiversity, reducing pollution also through remediation of polluted sites, promoting adaptation to climate change and combating local risks, managing water resources, managing the waste cycle and valorising, also for development purposes of natural resources
Culture	Interventions for the protection and enhancement of cultural heritage, landscape and promotion of cultural activities
Transport and mobility	Interventions for the development of networks and services for the transport of people and goods in highways, rail lines, maritime and air, both with reference to the TEN-T networks and the routes and access nodes to the same, as well as for the promotion of regional mobility and sustainable urban and urban logistics

Urban requalification	Redevelopment interventions for infrastructure, buildings and public spaces aimed at hosting services and activities of collective interest, including regeneration of the suburbs, urban green infrastructures, structures for the promotion of sports practice, improvement of safety and legality of the places
Health and society	Interventions to promote access to social-welfare and health services, to promote the inclusion of vulnerable categories of the population, including people with foreign backgrounds and marginalized communities, to combat the risk of poverty and material deprivation, also through strengthening of dedicated infrastructures
Education and training	Interventions aimed at promoting the strengthening of education and training systems, access to skills, lifelong learning, also through the strengthening of educational and training infrastructures
Administrative capacity	Interventions aimed at increasing the technical capabilities of the Administration, including technical assistance aimed at supporting management, monitoring, controls, checks and evaluations of the interventions

The nine thematic areas have their 15 intervention sectors, achievement indicators, and result indicators (see Table 62). This framework helps to better allocate the assigned funding and prepare evaluation and monitoring mechanisms.

Table 62: Cohesion Plan of the Metropolitan City of Reggio Calabria thematic areas, intervention sectors and indicators

Thematic area	**Intervention sector**	**Achievement indicator**	**Result indicator**
Business Competitiveness	Industry and services	Number of companies involved	Attendance at the facilities involved
		Surface area subject to intervention	Percentage of population in relation to the number of total residents of the Municipality affected by projects/interventions for the revitalization of degraded areas for new or improved services and business activities
Energy	Energy efficiency	Buildings and public spaces with improved energy performance	Reduction in energy consumption of buildings and public spaces

	Renewal energy	Projects to produce energy from renewable sources	Total renewable energy produced
Environmental and natural resources	Risks and climate adaptation	Recently constructed or consolidated protective works against landslides or floods	Population benefiting from protection measures against climate-related natural disasters
		Interventions for the safety of school buildings	Population benefiting from protection measures against natural risks not related to the climate and risks caused by human activities
		Strategic/relevant works improved or adequate from a seismic point of view	
	Water resources	Length of new or renewed pipelines for public water supply distribution systems	Users served by public water supply networks built or improved
		Length of new or renewed pipelines for the public wastewater collection network	Users who use at least secondary public wastewater treatment plants
	Waste management	Interventions to strengthen and/or improve separate waste collection services	Percentage increase in users served by separate waste collection services
	Nature and biodiversity	Green infrastructures benefiting from support for purposes other than adaptation to climate change: surface area of habitats benefiting from an intervention aimed at achieving a better conservation status	Population that has access to new or improved green infrastructure
Culture	Heritage and landscape	Number of new or modernized cultural/tourist buildings and sites receiving support	% of buildings and sites of historical-artistic interest recovered and made usable or accessible again, out of those subject to intervention
			Number of potential users of new or modernized buildings, sites or cultural/tourist services

Transport and mobility	Street mobility	Number of new or modernized road infrastructure	Linear meters of new or modernized road infrastructure being worked on
	Urban mobility	Number of new parking areas	Number of new stalls created
Urban requalification	Buildings and public space	Number of urban redevelopment interventions	Square meters of surface affected by urban redevelopment interventions on public spaces and buildings
		Number of services offered in redeveloped public utility spaces and/or buildings	Number of users benefiting from the new or modernized services offered, in redeveloped public utility spaces and/or buildings
Health and society	Social structures	Number of childcare facilities subject to intervention	Number of users of new or modernized childcare facilities
Education and training	Social structures	Number of classes in new or modernized school facilities	Annual number of users in new or modernized school facilities
Administrative capacity	Reinforcement	Public bodies involved in the implementation and management of the intervention	Study and planning tools acquired
			Information and communication activities implemented
			Number of vehicles and supplies acquired
	Technical assistance	Technical assistance initiatives to support the Offices of the Program Authorities	Number of human resources employed

Climate action is a key aspect of the plan as reflected in the Environmental and natural resources thematic area since it is the one with more intervention sectors and associated indicators. Risks and climate adaptation have an intervention sector and five associated indicators. In this thematic area, water also has a specific intervention sector and for associated initiators. Energy key to climate action has a thematic area and an energy efficiency intervention sector with two associated indicators.

Following the review of the Development and Cohesion Plan of the Metropolitan City of Reggio Calabria, the next step is to explore how some of the plan's proposed indicators interact with the five dimensions of water security (see Table 63).

Table 63: Relationship between the Development and Cohesion Plan of the Metropolitan City of Reggio Calabria and Water Security Dimensions

Indicator	Water security dimension

Population benefiting from protection measures against climate-related natural disasters	Resilience to water-related disasters
Recently constructed or consolidated protective works against landslides or floods	Resilience to water-related disasters
Length of new or renewed pipelines for public water supply distribution systems	Urban Water Security
Length of new or renewed pipelines for the public wastewater collection network	Urban Water Security
Users served by public water supply networks built or improved	Household Water Security
Users who use at least secondary public wastewater treatment plants	Household Water Security
Green infrastructures benefiting from support for purposes other than adaptation to climate change: surface area of habitats benefiting from an intervention aimed at achieving a better conservation status	Environmental Water Security
Population that has access to new or improved green infrastructure	Environmental Water Security

The Development and Cohesion Plan of the Metropolitan City of Reggio Calabria, with its indicators, is related to four dimensions of water security: Household Water Security, Environmental Water Security, Urban Water Security and Resilience to water-related disasters. The missing dimension (Economic Water Security) is delegated to the local water operator. The development plan has a gap in the economic dimension of water security since it doesn't consider the economic health of the water operator as a relevant aspect in the sustainable development of the city. Again the gap between land planning and water planning is evident.

8.3 Water system in the city

Sorical, the main water operator for the Calabria region on behalf of the Calabrian Governing Operating Body distributes approximately 270 million cubic meters of water every year through 160 aqueduct lines (see Figure 43). These lines are divided into interprovincial, inter-municipal and municipal. The freshwater is extracted from wells, springs, and surface water sources. After a treatment process, the water is transported by approximately 6000 km of pipelines and delivered to the approximately 900 tanks managed by Sorical and 100 managed by municipal services. Due to the particular morphology of the Calabrian territory, the transport of freshwater requires the use of lifting systems and over 2600 supply nodes. To power the electric pumps of the 400 wells and approximately 300 lifting systems, Sorical uses approximately 175 GWh of electricity every year (Sorical 2024a). This represents a vulnerability of the water system but also an opportunity to use more renewable energy sources to power the system.

The "Menta Dam" since the end of labors in 2021 has become the main source of freshwater for the metropolitan city of Reggio Calabria in an attempt by the national government to increase the water security for the city of Reggio Calabria (Direzione generale per le dighe e le infrastrutture idriche 2022). The dam is managed by Sorical who partially financed the project. It is located in the national park of the "Aspromonte" in the Metropolitan City of Reggio Calabria it has a basin of 14km and a capacity of approximately 18 million cubic meters. The renovation of the pipeline system allows to provide of between 500-700 l/s to the city (Direzione generale per le dighe e le infrastrutture idriche 2022; Sorical 2024b). Even though of the notorious advances the city of Reggio Calabria still faces challenges in providing a safe and reliable freshwater service. According to a report done by ISTAT Reggio Calabria in 2020 was among the Italian cities that reduced or restricted the supply of fresh water to its inhabitants, in the Calabrian context 28.9% of the population is unsatisfied with the water service provided by the local governments (ISTAT 2022). The report indicates that the city of Reggio Calabria reduced or restricted its water supply for 77 days in 2020 (ISTAT 2022). This means that for approximately 21% of the year 2020, the city of Reggio Calabria suffered from water shortages. This vulnerability can be aggravated in vulnerable and peripheral neighborhoods. This situation may be associated with the poor local water infrastructure to provide water for the different neighborhoods in the city.

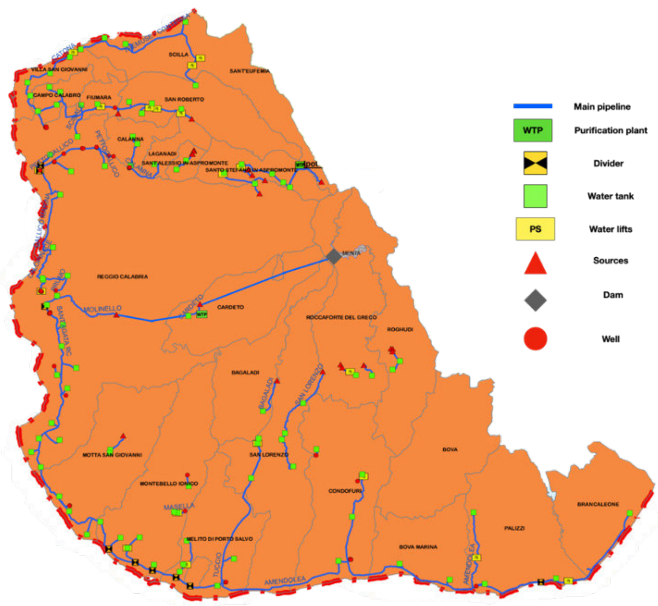


Fig. 43. Water system of Reggio Calabria. Based on the work of (Sorical 2024)

According to a report done by ISTAT Reggio Calabria in 2020 was among the Italian cities that reduced or restricted the supply of fresh water to its inhabitants, in the Calabrian context 28.9% of the population is unsatisfied with the water service provided by the local governments (ISTAT 2022). The report indicates that the city of Reggio Calabria reduced or restricted its water supply for 77 days in 2020 (ISTAT 2022). This means that for approximately 21% of the year 2020, the city of Reggio Calabria suffered from water shortages. This vulnerability can be aggravated in vulnerable and peripheral neighborhoods. This situation may be associated with the poor local water

infrastructure to provide water for the different neighborhoods in the city. Regarding water consumption, the average per capita consumption in the city of Reggio Calabria is approximately 181L (Istituto Superiore per la Protezione e la Ricerca Ambientale 2016), which means that the consumption falls within optimal levels of consumption (150L-200L); this can be associated that due to constant cuts of the water service the population has become more water wise.

Considering an average household of three people with an average consumption of 182 m3 per year, the average water bill for Italy is 406 Euros (Cittadinanzattiva 2024b). The Calabrian region's average water bill is 349 Euros, below the national average. In the case of the city of Reggio Calabria, the average annual water bill is 427 Euros, above the national average (Cittadinanzattiva 2024a). The water bill of Reggio Calabria is considerably high in comparison to cities such Milan and Cosenza, which are the ones with the lowest fares at 184 Euros (Cittadinanzattiva 2024b). The affordability of the water service in Reggio Calabria is a concern because the water bill represents 3.78% of the median household income, above the threshold of 3% of adequate affordability of the service.

To increase the affordability of water services, low-income assistance has been implemented in Italy called "Bonus Idrico". In the case of a household of three people with an income of 9,530 Euros who has access to the social bonus, it can save around 104 euros annually (Cittadinanzattiva 2024b), approximately 24% of savings in the case of Reggio Calabria. Despite this discount, the water service bill still represents over 3% of the median household income (3.33%). To face these challenges, there should be a combined strategy to reduce poverty and the water bill in the city.

8.4 Regulatory instruments for water security

The European Union presents the EU Water Framework Directive (WFD) that establishes a legal framework to protect and restore clean water in the EU and to ensure its long-term sustainable use (European Parliament 2023). It is complemented by more specific legislation, such as the Drinking Water Directive, the Bathing Water Directive, the Floods Directive and the Marine Strategy Framework Directive, as well as by international agreements between member states.

The EU Water Framework Directive establishes a framework for the protection of inland surface waters, transitional waters, coastal waters, and groundwater. It aims to prevent and reduce pollution, promote sustainable water use, protect and improve the aquatic environment and mitigate the effects of floods and droughts. The overall objective is to achieve good environmental status for all waters (European Parliament 2023). Member States are therefore requested to draw up so-called river basin management plans based on natural geographical river basins, as well as specific programs of measures to achieve the objectives (European Parliament 2023).

The revised Drinking Water Directive of 2020 defines essential quality standards for water intended for human consumption (European Parliament 2023). It requires Member States to regularly monitor the quality of water intended for human consumption by using a 'sampling points' method. Member States can include additional requirements specific to their territory but only if this leads to setting higher standards. The directive also requires the provision of regular information to consumers.

Sustainable development is a core objective of the European Union, whose Water Framework Directive (2000/60/EC) is based on the idea that water management needs to take account of economic, ecological, and social issues and that its prime objective is the sustainable use and management of water resources. Protecting the environment and sustainably managing natural resources such as water are among the broad activities supported by the EU Horizon 2020 framework (Guerrini and Romano 2014).

Although there is no specific policy for water shortage management in the European Union it is recognized as a priority in the European Green Deal and is reflected as such in several major European strategies like the 2021 EU Strategy on Adaptation to Climate Change and the 2020 Circular Economy Action Plan and the Biodiversity Strategy for 2030. The EU also provides financial support to the Member States and other authorities to address water scarcity and droughts; by financing more than 300 projects under Horizon 2020 and Horizon Europe (European Commission 2024f).

In this context, the Italian government enforces the Integrated Water Supply system as their water policy which presents a very complex landscape. Italy's water main and wastewater treatment plant network can be considered very heterogeneous. Best practices exist, where entire areas are fully served by drinking water flowing directly to their homes all day, but there are other areas where the water only arrives a few days a week (Guerrini and Romano 2014). From the mid-1990s to the mid-2000s in Italy there were several reforms aimed at outsourcing the management of utilities to private operators (D'Amore, Landriani, and Lepore 2021). This is reflected in the modification of Law 133/2008, article 23 bis in November 2009 (Guerrini and Romano 2014). The intent of this reform was to improve the water systems through the introduction of private investors whom the Italian government considers to be more oriented toward efficiency and effectiveness than public investors are. Under this reform, water services had to be franchised to private or public–private utilities in which the private partner held at least 40 % of the shares; no water management franchises could be awarded to totally publicly owned utilities after December 2011 (Guerrini and Romano 2014). This situation gave rise to an intense debate on the appropriateness of an essential service such as water being entrusted to private operators. This debate culminated in a referendum in 2011, which endorsed a proposal that prohibited tariffs from being used to remunerate invested capital (D'Amore, Landriani, and Lepore 2021). In this context, private operators are inclined to invest in the water sector only where they can achieve economies of scale or economies of scope, generally through the provision also of other utilities, like energy, gas or waste collection, in the form of multi-utilities (Guerrini, Romano, and Leardini 2018).

The Italian water management system is subdivided by Optimal Territorial Basins (OTB), which typically are of provincial size, identified by the regions, together with their local Governing Entities of the Area (GEA), that select and entrust all water services of its OTB to a unique provider, establish the operational guidelines for water utilities and have the responsibility of water resource management (D'Amore, Landriani, and Lepore 2021). There are still some exceptions to this general system today. The territory currently is distributed between 62 OTB and 91 basins, and in the

South, there are 13 still not entrusted basins (D'Amore, Landriani, and Lepore 2021). The instrument used to plan for the water resources on the OTBs is the Territorial Area Plans (TAP) these documents are the strategic planning tool for the integrated water service. The document which, based on the results of the analysis of the reference context, defines the objectives of the Integrated Water Service to be pursued during the assignment period, as well as the infrastructural interventions necessary to satisfy them, and evaluates the economic sustainability of the plan (Spanicciati 2017). At the same time, the Territorial Area Plan becomes a management control tool, representing the benchmark with which to compare the management results, to verify their correct implementation. In the case of the Calabria region the OTB coincides with administrative delimitation of the region which makes it less complex to handle. The current TAP for Calabria was published in 2020 and is expected to be updated soon as the GOB of the Calabria region changed in late 2022 (AUTORITÀ IDRICA DELLA CALABRIA 2020). Even though the current TAP for Calabria has a time horizon of 2033. In the case of Calabria for the water policy, the regional TAP has a specific section for the integrated water service for the provinces of Calabria and the Metropolitan City of Reggio Calabria and management areas with subdivisions of the region. The lack of local water policy at the city level can be considered a vulnerability because is not fully adapted to the specific needs and realities of cities and towns in the region. This leaves out the local administrations in the management of the water resources and reduces at the same time the water governance in the region.

The Governing Entities of the Area (GEA) are the institutions assigned by the regional governments for each OTB in which all the Municipalities falling within the OTA are obliged to participate and to which the exercise of the responsibilities of the Municipalities themselves in the matter of management of the water resources, including water infrastructure planning (Società Risorse Idriche Calabresi 2024b). The GEA for the Calabria region until 2022 was the Calabrian Water Authority, established by regional law in 2017. This public institution also worked closely with the inter-regional organism of the Southern Apennines District. Since 2022 the GEA has been Arrical (Autorità Rifiuti e Risorse Idriche Calabria) replaced the Calabrian Water Authority and is now the new regional governing body for the waste and water sector in the Calabria Region, and its functions are established by the national and state law (Autorità Rifiuti e Risorse Idriche della Calabria, n.d.). Currently, there is still a transition process where Arrical is working to update the TAP and take full capacity on managing the water and wastes in the region with an extraordinary commissar as the responsible of this transition. In particular, the attributions for Arrical respect to water are the preparation and updating of the Area Plan (consisting of a set of the following deeds: a survey of the infrastructures, program of interventions, management and organizational model, and economic-financial plan), assignment of the integrated water service, preparation of the management agreement for the regulation of relations between the governing body of the area and the managing body, based on the standard agreement adopted by the Authority for electricity, gas and the water system, and to update the economic-financial plan, preparation of the tariff in compliance with the tariff method adopted by the Authority and relative transmission to the latter for approval. Arrical also collaborates in territorial plans, coordination plans, landscape plans, urban planning, general and implementation tools, as well as their variants.

8.4.1 Water operator and management approach

The Italian Ministry of Infrastructure and Transport is the ministry that deals with the preservation and control of key water infrastructures such as dams and primary aqueducts (Ministero Infrastrutture e dei Trasporti 2022). In particular, the functions of a national water operator are technical approval of projects, supervision of construction, supervision of the control operations of the local water concessionaires through the verification and interpretation of the data collected from the monitoring of the dams, review and approval of hydrological, hydraulic and seismic redevelopment studies and it plans, programs and manages interventions in the water sector.

According to AREE, 2551 entities provide water services, of which more than half are municipalities or other public entities (D'Amore, Landriani, and Lepore 2021). There are only 366 utilities, of which only 164 provide all water services, from collection to sewage and wastewater treatment (Guerrini, Romano, and Leardini 2018). According to the official statistics of Blue Book Report 2020, private companies represent 2% of the total sales, public companies 59%, and mixed companies 39%. The small presence of private operators, that has always characterized Italian context, reveals the ideological motivation underlying the public referendum "against water privatization" in 2011 (D'Amore, Landriani, and Lepore 2021).

Even though in Italy universal access to water services is established by law, the quality of service and the prices change from one geographical area to another. This disparity affects service-user satisfaction but also on affordability. The Italian water sector can be characterized by low levels of environmental and social sustainability. The average water leakage nationally is 37,3%, and in some southern cities the situation is worst reaching 60%. Furthermore, users' satisfaction varies significantly from North to South; for example, while satisfaction with service continuity is 90% in the North, it is only 25% in the Islands, due to old infrastructure and poor management (D'Amore, Landriani, and Lepore 2021). In 2020 water rationing measures have been adopted in 11 provincial capitals cities, mainly in the southern part of the country (ISTAT 2022). In Italy municipalities served with high-quality water by innovative technologies coexist with poor areas characterized by outdated mains providing low-quality water (Guerrini and Romano 2014).

The Decree law 133/2014 establishes that, in the first application, the government bodies of the area, in order to guarantee the achievement of the principle of single management within the OTB, have the assignment to the single area manager upon expiry of the existing managements, operating on the basis of an approved assignment in compliance with the legislation (Società Risorse Idriche Calabresi 2024b). In particular, in the event that the OTB coincides with the regional territory, the assignment of the integrated water service is permitted in territorial areas in any case not lower than the territory corresponding to the provinces or metropolitan cities. The governing body of the area, in compliance with the area plan and the principle of single management, proceeds with the choice of the form of management among those envisaged by the European legislation, consequently providing for the assignment of the integrated water service. The company that provides and manages the water service selected by the Calabrian Water Authority is the Calabrian Water Resources Society (So.Ri.Cal.). The company is controlled by the Calabria Region which has been entrusted with the management, completion, modernization and expansion of large-scale adduction, accumulation and potable water schemes (Società Risorse Idriche Calabresi 2024b).

Sorical has a local branch in Reggio Calabria that operates in the surroundings of the city, not the full metropolitan area. Reggio Calabria is the first Calabrian municipality in which, from 2024, the water service is managed by Sorical, while the sewerage and purification services are still managed by the Municipality until June 2024, as the preparatory activities for the definitive takeover are underway (Società Risorse Idriche Calabresi 2024a).

