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Urban Planning Opportunities and Challenges in the Implementation of Secondary WasteWater Use Systems

MS In Urban Planning for Transition

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It's time for the next adventure

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Abstract

Water has always been central to urban development, yet rising consumption, climate change, and increasing scarcity demand a rethinking of how cities manage this essential resource. This study positions WasteWater reuse as a critical strategy for advancing sustainable urban development. Focusing on the implementation of Secondary Wastewater Use Systems (SWWUS), it explores how reclaimed water can be integrated into urban planning to reduce freshwater demand, enhance resilience, and support circular economy principles. Building on concepts of water-sensitive urban design and integrated urban water management, the research tries to illustrate how WasteWater reuse in public spaces can mitigate environmental pressures while fostering multifunctional benefits through synergies with blue-green infrastructure (BGI). Case studies from Italy and China illustrate both the historical role of water in shaping cities and the contemporary challenges of WasteWater reuse across diverse contexts. The findings highlight opportunities for embedding WasteWater systems into the urban fabric as drivers of ecological health, cultural value, and urban prosperity. In doing so, it argues that WasteWater reuse is not only a technical solution but also the first step toward resilient, water-centered cities.

Key Words: secondary WasteWater use, urban water management, WasteWater reuse systems, Italy, China, sustainable water management, circular economy, water-sensitive urban design, blue-green infrastructure.

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Foreword

The treatment and reuse of WasteWater have undergone significant transformations throughout history, reflecting advancements in technology, public health awareness, and socio-economic conditions. From ancient civilizations to modern cities, the evolution of WasteWater management illustrates society's growing understanding of hygiene and sustainability.

In ancient times, WasteWater management practices were rudimentary and largely dictated by geographic and environmental factors. The earliest recorded systems, such as those in Mesopotamia and the Indus Valley, utilized basic drainage systems to carry WasteWater away from populated areas. In these civilizations, the focus was primarily on preventing stagnation and controlling disease outbreaks rather than on the treatment or reuse of WasteWater. For example, the ancient Romans developed sophisticated aqueducts and sewer systems, with the Cloaca Maxima in Rome being a notable early example (Figure 1, 2). This system effectively removed waste from the city, demonstrating an understanding of sanitation's role in public health (UNRV, n.d.).

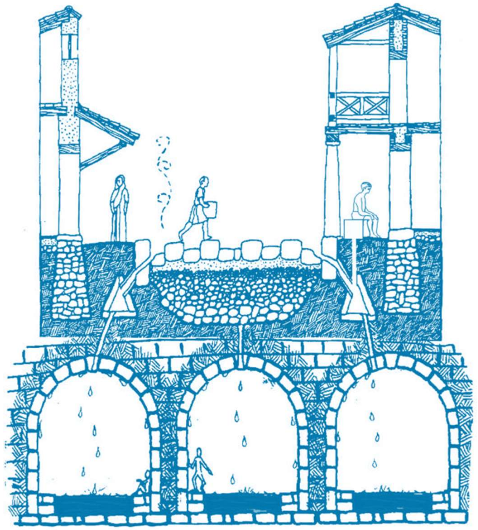

Figure 1. Roman Sewage System (Pinar, 2022)

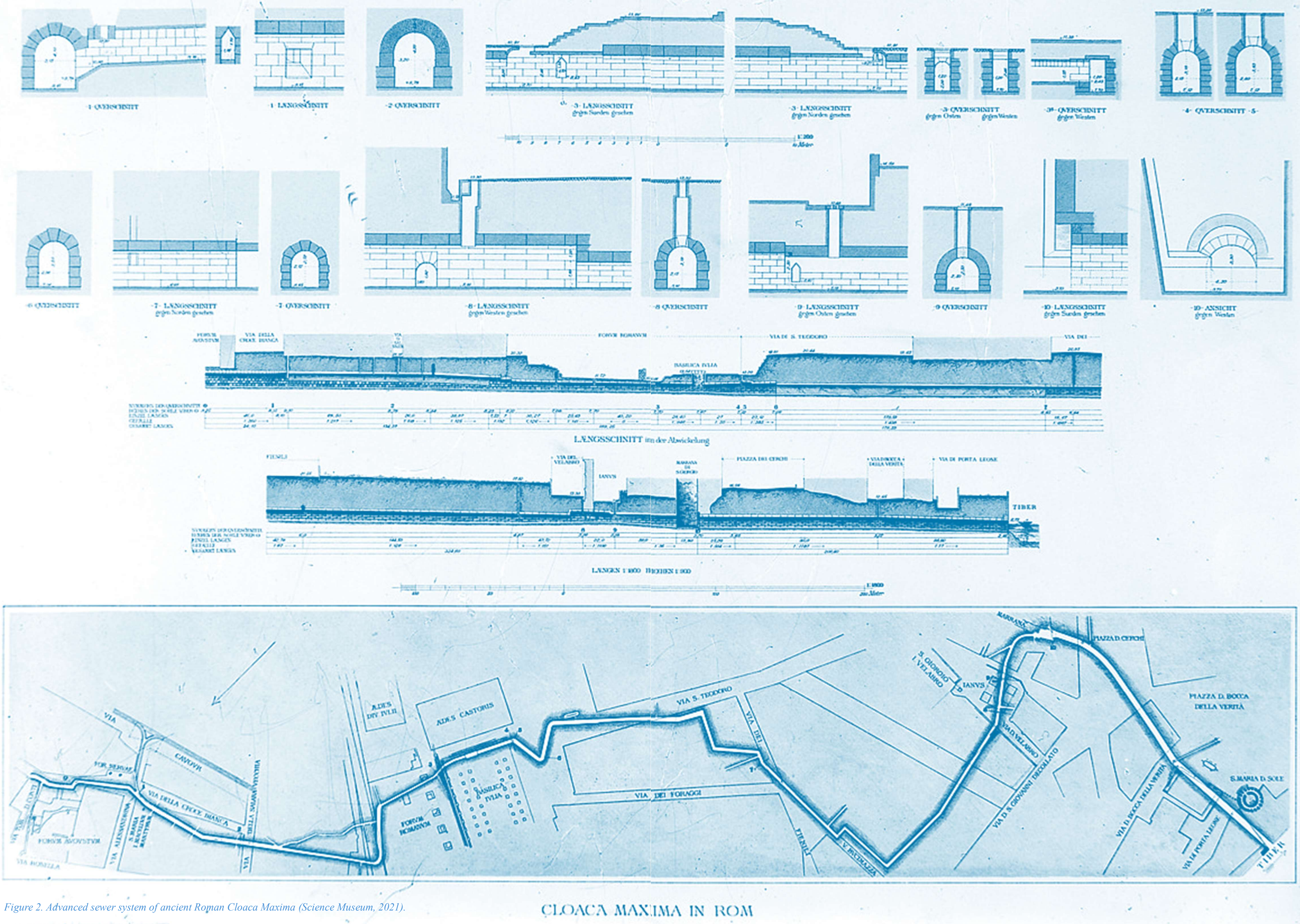

Figure 2. Advanced sewer system of ancient Roman Cloaca Maxima (Science Museum, 2021).

By the Middle Ages, urbanization led to increased waste production, which resulted in significant public health challenges. The Renaissance period prompted renewed interest in sanitation, leading to the development of more structured WasteWater management practices.

The introduction of the modern sewer system in the 19th century, particularly in cities like London, marked a significant shift towards organized WasteWater treatment. Joseph Bazalgette's design of London's sewer system (Figure 3) is a critical milestone, displaying the link between effective WasteWater management and urban public health.

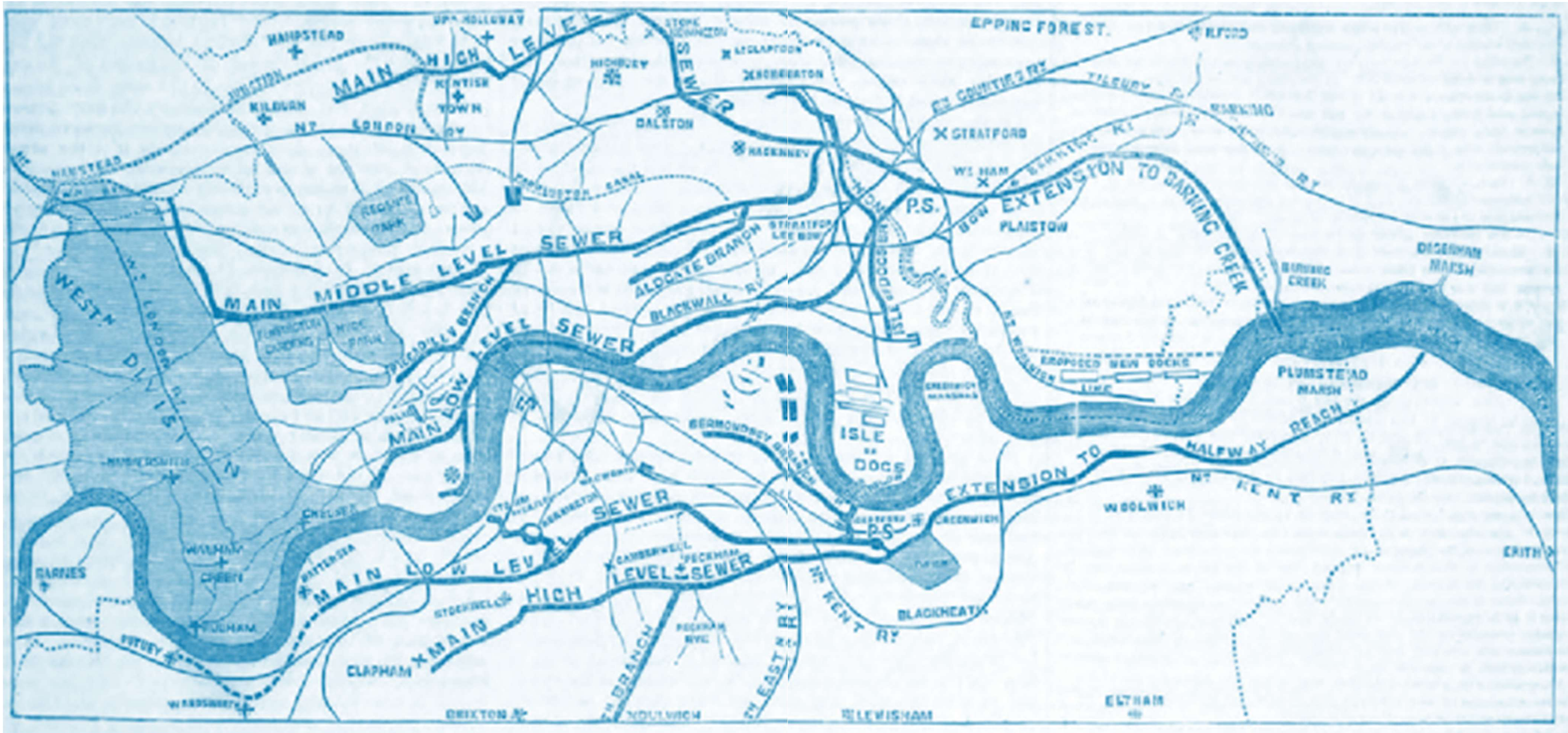

Figure 3. Map of London Main Drainage with the intercept sewers heading east parallel to the Thames and converging downstream of the metropolis (Schubert, 2022).