8.4.2 Innovation practices for water security

The city of Reggio Calabria developed a relevant communication practice to increase awareness of water issues in the city. The public platform developed by the municipality of Reggio Calabria "Segnaliamo Reggio Calabria" allows citizens to directly report issues to the local administration, such as roads, lighting, sewerage system, water network, and more (Comune di Reggio Calabria 2024). Also, it allows citizens to monitor the progress of the interventions to face the issue. This is an effective instrument to hold accountable local authorities, increase participation, and solve multiple infrastructure issues. Regarding water security issues, citizens can directly report water line leaks, interruptions of the water service, bulk water delivery, low-pressure, and issues with the sewage network. This platform serves to raise awareness on urban and household water security. Since the platform is designed to report and monitor current issues, it can only store 300 reports per issue. This makes it difficult to make historical reviews on water security issues.

8.4.3 Communication strategies to raise awareness of water security

The municipality of Reggio Calabria communicates when interruption to the service happen or are scheduled due to repairs on the network. The platform "Segnaliamo Reggio Calabria" is a good practice on communication and raise awareness on water related issues. On June 2024, the mayor of Reggio Calabria issued an order for citizens to have a rational and correct use of water in order to avoid unnecessary waste and limit the use of drinking water for strictly indispensable uses. This can be considered a first step to the implementation of a water-wise use strategy and increase awareness of water security in Reggio Calabria.

8.5 Water-related risks with respect to basin and urban link

Calabria is a region whose geological, hydrogeological, and climatic characteristics have made it rich in water resources (Dramis and Mottana 2013). However, this favorable context has not prevented drought events and water shortages in recent decades and has been aggravated by the climate change emergency. The main source of fresh water in Calabria is groundwater, mainly coastal aquifers. The aquifers in the region are subject to risks of qualitative degradation due to the effects of marine water intrusion and the pollution of the sources as a result of human activities, and to risks of quantitative degradation, associated with the growing and often unsatisfied demand for water, which leads to the overexploitation of underground water resources, and also the impacts of climate change that is affecting the recharging of the aquifers due to the reduction of precipitations (Dramis and Mottana 2013).

According to the WRI (Kuzma et al. 2023). For Quantity risks, the Crati sub-basin has an extreme risk due to extreme levels of water stress in the region. For Quality risks, the sub-basins show low-medium risk. Finally, for Regulatory and Reputational risk, the two sub-basins also show low risk.

In the European Union's Water Framework Directive, it is stated that all the 160 river basins in Europe should be managed using a River Basin Management Plan. The Member States shall ensure that a river basin management plan is produced for each river basin district lying entirely within their territory and the river basin management (European Environment Agency 2023). The Italian basin authorities are inter-regional organisms that emerge as a collaboration between the Italian national government and the regional governments that operate in the territory of defined hydrological basins composed of various regions. The Italian territory is divided into 7 basin authorities. The main attributions of these organisms are the protection and management of the regional water resources (groundwater and surface water) and the environmental aspects connected to them regardless of the administrative divisions. Inter-regional organisms are key to regional water management because hydrological basins usually do not follow administrative boundaries, so the management of water resources that are shared by more than one region requires an organism that manages them and mediates between regions (Autorità di Bacino Distrettuale dell'Appennino Meridionale 2021). The Water Management Plan is the instrument through which the governance action of the water resources is set. These plans that should be renovated every 6 years guarantee the long-term sustainability of the water management in the district and deliver the measures to improve and safeguard the overall environmental state of the water resource within the district, as well as to ensure the long-term sustainability of the system of anthropic pressures acting on the district water supply. The Calabria region is located in the Southern Apennines District and is composed also by the regions of Campania, Puglia, Basilicata, Molise and partially the Abruzzo and Lazio regions.

The permanent observatory on water uses constitutes one of the key measures of the Water Management Plan in the Southern Apennines District. This measure was also explicitly requested by the EU to implement a framework of necessary and shared actions for the proactive management of water resources to improve the resilience of the territory (Autorità di bacino distrettuale dell'Appennino Meridionale 2021). The main actions for the short term are the following: monitoring and updating of water availability scenarios to re-evaluate the water severity; definition of shared distribution actions for the main interregional and multiple district water systems, identification of further regulatory actions for the optimization of available resources and identification of any emergency structural interventions, where necessary. About medium-long term activities (Autorità di bacino distrettuale dell'Appennino Meridionale 2021), it is highlighted the importance of increasing the degree of resilience of the supply systems in the context of future water shortages and droughts. The most notorious ones are the implementation of interventions to improve the infrastructures under the district, the implementation of water loss recovery programs, the implementation and updating of the Reservoir Plan and Aqueduct Plan, the identification of possible new interventions, the implementation of programs to strengthen the monitoring and evaluation network of the district. Despite the presence of strong instruments for basin planning, there is a still at least for the Calabria region a gap to integrate the basin planning objectives into urban planning instruments fully.

8.6 Indicator Framework to Evaluate Water Security

Table 64: Water Security evaluation for Reggio Calabria

Economic Water security		Units	Ranges					Sources
Indicator	Subindicator		1	2	3	4	5	
Cost efficency of the service		%				5%		SORICAL (2023)
Non revenue economic water losses		USD/m3					ND	
Investments		USD				77.23		SORICAL (2023)
Payment collections efectiviness		%		92.20%				Comune Reggio Calabria (2023)
Operating expense ratio		%					93%	SORICAL (2023)
Debt ratio		Unit					0.75	SORICAL (2023)

Household Water security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Freshwater consumption		liters	181					ISPRA (2016)
Water quality reports		number of reports /1000 inhabitants					ND	
Bulk water delivery		%		0.3%				Comune Reggio Calabria (2024)
Interruptions to the service		outages/1000 inhabitants outages/reductions/ year					77 days	ISTAT (2022)
Metering efficiency		% of unmetered water					ND	
Service coverage	Freshwater	%	100%					ISPRA (2016)
	Wastewater	%		95%				ISPRA (2016)
Service complaints		number of reports /1000 inhabitants	2.85					Segnaliamo Reggio (2024)
Service efficiency		%					ND	
Billing issues		%				3.10%		Comune di Reegio Calabria (2023)
System failures	Reported leaks	number of reports /1000 inhabitants	0.6					Segnaliamo Reggio (2024)
	Reported sewerage fails	number of reports /1000 inhabitants	0.55					Segnaliamo Reggio (2024)
	Reported stormwater overflows	number of reports /1000 inhabitants					ND	
Water pressure		psi					ND	
Affordability of the service		%			3.78%			Sorical (2023), (Cittadinanzattiva 2024)
Low-income billing assistance offered		units			Moderate implementation			Sorical (2023)

Urban Water security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Water Metering Coverage		%					2%	
Network size	Freshwater	Meters of pipeline/inhabitant				3.53		Autorà Idrica Calabrese (2021)
	Wastewater	Meters of pipeline/inhabitant		6.47				Autorà Idrica Calabrese (2021)
	Stormwater	Meters of pipeline/inhabitant					0	Autorà Idrica Calabrese (2021)
Water Treatment Capacity	Freshwater	%	100%					Autorà Idrica Calabrese (2021)
	Wasterwater	%				78%		ISPRA (2016)
Water storage		Days					1 day	Autorà Idrica Calabrese (2021)
Energy consumption		%					ND	
Renewable energy use		%					ND	
Green house emissions		GHE per capita					ND	
Rainwater collector units		Number of units					ND	
Power failures		Hours	0					Autorà Idrica Calabrese (2021)
Water quality		%					ND	Comune Reggio Calabria (2016)
Water demand and supply ratio		units	1					Autorà Idrica Calabrese (2021)
Average age of the pipelines	Freshwater	years				46		ISTAT (2004)
	Wastewater	years					54	ISTAT (2004)*
Data availability		units				Low		Literature Review
Maintenance		%	7.20%					SORICAL (2023)
Water losses		%				47%		ISTAT (2022)
Staff levels		Number of employees/ 1000 connections				0.7		Hermes (2023)
Diversity of the sources in local supply system		%				28.10%		Autorà Idrica Calabrese (2021)
Recycled water use		%					ND	
Stakeholder participation		Unit					Information	Literature Review
Integrated Water Management plan		Unit		High implementation				Literature Review

Environmental Water Security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Quality level of wastewater discharge to the environment		%				33.84%		ISTAT (2017)
Storm water discharge		%					0%	Autorà Idrica Calabrese (2021)
Sludge management		%	100%					Regione Calabria (2019)
Green areas		%	38%					Comune Reggio Calabria (2016)
Blue areas		%	>15%					Comune Reggio Calabria (2016); Protezione Civile RC (2008)
Quality of potentail available surface freshwater		%					11%	Comune Reggio Calabria (2008)
Sustainability planning	Habitat/watershed protection goals	Unit			Moderate implementation			Literature Review
	Green infrastructure planning	Unit				Low implementation		Literature Review
	Energy optimization planning	Unit				Low implementation		Literature Review
Basin planning instrument		Unit			Moderate implementation			Literature Review

Resilience to water-related disasters		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Overall Water Risks	Physical Risks Quantity	Unit					Extremely high	WRI Aqueduct 4.0 (2024)
	Physical Risks Quality	Unit		Low Medium				WRI Aqueduct 4.0 (2024)
	Regulatory and Reputational Risk	Unit	Low					WRI Aqueduct 4.0 (2024)
Risk assessment and response preparedness	Risk assessment and response preparedness	Unit			Moderate implementation			Literature Review
	Water shortage planning	Unit					Very Low implementation	Literature Review

8.7 Performance per dimension of water security

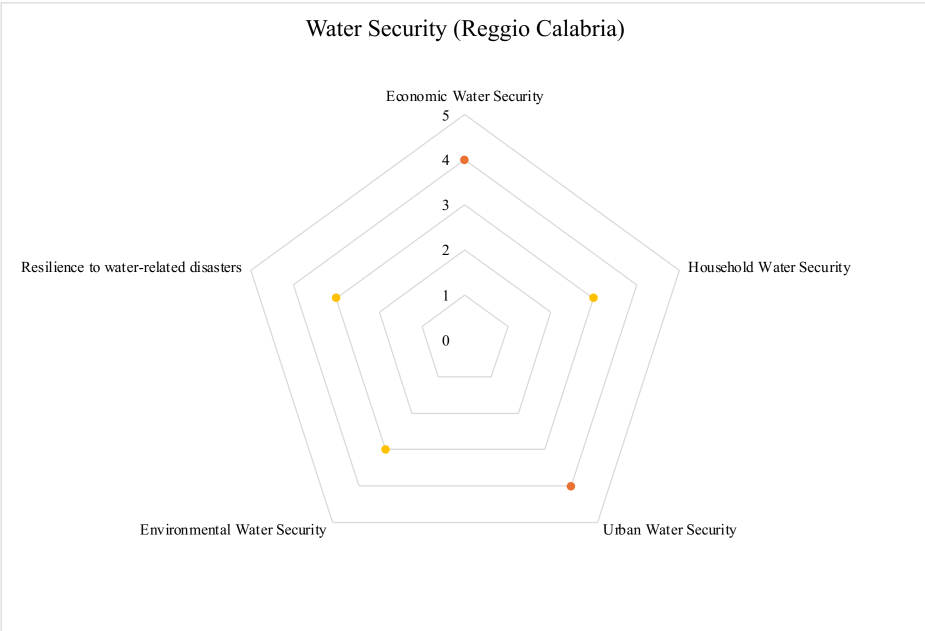


Fig. 44. Water security performance by dimension in Reggio Calabria. Source: Armando Cepeda Guedea, 2024

The indicator framework for water security in Reggio Calabria shows moderate to high concern for water security (see Figure 44). Differently from Mexico City, three dimensions of water security (resilience to water-related disasters, household water security, and environmental water security) present a moderate concern. Meanwhile, economic water security and urban water security are at high levels due to the mismanagement, poor infrastructure and institutional fragility of water management in the city. Reggio Calabria's overall water security leans more towards moderate concern, but with high vulnerability to increase to overall high concern. This urgent situation requires coordinated actions, regulations, and policies to stabilize it and reduce water insecurity. The inequalities that prevail in the city difficult the process of achieving water security since its performance does not match with a city of first world country in the European Union with an ambitious sustainable development and water action policy.

Fig. 45. Water security performance by indicator in Reggio Calabria. Source: Armando Cepeda Guedea, 2024

Economic water security: Due to the institutional fragility identified in Reggio Calabria, the economic water security in the city is quite concerning, with four indicators (debt ratio, non-revenue economic water losses, and operating expense ratio) with extremely high values. The cost efficiency of the service also raises high levels of concern. The only indicator that performs adequately is the payment collection effectiveness. The concerning vulnerabilities in economic water security could affect the overall quality of service by the water operator and directly affect other dimensions of water security, such as household and urban water security, since low investment capacity and high levels of debt do not allow optimal levels of maintenance, acquire new technologies to use water better or for new sustainable sources of water, respond efficiently to failures in the system, among others.

Household Water Security: Reggio Calabria household water security has more stable values, but several indicators still show concerning levels. Especially water service cuts are an extreme concern, alongside water quality, metering efficiency, water pressure, and billing issues. The affordability is an issue that should be taken into consideration since it levels are concerning and can become an urgent matter if the prices continue to be high in comparison with the average income. On the other hand, Reggio Calabria performs optimally on water consumption patterns and the number of complaints despite the fact that service efficacy indicates poor performance levels. This may indicate issues of communication between citizens and authorities or difficulty in accessing to adequate report channels to report issues such as the website. Meanwhile, there are low concerns regarding service coverage, bulk water delivery, and system failures.

Urban Water Security: the values obtained regarding urban water security in Reggio are quite concerning since most of them have extreme values. First, it is important to clarify that 6 of the indicators with very high vulnerability are because of a lack of data (water quality, rainwater collector units, GHG emissions, renewable energy use, energy consumption and water storage). This situation may distort the evaluation, but it is estimated that indicators performance without values might still have very undesirable levels, such as water quality, that even though there is not enough official data to measure the value, the reports indicate very low quality. The lack of stormwater independent pipelines, old wastewater pipelines, low participation, and low implantation of digital water meters also pose a high threat to urban water security in Reggio Calabria. On the positive side, the city performs optimally on the assigned maintenance budget, water demand-supply ratio, and no power failure, and it performs adequately on integrated water management planning.

Environmental Water Security: Reggio Calabria, due to its large territorial extension and its numerous torrents the city has optimal levels of green and blue areas. On the negative side, the low-quality levels of water discharges, the quality of water bodies, and sustainability planning are concerning. Basin planning exist in the city but significant are required to achive optimal performance.

Resilience to water-related disasters: Reggio Calabria is located in a region with extremely high levels of water stress that directly affects the physical availability of the resource, which requires considerable efforts to bring water from outside the city to satisfy the needs of its inhabitants. Despite this fact, there is not an ambitious and robust water shortage planning framework in the city, which represents a big vulnerability. Quality and regulatory risks are handled adequately, while there is a moderate concern on risk management planning, since its current framework needs to be updated and have a better climate risks mitigation and adaptation strategies.

Chapter 9

Ruston

West Monroe Water Reuse Facility: Armando Cepeda Guedea, 2023.

9.1 Context analysis

At the national level, Ruston shares the same context as California because they are in the same country which is the United States. Louisiana is a state located in the southern United States lying on the coast of the Gulf of Mexico bordering the states of Mississippi to the east, Texas to the West and Arkansas to the North. The total population is 4,573,749 and as the state of California, the state is experiencing a slow decrease in their population having an estimated 1.8% decrease from 2020 to 2023 (US Census Bureau 2023). The GDP of the state is USD 231.26 billion which is below the national average (US Bureau of Economic Analysis 2022). The state is divided into 64 parishes which are analogous to counties in other states. This a reflection of the rich past of the state with a strong French heritage before the adhesion of Louisiana to the United States in 1812 (Louisiana Government 2024).

Ruston is a city located in Lincoln Parish in central north Louisiana, situated at the eastern border of the Ark-La-Tex region (see Figure 46). Even though the city of Ruston in not properly part of the region it shares common cultural, geographical, and economic similarities (McEwen 2014). As of 2022, it has an approximate population of 22,166 (US Census Bureau 2022). The city covers an area of 54.75 square kilometers, resulting in a population density of 404.9 inhabitants per square kilometer (US Census Bureau 2022), similar to that of a town or semi-dense urban area. Ruston is notable for being home to Louisiana Tech University, which has an enrollment of 11,038 students and is recognized (Louisiana Tech University 2024). The floating population that the university attracts is considerable, representing approximately 50% of the total population of the city. The median household income in 2021 was $34,554, with 35.6% of the population living below the poverty line (US Census Bureau 2022). This socio-economic situation may pose a vulnerability in the event of potential water risks. The city is experiencing continuous growth due to the development opportunities and economic expansion associated with a good geographical position being at the heart of the I20 highway that connects South Carolina with Texas, good and affordable services and the presence of the University which is an economic engine for the city. This growth is expected to be accompanied by the arrival of an Amtrak train station by 2026 that will connect the city with Dallas Texas (The Ouachita Citizen 2022)increasing the potential to bring new business opportunities and attract new population to Ruston.

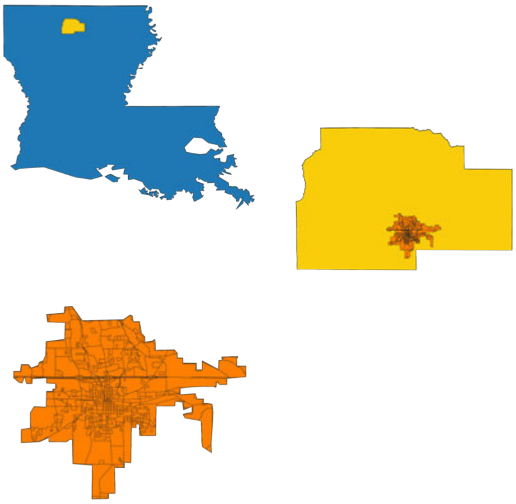


Fig. 46. Ruston’s general context. Armando Cepeda Guedea, 2024

Even though there is not a consensus on what is a water-rich state in the US. The state of Louisiana can be defined as water-rich state according to different standards such as having annual average precipitation higher than 1400 millimeters and a water area (or the area of each state covered by water) greater than 11 per cent (Commission for Environmental Cooperation 2008; Takacs 2018).

One of Ruston's significant water sources is the Sparta aquifer (see Figure 47), which serves as the primary freshwater source for the region and is utilized by 16 parishes in north Louisiana (Louisiana Sparta Groundwater Commission 2023). The Sparta aquifer in the State of Louisiana extends from Caddo Parish in the west to Morehouse Parish in the east (Louisiana Sparta Groundwater Commission 2023). Outside the state of Louisiana, the Sparta aquifer extends to the state of Illinois in the north and the state of Alabama in the east (United States Geological Survey 2004). In terms of surface water, Ruston falls within the Mississippi River major basin and in the intersection of the Bayou D'Arbonne and Dugdemona sub-basins (see Figure 48) (Kuzma et al. 2023).

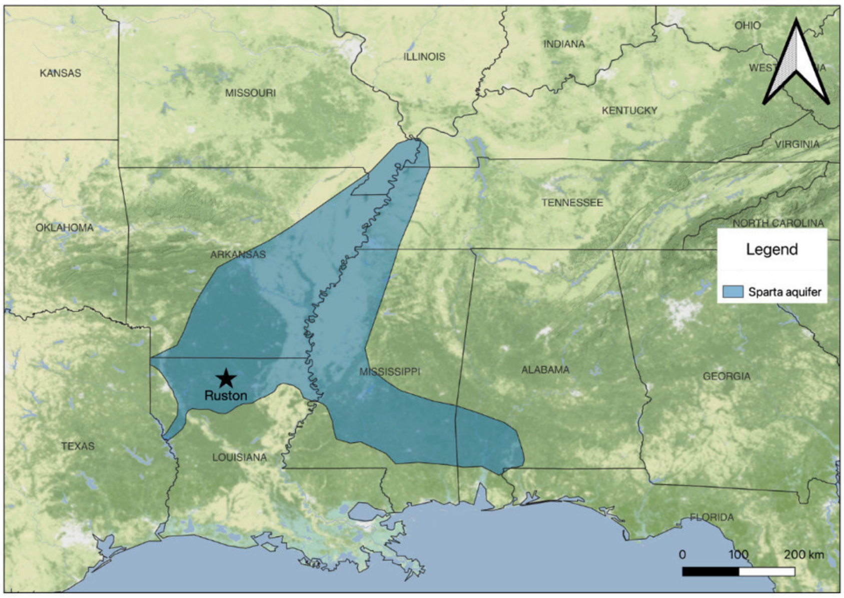


Fig. 47. Approximate area of the Sparta aquifer. Source: Armando Cepeda Guedea, 2024

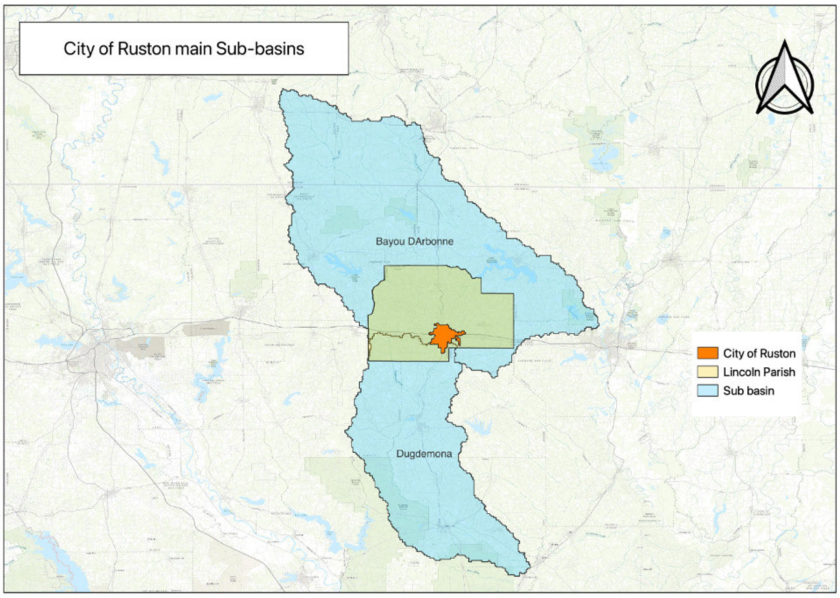


Fig. 48. Ruston minor sub-basins. Source: Armando Cepeda Guedea, 2024

9.1.1 Water insecurity drivers from context analysis

The city of Ruston aims to become a hub of innovation for the region, attract talent and high-end industries to the city, and increase its overall competitiveness. To achieve this, it is critical to more efficient and sustainable water management that accompanies the expected growth of the city. After a literature review and a field study between April and August 2023, the research identifies four main drivers to pursue water security in the City of Ruston: vulnerability of the infrastructure, high vulnerability to natural disasters, increasing demand, and climate change (see Figure 49).