In Italy, the city of Matera provides a historical case study of WasteWater treatment and reuse. The Sassi of Matera, with its ancient cave dwellings, relied on a system of cisterns for freshwater storage and used the natural topography for WasteWater drainage (Figure 4). The inhabitants channeled WasteWater into ravines or agricultural fields, a practice that, while functional, posed significant health risks due to the potential for contamination (Bobbink et al., 2023).

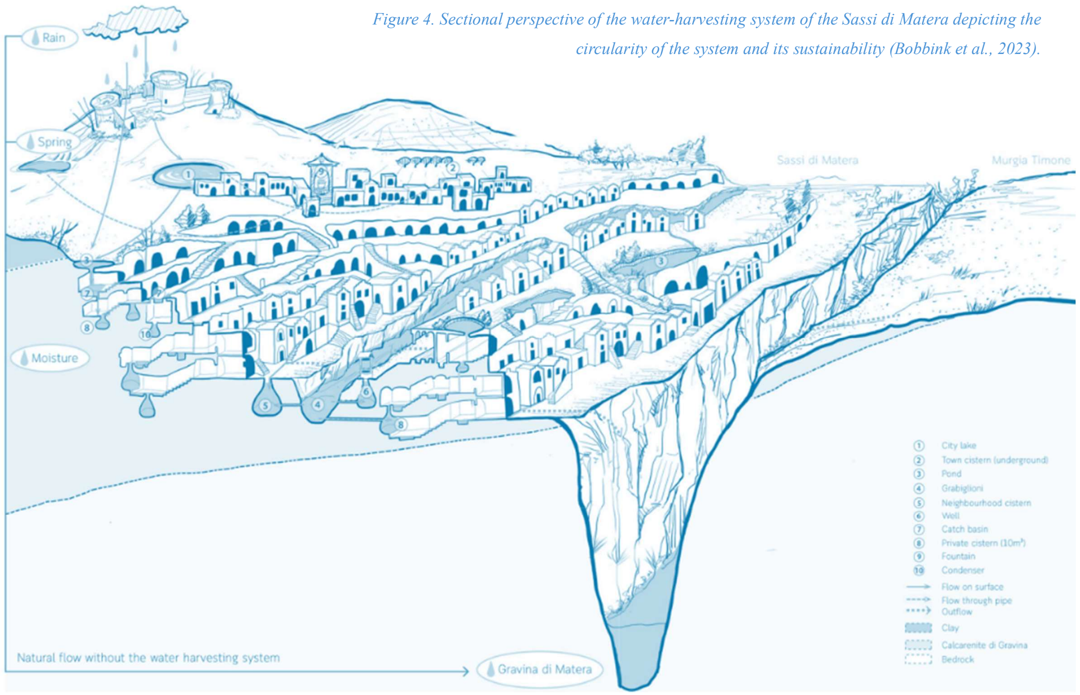

Figure 4. Sectional perspective of the water-harvesting system of the Sassi di Matera depicting the circularity of the system and its sustainability (Bobbink et al., 2023).

As Matera evolved through the 20th century, urbanization and population shifts created urgent sanitation challenges. The Italian government initiated a relocation program in the 1950s, encouraging residents to move to new developments outside the Sassi. This effort aimed to improve living conditions and sanitation infrastructure. However, as Matera gained recognition for its cultural heritage, particularly after being designated a UNESCO World Heritage Site in 1993, there was a renewed focus on the Sassi, leading to modernization efforts in WasteWater management.

In recent years, Matera has made strides in integrating sustainable practices into its water management systems. The introduction of advanced WasteWater treatment technologies allowed the city to establish modern treatment facilities capable of

effectively treating WasteWater. These facilities not only ensure that WasteWater is adequately treated to meet health and environmental standards but also enable the reuse of treated water for irrigation and other purposes. This approach aligns with broader regional goals of conserving water resources while promoting agricultural sustainability (Abdel-Shafy & Mansour, 2020; Silva, 2023a).

Matera's journey from informal drainage systems to modern WasteWater treatment and reuse serves as a compelling example of how cities can adapt their practices over time, emphasizing the importance of sustainability in managing water resources. The historical evolution of WasteWater treatment and reuse illustrates a complex interplay between societal needs, technological advances, and environmental considerations. And its implementation was often linked to water scarcity. But if back in ancient times and the Middle Ages it was mainly a matter of the natural surroundings and geographical context in which the city was located, nowadays it is also a matter of climate change and adaptation of cities to new realities for a more sustainable and resilient future.

In modern times, the invention of sewage treatment plants marked a significant advancement, enabling cities to manage both domestic and industrial WasteWater on a large scale. The development of sewage treatment plants revolutionized urban sanitation by centralizing the process of treating domestic and industrial WasteWater. These systems, using networks of pipes to collect and channel sewage to treatment facilities, reflected the need for more efficient, large-scale solutions as cities expanded. In contrast, ancient cities, which lacked such infrastructure, relied on decentralized methods for managing waste. While these early practices were often less efficient by today's standards and lacked the sophistication of today's infrastructure, they offer valuable insights. The study of ancient WasteWater management encourages us to consider sustainable approaches that optimize both cost and space.

And studying WasteWater management is an integral part of urban water resources management, because generally WasteWater is perceived as waste – something dirty that cannot be used –, but an effective and integrated WasteWater management at the urban scale [within the framework of urban water resources management] aims to change this perspective. The new perspective portrays WasteWater as a valuable resource, highlighting that water resources are limited on Earth, and the scale of their consumption is growing against the background of the general growth of pollution of natural water resources (Water Footprint Network, 2010).

So, what is WasteWater and how can we benefit from it?

Chapter 1 Introduction

Many experts call the *water issue* one of the most serious challenges to humanity in the future (UN, 2014). While Earth is called is called *the Blue Planet* since 75% of the planet is covered by water, only 2.5% is freshwater. And less than 1% is available for human use. With these limited resources freshwater withdrawals have tripled over the last 50 years: the demand for freshwater increased by 64 billion cubic meters per year.

The increase in freshwater use is happening not only because of population growth, but also because of changes in lifestyles and eating habits, which require more water consumption per capita now than before. The global water footprint[1] (Figure 6) is distributed between agricultural products (92%), industrial products (4.4%) and domestic water use (3.6%). Freshwater is used almost everywhere: in production of biofuels, as an energy source, in agriculture, sanitation, direct consumption, etc.

However, the issue is not the water use, but how it is used. If the water is withdrawn is removed from its original source, but then at least a portion of this water is often returned to the source and is available to be used again, it is "renewable water source". But usually water is being consumed – this means that water was removed from its original source for use and never returned. Of course, water cannot always be returned to its original source (e.g., if we drink a glass of water from a dwell, we cannot put it back), but it is also possible to reuse the water after proper treatment (Figure 5).

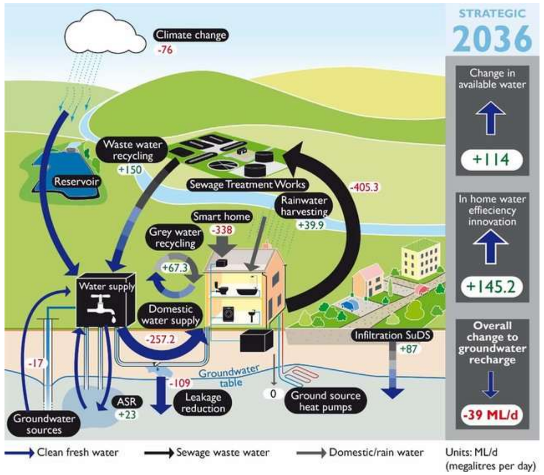

Figure 5. Scheme of urban water cycle showing for a strategic future (Bricker et al., 2017).

[1] A *water footprint* is defined as "the total volume of freshwater used to produce the goods and services consumed by an individual, community, or produced by a business". It includes three components: blue water (surface and groundwater), green water (rainwater), and grey water (polluted water that requires treatment to be reused) (Hoekstra & Chapagain, 2008).

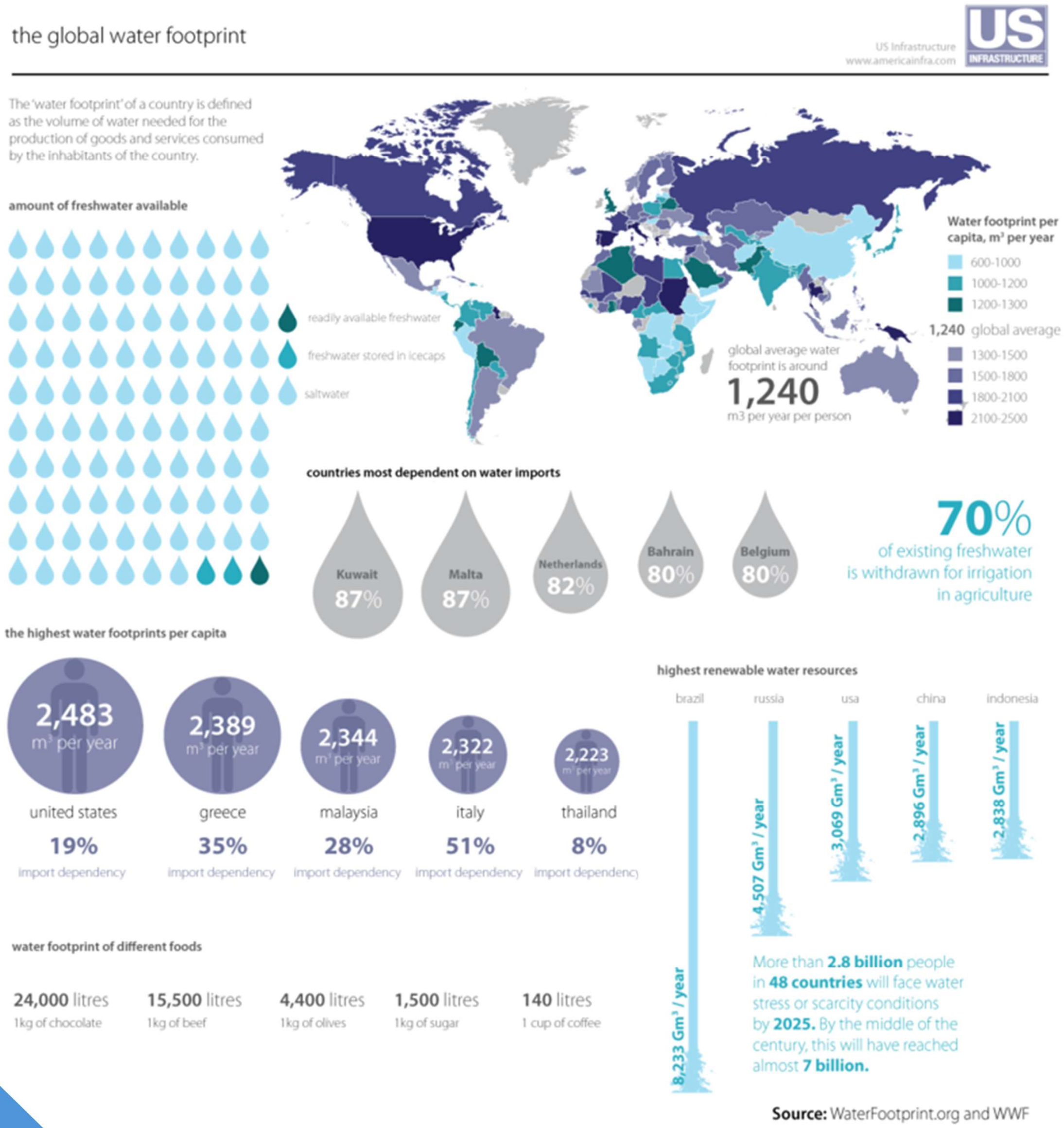

Figure 6. The global distribution of water footprints (Water Footprint Network, 2010).