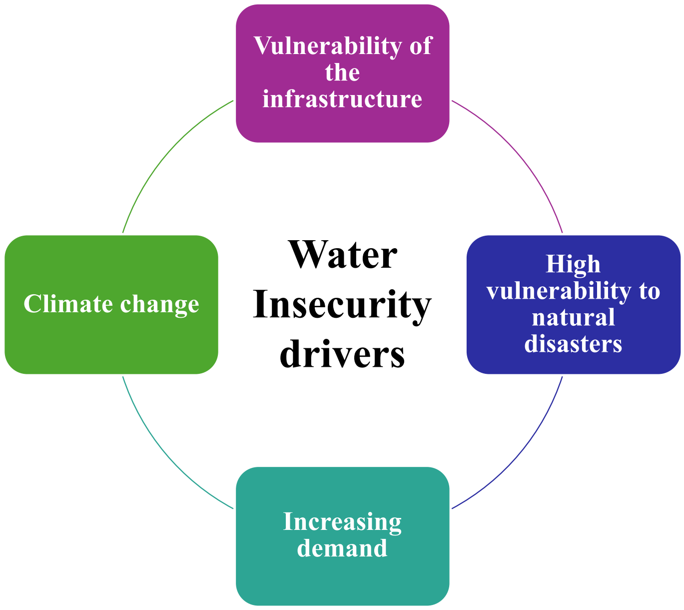


Fig. 49. Main water insecurity drivers for Ruston. Armando Cepeda Guedea, 2024

Vulnerability of the infrastructure: Ruston lies in an area vulnerable to natural disasters such as flooding, thunderstorms, tornados, tropical cyclones, and winter storms that can affect the supply of the water system. The lack of adequate runoff management strategies can also affect other systems, such as energy and transport. During the field study, severe storms interrupted the electricity service and blocked some of the main avenues in the city. The impacts of the storm have the potential to affect the water service since the water pumps and distribution of water rely on electrical energy.

High vulnerability to natural disasters: as previously mentioned, Ruston lies in a vulnerable area to natural disasters, which requires an ambitious risk management strategy. The main natural risks that Ruston is vulnerable are drought, flooding, extreme heat, thunderstorms, tornados, tropical cyclones, wildfires, winter storms, and dam failure.

Increasing demand: The city of Ruston has a considerable floating population since every year it hosts more than 11,000 thousand students that attend Louisiana Tech University. The city is experiencing continuous growth due to the development opportunities and economic expansion associated with a good geographical position being at the heart of the I20 highway that connects South Carolina with Texas, good and affordable services and the presence of the University which is an economic engine for the city and an innovation hub. This growth is expected to be accompanied by the arrival of an Amtrak train station by 2026 that will connect the city with Dallas Texas (The Ouachita Citizen 2022)increasing the potential to bring new business opportunities and attract new population to Ruston. Ensuring a safe and accessible freshwater supply has become crucial for the sustainable growth of cities (Heidari, Arabi, and Warziniack 2021), in this context the city of Ruston must be prepared to accompany this growth with clear actions to ensure the sustainability of its freshwater supply system.

Climate change: Although Louisiana and Ruston are commonly considered a "water-rich" state, they actually face significant threats to their water resources (Borrok et al. 2018; Louisiana Legislative Auditor 2020). These threats include declining water levels due to drought or excessive pumping, resulting in reduced surface water flows, impaired water quality, and groundwater degradation due to saltwater intrusion in certain areas of the state (Louisiana Legislative Auditor 2020; Borrok et al. 2018). The vulnerability is further exacerbated by the impacts of climate change and rapid urbanization processes occurring in the city.

9.2 Strategic vision for sustainable development and climate action

The main planning document for the city of Ruston is the Ruston Zoning Ordinance, which is synchronized with the citizen-based "Ruston 21" master plan (City of Ruston 2012). The core of this plan was to stimulate the development of the area around its university and its central business district that was left behind due to the new developments in the northern part of the city and reverse the decay of vulnerable neighborhoods in the southern part of the city. To do so, the Ruston Zoning Ordinance proposes the Core Downtown District that intends to become a vibrant pedestrian area where civic, cultural, and commercial uses blend together and interact with the considerable floating population of the university to boost the economic development of the city and regenerate the downtown area. Also, the plan considers the development of green corridors to connect the city where sustainable mobility, such as bikes, can be used. The current planning documents of the city of Ruston do not provide clear guidelines on climate action and neither water security. This document reflects the insufficient efforts of the city administration to address climate and water security issues.

9.3 Water system in the city

The data obtained to analyze and study the local water system in Ruston was obtained after a series of interviews with local water authorities and members of the academia of the region. The primary source of freshwater for the city of Ruston is derived from 12 wells (all located inside the city limits), which are stored in three water towers with a capacity of one million gallons (3.78 million liters) each (see Figure 50). The distribution system comprises approximately 180 miles of water lines, serving approximately 9,500-

meter connections and providing for 5,298 households (US Census Bureau 2022). In 2010, the US Geological Survey estimated that the city extracted 4.18 million gallons of water per day (McGee and Brantly 2015). Considering population growth, it is estimated that freshwater extraction in Ruston reached approximately 4.26 million gallons per day in 2022 to meet the city's demand. Residential water usage accounts for around 2.56 million gallons per day, based on an average daily usage of 115 gallons per capita, which is higher than the United States average which is 82 gallons per capita (Dieter et al. 2018). This indicates the potential for using water resources more efficiently and sustainably within households. The city's freshwater pipeline system primarily consists of PE100 pipes, with main lines ranging from 10 to 12 inches in diameter and residential areas and secondary streets utilizing pipes with diameters of 6 to 8 inches. These plastic pipes offer greater resistance and hygiene compared to older iron pipes. However, certain areas of the city, particularly Barnett Springs and University Hills, which have lower incomes than the city average, still rely on an undersized water system from the 1970s, with diameters ranging from 4 to 6 inches. This represents a vulnerability for the specific areas and the city as a whole.

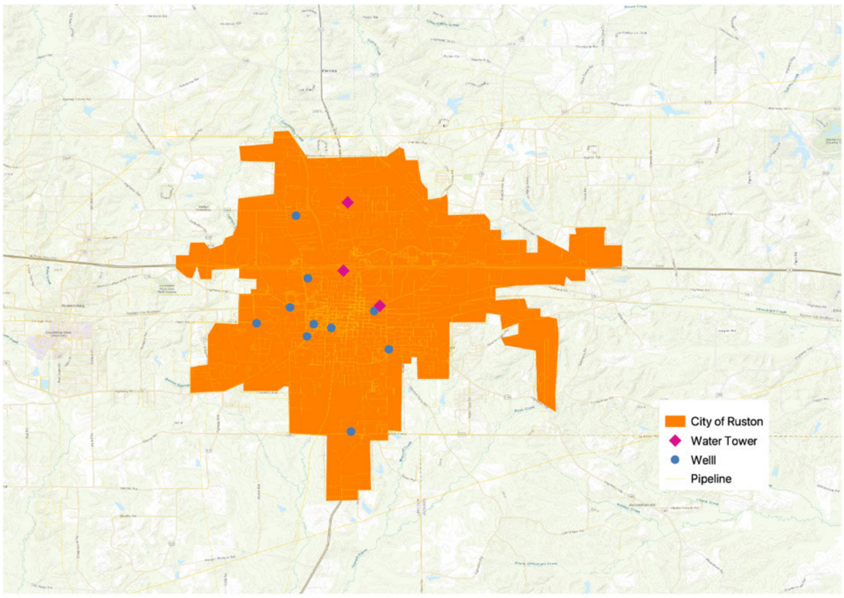


Fig. 50. Water system of Ruston. Source: Armando Cepeda Guedea, 2024

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One of Ruston's competitive advantages is its low price for freshwater supply, with a cost of approximately 0.02 USD per gallon, which is less than half the price in neighboring Monroe (0.046 USD per gallon) (City of Monroe 2023). The Water Division justifies this low price through efficient management of economic resources, a streamlined water purification process, and frugal practices by the managers. The reduced fares not only ensure local population's ability to afford the service but also serve to attract business activity to the city.

9.4 Regulatory instruments for water security

In Ruston as in San Diego the United States National Water Policy is the same. The differences start at the state level where Louisiana has a different policy approach to water than in California. In the last decades, the state of Louisiana has invested $5.3 million USD to develop water management strategies and studies for a comprehensive plan. However, to date, Louisiana still lacks such a plan, which could play a vital role in safeguarding, conserving, and replenishing the state's water resources for the well-being and safety of its citizens (Louisiana Legislative Auditor 2020). Furthermore, it would provide valuable tools for local authorities to manage their water resources more sustainably. The Department of Energy and Natural Resources of Louisiana through the Louisiana Groundwater Management Commission presented a document named "Recommendations for Statewide Ground Water Management Plan" This document is divided into three volumes and presents all the basic characteristics for a comprehensive water management plan for the state. This is a long-term planning document that expresses the state's overarching vision, goals, objectives, and strategies to ensure that adequate water supplies are available to meet existing and future water needs. At the local level, the water operator in Ruston does not have a specific water policy and just focuses on technical matters regarding the water supply and the enforcement of federal regulations.

In the context where Louisiana does not have a comprehensive water management policy and agency, different state agencies are the ones responsible for regulating the state water resources (Louisiana Legislative Auditor 2020). The Department of Natural Resources oversees groundwater conservation and sustainability; registers wells and groundwater users; and administers surface water cooperative endeavour agreements. The Department of Environmental Quality enforces the Clean Water Act and protects groundwater and surface water from contamination through permitting and monitoring. Finally, the Department of Health Enforces the Safe Drinking Water Act and protects groundwater and surface drinking water supplies. At the county level, the Lincoln Parish Water Works District is responsible for regulating and operating the water resources at the Parish level. Meanwhile, at the city level, the Ruston Department of Water Utilities is the public agency to regulates and operates the water resources in the city.

9.4.1 Water operator and management approach

At the state level, the Department of Transportation and Development can be roughly considered as the water operator in Louisiana because is the one that administers construction requirements for surface water impoundments, such as reservoirs, and manages state-owned water control structures (Louisiana Legislative Auditor 2020).

The presence of multiple agencies can hinder the efficient management of water resources when there is a lack of clear guidelines and effective communication among them. At the local level, water resources are primarily overseen by individual cities through their respective water agencies. These agencies bear the responsibility of supplying freshwater, ensuring its quality, and appropriately charging for the services rendered. In rural areas not incorporated into cities, the water services are managed by parishes. Residents of rural areas typically rely on privately-owned wells to meet their water needs.

The freshwater supply in the city of Ruston is managed exclusively by the Department of Water Utilities and the Water Division, which collaborates closely with the city council on various aspects such as project development, financing, policy-making, and addressing citizen concerns. However, the participation of organized civil society and individuals in the decision-making process is limited, and there is a lack of efficient communication tools to enhance citizen involvement. The annual water quality reports provided to citizens are highly technical and do not effectively encourage their engagement in building a more sustainable and efficient freshwater supply system.

9.4.2 Innovation practices for water security

Despite the fact that the city of Ruston does not have relevant innovation practices to review, important innovation practices are being developed in the region. A relevant example is the Sparta Reuse Facility located in West Monroe. Thanks to the proximity to the city of Ruston (approximately 50 km) it was possible to visit the facility in May 2023 and interview the manager to better understand the technical features and the socio-political context that led to the construction of the facility. The Sparta Reuse Facility has been rewarded at the state, national and international levels for the innovative approach to ensuring water security in the city. In the 1990s and the 2000s, the levels of the Sparta aquifer which is the main source of freshwater for the region decreased considerably endangering the continuity of the paper mill which was and is the main source of jobs and economic development for the city and the region. This situation marked an inflexion point in the water management policy in the city. For the first time, water was considered a valuable resource that shouldn't be taken for granted. To face the challenge an interesting alliance between local government, the private sector and civil society was made to find a creative and innovative solution. In 2012 this alliance materialised in the Sparta Water reuse facility when it became fully operational after one year of testing. The water reuse facility produces potable water after treating the channelized stormwater from the city of West Monroe and sending it directly to the paper mill. The potable water produced in the Sparta Water reuse facility is enough to cover all the water needs of the paper mill guaranteeing its operations and ensuring the jobs of an important part of the city inhabitants. All of this without overexploiting the groundwater resources of the city and the region.

The facility is located on the outskirts of West Monroe next to two 50-acre retention ponds (20.23 hectares) that hold all the stormwater in the city and are discharged directly to the Ouchita River before the facility was created. The retention ponds also serve to reduce the flooding risk in the city by retaining the overflow of water when flooding occurs. Currently, the water collected in the retention ponds provides the water for the facility to be purified ensuring a constant supply.

The facility treats between 5 to 6 million gallons per day (18.92 to 22.71 million liters) but has the potential to produce 10 million gallons daily (37.85 million liters). The facility is composed of 10 independent modules of approximately 13x3 meters that can produce 1 million gallons per day (3.78 million liters). Also, the facility has a container to store 100,000 gallons (378,000 liters) to avoid discharging purified water that can't be transported to the paper mill. The process to purify the water is as follows. Firstly, a blend of polymers gets added to a water tank outside the main facility to make the algae stick together and float in before it gets pumped to the main facility. Next is transposed to each of the 10 autonomous modules' open-topped vats, where the air gets forced in from the bottom, which makes the algae rise to the top. Skimmers slowly remove the slime on the surface and floor of the tank. Following the water goes into a pressurized reservoir with activated carbon, which dissolves any remaining solid matter. Finally, chlorine is added as it's moved to the paper mill. It is also important to point out the efforts to increase the sustainability of the facility by implementing a solar farm that is able to produce 300 kilowatts of electricity and is expected to provide 20% of the power to the plant. In May 2023 it was around 8% of the total power of the plant.

9.4.3 Communication strategies to raise awareness of water security

The economic development of Ruston should be accompanied by a coherent water policy that accompanies this development in a sustainable way and increases the competitiveness of the city against other cities in the region. This is the premise that arises the creation of the Sparta Group, which is a multi-disciplinary group hosted by the Ruston Chamber of Commerce that combines the efforts of members from academia, the business community, real estate developers, local authorities, and water engineers. It is expected that the work of this group can provide arguments to the local and state levels to adopt measures for better water management by pointing out the challenges the local water system has, the solutions to face these challenges, and key projects that not only provide environmental benefits but economic benefits to the city and the possibility to attract federal funding to finance them. Overall, it also raises awareness to the citizens of Ruston to value their water resources and get more involved in the decision-making process of water planning.

9.5 Water-related risks with respect to basin and urban link

Despite being a small city, Ruston is at the intersection of two sub-basins, Bayou D'Arbonne and Dugdemona, which show different levels of water risks, according to the WRI (Kuzma et al. 2023). For Quantity risks, Bayou D'Arbonne is medium-high, and for Dugdemona, it is low-medium. For Quality risks the sub-basins show low-medium risk. Finally, for Regulatory and Reputational risk, the two sub-basins also show low-medium risk.

A hazard mitigation plan update from Louisiana State University for Lincoln Parish has identified a high risk of flooding and thunderstorms that can directly impact water quality and the functioning of the distribution system (Stephenson Disaster

Management Institute 2017). It shows that Ruston is surrounded by AE flood zones with a 1% annual chance of flooding and a 26% chance over the lifespan of a 30-year mortgage, as defined by the Federal Emergency Management Agency.

As a consequence of the severe flooding in 2016, the state launched the Louisiana Watershed Initiative (LWI) in 2018 (Louisiana Watershed Initiative 2024). This new framework introduces a new watershed-based approach to reducing flood risk and other water-related risks in Louisiana, guided by the following principles: use of scientific tools and data, enable transparent, objective decision-making, maximize the natural function of floodplains, and establishing regional watershed-based management of flood risk. Following the launch of LWI, the federal government announced a funding package of $1.2 billion (USD) for flood mitigation and enhanced LWI efforts. Guided by a federally approved Action Plan presented in 2019, the funds will support statewide planning, watershed modeling, data collection, and projects that reduce flood risk.

The Action Plan emerged after the launch of the LWI named "Master Action Plan for the Utilization of Community Development Block Grant Mitigation Funds" developed in collaboration between the State of Louisiana and the U.S. Department of Housing and Urban Development (Louisiana Office of Community Development and U.S. Department of Housing and Urban Development 2019). The document identifies the main hazards that each of the 64 parishes is vulnerable; for Lincoln Parish, where Ruston is located, the main hazards are the following: drought, flooding, extreme heat, thunderstorms, tornados, tropical cyclones, wildfires, winter storms, and dam failure.

The Louisiana Watershed Initiative (LWI) aims to enhance the establishment of regional watershed-based management (Louisiana Watershed Initiative 2024). To do so, eight provisional watershed regions were approved in 2019 and a ninth region in 2023 to coordinate flood risk reduction efforts among parishes and distribute project funds. The boundaries are subject to change based on regional input. Lincoln Parish is divided in region and 3. Most of Ruston is located in LWI region 3. The main objectives of the region are to drive collaboration with open, accurate data and academic tools, account for time needed to realize results in flood risk reduction strategies, focus on equity in project cost- benefit analyses, and provide links for watershed-to- watershed coordination. The coordination between watershed regions is critical since there are parishes such as Lincoln that lie between regions. In the case of Louisiana, there is a need for a better link between watershed, parish, city, and water operator.

9.6 Indicator Framework to Evaluate Water Security

Table 65: Water Security evaluation for Ruston

Economic Water security		Units	Ranges					Sources
Indicator	Subindicator		1	2	3	4	5	
Cost efficency of the service		%	32.8%					City of Ruston (2021)
Non revenue economic water losses		USD/m3					ND	
Investments		USD		189.52				City of Ruston (2021)
Payment collections efectiviness		%	99.80%					City of Ruston (2021)
Operating expense ratio		%	75.3%					City of Ruston (2021)
Debt ratio		Unit					99%	City of Ruston (2021)

Urban Water security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Water Metering Coverage		%	100%					Ruston Water Department (2023)
Network size	Freshwater	Meters of pipeline/inhabitant	12.99					Ruston Water Department (2023)
	Wastewater	Meters of pipeline/inhabitant	11.04					Ruston Water Department (2023)
	Stormwater	Meters of pipeline/inhabitant					0	Ruston Water Department (2023)
Water Treatment Capacity	Freshwater	%	100%					Ruston Water Department (2023)
	Wasterwater	%			90%			Lee et al. (2022)
Water storage		Days			4.76 days			Ruston Water Department (2023)
Energy consumption		%					ND	
Renewable energy use		%					ND	
Green house emissions		GHE per capita					ND	
Rainwater collector units		Number of units					ND	
Power failures		Hours	0					Ruston Water Department (2023)
Water quality		%		97% aprox				Louisiana Health Department (2022)
Water demand and supply ratio		units	1					Ruston Water Department (2023)
Average age of the pipelines	Freshwater	years	Less than 35 years					Ruston Water Department (2023)
	Wastewater	years	Less than 35 years					Ruston Water Department (2023)
Data availability		units				Low		Literature Review
Maintenance		%			2.70%			City of Ruston (2021)
Water losses		%		20% aprox				Ruston Water Department (2023)
Staff levels		Number of employees/ 1000 connections				3.78		City of Ruston (2021); US Census (2022)
Diversity of the sources in local supply system		%					0%	Ruston Water Department (2023)
Recycled water use		%					0%	Ruston Water Department (2023)
Stakeholder participation		Unit					Informing	Literature Review
Integrated Water Management plan		Unit				Low implementation		Literature Review

Household Water security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Freshwater consumption		liters		4351				Ruston Water Department (2023)
Water quality reports		number of reports /1000 inhabitants	0.52					EWG (2021)
Bulk water delivery		%	0%					Ruston Water Department (2023)
Interruptions to the service		outages/1000 inhabitants outages/reductions/year	0					Ruston Water Department (2023)
Metering efficency		% of unmetered water					ND	
Service coverage	Freshwater	%	100%					Ruston Water Department (2023)
	Wastewater	%	100%					Ruston Water Department (2023)
Service complaints		number of reports /1000 inhabitants					ND	
Service efficiency		%					ND	
Billing issues		%	0%					Ruston Water Department (2023)
System failures	Reported leaks	number of reports /1000 inhabitants	0					Ruston Water Department (2023)
	Reported sewerage fails	number of reports /1000 inhabitants	0					Ruston Water Department (2023)
	Reported stormwater overflows	number of reports /1000 inhabitants	0					Ruston Water Department (2023)
Water pressure		psi	Very good					Ruston Water Department (2023)
Affordability of the service		%	1.38%					Ruston Water Department (2023)
Low-income billing assistance offered		units					Not offered	