When talking about reusing water after human use, the proper term is (secondary) WasteWater use. Wastewaters consist of *greywaters* (WasteWater from places such as shower, basin, bath and washing machine) and *blackwaters* (WasteWater from places such as toilets, dishwasher where the level of contamination is high). And while the blackwaters are complicated to purify both technically, economically, and policy-wise (sanitary norms), greywaters are more easily purified and can be purified to different degrees, since not always we need *freshwater* or *whitewater* (completely sterilized). The secondary use of WasteWaters has a lot of benefits (Fontana & Fontana, 2016):

1. It is more economical, since for the discharge of WasteWaters according to the regulation they need to be purified from nitrogen and phosphorus, which is a pricey process, whilst for secondary use such purification is not mandatory;
2. It is more economical also because there is no need for additional water sources and expansion of the water system that may occur with the increasing demand for water: the WasteWaters are already “in the system”;
3. Being “in the system”, it allows to preserve other resources, like energy: to pump the water in and out of a house from the source requires a lot of energy, the WasteWaters on the other hand are already there and need just to be recirculated;
4. The fact that the WasteWater is already there also is a guarantee that there will be water during the droughts that are increasing in the summer times, and the quality of these waters is known;
5. The secondary use of WasteWater allows to preserve the existing freshwater resources and diminish the pollution of the environment with the WasteWaters.

Besides the benefits of secondary use of WasteWaters, there are a lot of options on the ways to use the greywaters. In international practice there are three ways to use the greywaters:

- Industrial use; for washing machinery, diminish dust in work areas and for supply of fire extinguishing systems;
- Civil use; washing roads and buildings, fountains, toilette water, air conditioning;
- Irrigation; of landscape elements (e.g., parks), green urban areas (e.g., urban gardens), sportive elements (e.g., golf parks) and in agriculture (e.g., crops for human or animal consumption).

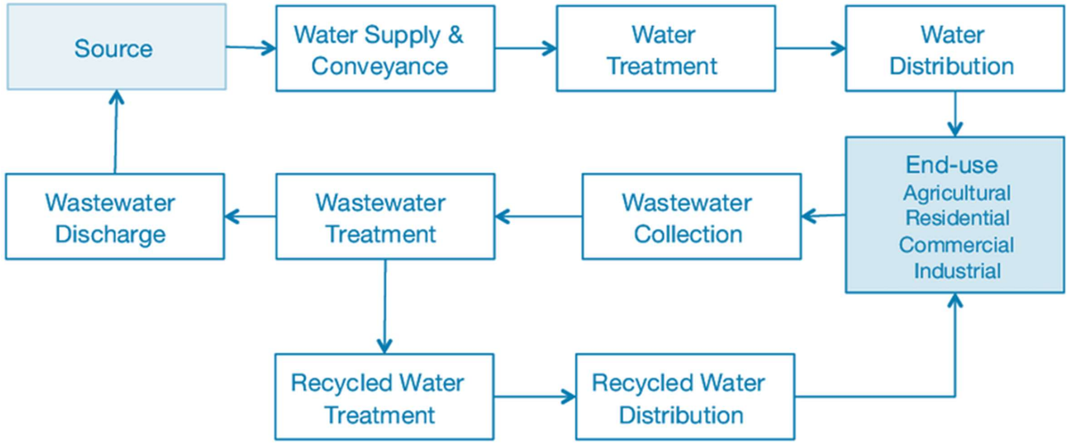

Figure 7. General scheme of urban water uses with WasteWater treatment and secondary WasteWater use included (Yoon, 2018).

One of the examples of secondary WasteWater use is Nosedo Wastewater Treatment Plant in Milan, Italy, which collects the WasteWater from the metropolitan area to be reused in the agricultural sector of the municipality. The Nosedo Wastewater Treatment Plant is an excellent example of a technological urban and peri-urban development. However, while being technologically an interesting case, the matter of WasteWater treatment must be approached not only from a technical perspective, but also from regulatory aspects and government tools, especially since water sources for an urban unit are usually part of a bigger water system which make important to at least consider other urban units besides the one of the case studies if not work together with those others urban units to create a multi-level policy.

That is why the key issues in sustainable innovation are related to the regulatory systems that initiate the innovation and is responsible for the maintenance. And whilst secondary WasteWater use exists nowadays in almost all developed countries, the practices vary based on socioeconomic factors, cultural and religious practices, existing laws, and participation in various programs. This is why it is important to share all the available data and knowledge about practices when planning for secondary WasteWater treatment and use (U.N. Environment, 2002) to create a knowledge network of policy design and regulation in the field of water management.

In recent years, the concept of a circular economy has increasingly been applied to water management, wherein WasteWater is seen not as waste but as a resource that can be treated and reused. The reuse of treated WasteWater for purposes such as irrigation, industrial processes, or even potable water supply is gaining momentum in many parts of the world. This shift aligns with sustainable development goals, addressing both water scarcity and environmental concerns.