Environmental Water Security		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Quality level of wastewater discharge to the environment		%					0%	Leee et al. (2022)
Storm water discharge		%					0%	Field study 2023
Sludge management		%	100%					Lee et al. (2022)
Green areas		%	49%					Global Forest Watch (2010)
Blue areas		%	50.14%					Global Forest Watch (2010)
Quality of potentail available surface freshwater		%	100%					Field study 2023
Sustainability planning	Habitat/watershed protection goals	Unit			Moderate			Literature Review
	Green infrastructure planning	Unit			Moderate			Literature Review
	Energy optimization planning	Unit					Very low implementation	Literature Review
Basin planning instrument		Unit		High implementation				Literature Review

Resilience to water-related disasters		Units	Ranges					Description
Indicator	Subindicator		1	2	3	4	5	
Overall Water Risks	Physical Risks Quantity	Unit			Medium high			WRI Aqueduct 4.0 (2024)
	Physical Risks Quality	Unit		Low Medium				WRI Aqueduct 4.0 (2024)
	Regulatory and Reputational Risk	Unit		Low Medium				WRI Aqueduct 4.0 (2024)
Risk assessment and response preparedness	Risk assessment and response preparedness	Unit				Low implementation		Literature Review
	Water shortage planning	Unit					Not present	Literature Review

9.7 Performance per dimension of water security

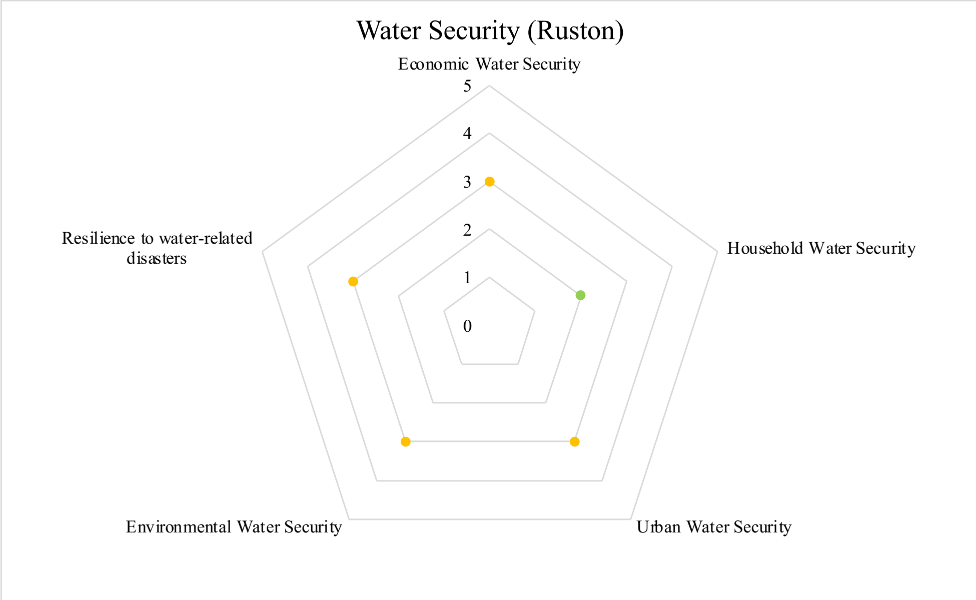

Fig. 51. Water security performance by dimension in Ruston. Armando Cepeda Guedea, 2024

The indicator framework for water security in Ruston shows mainly moderate concern for water security; and only household water security shows an adequate value (see Figure 52). The adequate levels of household water security can be explained as a combination of good service from the water operator and the financial capacity of citizens to have adequate household water facilities to enhance the quality of their water service. Despite the fact that Ruston is a water-autonomous city and does not currently have considerable issues regarding their water and sanitation service, the moderate concern values are the result of the mainly XX-century traditional water management approach in the city, where sustainable development, climate action, and integrated water management frameworks, and water-wise actions are not fully implemented, leaving the city behind the path of urban transition where water plays a critical role. Ruston should rely on more than their condition of being a water-rich city since this condition can rapidly change due to climate change and overexploitation of the available water resources, leading to endangering the water security of the city. The ambition of Ruston to attract talent and high-end industry from the big cities and become an innovation cluster needs to be accompanied by a coordinated strategy that aims for long-term water security since water is a key element for economic and social development. Another issue when evaluating Ruston's water security is the lack of data to fully evaluate each indicator due to the absence of the indicator in the city, not being recorded by the water operator, or simply not being readily available due to the scattering of information. Also the lack of a public data portal that provides general information regarding the water and sanitation service in the city is also an aspect to improve. The advantage of small cities such as Ruston is that due to their dimension, the results of successful projects and policies are more evident and can serve as an example for bigger cities (Concilio et al. 2019).

Fig. 52. Water security performance by indicator in Ruston. Source: Armando Cepeda Guedea, 2024

Economic water security: Ruston's economic water performance is predominantly optimal or adequate. There are considerable issues regarding the water operator's debt levels, and due to a lack of data, it was not possible to estimate the nonrevenue economic water losses. For that reason, the overall score of economic water security resulted on moderate concern.

Household Water Security: The water security dimension has the best performance in the city, with the majority of the indicators showing optimal values. As mentioned before this can be associated to a combination of good service from the water operator and the financial capacity of citizens to have adequate household water facilities to enhance the quality of their water service. The indicators that show very high concern (metering efficiency, service complaints, and service efficiency) have this score due to a lack of data; only the lack of low-income assistance for the water bill indicator was able to be evaluated. Freshwater consumption levels are also a concern since they are over the US average, and the United Nations recommended 150 liters per day per person.

Urban Water Security: Due to traditional water management approach the city of Ruston has important practices for urban water security, such as use of recycled water, rainwater harvesting, widespread use of renewable energies for the water service, lack of a full integrated water management plan and full participation of stakeholders in water decision making are not adopted in the city. This greatly affects the achievement of lasting water security. The water storage capacity and water loss levels present a moderate concern. On the hand, indicators associated with conventional water management approaches such as water quality, water demand and supply ratio, the average size of the network, water treatment capacity, and water losses show optimal or adequate levels.

Environmental Water Security: Ruston's territorial context allows the city to have plenty of permeable areas and blue areas to ensure the filtration and the adequate natural recharge of aquifers. On the negative side, the traditional water management approach in the city doesn't allow the city to fully take advantage of the runoff water, using only secondary treatment on wastewater and the lack of a full integration of water in sustainability planning can hamper the environmental water security of the city.

Section 4

Determinants of water security in cities and conclusions

Venice Canal. Armando Cepeda Guedea, 2024

Chapter 10

Water security increasers and reducers as a result of a systemic review

Lugano. Armando Cepeda Guedea, 2024

10.1 Common increasers of water security in cities

As a result of testing the evaluation framework in the case studies, it was possible to identify practices the reviewed cities are applying and can possibly increase Water Security in cities. These practices have been organized into the five main dimensions of Water Security. It is essential to mention that even though they are categorized in a specific dimension, they can also impact others.

10.1.1 Economic Water Security

Table 66: Identified increasers for Economic Water Security

Water Security Dimension	Identified increaser	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Economic Water Security	Boost the Water-Energy-Food Nexus	Not Identified	Identified: articulated in water an land planning	Partially Identified: implemented at the European level	Not Identified
	Efficient payment collection of the water operator	Not Identified: Less than 80%	Partially Identified: Over 90%	Partially Identified: Over 90%	Identified: Effectiviness very close to 100%
	Adequate Water Allocation	Not Identified	Not identified: challenges due to outdated price structure	Not Identified	Partially Identified: due to the abundance of the resources there is no need for thoughtfully assessments to allocate resources
	Investment in innovative technologies and good practices	Partially Identified: recent advances to a coordinated investment framework	Identified: integral part of the water policy at the city, county and state levels	Partially Identified: supported by the European Union and National funds, still further implementation is needed	Partially Identified: mainly carried by the private sector
	Coordination between land and water budgeting	Identified: water and land share same budgeting scheme	Identified: water and land share same budgeting scheme	Not Identified: separate entities	Partially Identified: water and land share the same budgeting scheme, and more coordination is needed
	Sustainable levels of debt levels	Identified: Water operator does not have any debts	Partially Identified: barely sustainable levels of debt	Not Identified	Not Identified
	Low non-revenue economic water losses	Not Identified: high levels of water losses which impact the earnings of the water operator and create a considerable waste of water	Identified	Not Identified: high levels of water losses which impact the earnings of the water operator and create a considerable waste of water	Identified

Boost the Water-Energy-Food Nexus

Water is a key resource that supports the economic development of cities and territories. Economic growth should be accompanied by a holistic water management approach, such as the Nexus approach, that coordinates different sectors that benefit from water. The Water-Energy-Food Nexus approach provides the framework for determining the proper trade-offs and synergies between water, energy, and food and maintaining the integrity and sustainability of ecosystems. This contributes to reducing the competition between sectors since they are interconnected with the common goal of sustainable development and advance towards a lasting Economic Water Security. The Water-Energy-Food Nexus is generally used at the national level but should be fully implemented in city and provincial planning as an integral aspect the broader water security strategy. This is the case of Reggio Calabria, where, at the European level, the use of this framework in water and land policy is encouraged. However, no such coordination exists for its implementation in Reggio Calabria and its surrounding region, leaving the development strategy of economic sectors where water is key fragmented. In the case of San Diego, this framework is used to manage and coordinate since 2003 the transfer of agricultural water from the "Imperial Irrigation District" to the city of San Diego in a sustainable way and where no sector is harmed in addition to taking advantage of the transfer of water to produce energy during the process. The case of San Diego represents a good example of how different institutions at different levels and fields coordinate to ensure the economic water security of the city and its surrounding region. Mexico City, in its development plan document, proposes using a rationale similar to the Water-Energy-Food Nexus. Still, its implementation seems difficult due to the complexity of water insecurity in the city. For Ruston, which aims for sustainable economic development but still does not have a long-term blueprint, adopting the Water-Energy-Food Nexus looks like a good fit for its aspirations, although no state-level policy fully supports it.

More efficient payment collection of the water operator

Water operators handle themselves as an industry since it involves the organized extraction, treatment, and distribution of an essential resource such as water for a fee. Although several water operators are public entities funded by governments, they are organized similarly to private sector industries, with financial performance metrics, efficiency goals, and service targets. Consequently, the economic stability of the water operator is relevant to the Economic Water Security of cities since a water operator with a healthy economy is important to sustain economic growth. One of the great challenges of water operators is to efficiently collect payments from the different consumers of the resource, such as agriculture, industry, and municipal. An adequate payment collection system allows water operators to have more capital to invest in new technologies, infrastructure maintenance, and various projects that help improve the quality of service. To increase the payment collection effectiveness, the research identified key practices such as tiered pricing for high-volume consumers such as industry and agricultural sectors by charging higher prices as usage increases; this stimulates a more efficient use of water resources by these sectors and ensures that large users contribute according to the costs of the water infrastructure they use, the reduction of non-revenue water (water that is lost before being billed), improving water metering efficiency, tariff design for social inclusion to increase payment compliance from vulnerable sectors, the use of digital payment methods to make more accessible the collection and increase the transparency and communication of the water service bill between the operator and the users.

Adequate Water Allocation

To adequately sustain the productive use of water, an adequate water allocation is critical. Water allocation is the process of distribution of water in terms of quantity, quality, or timing between different sectors. Due to increasing water demand, climate change, and growing water scarcity, water needs to be wisely distributed to sustain development. To have an adequate water allocation, the research proposes the following actions. Flexible and adaptative allocation, which means that the distribution of water between sectors is not set and responds to climate conditions, needs of the population, punctual objectives, and other external factors, supported with real-time monitoring technologies. Participatory water allocation means that citizens take part in the decision process of allocating water resources according to their needs and develop a water allocation strategy in case of severe scarcity in order to prioritize key sectors in water distribution.

Investment in innovative technologies and good practices

Water investment plans need to follow the current challenges to water security. The current trends show that several countries and cities need to catch up with the required investment to advance toward long-term water security. Investments are generally allocated to new reservoirs, treatment plants, and pipes, which will help to improve the quality of integral water service now and in the future. These investments should also be allocated to the maintenance and operations of existing stock to improve efficiency and reduce water losses, as well as new technologies and practices to make the water service more efficient. First, it is required a comprehensive budget assessment to identify the current and future needs of the water system, and subsequently identify the technologies and practices that can increase the efficiency of the service while saving water resources and money at the same time.

Coordination between land and water budgeting

Despite recent efforts, there is still a notorious gap in the coordination between urban and water planning; this lack of coordination is also reflected in the budgeting processes. As mentioned before, water is a key resource for economic development. Still, it is widely taken for granted, and its impact on the economic development of cities and territories is not fully acknowledged. To increase economic water security, it is important to quantify the value of water in the economic activities of the city and how they impact in the city budget. The budgets developed by the water operator must be coordinated with the economic aspirations of the city reflected in its budget. This prevents the budget developed by the water operator from not meeting the economic expectations of different sectors, including the municipal and vice-versa.

Maintain sustainable levels of debt levels

Whether with the intention of improving the service by investing in new infrastructure or technology or that the amount of money collected or public financing is not enough to continue with the normal water service, water operators resort to borrowing in the markets, creating debt. Going into debt is not a bad practice since it serves to finance large projects to improve the service or face an emergency that affects the system, the problem emerges when debt levels are no longer sustainable. Maintaining sustainable debt levels is key to economic water security as it helps water operators not to compromise their activities to cover their debts and continue providing an adequate service for the economic development of cities. A useful parameter to measure the sustainability of debt is the Debt Service Coverage, which measures the sufficiency of net operating revenues to cover debt service. This measure tracks the capacity of water operators to repay their debts; this indicator is important because it communicates to investors and other stakeholders the financial ability of water operators to repay their debt. Optimal levels of Debt Service Coverage are 2.0 and above, which means that the revenues of the operator are enough to cover more than two times their debts.

Reduction of non-revenue economic water losses

The financial viability of water operators and their capacity to provide adequate levels of water to different sectors to sustain the economic activities of cities is endangered by high levels of non-revenue economic water losses (NRW). NRW is the difference between the amount of water put into the distribution system and the amount of water billed to consumers. High levels of NRW reflect huge volumes of water being lost through leaks, water not metered or invoiced to customers, or both. Low levels of NRW (less than 0.10 USD per m3) are a good step towards economic water security since it contributes to less water being wasted. Different economic sectors can use it, and the finances of water operators could be more solid because of the increase in their capacity to collect payments. To reduce the non-revenue economic water losses, the following: district metering to detect areas with unusual levels of waste, constant rehabilitation and renewal of infrastructure, detection of illegal connections, and real-time detection of leaks and reduction of pressure using information technologies and artificial intelligence.

10.1.2 Household Water Security

Table 67: Identified increasers for Household Water Security

Water Security Dimension	Identified increaser	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Household Water Security	Low-income assistance program	Identified: Effective program to make affordable the service	Not Identified: program no longer active since 2024	Partially Identified: Identified but not effectively helping low-income households to pay the service	Not Identified
	Increase water autonomy of households	Identified: public-funded program to install rainwater collectors in households	Partially Identified: discount and technical assistance to collect water from alternative sources in households	Not Identified	Not Identified
	Effective service response	Not Identified: due to numerous issued in the service the water operator is overwhelmed	Partially Identified: the service response is effective in some districts and some specific issues	Not Identified: the water operator does not respond effectively to issues as reflected in the "segnaliamo" platform	Identified: the water operator responded effectively to any related issues with the service
	Water wise culture	Partially Identified: included in the city policy still not reflected in the consumption reduction	Identified: reflected in the main development document in coordination with the water operator. Consirebale reduction of water consuption in the last decades	Partially identified: recent call from the city goverment to use more wiseley the water resources in case of contigencies	Not Identified
	Adequate water metering	Not Identified	Identified: Acceptable leveles of effieny of metering	Not Identified	Not Identified
	Increase awareness of the water security situation in the city	Identified: high levels of awareness of the water security of the city due to high access to public data related with water	Identified: high levels of awareness of the water security of the city due to high access to public data related to water	Partially Identified: civil movements pushing for more participation in water-related decision-making processes and the presence of public data portals regarding water-related issues	Partially Identified: civil movements aiming to increase awareness on the economic potential of water

Low-income assistance program

Accessibility to water by all households is key to water security in homes. Vulnerable groups in several cities may have difficulty covering service fees and may default on payments. This situation can generate a reduction in supply or direct cuts in supply. This collides directly with the universal right of accessibility to safe and reliable water for all people. This requires a solid low-income assistance program for vulnerable groups where public funds cover a part of the bill. The part of the water bill that the citizen should pay directly should always be below 1.5% of the monthly income to be manageable for vulnerable households. This requires greater flexibility in the construction of the rate so that it is always affordable to all citizens. An effective assistance system can increase the revenue base for the water operator and provide unrestricted quality service for vulnerable groups, thus reducing inequalities in cities. In the case of San Diego, there was a temporary assistance program for vulnerable groups until the beginning of 2024. In this case, it would be advisable to advance to a lasting program, considering the high cost of the service in the city. Mexico City has almost optimal levels of accessibility in metered homes; however, the high number of homes without regulated and metered services, generally belonging to vulnerable groups, greatly reduces the general quality of service in the city and increases the already existing large inequalities. Reggio Calabria has an assistance program that is insufficient since even if the water rate is applied it is still unaffordable, which is why greater flexibility is required in the current assistance program in the city. In the case of Ruston, the population that incurs payments is low but there is no assistance program that helps these families cover the costs of the service, so they are always at risk of having their water service cut off.

Increase water autonomy of households

Through the study, it has become clear that cities must adapt to a reality where the amount of water resources can be reduced and where the water operator has to apply forced reductions in supply in case of contingency. This causes households to look for alternative sources to cover their supply, such as rainwater collectors in homes, which is an optimal solution to use resources in a more effective and sustainable way. By increasing the water autonomy of households, demand levels for water operators are reduced, long-term users pay less in their rate, and the culture of sustainable water use increases. Comprehensively increasing the water security of homes. It is advisable to implement a public program that helps a massive number of rainwater collectors, as in the case of Mexico City; however, it is a program that still needs to be more ambitious and increase the number of beneficiaries as well as requiring that businesses and industries have their rainwater collection systems in the form of wetlands and artificial lakes.

Effective service response

In order to move towards lasting water security in homes, the water operator must have an efficient and effective response service that resolves service-related problems in homes. These problems can include water quality problems, water or wastewater line leaks, low pressure, and service interruptions. The water operator can rely on the use of digital tools so that citizens can directly report any situation. In addition, the operator should have a system that analyzes the number of reports per district to identify failures in the main water and sanitary lines, quality of the wells or local sources, and in the distribution system. In addition to having an adequate number of technical personnel to deal with problems effectively in the shortest time possible. In the case of Reggio

Calabria, there is an adequate digital public platform to report problems with water service in homes, as in Mexico City. San Diego has a reporting program for urban services issues where the water section is incomplete and only addresses problems related to the sewer network. Ruston manages the traditional response system based only on telephone operators or direct reports in the operator's central office in the city.

Water wise culture

Water systems around the world are increasingly vulnerable and require everyone to make an effort to use water resources in a more responsible way. All sectors of society must be involved in the efforts. The study has revealed that water consumption levels remain high, even far from the 150 liters per day per inhabitant recommended by the United Nations. This requires a change in the culture of households in how they use their resources. It is recommended that households recycle water and give it multiple uses, use bathroom furniture that requires less water than traditional ones, use plants that require less water in the gardens and adapted to the particular climate of the city, as well as take advantage of water. of rain. Water wise strategies must be accompanied by an awareness program so that citizens understand the need to adopt saving practices and move towards water security in homes. The case of San Diego is relevant since by 2020 San Diegans used 30% less water than in 1990 when the last water crisis happened; this was the result of the implementation of an ambitious campaign that included water-sensitive practices such as more efficient showers, toilets, and taps, rebates to tear out grass and the use of recycled water have significantly reduced the consumption of water in the city.

Adequate water metering

Water metering is the process of water operators measuring the volume of water used by residential, commercial, or industrial consumers through devices called water meters. Traditionally, water meters are mechanical, which causes various imprecisions when measuring the volume of water consumed in homes, which can increase the NRW. In recent times, governments, as can be seen in the study, are betting on the implementation of digital meters, which increase the reliability of measurements, reduce the loss of non-billed water, allow water operators to monitor water consumption in real-time and increase citizens' confidence in the water service by having a more transparent process when counting the volume of water consumed.

Increase awareness of the water security situation in the city

Raising awareness about the importance of water conservation is crucial for advancing toward water security in cities and households. This is done by engaging the community in water conservation efforts and promoting sustainable urban water management. This can be done by public education and awareness campaigns for water security, increasing the participation of citizens in the decision-making process on water management through public participation platforms and community-based projects, and providing public access to relevant data for water security so citizens can get informed on the current situation of its city, neighborhood, and even their household.

10.1.3 Urban Water Security

Table 68: Identified increasers for Urban Water Security

Water Security Dimension	Identified increaser	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Urban Water Security	Implementation of Green/Blue infrastructures in urban areas	Partially Identified: implemented in recent times on selected neighborhoods	Identified: a proposed network of green/blue infrastructures in the city	Partially Identified: new projects aiming to the integration of new blue and green infrastructures	Partially Identified: recent projects of green corridors
	Adequate water, sanitation, and runoff infrastructure	Not Identified: infrastructure not in condition for an adequate water service for all	Identified: adequate infrastructure for the needs of the city and in continued upgrade for a more efficient service, reducing failures and saving water	Not Identified: infrastructure not in condition for an adequate water service for all	Partially Identified: adequate infrastructure and in good condition but still from an XX-century setup
	Automatization and digitalization of the water service	Partially Identified: recent implementation of digital monitoring in the water districts	Identified: use of high end information technologies to monitor and automize the water service to make it more efficient	Not Identified	Not Identified
	Use of renewable energies	Not Identified: not significant use	Identified: use of renewable energies in the service operation	Partially Identified: the potential of further use to make it significant due to possible EU funding	Not Identified
	Diversity in the water sources	Partially Identified: diversity is Identified, but still heavily rely on one source (Cutzamala system)	Identified: shared objective between city and county to diversify as much as possible the sources	Not Identified	Not Identified
	Use of Recycled water	Partially Identified: potential not fully developed with sparse practices	Identified: significant percentage of the water in the system is recycled	Not Identified	Not Identified
	Coordination between land and water planning	Partially Identified: coordination not fully executed despite being an objective of the local government	Identified: water is a crucial element when developing urban projects; this is reflected in the water feasibility assessments	Not Identified	Not Identified
	Implementation of an Integrated Urban Water Management framework	Partially Identified: efforts to make the approach predominant in the management of the water resources	Identified: approach used in the last decades in the city, county and state	Identified: nationl adopted approach by the water operators	Not Identified
	Increase the participation of civil society on the decision-making process	Partially Identified: high levels of participation in some districts	Identified: high levels of participation in water related decision-making processes as reflected in multiple participatory processes	Partially Identified: recent adoption of initiatives to increase participation such as "Segnaliamo"	Not Identified
	High public data availability	Identified: robust public data portal on multiple water-related aspects	Identified: robust public data portal on multiple water-related aspects	Not Identified: insufficient public data to understand the water security reality of the city	Not Identified

Implementation of Green/Blue infrastructures in urban areas

Green infrastructures can be described as interconnected networks of multifunctional green spaces that provide multiple benefits for sustainable development, such as improving air, soil, and water quality. Green infrastructures include parks, open green spaces, playing fields, natural preserved areas, private gardens, allotments, and green roofs and walls. Blue infrastructures are water bodies embedded in the urban context, such as watercourses, ponds, and lakes. Integrating blue and infrastructures makes urban spaces more resilient, pleasant, and healthy for citizens. Green/Blue infrastructures provide multiple ecosystem services, which are the benefits that humans obtain from nature. They provide provisioning services by increasing the water supply through natural and artificial water bodies and providing food and raw materials through urban agriculture and community natural spaces. They provide regulating services by helping to reduce the effects of flooding, regulates climate and reduce erosions. They support the thriving of biodiversity and quality soil as ecosystem-supporting services. Finally, they provide cultural services by providing spaces for recreation, the well-being of citizens, and aesthetic and spiritual value. Green/Blue infrastructures are key elements for advancing to water security by increasing the infiltration capacity and helping to recharge aquifers, increase water reservoirs, reducing the impacts of floods and storms, and help to increase the acknowledgment of the value of water. Even though those elements intersects into different dimensions of water security it better fits into urban water security since they are physical spaces that should occupy large spaces in cities and integrated in land planning as critical elements.

Adequate water, sanitation, and runoff infrastructure

The water service infrastructure is responsible for extracting, purifying, transporting and distributing drinking water; transport, treat and discharge wastewater; and transport, treat and discharge rainwater. The optimal functioning of the water infrastructure is necessary for the water security of cities. However, due to the complexity of these systems, they are vulnerable to various events that can affect their operation such as storms, floodings, earthquakes, power failures, among others. This can cause leaks in the pipes, reduction in pressure, overflow of pipes, failures in the transport pumps, among others. What is recommended is that the infrastructure in cities does not exceed its operational life (in the case of pipes less than 35 years), adequate levels of investment for preventive maintenance of the system, and prompt detection and repair of failures supported by information technologies. Traditional water systems generally use the same piping system to transport wastewater and rainwater, so the potential for rainwater use in several cities is lost. An important aspect that emerges from the research is the need for more cities to adopt the use of a separate rainwater pipe system, with the intention of making greater use of the resource since it can be recycled and used more easily than wastewater.

Automatization and digitalization of the water service

Automation of the urban water system is a set of theories, methods, and technologies such as sensors, control systems, remote monitoring and data to make a system work automatically and improve its efficiency. Adequate automatization can help to reduce the waste of water, improve water quality, reduce operational costs, quicker responses, and more efficient use of the water resources overall. The main components for the automation of the water are: the implementation of SCADA systems (Supervisory Control and Data Acquisition) to gather and analyze real-time data on the water service through digital networks and computer systems; placement of sensors throughout the water network to measure key parameters such as water quality, pressure, and flow rate, smart metering to collect real-time data on consumption patterns; use of artificial intelligence to manage all the incoming data to develop projections on water use, maintenance schedules and possible future failures, and the implementation of remote automated control systems to automatically adjust pumps, valves, and other components based on sensor data without the need of manual intervention.

Use of renewable energies

The use of renewable energies in the urban water system is a key element that is in line with climate action by reducing the emissions produced by the water sector by extracting, distributing, treating, and distributing water. The most common sustainable energies used in water systems are hydroelectric, wind, and solar, as can be seen in the cases of San Diego with its solar parks and wind farms, and dams that produce electrical energy, Reggio Calabria with the Menta dam which produces renewable electrical energy for the metropolitan city, and the West Monroe water reuse plant that partially uses solar energy for its processes. The use of renewable energies in water systems can help reduce costs for operators, increase the sustainability of the water system and the city in general, in addition to contributing to climate action by mitigating its impacts.

Diversity in the water sources

Having several water sources increases the sustainability of the water system since, in the first instance, if a source is temporarily inaccessible, other sources can be used to compensate. Also, by using different sources, overexploitation of the resource can be reduced since the demand is distributed among several sources. The diversity of sources is a key element for large cities that have high demand for water or cities that are located in geographic contexts with little availability of the resource. In the case of San Diego, the high demand for water intersects with a context of low water availability, this has led the city to adopt an ambitious strategy of diversifying water sources from neighboring regions in the state of California where around 85% of the water comes from outside the city. However, depending so much on external sources represents a vulnerability to the city's water autonomy, which is why in recent times the city has decided to invest in desalination plants and greater use of recycled water to compensate for this vulnerability. In the case of Mexico City, 56% of the water comes from outside the city, mainly from the Cutzamala system, which is more than 300 km away from Mexico City, however, due to the high levels of demand, the production capacity of the system has become insufficient, this has caused Mexico City to look for alternative, closer sources such as Lake Guadalupe and the Madin Dam, which require large investments to recover these sources. In addition to starting to take seriously the use of recycled water to compensate for the excess cans. In the case of small cities like Ruston that only use underground water with a system of 12 wells, diversification does not represent a great concern; however, to increase the city's water resilience, it would be advisable to have some surface water source enabled in case of overexploitation. of the aquifers.

Use of Recycled water

Using recycled water gives cities a reliable, year-round, and locally controlled water resource. This helps to meet future water demands while reducing dependence on imported water. Recycled water can have various uses depending on the level of treatment given to the wastewater. In the case of secondary treatment where organic waste is filtered, the recycled water can be used to irrigate fields and some agricultural uses. It is when the water receives a tertiary treatment that the uses are greater since the advanced filtration and disinfection processes provide high quality water that can be used for industrial uses, irrigation of public and agricultural spaces of higher quality, recharge of aquifers, use indirect potable (discharge water with tertiary treatment to water sources that will be treated to be potable). The advantage of having an independent runoff pipe system allows that water to receive tertiary treatment in the water reuse facilities that allow the water to be reintegrated into the drinking water distribution system. This is the case of the West Monroe Reuse Facility that, thanks to an independent rainwater piping system, allows the treated water to have drinking quality and can be used for the production of paper. For the effective use of recycled water, there must be legislation and regulations that establish the quality levels required for the different sectors that use recycled water. Since it may be the case that rainwater with tertiary treatment has drinking quality, but the regulations do not allow its use for human consumption, so legislation is required that recognizes the benefits of quality recycled water.

Coordination between land and water planning

When developing policies and plans to address water security in cities one of the main challenges is the integration between water planning and land planning. Meaning, that the water security goals and strategies developed by water planners and operators do not transfer properly into the main planning documents such as comprehensive plans, sustainability plans, and zoning plans. Water and land use planners are usually disconnected from what they do, and the tools at their disposal. Water planning is usually done by local or regional water operators, or basin regional authorities who are subject to a differing array of national, regional, and local water planning and regulatory requirements. The land use planning that drives future water demand, and allocation of water resources, however, is done predominantly at the local level by regions and cities. To achieve water security in cities water and land use planning must be connected effectively. Water providers need to understand the growth and development patterns anticipated by land use planners and consider that information when projecting water demands and be prepared, and land use planners need to understand how development patterns affect water use and water loss and consider what rate and style of growth is possible given water-supply availability.

Implementation of an Integrated Urban Water Management framework

Integrated water planning incorporates adaptive decision-making and the effective use of water management tools such as financial, environmental, and social indicators, assessment tools for evaluation purposes, and guidance manuals detailing the sustainable practices and participation models for the stakeholders (Ojha, Surampalli, Bárdossy, Zhang, & Kao, 2017). The regulatory change includes establishing sustainable standards to address the planning needs. The development of ordinances, codes and policies belongs to this component. The management and financing component includes an integrated decision-making approach which can identify the interconnections between the management at the city, regional, country, and global levels. Market mechanisms, utilities and service providers are structured to maximize the efficiency of the management in the most sustainable way possible (Ojha, Surampalli, Bárdossy, Zhang, & Kao, 2017).

While sustainable water resource management is the goal to attain sustainability and resilience in the freshwater system, integrated water management (IWM) is the strategy for pursuing this critical goal. IWM can be defined as a process which promotes the coordinated development and management of water, land, and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of the ecosystems (Ojha, Surampalli, Bárdossy, Zhang, & Kao, 2017). IWM is a complex process which involves the allocation of resources between competing uses and users and hence requires political drive. It is not always possible to come up with win-win solutions and sometimes, compromises must be made for the common cause and the sustainability of the system.

Meanwhile, IWM can be used in regional contexts. A more specific term tailored for the city level can be Sustainable Urban Water Management (SUWM) which can be defined as the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it (Gleick 1998; Hurlimann and Wilson 2018). This implies the consideration of climate change and the inclusion of both supply and demand side initiatives. To integrate a SUWM approach, new paradigms to water management should be implemented, including Integrated Urban Water Management (IUWM) and Water Sensitive Cities. Yet, despite this, the widespread implementation of SUWM remains elusive. SUWM can be a comprehensive term useful for the research since it searches to encompass the complexity of urban water management (Marlow et al. 2013; Hurlimann and Wilson 2018).

In the case of San Diego, a higher level of IWM implementation is observed since the different aspects that involve sustainable management are integrated and coordinated by the water operator together with the other sectors of the city. In the case of Reggio Calabria, the implementation of an integrated water management system is advocated despite its institutional complexity, which contradicts the concepts of efficiency and institutional coordination that the UIWM advocates. In addition to institutional instability where in a short time the institutions involved in water management (operator and regulator) constantly change their rules and composition, which makes long-term planning difficult, another important value in the IWM.

Increase the participation of civil society on the decision-making process

Until recent times, natural resource management governance was dominated by centralized government institutions, international organizations, and industry (Cox, Arnold, and Villamayor Tomás 2010), where top-down solutions, usually under the control of a few, were deemed necessary to avoid local people overusing their resources (Mistry et al. 2016). However, there has been growing support to increase the participation of local communities in playing a leading role in developing governance strategies for the sustainable management of natural resources (Mistry et al. 2016; United Nations Development Programme 2012). Active participation of communities has the potential to complement the existing water management institutions by involving the local population and providing opportunities for aligning the needs of the communities with the whole process of the water management system, consequently creating a sense of ownership and accountability of the local community and viewing the water management system as part of them rather than a detached institution (Monyai et al. 2022).

Citizen participation ranges from common sense customer care to cooperative ownership and management. Intermediate forms of participation include structured consultation procedures such as public hearings, and the participation of advisory committees or regulatory boards. This demand for transparency and participation by stakeholders is particularly strong concerning the issue of public-private water operators (Daniell, Rinaudo, Chan, Nauges, & Grafton, 2015). However, there remains a significant gap between the recognition of participation as a citizenship right, as outlined in legal frameworks and the actual practices to allow citizens to express their preferences and concerns. Bridging this gap is one of the main challenges policy makers, water operators and citizens needs to face (Daniell, Rinaudo, Chan, Nauges, & Grafton, 2015).

High public data availability

Data plays a key role for urban water security; first, it is a key tool for better management of water resources since it allows evaluating the situation of the system and planning for future scenarios, in addition to collaborating for the automation of the management system. of water such as SCADA systems, in addition to increasing citizen participation since a public data system on the local water system allows citizens to know the water security situation in the city and to be able to participate in an informed manner in decision-making.

10.1.4 Environmental Water Security

Table 69: Identified increasers for Environmental Water Security

Water Security Dimension	Identified increaser	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Environmental Water Security	Low pollution levels of water sources	Not Identified	Partially Identified: some sources are facing some quality issues	Not Identified	Identified: low levels of pollution in local water bodies allowing the recreative and cultural use of water
	Tertiary treatment before water discharge	Partially Identified: only on some districts, especially in high income areas	Identified: high levels of this level of treatment allows to maintain a good quality water bodies and increase the potential of recycled water	Partially Identified: only some facilities	Not Identified
	Preservation of green areas	Partially Identified: recent efforts that face significant challenges due to the high levels of urbanization	Identified: key element to maintain the quality of water reservoirs	Identified: There is a high presence of green areas in the municipality, still there is still room to increase the blue and green nexus	Identified: green areas are preserved and protected since they are an integral part of the lifestyle of the city inhabitants
	Stimulate Basin urban link	Identified: basin level entities that stimulate the link	Identified: basin level entities that stimulate the link	Partially Identified: basin-level entities that stimulate the link, not fully coordinated with the city level	Partially Identified: recent efforts to create the link, still not fully implemented at local level
	Full integration of water in the climate action strategy	Identified: water a key element in the climate action strategy as reflected in the development plan	Identified: water a key element in the climate action strategy as reflected in the development plan	Identified: water a key element in the climate action strategy as reflected in the development plan	Not Identified

Reduce pollution levels of water sources

It is not necessary that all water sources in a city be used to produce drinking water, but they can have value as elements of recreation, health, preservation of biodiversity and as a natural barrier in case of floods and storms. These bodies also include coastal maritime waters that are also involved in the water system of coastal cities since discharges occur in these bodies. It is key for water security to maintain these sources with optimal quality since, in addition to the benefits mentioned above, they can also eventually become sources of drinking water, whether in an emergency or permanently. The quality of water bodies that are not used as sources of drinking water can be vulnerable to low quality of discharges, illegal industrial discharges, and contamination by individuals. To advance towards environmental water security it is important constant monitoring of the quality of these bodies, tertiary treatment in discharges, regulation of industrial discharges, policies for the preservation of natural heritage, and awareness campaigns about the value of water.

Tertiary treatment before water discharge

In addition to being mentioned as a key element in urban water security, tertiary treatment of discharge waters, since it helps maintain a high quality of the water bodies where the treated water is discharged, whether fresh or salt water, which allows the conservation of aquatic ecosystems and maintaining the cultural, recreational, and well-being values of these bodies. It is recommended that cities move from conventional secondary treatment for discharges to tertiary treatment as it is a factor that can increase environmental health and move towards lasting water security.

Preservation of green areas

The preservation of natural areas in cities and their surrounding territories helps to maintain good soil quality that reduces the risk of landslides, tree areas that reduce the impacts of floods and storms, improve air quality and areas with high permeability that allow adequate recharge of aquifers. It is recommended that around 30% of the area of cities be allocated to permeable green areas. To achieve this, it is important that planning instruments consider preserving existing green areas and seeking to expand them within the general climate action strategy. Natural areas can be complemented by semi-natural blue and green infrastructures that are more adapted to urban contexts and collaborate to manage rainwater in a more sustainable way, improve soil quality and its permeability, improve air quality, purify water naturally, in addition to increasing the resilience of cities in the event of natural disasters.

Stimulate Basin urban link

As mentioned previously, the connection between urban and water planning is key, going more specifically, the connection between planning at the basin and urban level is key for environmental water security specifically. When talking of the urban basin, the link usually refers to the sub-basin level where the city and its surrounding context are inserted. The objectives of the plan at the basin level should go in the same direction as the planning of the water operator and the city since several sources of water come from the surrounding territory of the city, generally at the sub-basin level. Planning at the basin level should involve governments of different cities and provinces that must share the same objective of advancing toward the territory's water security. The water security of cities cannot be separated from the water security of the surrounding territory of which the city forms an integral part. One of the challenges is the lack of a unified criterion to define the sub-basins and the local watersheds, since each government or institution has its own criteria when defining them, this requires a unification of criteria at the international level, national and local to delimit the basins. In this way, planning can be carried out more effectively and coordinated between the different governments involved.

The case of San Diego the connection between planning at the sub-basin and urban level follows a common thread through the Regional Water Management Group (RWMG) where the governments of different cities in San Diego County along with other counties, and the operators at the county and city level where they develop joint projects to improve the territory's water security. Also at the city level San Diego has specig plans for each of its local watersheds, this to plan accoridigly to the needs of each particular watershed. In the case of Mexico City, despite there being administrative divisions of basins and reports for each water region, the link with urban planning is weak. In the case of Reggio Calabria there is the institutional framework that can favor a city-basin connection that has not been adequately exploited. Finally, in Ruston, planning at the basin level lacks greater coordination between the city, operator, and basin.

Full integration of water in the climate action strategy

As has been developed throughout the thesis, the water crisis should be understood within the global climate crisis. It is for this reason that water must play a leading role when planning the climate action of a territory and a city and not be seen as separate elements. In the case of San Diego, it can be seen how water is a key element in its climate action strategy, as well as in Mexico City. In the case of a small city like Ruston where the climate action strategy is limited, the link with water is also not clear, this can be associated in the first instance in a context where the climate crisis is not a priority in the city, in addition to the lack of technical resources for the development of a comprehensive climate action plan. One way to address the challenge is to require state and national governments to require their cities to develop a comprehensive climate action plan where water plays a key role.

10.1.4 Resilience to water-related disasters

Table 70: Identified increasers for Resilience to Water Related disasters

Water Security Dimension	Identified increaser	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Resilience to water-related disasters	Widespread of water shortage risk management plans at different levels	Partially Identified: recent initiatives are advancing to coordinated water shortage risk management	Identified: water shortage risk management plans at the state, county, and city levels	Not Identified	Not Identified
	Risk management plan of water-related risks	Identified: hydrogeological risks present in the local risk management strategy	Identified: hydrogeological risks present in the local risk management strategy	Partially Identified: hydrogeological risks present in the local risk management strategy, but updates may be required	Partially Identified: hydrogeological risks are present in the local risk management strategy, but still further development is required

Widespread of water shortage risk management plans at different levels

In the context of the climate change emergency that is affecting the supply of fresh water in the cities and territories, it calls for a transformation in the water management system to ensure the sustainability and development of communities. This requires a planning instrument to ensure that adequate water supplies are available to meet existing and future water needs and avoid water shortages. The plan should include assessment information on forecasts of water shortages, response actions, compliance and enforcement actions, monitoring instruments, and communication actions. Also, these plans have to be updated with certain periodicity to have clear forecasts and scenario planning on water shortages and also to evaluate the progress of the previous plan. It is recommended to update the plan every five years. Also, the water shortage management plan should be implemented at the state, municipality and city levels, to act in a manner consistent with the needs of each territorial dimension. One example of a solid framework on water shortage planning is the case of San Diego where there is a coordination between the state, county, city and district levels and each level has its own water shortage plan.

The state of California through the Department of Water Resources developed the Urban Water Management Plans (UWMPs). These plans are prepared by urban water suppliers every five years. These plans support the suppliers' long-term resource planning to ensure a safe and reliable water supply to meet the current and future needs. The California Water Code establish that every urban water supplier that either provides over 3,000 acre-feet of water annually or serves more than 3,000 urban connections is required to submit a UWMP (California Department of Water Resources 2024b). The DWR guides local urban water suppliers by preparing a UWMP Guidebook, conducting workshops, developing tools, and providing staff to help local water suppliers develop the plan and understand the requirements in the California Water Code that regulates Urban Water Management Planning. The main features the plans should have are assessing the reliability of water sources over a 20-year planning time frame, describing demand management measures and water shortage contingency plans, reporting progress toward meeting a targeted 20 % reduction in per-capita (per-person) urban water consumption by the year 2020 and discuss the use and expected use of recycled water. The information produced by the UWMPs can be useful for local, regional, and statewide water planning. In the line of increasing the resilience and preparedness of water operators in the case of severe droughts and water shortages since 2018 the state of California requires to prepare an Annual Water Supply and Demand Assessment (Annual Assessment). Each water operator has to provide with their assessment information on forecasts on water shortages, response actions, compliance and enforcement actions, and communication actions. The results of these evaluations are included in the Water Shortage Contingency Plan (WSCP) that each local operator has to present at the city and county level.