A comprehensive study by (Sato et al., 2013) reveals that approximately 44 countries reuse WasteWater to some extent, particularly for agricultural purposes. This may be due to the fact that the in-city re-use of WasteWater is more complicated; partially this is because of the regulations about water quality that are becoming more severe by such organizations as the EU.

And while the study by Sato et al. (2013) emphasizes that the reuse of WasteWater can mitigate water scarcity in arid and semi-arid regions, contributing to water security, there are few programs that stimulate secondary WasteWater use.

There will be dedicated chapters for each system with local cases studies, but a general overview shows that Europe has long been at the forefront of sustainable water management, with several countries adopting advanced WasteWater treatment and reuse practices. The European Union (EU) has developed strict regulations for WasteWater treatment and reuse to safeguard public health and protect the environment. One of the key legal frameworks guiding WasteWater treatment in the EU is the Urban Wastewater Treatment Directive (91/271/EEC), which mandates that member states implement treatment systems to prevent untreated WasteWater discharge into sensitive water bodies (Council Directive 91/271/EEC of 21 May 1991 Concerning Urban Waste-Water Treatment, 1991).

The secondary use of WasteWater, primarily in agriculture, landscape irrigation, and industrial applications, has been gaining traction in Europe, although it varies across countries. Southern European countries, particularly those facing water scarcity, such as Spain and Italy, have made significant advances. A study by Lubello et al. (2004) demonstrated that treated WasteWater can effectively support plant nurseries, highlighting its potential for broader agricultural use. These initiatives exemplify how WasteWater reuse can address water challenges while promoting sustainability. The European Commission has further supported this initiative by proposing the Regulation (EU) 2020/741, which sets minimum quality requirements for water reuse in agricultural irrigation across the EU (Regulation - 2020/741 - EN - EUR-Lex, 2020).

In Northern Europe, water reuse has not been as widespread due to the relative abundance of freshwater resources. However, the increasing emphasis on circular economies and sustainable resource management across the EU is driving greater interest in the reuse of treated WasteWater. In essence, the idea of the closed-loop economy, also known as circular economy, is that the resource [product, material] remains in use as long as possible by using various R-strategies (reuse, repair, restoration, modernization, etc.), as it will be explained accurately in Chapter 5 Circularity and WasteWater. Therefore, the concept of the closed-loop economy is aimed at closing the cycle and reuse of WasteWater supports this idea by leaving the water resource after primary use as long as possible in the system.

This trend aligns with broader EU goals to optimize resource use, reduce reliance on non-renewable water sources, and implement circular water solutions (Mannina et al., 2021; Qtaishat et al., 2022). Countries like Sweden, Denmark, and Finland, which traditionally have not faced significant water scarcity, are beginning to explore secondary WasteWater applications more actively. This shift is partly due to EU initiatives that promote water recycling as part of the Green Deal and Circular Economy Action Plan (European Environment Agency, 2022). By focusing on WasteWater treatment and resource recovery, these countries are exploring new ways to manage water more sustainably, even in regions with relatively abundant water resources.

China, on the other hand, is one of the most water-stressed nations due to its rapid industrialization and population growth. It has made significant strides toward adopting WasteWater reuse strategies, especially in urban areas. The country faces major water scarcity issues in the northern provinces and megacities like Běijīng and Shànghǎi. A combination of industrial demand, agricultural needs, and municipal water consumption has put immense pressure on China's freshwater resources.

China's push for WasteWater reuse is part of its broader strategy to combat water scarcity and pollution, outlined in several key national policies. The 14th Five-Year Plan (2021-2025) outlined plans to enhance the construction of reclamation facilities and promote the utilization of sewage resources during this period. It specifies that the newly built, renovated, and expanded reclaimed water production capacity should reach at least 15 million cubic meters per day. As a result, there is significant potential for further expanding water reuse both in terms of volume and application. The primary factors influencing the development and advancement of water reuse in different regions are local water scarcity and the level of economic development (Hayward, 2021).

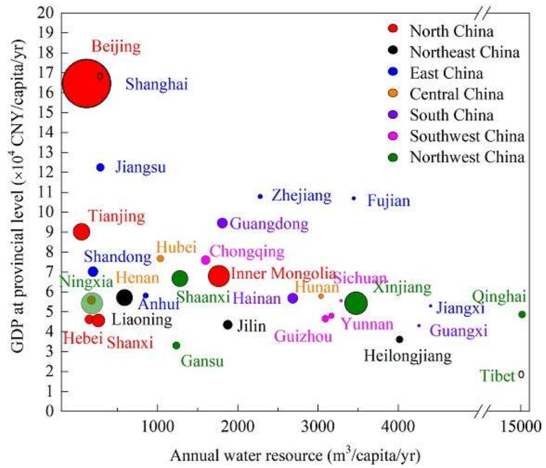

Figure 8. Correlations between the scale of reclaimed water facilities (cubic meters per capita per year) in urban areas and the quantity of water resources and GDP levels across 31 provinces in mainland China (Hayward, 2021).

Běijīng and Shànghǎi have both implemented large-scale WasteWater reuse projects. In Shànghǎi, for instance, reclaimed water is being used extensively for landscaping, industrial processes, and even groundwater recharge. For example, Shànghǎi's approach to urban water management integrates WasteWater reuse as part of its broader sustainability goals. This strategy is embedded within the city's comprehensive urban water management system, which includes advanced technologies and infrastructure aimed at addressing both water scarcity and pollution challenges. The city's long-term urban drainage masterplan, aligned with national policies, emphasizes improving water quality and managing stormwater through both green and grey infrastructure. The reuse of treated WasteWater is particularly crucial in supporting Shànghǎi's sustainability objectives, reducing pressure on natural water sources, and enhancing urban resilience (CIWEM, n.d.). The city already started implementing solution for the reuse of treated WasteWater, such as the "*Zero Liquid Discharge*" projects, implemented in several industrial parks, recycle WasteWater for industrial cooling and cleaning, reducing freshwater consumption.