The San Diego County Water Authority as water operator in the state of California in 2021 presented its Water Shortage Contingency Plan (WSCP). The plan includes a supply allocation methodology, levels and response actions, a communications plan and procedures to carry out an annual water supply, and a reliability analysis. The document is divided into 10 sections (San Diego County Water Authority 2021b). The first section provides an introduction to the relevance a pertinence of developing a WSCP and provides some basic concepts. The second section provides information for the preparation of the plan and outlines the procedure to evaluate implementation and make updates to the WSCP. The third section includes a review of the previous droughts and the actions of the water authority during those periods, it also includes the lessons learned from these events. The fourth section contains a discussion on the annual water supply and demand assessment, it provides details on the evaluation criteria to be used and basic supply and demand assumptions. The fifth section provides an overview of the six shortage response actions and levels including the thresholds and the water supply conditions that trigger the response levels, the section also discusses the potential scenarios that would trigger a certain shortage response level. Section six identifies a list of potential consumer water use restrictions and extraordinary measures during shortage events. These measures, along with the response level information discussed in the previous section, also discuss the potential measures that the member agencies and municipalities can take to conserve water. Section 7 provides a detailed description of the methodology for the allocation of freshwater resources to its member agencies in the case of water shortage. The eighth section describes how the Water Authority manages catastrophic water shortages caused by unexpected natural disasters. The section includes a discussion on the Integrated Contingency Plan, Emergency Water Delivery Plans, and Emergency Storage Program. Section nine describes the elements of the communication plan, including coordination, key audiences, and communication objectives. It also discusses strategies and tactics for each water supply shortage level. The tenth and last section summarizes the role of the agency board in activating the plan and considers potential shortage response actions. It also includes a discussion on the role of the Member Agency Advisory Team during a water supply shortage event and how the Water Authority will manage reduced revenues due to the implementation of demand reduction measures.

The city of San Diego also a local operator and in synergy with the San Diego County Water Authority (WSCP), presented in 2020 the City of San Diego Water Shortage Contingency Plan (SDWSCP). The document is smaller than the plan at the county level to avoid repeating subjects previously explained in the county plan. The plan is divided into nine sections (City of San Diego 2020). The first section is a synthesis of the annual water supply and demand assessment with key inputs of the document such as the projected water supply, the existing infrastructure, projected water demand, evaluation criteria, decision-making processes and proposed alternative actions. The second section presents the proposed water shortage levels. The third section presents the penalties and charges to enforce the restrictions. The fourth section presents the water shortage response actions. The fifth section presents procedures to determine the water shortage reductions and the reporting and monitoring mechanisms to determine it. The sixth section defines the action to pursue in the case of economic revenue reduction in the case of shortages. The seventh section presents the catastrophic supply interruption planning measures which include the measures at the county and state levels and the emergency storage of water policy at the city level. The eighth section presents the legal details of how the city council should implement the SDWSCP. The ninth and final section presents the communication mechanisms for current and predicted shortages and awareness on the sustainable use of water resources.

A water supply assessment (WSA) must be presented to cities and counties for inclusion in any environmental documentation of projects that propose to construct a project having more than 500,000 square feet (City of San Diego 2022). This is a useful document for local planning that oversees the pertinence to develop a project using water criteria. This means that water availability can legally determine the characteristics of projects of urban impact going beyond the already existing environmental assessments. The documents contain a brief description of the San Diego water system, existing and projected water supplies, projected demands and the conclusion. Some communities in San Diego submitted a WSA to update their community plans with the intention of verifying if it is possible to develop certain projects in their communities that require considerable amounts of water. This instrument is the closest document to a water shortage management plan at the neighbourhood level.

San Diego has a strong framework for water shortage management with a broad set of policies and guidelines at different government levels due to a strong awareness of local governments and civil society to transform their traditional water management approaches into a new one that is conscious of the challenges the state and the city faces to ensure water security.

Risk management plan of water-related risks

Overall, risks related to natural hazards and climate change are not autonomous or externally generated circumstances to which society reacts, adapts, or responds. They are, rather, the result of the interaction of society and the natural or built environment. Consequently, effective risk management essentially requires an improved understanding of this relationship, and the factors influencing it (Birkmann, Risk 2013). Understanding the various types of relationships and interactions between nature and society is, therefore, key to better understanding risk. Considering a risk-based approach to water security, a risk is considered acceptable if the likelihood of a given hazard is low and the impact of that hazard is low. In such cases, there is no pressure to reduce acceptable risks further, unless more cost-effective measures become available. The acceptability and tolerability judgement process enables policymakers to prioritize risk management decisions when risks exceed acceptable levels (Organisation for Economic Co-operation and Development, 2013).

The OECD proposes four water risks

Risk of shortage (including droughts): Lack of sufficient water to meet demand (in both the short- and long-run) for beneficial uses by all water users (households, businesses and the environment).
Risk of inadequate quality: Lack of water of suitable quality for a particular purpose or use.
Risk of excess (including floods): Overflow of the normal confines of a water system (natural or
built), or the destructive accumulation of water over areas that are not normally submerged.
Risk of undermining the resilience of freshwater systems: Exceeding the coping capacity of the surface and groundwater bodies and their interactions (the

"system"); possibly crossing tipping points and causing irreversible damage to the system's hydraulic and biological functions.

All four risks should be assessed at the same time as they can impact each other given the nature of water as a hydrologically interconnected resource. Indeed, these risks are interrelated; for instance, the risks of shortage, inadequate quality and excess may all increase the risk of undermining the resilience of freshwater systems. Managing all of these water risks is central to achieving the objective of water security. In this sense, in the development of risk management plans, the risks that affect the water security of the city and its territories should be evident. For example, earthquakes can damage water infrastructure and cause cuts in water distribution, or floods can contaminate surface and underground water sources, damaging the water supply and the quality of water bodies. This should be supported by digital platforms that collect information in real time that allows predicting the frequency and impact of different eventualities and what their impact would be on the water security of the city.

10.2 Common reducers of water security in cities

Just as the case studies allow to identify practices that can increase water security in cities, they also allow to identify practices that can reduce water security in cities. This section summarizes the actions that the reviewed cities apply that are affecting progress towards water safety. The identification of the reducers helps to understand which are the more challenging aspects that cities should prioritize when developing a water security strategy.

10.2.1 Economic Water Security

Table 71: Identified reducers for Economic Water Security

Water Security Dimension	Identified reducer	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Economic Water Security	Misallocation of water	Identified: the scarce water resources are not adequately distributed among the different sectors	Not Identified	Identified: the available water resources are not adequately distributed among the different sectors	Not Identified
	High debt levels	Not Identified	Not Identified	Identified: high level of debt that may not allowed to update the water service infrastructure	Identified: high levels of debt that may become an issue if it continues to grow
	Inefficient payment collection	Identified: considerable amounts of households are not metered, and high levels of nonpayment of the water bill are reported	Partially Identified: payment collection levels are still improvable	Partially Identified: payment collection levels are still improvable	Not Identified
	Low levels of investment	Identified: insufficient investments to maintain and update the complex water system of the city have been Identified	Not Identified	Identified: outdated infrastructure is largely present in the city that affects all the stages of the water service	Not Identified

Misallocation of water

Although there is an availability of water resources, the misallocation of water can affect the water security of a city, since an inadequate distribution of the resource between sectors, whether in quantity, quality or time, can cause the water to not be used correctly. This can provoke that the resource not being used efficiently, reducing its economic potential, in addition to increase the waster of water. The misallocation of water can evidently be observed in Mexico City where entire districts of the city do not have continuous water service, which damages the economic activity of this area.

High debt levels

High levels of debt of the water operator endanger the operational capacity of the operator, reduce its capacity to invest in new technologies and projects to improve the water security of the city, maintenance levels may be lower, making the water infrastructure vulnerable, reduce the financial autonomy of the operator and depend on national public funds for the development of projects. In Reggio Calabria, high debt levels of the water operator are observed, which has made the necessary investments in infrastructure and technologies difficult for a water system that is operating in a challenging natural context.

Inefficient payment collection

Water operators need adequate collection of payments in order to guarantee the proper functioning of the integrated water service, invest in maintenance, new technologies, preservation of water sources, among others. That not all homes have a meter, the prices are unaffordable for some sectors of the population, little culture about the value of water, lack of information from the operator about unregistered homes that do not pay for the service, water theft, and that the industrial and agricultural economic sectors do not pay according to their tariff band may affect the operator's ability to correctly collect payments. In the case of Mexico City, the low implementation of water meters, high levels of poverty, numerous households that pay a fixed rate because they do not have a meter, water theft by individuals and informal companies, make it difficult to optimally collect payments.

Low levels of investment

Related to the lack of high levels of debt and a low collection of payments from the operator can significantly affect the ability of the water operator to invest in key projects and technologies for water safety. Low levels of investment can reduce the quality of service, increase the risk of infrastructure failure, and continue with a conventional XX century water service.

10.3.2 Household Water Security

Table 72: Identified reducers for Household Water Security

Water Security Dimension	Identified reducer	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Household Water Security	High prices of the water service	Not Identified	Partially Identified: prices of the service have been steadily increasing, risking to become unaffordable for citizens	Identified: the water service bills are considerably high, considering the median income in the city	Not Identified
	Low household water autonomy	Not identified: due to constant water shortages, the local government has been investing in public-funded rainwater collectors for low-income households	Partially Identified: discount and technical assistance to collect water from alternative sources in households	Identified: not a clear investment scheme to increase the autonomy of households	Identified: due to the high abundance of water resources, most citizens do not find it pertinent to adopt alternative water sources in their households
	High levels of water consumption	Not Identified: adequate levels of consumption	Partially Identified: consumption levels are still over 200 L, but still levels are constantly reducing	Not Identified: adequate levels of consumption	Identified: high levels of consumption
	Low levels of service response	Identified: the water system is overwhelmed by the multiple issues	Partially Identified: some areas of the services may report insufficient response	Identified: low effectiveness in the response	Not Identified: adequate response levels
	Inefficient water metering	Identified: water meters are outdated and not implemented in numerous households	Not Identified	Partially Identified: there is need to update the water meters to digital ones	Not Identified
	Low levels of awareness of water security issues	Not Identified: citizens are aware of the water security issues in the city thanks to public information platforms	Not Identified: citizens have high levels of participation in water decision making	Partially identified: citizens are aware only of water shortages but not of the whole dimension of the crisis the city is facing in their others dimensions	Identified: citizens are not familiar with water security-related issues
	Non drinkable tap water	Identified: water quality is not enough to be safely drinkable, increasing the overall distrust in the service and potentially affecting the health of consumers	Not Identified: tap water is satisfactory	Identified: water quality is not enough to be safely drinkable, increasing the overall distrust in the service and potentially affecting the health of consumers	Partially Identified: despite being fully safe and drinkable some issues regarding color and taste have been reported

High prices of the water service

High prices on the service bill where they do not exist or the price tabulators adjusted by consumption and sector are insufficient can create high levels of non-payment, or affect the levels of affordability of the service, making it unaffordable for certain sectors of the population if there is not an adequate Low-income assistance program. Also, high prices in the service can be a factor that discourages industrial and agricultural activities from being undertaken in the city and its surrounding territory, directly affecting economic development.

Low household water autonomy

The water autonomy of homes should be supported by public programs that help collect rainwater, and build small wetlands and cisterns. If these programs are not applied, households may have difficulty having a water supply in the event of service interruptions. This also generates inequalities since households that can implement measures to obtain water from alternative sources with private means will be more resilient than low-income households that cannot afford it. In addition to the fact that they do not contribute to awareness of the value of water to advance a water wise culture.

High levels of water consumption

High levels of consumption reveal a low water-wise culture in the city, where the waste of water is normalized or or the lack of means for the implementation of techniques that save water such as efficient showers, toilets and taps, rebates to tear out grass and the use of recycled water. Agricultural and industrial activities play a key role in consumption levels in cities, if policies are not applied that would require the use of techniques that reduce water consumption by these sectors or studies that analyze the water feasibility of certain economic activities can be developed in the area, these sectors can consume large quantities of water, leaving an insufficient amount for the consumption of citizens.

Low levels of service response

Due to various factors such as lack of budget, low staffing levels, lack of technologies that make the service efficient, among others, the quality of response in the water service can be insufficient. This can increase the impacts of service failures such as leaks, pipe overflows, power outages, low pressure and service interruptions, among others that affect the water security of cities. In addition to the fact that the costs of maintenance or renewal of damaged infrastructure are higher and generate greater distrust among citizens towards the water service operator. This can be observed in Mexico City (service overwhelmed by high demand, old and poor infrastructure, low staffing levels, lack of resources and various external factors) and Reggio Calabria (low staffing levels, and old infrastructure) where service levels response are insufficiencies that reduce the quality of the service.

Inefficient water metering

An inefficient water meter system affects the collection of payments, increases in non-revenue economic water losses, the ability to monitor the quality of the service, and increases distrust of the service on the part of citizens. That is why the implementation of electronic meters that connect directly to the water operator and that can provide real-time information on the service situation and user consumption levels is required.

Low levels of awareness of water security issues

The lack of information about the value of water for sustainable development is one of the great challenges that the reviewed cities present, since it is taken for granted, that water is an ever-present resource that is not in danger due to the climate crisis. This situation causes high water consumption, lack of adoption of techniques that save water, in addition to the fact that the water operator is not asked to adopt policies and measures towards sustainable and lasting water security.

Non drinkable tap water

That the tap water is drinkable is a basic requirement of an adequate water service, the water that reaches homes must not be contaminated, have a good taste and color that promotes citizens to consume with confidence the water that the water operator water supplied. However, this is not a reality in several cities around the world since due to poor infrastructure, high levels of contamination of sources or lack of treatment, the water that reaches users is not drinkable and they have to resort to pure water. bottled or to particular filter systems. This situation also generates distrust in the service. In the case of Mexico City and in several parts of Reggio Calabria, the tap water is not drinkable, demonstrating an important vulnerability in the water supply service, in addition to the fact that citizens have already normalized the situation to the point that non-potability of tap water is no longer reported.

10.2.3 Urban Water Security

Table 73: Identified reducers for Urban Water Security

Water Security Dimension	Identified reducer	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Urban Water Security	Institutional fragmentation and instability in water management	Partially Identified: lack of more coordinated action between jurisdictions at the metropolitan level	Not Identified	Identified: a complicated institutional framework that can hinder the effectiveness of the service	Not Identified
	Outdated water and sanitation infrastructure	Identified: outdated infrastructure vulnerable to failures and that provides an inefficient service	Not Identified	Identified: outdated infrastructure vulnerable to failures and that provides an inefficient service	Not Identified
	Lack of independent runoff infrastructure	Partially Identified: only present in some districts, many of high income	Not Identified: although more efforts are required to increase their presence	Identified: the city combines wastewater and runoff in the same pipe system, losing the more significant potential of reuse of runoff water	Identified: the city combines wastewater and runoff in the same pipe system, losing the more significant potential of reuse of runoff water
	XX- Century Urban Water management approach	Partially Identified: recent efforts to adopt a more integrated management approach adapted to the current climate challenges	Not Identified	Partially Identified: recent efforts to adopt a more integrated management approach adapted to the current climate challenges	Identified: the management approach of the city is still grounded following the XX-century rationale relying mainly on gray infrastructures
	Low maintenance levels	Identified: due to low maintenance constant failures in the system are reported	Not Identified	Identified: due to low maintenance, constant failures in the system are reported	Not Identified
	Understaffed service	Identified: staff levels of the water operator are not enough for the needs of the water system as reflected in the response time and low maintenance	Partially Identified: staff levels are below optimal levels and may reflect in the service efficiency	Partially Identified: staff levels are below optimal levels and may reflect in the service efficiency	Partially Identified: staff levels are below optimal levels and may reflect in the service efficiency
	Lack of water and land planning link	Partially Identified: recent efforts, as reflected in presented initiatives and plans, still need to be fully implemented	Not Identified	Identified: due to the institutional fragmentation the link between land and water planning may be complicated, as reflected in action plans in the city	Identified: water does not play a critical role in the land planning of the city
	Income inequalities increase the gap between water users	Identified: depending on the income level households are more resilient to water shortages or quality issues	Not Identified	Identified: low-income districts face more water shortages than more centric and wealthy areas	Not Identified

Institutional fragmentation and instability on water management

To move towards stable and lasting water security, a solid institutional framework is necessary, with a clear guide on how to move towards water security, the role and attributions that each institution will have where the IWM functions as a vehicle to achieve it. In this direction, the water operator should be institutionally solid with clear attributions and long-term planning. When this is not met, the functions of the water service may be fragmented between different institutions with unclear functions that hinder the quality of the service in addition to making long-term planning difficult.

Outdated water and sanitation infrastructure

An important challenge for water operators is to keep their infrastructure updated within the optimal limits of its useful life so that leaks, poor water quality, interruptions in water supply and sewer overflows can be reduced. Due to lack of investment, low levels of maintenance and a conventional approach to water management can lead to a city's water infrastructure becoming obsolete. This situation also affects the health and wellbeing of citizens since outdated infrastructure can impact the levels of drinking water quality due to high levels of sediments and low capacity of the purification planta to make the water drinkable, and also associated to outdated treatment facilities the low quality of discharges can affect the quality of water bodies making it water impossible to use for recreational and cultural use. This could be observed in the cases of Mexico City and Reggio Calabria where the infrastructure is obsolete and neglected, directly affecting the urban water security of the city.

Lack of independent runoff infrastructure

Cities that still have a conventional water management system combine wastewater with the run-off water in the same pipelines by considering both in the same category, this reduces the potential to recycle and reuse of rainwater and increasing the water autonomy of cities. Cities like Ruston and Reggio Calabria and mostly Mexico City have not yet taken advantage of the potential of run-off water by not using a system of independent pipelines and thus take advantage of the resource in a more efficient and sustainable way.

XX- Century Urban Water management approach

The current model of water management is based on a XX-century approach, where it was sustainable if water demand and revenue continued to increase, and new water supplies could meet the growing demand (Organisation for Economic Co-Operation and Development 2015). Traditionally water in cities has been managed with the so-called Grey Infrastructures which just channelled away the water through gutters, pipes, and tunnels to treatment plants or straight to local water bodies without taking the full potential of the resource and not using nature-based solutions that over time has been proven to be more efficient and sustainable (United States Environmental Protection Agency 2023). The grey infrastructure in many cities is ageing, and its capacity to manage large volumes of stormwater is decreasing.

Due to climate change reducing the quality and quantity of available fresh water and rapid urbanization processes increased the demand for the resource, making the current water management model unsustainable (Organisation for Economic Co-Operation and Development 2015). Public authorities and operators relied just on technical innovation to control water pollution and fulfil the demand. Today, cities face three sets of challenges regarding water management: water-related risks, ageing infrastructures, and trends in institutional reforms (Organisation for Economic Co-Operation and Development 2015). This is most evident in a small city like Ruston that continues to manage water from a 20th century approach focused on using gray infrastructure, fragmented management of the different aspects of water, and relying only on technical improvements to improve service.

This situation requires a change of the current water management system, from a transformative approach (Daniell, et al. 2015). In urban water systems, over time there have been established several key water system management desired indicators of system state that have driven transitions to different configurations of water systems that are designed to provide a more sustainable and resilient water delivery service

(Daniell, et al. 2015). These water system management objectives and resultant changes in idealized urban water system types have come about because of several socio-economic, environmental and governance-related drivers (Daniell, et al. 2015).

It can be concluded that the process of transitioning urban water systems towards more integrated, adaptive, and sustainable configurations is a multi-dimensional process (Daniell, et al. 2015). Different objectives need to be increasingly integrated into urban water system management to be able to provide a better variety of service delivery functions. The scope and dimensions of urban water systems that need to be considered also expand along with these objectives: from local to regional; from an intra-generational to inter-generational scale; and from sectoral to trans-disciplinary expertise requirements and approaches (Daniell, et al. 2015).

Low maintenance levels

Due to a small budget or inadequate management, low staffing levels, or lack of planning, maintenance levels may be low and insufficient for the needs of the system. This situation could affect water pressure, increase leaks and service interruptions, problems in the sewage network, among others. The costs of preventive maintenance actions are generally lower than the costs of an urgent corrective intervention. It is recommended that water operators maintain an active maintenance program following the technical recommendations of each element so that the infrastructure functions at its optimal potential.

Understaffed service

Despite technological advances in water management, which help reduce the number of personnel necessary to adequately manage the water service in a city, the technical and operational staff of water operators continues to be a key factor, since They are the ones who respond and evaluate complaints from citizens or spontaneous service failures, repair infrastructure failures, manage the operator's day-to-day resources, develop new projects and communicate to citizens about the status and quality of services. your water service. Low staffing levels, generally below 3 employees per connection (WAREG 2017; World Bnak 2014) , can affect response levels in the event of a problem with the service, low capacity to monitor and evaluate the service, low levels of infrastructure maintenance, and citizen participation in issues. related to water may be affected.

Lack of water and land planning link

One important challenge for urban water security is the integration between water planning and land planning. Generally, water security goals and strategies developed by water planners and operators do not transfer properly into the main planning documents such as comprehensive plans, sustainability plans, and zoning plans. As mentioned before water and land use planners are usually disconnected from what they do, and the tools at their disposal. Water planning is usually done by water operators, or basin regional authorities who are subject to a differing array of planning and regulatory requirements. The land use planning that drives future water demand, and allocation of water resources, however, is done predominantly at the local level by regions and cities. Water providers need to understand the growth and development patterns anticipated by land use planners and consider that information when projecting water demands and be prepared, and land use planners need to understand how development patterns affect water use and water loss and consider what rate and style of growth is possible given water-supply availability.

This lack of connection can be clearly observed in Ruston, where the objectives of the water operator and the urban development of the city are poorly coordinated. In the case of Reggio Calabria, due to the institutional fragmentation surrounding water management, an efficient connection is difficult. Mexico City is in an intermediate step of moving towards an integrated water and urban policy since water begins to be a key element in planning documents, however the efforts are inconsequential considering the dimension of its water crisis. In the case of San Diego, the integration between water and urban planning is solid, as reflected in the water feasibility documents developed by the city.

Income inequalities increase the gap between water users

As a result of the research, it has been observed how income levels influence the resilience and water security of the homes and districts of a city. This is because in high-resource areas, technologies that allow more efficient use of water can be afforded, such as being able to collect alternative sources of water such as rain, in addition to having a greater water storage capacity to better handle in the event of service interruptions. Furthermore, from an urban perspective at the neighborhood level, generally the highest-income neighborhoods are those that attract the development of innovative climate action projects that include some linked to water security such as the implementation of green and blue infrastructure in the area. The phenomenon of inequalities in the distribution of practices that help the sustainable development of the city is known as Green Gentrification. In the case of water, the term blue gentrification can be proposed, where urban infrastructures that help increase the water security of cities are located in high income neighborhoods that make the population that does not have sufficient income move to more peripheral areas that do not have the same quality of water infrastructure, marginalizing them from the benefits of a modern and sustainable water infrastructure.

These inequalities are evident in Mexico City where neighborhoods with more resources can adopt measures that guarantee a greater water supply such as the purchase of pipes, construction of large cisterns and water collection systems. While the most vulnerable neighborhoods that constantly suffer from service interruptions do not have the means to adopt these practices and suffer more from water scarcity, putting their well-being and health at risk. In the case of Reggio Calabria, although to a lesser extent, it is observed that peripheral and low-income neighborhoods such as Arghilla suffer from constant interruptions in the water supply and do not have the means to face the crisis.

10.2.4 Environmental Water Security

Table 74: Identified reducers for Environmental Water Security

Water Security Dimension	Identified reducer	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Environmental Water Security	Low quality of water discharges	Identified: lack of full implementation of tertiary treatment of discharges, plus a considerable amount of illegal discharges	Not Identified	Partially Identified: recent efforts to a wider implementation of tertiary treatment	Identified: lack of tertiary treatment, reducing the potential of water reuse, following a XX century rationale
	Lack of preservation strategies of the surrounding environment	Partially Identified: present in the planning documents not adequate implemented as reflected in the low environmental quality in several natural areas in the city	Not Identified	Partially Identified: present in the planning documents not adequately implemented in the city	Identified: environmental preservation is not a central aspect
	Pollution of water sources	Identified: high level of pollution in water bodies	Not Identified	Partially Identified: the city still faces challenges to ensure the quality of water bodies	Not Identified
	Overexploitation of the resources	Identified: aquifers in the region are overexploited and surface water sources in general, which require to extract water from other regions	Not Identified: adequate balance between the different sources	Not Identified	Not Identified

Low quality of water discharges

The quality of the water discharges used in the system is a key element for environmental sustainability. When wastewater is treated correctly at the tertiary level, this water can be returned to the environment safely without affecting the flora and fauna of the place, in addition to being returned to the environment it can eventually be reused for consumption (discharge water with tertiary treatment to water sources that will be treated to be potable). However, this is not the reality in several cities where the quality of discharges (primary treatment or no type of treatment) or illegal industrial or household discharges severely affects the quality of the water of the bodies that receive the discharges, in the first instance causing that water is not suitable for human consumption and affecting the potential of becoming a reliable source of water, damaging the continuity of species that depend on those bodies of water, in addition to affecting the economic potential of those bodies of water since fishing activities cannot be developed or their recreational and cultural value is lost. In the event that they are discharged into marine water, in addition to harming marine flora and fauna, it can also make coastal waters unbathable.

Lack of preservation strategies of the surrounding environment

Water should play a leading role in the environmental preservation strategy of cities and their territories, since water is related to various aspects of the environment in different contexts. This has to be reflected in urban planning documents where water represents an axis where a series of environmental preservation policies and actions are articulated, as can be seen in the case of San Diego. When this is not the case and this integration does not exist, environmental water safety may be affected since there is no coordination between the different environmental conservation policies, causing efforts to be insufficient, or water not having the priority it deserves, leading to possible pollution and overexplotation of the water sources.

Pollution of water sources

Closely related to the quality of water discharges is the concern of the vulnerability of water bodies to pollution, whether they are actively used as sources of water supply or that fulfill other functions such as preservation of biodiversity or recreational value cultural for people. Pollution of water bodies may be due to low quality of urban water discharges, low standards for industrial and agricultural discharges, illegal discharges by individuals or companies or due to the impacts of natural disasters linked to climate change such as floods and storms if not well managed.

Overexploitation of the resources

Unfortunately, the quantity of available freshwater suitable for human consumption continuously decreases due to multiple factors such as droughts and changes in precipitation cycles mainly driven by climate change, pollution of the sources mainly by human action and overexploitation of the resource that doesn't allow the natural regeneration of the resource (Pereira, Cordery, & Iacovides, 2009). Studies show that countries around the world are rapidly heading towards the limits of easily exploitable or renewable resources and that this overexploitation is creating critical impacts on many human communities and the surrounding environment (Dumont-Bergeron & Gramlich, 2021).

The local resources that initially were the main source that cities relied on, in particular groundwater, are often overexploited, generating a series of negative impacts including seawater intrusion or the decline of groundwater-dependent ecosystems (Majumder, 2015). As local resources become insufficient to sustain the needs of the population, cities typically seek increasingly distant resources, through the development of dams, canals or piped transfers. This increases the technical challenges to water operators and often leads to conflicts with stakeholders of rural territories, who oppose the predatory behaviour of cities that can be considered as water grabbing (Organization for Economic Co-Operation and Development, 2015).

10.2.5 Resilience to water-related disasters

Table 75: Identified reducers for Resilience to water related disasters

Water Security Dimension	Identified reducer	City			
		Mexico City	San Diego	Reggio Calabria	Ruston
Resilience to water-related disasters	Lack of an integral water shortage management strategy	Partially Identified: recent initiatives to integrate water shortage risk management plan	Not Identified	Identified: no presence of a water shortage risk management plan	Identified: no presence of a water shortage risk management plan
	Lack of a comprehensive water-related risk management plan	Not Identified	Not Identified	Partially Identified: the plan requires updates considering the current climate challenges	Identified: the city requires further acknowledgment of their water-related risks

Lack of an integral water shortage management strategy

Urban water shortage management plans are expected to play a critical role in the transformation of urban water management systems because they consider water shortage as a relevant risk that should be considered in urban risk management and also provide relevant information to planners and decision-makers into the future development of cities by identifying the most vulnerable areas and avoid to over stress the area with future urban developments or industrial activity.

The lack of these documents can first provoke that water shortage is not to be considered a real risk by citizens and local authorities, not being clear about how to act in case of water shortage depending on its intensity, not being able to evaluate the elements that could increase the risk. risk of scarcity (demand and consumption analysis), not being able to integrate the risk of water scarcity within the general risk management strategy, and not being able to plan long-term urban development of the city based on vulnerability to water scarcity and thus evaluate the relevance of new urban developments.

This may be evident in cities such as Reggio Calabria and Ruston where water scarcity is not considered a high priority risk in their risk management strategy. In the case of Ruston it is understood within the context of being a territory rich in water, but that still requires preparing in case of any eventuality more than anything considering the high levels of risk to floods and storms that can affect the quality and continuity of the water supply. Meanwhile in Reggio Calabria there must be a paradigm shift regarding the perception of a false abundance of the resource when high levels of water stress are evident in the area coupled with high levels of pollution and poor infrastructure, all of these factors. These factors considerably increase the risk of water shortage in the city, so the adoption of management plans for water scarcity management by the city's local authorities is recommended, taking the San Diego model as a reference.

Lack of a comprehensive water-related risk management plan

Overall, risks related to natural hazards and climate change are not autonomous or externally generated circumstances to which society reacts, adapts, or responds. They are, rather, the result of the interaction of society and the natural or built environment. Consequently, effective risk management essentially requires an improved understanding of this relationship, and the factors influencing it (Birkmann, 2013). Understanding the various types of relationships and interactions between nature and society is, therefore, key to better understanding risk. The hydrological risks, as confirmed in the research project, are linked and the climate crisis affected their intensity and presence. In traditional risk management approaches, hydrological risks such as floods, storms, droughts and others are treated separately without considering their close relationship. The lack of this systemic vision of risks can affect the processes of prevention, reduction and mitigation of risks.

10.3 Relationship between the common increasers of water security in cities

The research identifies thirty determinants that increase the water security of cities. For Economic Water Security seven were identified, for Household Water Security six were identified, while for Urban Water Security there were ten, for Environmental Water security there were six, and finally two for Resilience to Water Related Disasters. As mentioned previously, to achieve lasting water security the different dimensions should interact harmoniously and must be approached from a synthetic approach. In this sense, the relationship between the identified determinants is explored. Following the

World Economic Forum in the Global Risks Report 2024 (World Economic Forum 2024b) model to represent the relationships between the different risks, four levels of relationship were established with a specific weight: no relationship, light relationship, moderate relationship and strong relationship (see table 76). Thus, 255 relationships will be identified, which are reflected in the following diagram built through the Rstudio software (see Figure 53).

Table 76: Relationship levels between determinants

Relationship level	Description	Value
No relationship	The determinant has no relationship with the achievement of the other determinant.	**0**
Light relationship	The determinant has a light impact into the achievement of the other one. It can be a support element or indirectly influence.	**1**
Moderate relationship	The determinant has a moderate relationship, it means that is important for the achievement of the other one but not critical. In the literature can be named as an element key for the achievement of the other determinant or a direct result of its application.	**2**
Strong relationship	The determinant is key for the achievement of the other one. This means that without this determinant the other determinant cannot be implemented or not in an optimal way. They are deeply connected between each other and can be inserted in a same strategy.	**3**

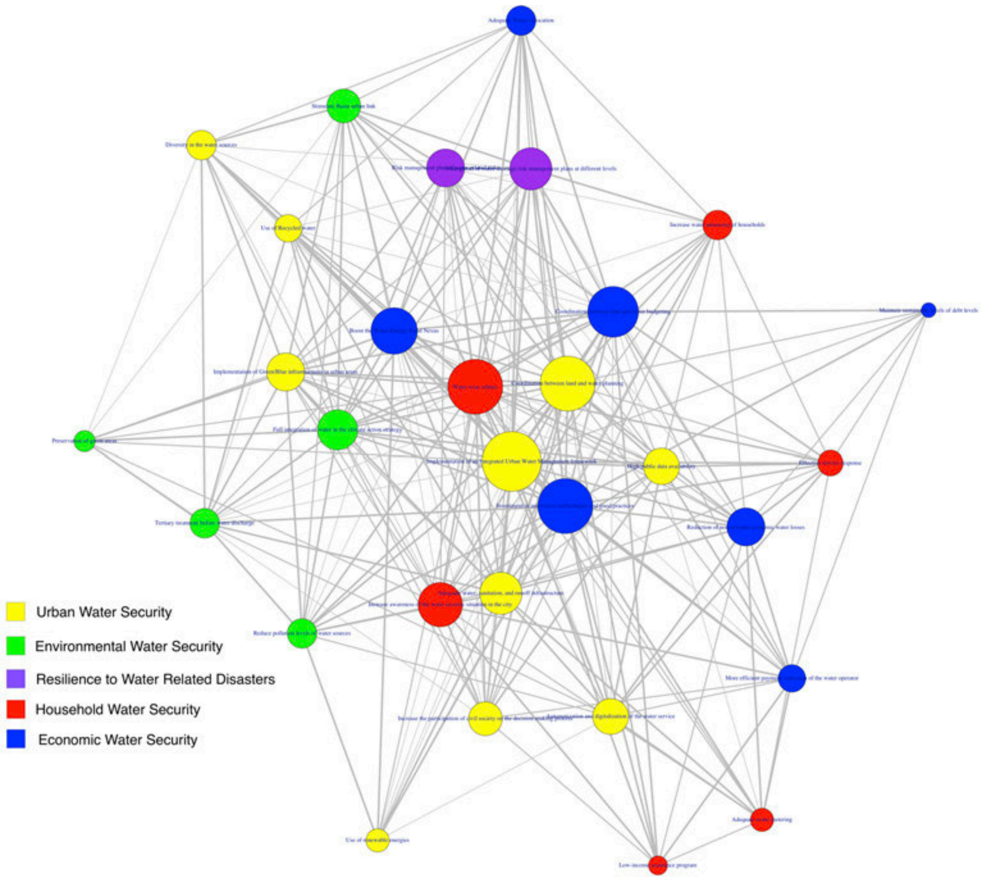

Fig. 53. Relationship between identified determinants. Armando Cepeda Guedea, 2024

With the proposed scoring system, the determinants with the greatest number of relationships could be identified (see Table 77). These were classified into three categories of 10 elements each: primary, secondary, and tertiary determinants. The research proposes to visualize these determinants in a radial diagram where the primary determinants allow the development of the secondary determinants and the secondary determinants, in turn, of the tertiary ones (see Figure 54). The scores with the greatest number of relationships can be considered primary determinants or facilitators. This means that they are the ones who lay the foundations to move towards stable and lasting water security, they are the ones who facilitate the development of the other determinants. Cities that aspire to take action for water security should start with these top ten (Investment in innovative technologies and good practices, Implementation of an Integrated Urban Water Management framework, Coordination between land and water planning, Water wise culture, Coordination between land and water budgeting, Full integration of water in the climate action strategy, Adequate water, sanitation, and runoff infrastructure, Boost the Water-Energy-Food Nexus, Implementation of Green/Blue infrastructures in urban areas, and Increase awareness of the water security situation in the city). The next level is occupied by secondary or development determinants, this means that once a nuclear framework for water safety is established. These allow cities to reinforce their water security strategy and guide the next steps. The last level are the tertiary or consolidation determinants, they are the determinants that are mainly related to the other determinants within their dimension and serve to support the specific development of each dimension of water safety.

Table 77: Strength of relationship between the identified determinants

Water Security Increaser	Strength of relationship
P. Investment in innovative technologies and good practices	73
P. Implementation of an Integrated Urban Water Management framework	69
P. Coordination between land and water planning	68
P. Water wise culture	67
P. Coordination between land and water budgeting	56
P. Full integration of water in the climate action strategy	53
P. Adequate water, sanitation, and runoff infrastructure	51
P. Boost the Water-Energy-Food Nexus	50
P. Implementation of Green/Blue infrastructures in urban areas	48
P. Increase awareness of the water security situation in the city	45
S. Reduction of non-revenue economic water losses	43
S. Widespread of water shortage risk management plans at different levels	43
S. High public data availability	40
S. Automatization and digitalization of the water service	36
S. Reduce pollution levels of water sources	36
S. Stimulate Basin urban link	36
S. Risk management plan of water-related risks	36
S. Increase the participation of civil society on the decision-making process	33
S. More efficient payment collection of the water operator	32
S. Tertiary treatment before water discharge	32
T. Effective service response	31
T. Use of Recycled water	31
T. Adequate Water Allocation	30
T. Increase water autonomy of households	29
T. Diversity in the water sources	28
T. Adequate water metering	26
T. Low-income assistance program	24
T. Use of renewable energies	20

T. Preservation of green areas	20
T. Maintain sustainable levels of debt levels	16
P: Primary determinants; **S:** Secondary determinants; **T:** Tertiary determinants	

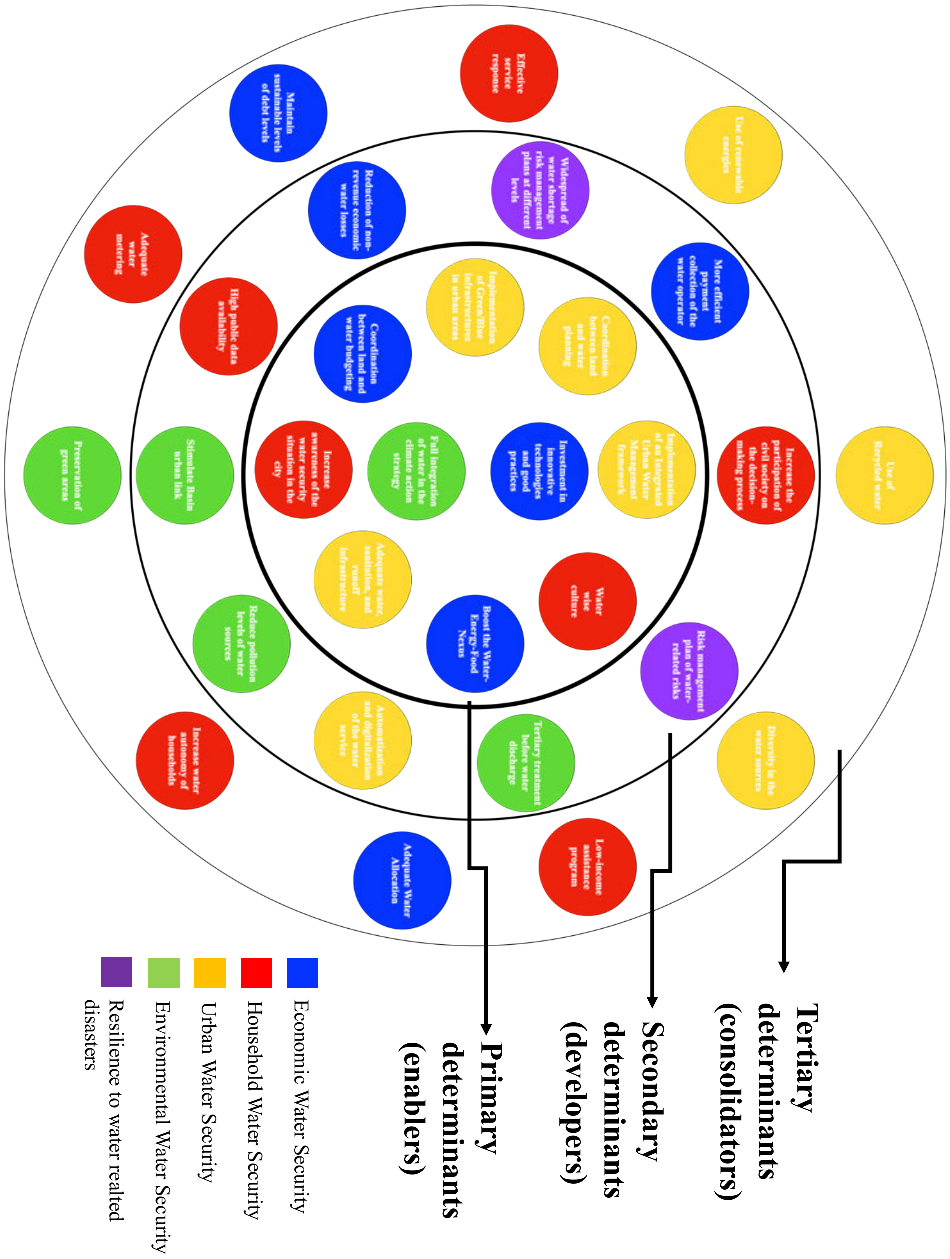

Fig. 54. Radial diagram of the function of the determinants. Armando Cepeda Guedea, 2024

Chapter 11

Conclusions

Boston Common Park. Armando Cepeda Guedea, 2023

Water is indispensable resource for the survival development of human communities and ecosystems. Due to climate change that provokes droughts and change in the precipitation patterns, and other non-climate drivers such as rapid urbanization processes, pollution of the water sources and increasing demand, are endangering this valuable resource worldwide. Although water is one of the resources more affected by climate change, on the other hand, water is a key element for climate change action since sustainable water management is central to building the resilience of human communities and ecosystems and reducing carbon emissions (UN Water 2024). Water is required to produce renewable, sustainable energy (hydropower and geothermal) and for the development of carbon sequestration sinks through reforestation, bioenergy production, and carbon capture and storage. Also, climate change adaptation measures such as water retention by forests, wetlands, and artificial storage facilities, soil improvement and water management in rain-fed agriculture, and flood protection measures are critical to contributing to water security.

The strategic value of water for sustainable development and climate action makes water as a key connector of the three main international agreements on climate action and sustainable development encouraged by the United Nations (2030 Agenda, Paris Agreement, and the Sendai Framework), since water should be holistically approached considering its multiple dimensions. This is mainly reflected in the Sustainable Development Goals where freshwater plays an important role with its particular SDG (6) and considerable number of interlinkage with the rest of the SDG, again proving the prominent role of water in the global sustainable development strategy. Despite all the above mentioned the advances towards the achievement of SDG 6 (Clean water and sanitation) are not going as expected even some of the targets are stagnated or receding. This could be due to the lack or minimal legal, political and economic consequences for not meeting the objectives, the lack of international cooperation on the part of developed nations to finance and technically support more disadvantaged nations to have a stable and secure supply of water, considering that since 2010 water has been a human right according to the United Nations, or it may be that the current approach to water management does not respond to the needs of the water crisis.

This is where water security comes in as an innovative approach that can contribute to the sustainability of water worldwide, since in several countries, both developed and developing countries, still use a traditional water management framework from the 20th century based on infrastructure. grays where water is still considered an almost infinite resource where only technological advances are needed to continue extracting the resource. This hinders the sustainable use of the resource and the continuity of a reliable and safe supply of water. Water security can be defined as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability. This translates into five closely interlinked dimensions (Economic Water Security, Household Water Security, Urban Water Security, Environmental Water Security, and Resilience to Water Related Disasters) that should be coordinately approached to ensure a safe and sustainable supply of water, an adequate sanitation service without endangering the surrounding environment and the economic development of a city or territory. The comprehensive approach that water security provides on how to address the water crisis by considering the multiple dimensions involved can help governments carry out an ambitious sustainable development strategy where water is a critical element. Water security is a complex approach that requires a deep analysis of its various dimensions already mentioned previously from a systemic approach where the elements that make up water security are closely interlinked. Although urban water security can be considered a central element when studying the water security of a city, the analysis may remain incomplete if the other dimensions are not considered and integrated since cities are not isolated entities but rather complex systems that interact with their environments.