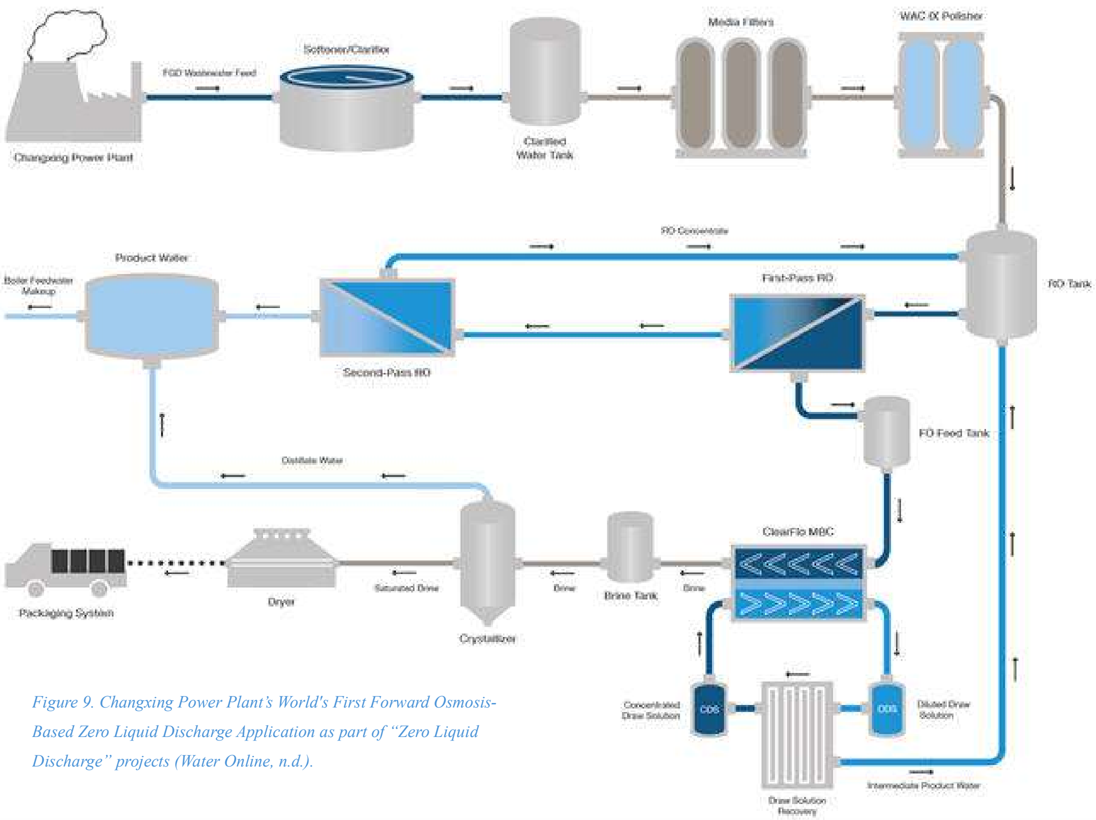

Figure 9. Changxing Power Plant's World's First Forward Osmosis-Based Zero Liquid Discharge Application as part of "Zero Liquid Discharge" projects (Water Online, n.d.).

However, despite these advances, China faces significant challenges. Public perception and acceptance of reclaimed WasteWater remain low, particularly for uses beyond industrial and landscaping purposes. The reluctance to adopt reclaimed water [not only in China] for domestic or agricultural use stems from concerns over water quality and safety, despite government efforts to enforce stringent quality controls (Chapman, 2005). Moreover, uneven enforcement of WasteWater reuse policies and insufficient infrastructure investment in rural areas hinder the full-scale implementation of secondary WasteWater systems.

Just by doing such a quick overview, it is possible to see the need of efficient strategies to enforce WasteWater reuse and WasteWater treatment plants implementation policies to change the water consumption approach and the mentality of society.

However, policymaking requires a step before – analyses of the current situation. In the case of secondary WasteWater use, we must understand how much water is being consumed; how it is being consumed to label it and properly treat it for secondary use; where it comes from and where does it go now.

Figure 10. Percentiles of used water in the United States of America from 2016 (US EPA, 2024).

With such an analysis it will be possible to make an evaluation and indicate the risks and opportunities for future development through policy making and ordinary planning. Ordinary planning is fundamental in secondary WasteWater use because we are talking about sustainable development of the city where we must also rethink the (urban) spaces, their use and maintenance. The relationship between space and secondary WasteWater is important in the matters of the available space is one of the problems of implementation of Secondary WasteWater Use Systems that will be covered in this study.

1.1 What is WasteWater?

The first step in any analyses is to understand the key element of the matter. There are many definitions of WasteWater, but in a general sense WasteWater can be defined as any water that has been adversely affected by human use (Eddy et al., 2002). These pollutants make untreated WasteWater unsafe for direct environmental discharge or human consumption, necessitating treatment before reuse or disposal. According to Tchobanoglous et al. (2003), WasteWater is composed of water (more than 99%) and relatively small concentrations of suspended and dissolved organic and inorganic solids (less than 1%). Organic matter primarily consists of proteins, carbohydrates, and fats, which decompose biologically and are the primary focus of biological WasteWater treatment processes (Eddy et al., 2002). Inorganic components include dissolved minerals, heavy metals, and other chemical compounds, which require physical or chemical treatment to remove.