It is also important to note that the research concludes that the best vehicle to advance towards water security in cities is the Integrated Water Resources Management approach which offers a comprehensive framework for achieving water security (Global Water Partnership 2024b). This approach aims to identify effective water investments to increase economic development that contributes to overall socio-economic well-being (economic, household, and urban water security) and ecological sustainability (environmental water security and resilience to water-related disasters). IWRM can foster a more efficient and sustainable use of water resources by aligning and integrating policies, legislations, planning documents (zoning and master plans), and actions that are traditionally seen as unrelated or that, despite clear interrelationships, are not coordinated. It also promotes a way of thinking that enhances the capacity to tackle multi-objective, multi-sectoral development planning, this being key to approach complexity of water security. IWRM has a subset known as Integrated Urban Water Management (IUWM), which can be considered the vehicle for achieving urban water security. This framework calls for the alignment of urban development and basin management to achieve sustainable economic, social, and environmental goals in cities (Global Water Partnership 2013). It brings together water supply, sanitation, storm- and wastewater management and integrates these with land use planning and economic development. The components of IUWM fit with the main aspects of urban water security proposed by Brears (Brears 2017b), contributing to the proposed statement that IWRM is the vehicle to advance toward water security.

The concept of water security is relatively recent, despite this, multiple frameworks have appeared that attempt to evaluate and study water security by government institutions, international organizations, civil associations, and academia. The research as a product of an exhaustive literature review has uncovered that several of these frameworks do not fully address the five main dimensions for water security, but rather focus on only one specific one or a combination of two or three dimensions. On the positive side, these frameworks work for specific objectives of water planning, for example the evaluation frameworks of water operators trough Performance Indicators focuses on three specific dimensions of water security (household, economic and urban water security), which allows the performance of water operators to be effectively measured and to plan the operator's future strategies. However, the other remaining dimensions are left aside or minimally mentioned, making them incomplete water security evaluation frameworks. There is also the challenge of scale since there are evaluation frameworks that work on a national scale due to the lack of data at the urban and local levels, as is the case of the Global Water Security 2023 Assessment. This also the need to have sufficiently robust public data banks at the local level to be able to evaluate safety adequately and with updated data, which is why it is important to move towards greater digitalization and automation of urban water systems. Also, there are frameworks thar focus more in the risk managements aspect of water security such as the Water Risk Atlas which describes the risks that can impact the water security of countries and regions, by evaluating the physical risk quantity, quality and regulatory an reputational risks. In this sense, the research aims to close this gap by proposing a framework for evaluating water security from a systemic approach that allows evaluating the five dimensions of water security, and thus being able to obtain a more complete vision of the situation of the water security of cities and its territories.

Due to the complexity of articulating the proposed comprehensive framework for water security, the research considered appropriate to adopt a mixed research approach which combines both the quantitative and the qualitative sides of water security. Only using quantitative or qualitative approaches may become limiting and incomplete for the challenge. Among the different typologies of mixed approaches, the more suitable is the exploratory sequential method. The exploratory sequential method is based on the idea that qualitative and quantitative approaches are sequential and complementary. In this sense, it is proposed to initially articulate a quantitative evaluation based on five aspects that allows analyzing the various aspects that make up the water security of a city and its surrounding territory. These five aspects, as already mentioned, emerge as the result of an exhaustive review of the available literature on the subject as well as the experiences acquired in the different places where the research was carried out (Boston, Ruston, Reggio Calabria, and Mexico City).

In the case that a city or province that wants to use this framework and does not have enough data, it can only begin by applying the qualitative phase and thus obtain relevant information about its security situation and then, with more data available, apply the quantitative phase. The quantitative phase was built by consulting more than 56 sources from different national, international, and academic organizations in order to obtain in the first instance the most relevant indicators to measure the water safety of each dimension as well as obtain the ranges, which allow estimating more precisely the progress towards the city's water security, and whether the water system has a real risk of collapse and requires urgent intervention. The quantitative indicators framework consists in 49 indicators and 20 sub indicators, that aims to cover the five dimension of water security. To make this framework more complete the research also explores the interlinkages with the SDGs showing a clear effort to face the complexity of water security by involving 9 SDGs (1, 3, 6, 7, 8, 10, 11, 13, 14,15, and 16) and 32 indicators. This indicator framework provides a wider understanding of the relevance of water security for sustainable development of cities and territories, since it has more involved SDGs than the reviewed existing indicators frameworks for water security. This more holistic approach may contribute to the address more effectively water security by considering the multiple relationship between the indicators and its dimensions, and by consequence unclog the stagnation or recession of SDG 6 Targets progress, such as Target 6.5 which aims to implement integrated water resources management (IWRM) at all levels. The proposed evaluation framework that combines qualitative and quantitative phases has a considerable potential of replicability on other cities as proven in the case studies phase of this research and can also contribute to a better understanding of the urban water system and how various factors interact with each other, it helps decision-makers to prioritize interventions by identifying the elements that, if intervened, will have the greatest benefit, it also can stimulate sustainable and resilient planning by anticipating potential risks and vulnerabilities in the water system that can be integrated in future risk management plans, and finally it can help to increase awareness levels of the global water crisis and facilitates the adoption of more water wise consumption habits in communities.

The diversity of the selected case studies (Mexico City, San Diego, Reggio Calabria, and Ruston) allowed to obtain relevant information regarding how cities address water security. This contributes to confirming that to study water security and be able to understand it more completely, several case studies should be studied since the water security varies greatly depending on the context. The results of this research can be more refined in the future if it is possible to analyze more case studies. The reviewed case studies made possible to identify the main elements that increase and decrease water security after the implementation of the evaluation framework proposed in this research. In addition to this, some interesting conclusions could be obtained from each case that are worth mentioning in this section.

Mexico City

1. Mexico City is a global city with the potential to be a beacon for urban transformations in the Latin American region.
2. There are moderately enough normative instruments to pursue an IWRM for water security.
3. Water policy is aligned with the values of urban transition.
4. Enough public data to evaluate water security.
5. Use of innovative technologies to improve water management.
6. A growing civil participation and awareness regarding water issues in the city.
7. Infrastructural issues due to the complexity of the current water system and low maintenance.
8. Poor water culture in wealthy areas of the city
9. Organic response to water shortage by citizens due to poor response of local authorities.
10. High-income areas are more prepared for water shortages.

San Diego

1. An international city that its actions can impact municipalities in two countries.
2. There are enough normative instruments to implement a comprehensive water security strategy.
3. Water policy is aligned with the values of urban transition.
4. Enough updated public data and interactive maps to evaluate water security.
5. Use of innovative technologies to improve water management.
6. Civil society and local governments are aware of the importance of transforming the previous water management approach to ensure water security, resilience, and sustainability.
7. Water shortage management is a relevant element in regional and urban planning.
8. Constant reduction of water consumption per capita (below the national average)
9. The Water Shortage Assessments (WSA) serves to determine the viability to develop urban projects in community planning.

10. The climate emergency is severely affecting the availability of water resources in the city.
11. The city relies most of their water supply on sources outside the city and county.
12. The high prices of the water service in the city are becoming restrictive.

Reggio Calabria

1. Being part of the European Union there is a strong framework to implement policies and projects to increase water security.
2. National and European funding to stimulate innovative practices, such as urban regeneration projects and the development and implantation of a water security strategies.
3. The recent transition of the water operator from public-private to entirely public to increase a better economic water security, even though there are still big financial challenges.

1. The water operator and regulator are two separate figures, which fragmentates the water management of the service.
2. Local institutional uncertainty with constant change in the attributions of water regulators
3. Poor water infrastrucure
4. There is no city-level water operator.
5. Lack of data for water management.
6. Clear environmental risks that can aggravate the freshwater supply.
7. Water is not a key element in planning and citizens do not fully acknowledge the high risk of water shortage contingencies the city may face in the future.

Ruston

1. Ruston is a city with high abundance of local water resources.
2. Local citizen initiatives to make more efficient their water resources as a competitive advantage.
3. Local public water operators are autonomous, and all the sources are inside the city limits.
4. Affordable water service due the simplicity of the infrastructure.
5. Lack of a comprehensive normative framework for urban water management at the state level.
6. Poor water culture, due to the low value water has in the community.
7. Historical inequalities affect the quality of the service.
8. No neighborhood planning
9. Local university represent a big portion of the water consumption of the city.

Identifying increasers and reducers for water security contribute to better understand the urban water system and its surrounding territory, and how various factors interact with each other that can positively or negatively impact water security; it helps decision-makers to prioritize interventions by identifying the elements that, if intervened, will have the greatest benefit or the elements that if not properly addressed could have the more negative consequences; it stimulates sustainable and resilient planning by anticipating potential risks and vulnerabilities in the water system that can be integrated in future risk management plans, reducers de gap between water and land planning, and finally it can help to increase awareness levels of the global water crisis and facilitates the adoption of more water wise consumption habits in communities.

With the intention of increasing the value of the thesis, it was proposed to analyze the relationship between the different identified determinants that increase water security. This is with the intention to identify possible nuclear elements to develop an effective water security strategy for a city. The results showed that ten determinants are key to develop the rest of identified increasers for water security (Investment in innovative technologies and good practices, Implementation of an Integrated Urban Water Management framework, Coordination between land and water planning, Water wise culture, Coordination between land and water budgeting, Full integration of water in the climate action strategy, Adequate water, sanitation, and runoff infrastructure, Boost the Water-Energy-Food Nexus, Implementation of Green/Blue infrastructures in urban areas, and Increase awareness of the water security situation in the city). These ten nuclear determinants are closely linked to a planning and conceptual framework that allows the following determinants to be established, they can also be labeled as trigger determinants. For example, the presence of an Integrated Urban Water Management framework allows the coordination of the urban-basin link, increase citizen participation and improving payment collection, among others. Another case is that the implementation of the Nexus framework unlocks a better water allocation, a greater use of renewable energy and recycled water. It is also interesting how the implementation of Green/Blue Infrastructures provoke a series of practices that contribute to an environmental preservation strategy where water has a predominant role, since it allows creating alternative sources of drinking water, reducing water risks, and increase the general well-being of the population. Finally, by integrating water and land planning it allows having a coordinated strategy for managing water-related risks, developing an assistance program, increasing citizen participation, adoption of innovative technologies, and preserving the environment. All the above should accompanied by an adequate budget design that knows how to prioritize the water needs of the city and a change on the mindset of citizens and governments that water security is critical element for the development and continuity of cities and communities, which are also proposed as nuclear elements. The next level is occupied by secondary or development determinants, this means that once a nuclear framework for water safety is established, cities can follow the implementation of further practices. These allow cities to reinforce their water security strategy and guide the next steps. The last level are the tertiary or consolidation determinants, they are the determinants that are mainly related to the other determinants within their dimension and serve to support the specific development of each dimension of water security. The proposed framework provides a sort of blueprint to decision makers that can use to guide a harmonious strategy to advance towards water security.

Water plays a critical role in climate adaptation in cities. Climate change requires a new approach to how cities manage and live with water to be resilient and thrive sustainably. The full integration of water-sensitive strategies such as stormwater ponds, canals, infiltration facilities, and green roofs in urban development projects greatly contributes to long-term water security (de Graaf and der Brugge 2010). This approach is highly encouraged by international organizations such as the Resilient

Cities Network, as reflected in multiple documents developed by the organization. The network currently has around 100 members from different continents committed to urban resilience, which provides a wider perspective of the challenge and multiple ways to approach it (Resilient Cities Network 2023). Reviewing relevant case studies of cities belonging to the network, it is possible to create a simple classification framework of three stages of water security strategies implementation (early, intermediate, and advanced) that can help cities understand where they stand regarding water security based on the identified determinants of the research. The early stage corresponds to cities that are starting or are willing to shift their traditional water management approach. They are characterized by having partially or not yet implemented the proposed primary or core determinants. The intermediate stage is when a city is already on a positive trajectory toward water security, the primary determinants are consolidated or almost, and the secondary determinants are characterized by having partially or not yet implemented. The advanced stage means the city has a consolidated transformative water security strategy where the primary and secondary determinants have already been implemented for some time. At this level, the tertiary determinants may be partially developed or almost. Cities in this classification can be international benchmarks for good practices in water security. This can help to understand how the results of the research work can insert and contribute to the efforts of cities that are pursuing a sustainable and long-term water security. Below are three cities belonging to the Resilient Cities Network in the different proposed stages (Rotterdam: advanced, Milan: intermediate, and Monterrey: early).

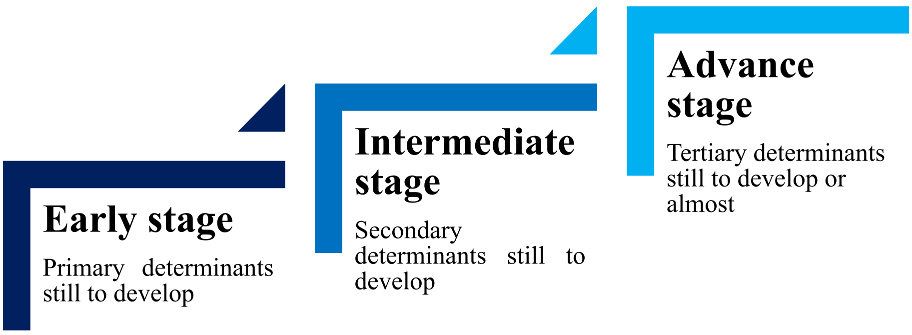

Fig. 55. Proposed stages of water security strategy implementation. Armando Cepeda Guedea, 2024

A city that is at the forefront of integrating water security into urban planning is the city of Rotterdam in the Netherlands (Resilient Cities Network 2020; Stead 2014). Rotterdam lies mostly below sea level and is strategically located at the mouth of a river, which makes water an omnipresent element in the city (DE URBANISTEN 2005). For centuries, the people of the region have known how to adapt to their environment and build water resilience organically (DE URBANISTEN 2005; Dunn et al. 2017). Due to climate change, water is posing an increasing threat since sea levels are rising rapidly, so the city needs to be able to manage flooding and adapt effectively to this new reality (Resilient Cities Network 2020; de Graaf and der Brugge 2010; Dunn et al. 2017; Stead 2014). The transformation of Rotterdam into a more water-sensitive city is the consequence of decades of efforts and a change of mindset in how governments and citizens view and manage water, which started in the 1980s when the city adopted a more integrated water management approach and transferred water management from the municipality to the waterboards (de Graaf and der Brugge 2010). The project Rotterdam Water City 2035 has been crucial in building water security in the city and facilitated by changes in the regime during the preceding years (DE URBANISTEN 2005; de Graaf and der Brugge 2010). For the first time, urban and water planners developed a joint long-term vision for the city. Its innovative approaches highlight how urban areas can address water challenges proactively. Such innovations included green roofs, water retention squares, and floating urbanizations (DE URBANISTEN 2005; de Graaf and der Brugge 2010; Resilient Cities Network 2020). This project aligns with the national project "2025 Delta Program" which aims to protect the Netherlands against high water and flooding, ensuring enough fresh water supply, and contributing to climate-resilient and water-robust planning for the country (Ministry of Infrastructure and Water Management 2024). The project's main recommendations are: to prioritize perspective for future-resilient agricultural land use that also contributes to the water and soil challenges, make room to store surplus precipitation water in urban and rural contexts, and increase operational capacity to face the current and future challenges. The water strategy in Rotterdam aligns with the five main dimensions of water security, because it ensures the economic development of the city and surrounding region linked to water following the Nexus rationale, preserves and create new natural areas to reduce the negative impacts of floodings, increase the operational capacity of the water services and include more nature-based solutions, increase the water autonomy of households by increasing freshwater storage spaces through water squares, and increase the awareness in the society to adapt to the new water reality in the city.

The research work can contribute to ambitious, transformative water management strategies in cities such as Rotterdam to create a more refined evaluation instrument that can first assess the impact of policies already implemented such as Rotterdam 2035, identify areas of opportunity, raise a bigger awareness among decision-makers and citizens, and monitor the progress of ongoing policies such as Rotterdam Water City 2100. Using as a reference the proposed model of determinants, the Tertiary or consolidator set can support the positive trajectory the city is having, such as increasing the diversity of sustainable freshwater sources or improving its low-income assistance program.

Milan in northern Italy is a city that aims to achieve water security inside a wider climate adaptation strategy due to increasing population, pollution of potential sources, infrastructural challenges, and citizenship calling for ambitious climate adaptation measures (MM S.p.a 2024). In this sense, the municipality of Milan developed PGT of Milan (Land Management Plan), which is the only Italian urban planning instrument that contains a technical prescription on the climate reduction index. Inside the plan, there is a strategy specifically aimed at making space in the city for green and blue infrastructures, making possible better use of runoff water, regenerating the soil, and reducing water-related risks such as flooding (Comune di Milano 2019). The execution of the vision of the plan in the water aspect is the responsibility of the public agency

MM S.p.A, which, in recent years, has been developing ambitious climate adaptation projects for water security, such as the sustainable water drainage project in Pacini Street (MM S.p.a 2023; Arsuffi 2023), which is the first Sustainable Urban Drainage System (SDUS). It aims to ensure the best possible use of rainwater for the irrigation of the surrounding green areas. Its operation consists of a system of street drains that discharge the first wave of rainwater (the first drops that fall to the ground and the most loaded with pollutants) directly into the sewer system. The second wave of rainwater is instead collected and infiltrated into the ground using the surface of the street green areas. This model of green and hydraulic infrastructure, in addition to ensuring water savings for irrigation, also helps reduce water-related risks such as storms. This project can be the starting point for further interventions in the city. It can be considered that Milan can be classified as an intermediate stage of climate adaptation and water security development if compared to other cities of the Resilient Cities Network since the measures are not as widespread as Rotterdam and the synergies between urban and land planners are not fully developed.

In the case of Milan, the research work can contribute to the transformative water management strategy in the city to create a more refined evaluation instrument that can first assess the impact of policies already implemented in the PGT of Milan, identify areas of opportunity and for development of new projects, and raise awareness among decision-makers and citizens of the importance of water security. Using as a reference the proposed model of determinants, the Secondary or developer set can support the trajectory the city is having, such as water shortage planning, stimulating the urban-basin link, and improving the quality of potential water sources.

A city that can be considered at an early stage of advancing toward water security is the city of Monterrey in northern Mexico. The city is one the most important economic centers of the country and the second largest city by population, with more than 5 million inhabitants (INEGI 2020). Like Mexico City, Monterrey is facing a severe water shortage contingency, threatening the development and subsistence of the city (Congreso de Nuevo Leon 2023). The city acknowledges the crisis it faces and presents the "Master Plan to Guarantee Water Supply until 2050" in 2021 (Nuevo Leon Government 2021). The plan aims to transform the traditional water management in the state and the city to adapt to a scenario where water is scarce. This means the modernization of the existing water infrastructure with more digital tools and automatization processes, recuperation and exploration of new water sources, and improvement of metering and billing techniques (Nuevo Leon Government 2021,2023).

In the case of Monterrey, the research work can contribute to igniting the transition to a transformative water management approach by creating an evaluation instrument that can first assess the context of the city regarding water security and the first phase of the "Master Plan to Guarantee Water Supply until 2050", identify areas of opportunity for the next proposed phases and development of new projects, and raise awareness among decision-makers and citizens of the importance of water security.

Using as a reference the proposed model of determinants, the primary or enabler set can support the initial effort the city is making to pursue effective water security, such as investment of new technologies and innovative practices, a more integrated water management approach, integration of water and land planning, implementation of green and blue infrastructures, and boost the Energy-Water-Food Nexus.

11.1 Final considerations

The proposed hypothesis "Identifying the possible main increasers or reducers of water security in cities could provide a better understanding of the urban water system, stimulate sustainable and resilient planning, contribute to the prioritization of decision-making, and increase the awareness of water security among citizens" after the research work can be considered valid since it was proven that by identifying the determinants that increase and reduce the water security of cities, it was possible to understand the situation of water and its water system as demonstrated in the case studies. The information produced clearly contributes to citizens being informed about the water security of their city, increasing their ability to actively participate in decision-making about water. Finally, it was also possible to confirm the importance of identifying the possible main increasers or reducers of water security to connect water and land planning and give tools to decision-makers when prioritizing their action plan for water security. In this direction, the research presents how it collaborates to planning in the five main dimensions of Water Security.

Economic Water Security: The research findings can contribute to allocating more effectively the available water resources between the different economic sectors in the city and orientate decision makers into balancing economic development and sustainability of the water resources.

Household Water Security: contributes to poverty reduction strategies since water is fundamental for public health and the well-being of citizens since it is used in households for drinking, personal hygiene, and cooking. Also to maintain the affordability of the resource to reduce marginalization.

Urban Water Security: this dimension is crucial for the sustainable development of cities since it requires the coordination of different sectors such as transport, housing, energy, and water operators. Same as at the global level, water should play the role of connector between the different planning strategies in the city. The research results show the multidimensionality of water and how it interacts in various aspects of the city outside the water supply and sanitation services and how water should play a crucial role in the design of urban infrastructure. Contributing to decision makers to make more informed decisions regarding water in cities.

Environmental Water Security: The research argues to view the city not as an isolated entity but as an element that interacts with its surrounding environment. This also means understanding the interactions of urban water with its surrounding context since healthy ecosystems depend on water bodies, which are essential for biodiversity, climate regulation, and human wellbeing, including the recreational and cultural value of water. Also, it contributes to informing decision-makers about better coordinating urban development and natural preservation. This can help to reduce pollution and enhance the biodiversity.

Resilience to Water-Related Disasters: the results argue the integration of disaster risk reduction strategies such as flooding management, early warning systems, and the development of resilient and adaptive water infrastructure into planning. Also, a more widespread consideration of water shortage as a risk should be integrated into the city disaster planning strategy to ensure water supply in the case of contingencies.

Using a systemic approach to Water Security and coordinating its multiple dimensions helps ensure that water is managed to support sustainable economic growth, reduce poverty and marginalization, ensure environmental preservation, increase the health and well-being of citizens, and provide resilience to disasters. This can make cities more adaptable and resilient for the long term in a context of uncertainty due to the climate change emergency.

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