Considering all the above, WasteWater can be categorized into several types: domestic sewage, industrial effluents, stormwater runoff, and agricultural runoff, each posing unique environmental challenges and treatment requirements (Eddy et al., 2002). Having unique treatment requirements, each category of WasteWater may require its own strategy for implementation besides the spatial factor which also affects the policy making process: we may assume that the implementation of a treatment plant is different in high-density historic urban area from a low-density peri-urban area.

But generally, all types of WasteWater treatment aim to reduce pollutants to safe levels before discharge or reuse. The processes are generally divided into primary, secondary, and tertiary treatments based on the level of pollution and the desired level of treatment, meaning which type of WasteWater – blackwaters, greywaters or white waters as defined above – is meant to be obtained in the end and for what type of reuse.

To sum up, WasteWater is a complex mixture of water, organic matter, and pollutants originating from various human activities. Its treatment is crucial to protect the environment and public health. With the growing global focus on sustainability, WasteWater is increasingly viewed as a resource in a circular economy model. The reuse of treated WasteWater, particularly in urban areas facing water scarcity, is a vital strategy for sustainable water management. Effective WasteWater management requires ongoing research, technological innovation, and stringent policy frameworks to ensure that this valuable resource is used responsibly and sustainably.

1.2 Problems of Implementation of SWWUS

Implementing secondary WasteWater use systems (SWWUS) is a critical step toward achieving sustainable water management, particularly in regions facing water scarcity. However, the integration of these systems faces numerous challenges, ranging from regulatory and legal barriers to societal resistance and logistical issues.

One of the most significant hurdles to secondary WasteWater use is the lack of comprehensive legal frameworks and inconsistent regulations across regions and countries. In many parts of the world, there are no clear, unified standards for the reuse of treated WasteWater, particularly for non-potable uses such as irrigation, industrial cooling, or urban landscaping.

For example, in the European Union, the Regulation (EU) 2020/741, which sets minimum requirements for water reuse, was only introduced recently, and many member states are still in the process of integrating these standards into their national legislation (Regulation - 2020/741 - EN - EUR-Lex, 2020). However, even with the regulation in place, the stringent requirements related to water quality and monitoring make the process expensive and complex, thus discouraging investment in water reuse technologies. And the variability of local implementation strategies across EU member states creates further complications for regional-scale WasteWater reuse projects, making it difficult to achieve widespread adoption.

In China, while policies like the 43th Five-Year Plan for Urban Wastewater Treatment and Reuse Facilities Construction (2021-2025) have been rolled out, local enforcement and clarity on specific water quality standards are inconsistent (Hayward, 2021). The uneven implementation of national policies at local levels often results in inefficiencies and gaps in the adoption of WasteWater reuse technologies, especially in rural areas where enforcement capacity is lower.

Public perception and societal acceptance of WasteWater reuse are also critical barriers to implementation. The idea of using treated WasteWater, especially for potable purposes, often triggers what researchers refer to as the “ick factor” (Rettner, 2011), wherein people are uncomfortable with the notion of reusing water that has already been consumed or contaminated. Even though advanced WasteWater treatment processes ensure that the reused water is safe for non-potable applications, such as irrigation or industrial use, public skepticism remains a considerable obstacle.

And the successful implementation of WasteWater reuse projects depends on strong public engagement and transparency. Without clear communication of the benefits and safety measures associated with WasteWater reuse, public pushback can delay or even derail projects. For example, the failure of some WasteWater reuse projects in Australia and the U.S. has been attributed to insufficient public consultation and education, further illustrating the importance of this issue (Dolnicar & Hurlimann, 2009).

Besides legal and social factors, it is also important to consider the spatial factor. In urban settings, secondary WasteWater reuse systems face considerable logistical and infrastructural challenges. Existing urban infrastructure is often not designed to accommodate new WasteWater treatment and reuse technologies. For instance, retrofitting WasteWater treatment plants to integrate reuse facilities in densely populated cities can be both costly and disruptive. In cities where space is limited, finding adequate land for new treatment plants, and building separate pipelines for the distribution of reused water can be challenging.

The challenge of integrating WasteWater reuse systems in Shànghǎi and other megacities often arises from a combination of high population densities and space constraints, which significantly limit the available land for WasteWater treatment facilities. In cities like Shànghǎi, existing infrastructure is often costly to modify or expand, further complicating efforts to scale up WasteWater reuse. The combination of urban space scarcity and the need for costly upgrades to treatment plants has made expanding WasteWater reuse a significant challenge (Huang et al., 2023; Kazmi & Furumai, 2005).

Furthermore, in many older European cities, such as Rome and Paris, the integration of WasteWater reuse systems is complicated by the challenges of working with historical infrastructure. Installing these systems often requires significant modifications to old pipelines and treatment plants, which are both costly and complex. Additionally, the limited space for new facilities, the excessive cost of retrofitting existing structures, and the potential disruptions to transportation networks further complicate efforts (Silva, 2023b).

Economic considerations are also central to the difficulties of implementing secondary WasteWater use systems. The initial investment costs for developing treatment plants and pipelines can be prohibitively high, especially in regions with limited financial resources. For many municipalities, the costs associated with setting up and maintaining the necessary infrastructure for WasteWater reuse outweigh the perceived long-term benefits.

In China, one of the key challenges to expanding WasteWater treatment and reuse, particularly in rural areas, is the excessive cost involved in treatment processes. The expenses are compounded by the lack of adequate funding and technical expertise to implement and maintain these systems, especially in less developed regions. For instance, rural areas often struggle with decentralized WasteWater treatment systems that are more costly and energy-intensive compared to centralized urban treatment plants (Y. Gao et al., 2024). Additionally, the Chinese government has established policies to address rural sewage treatment but faces difficulties in ensuring efficient implementation, especially with smaller, less-funded localities (Fan, 2022).

The challenges associated with the implementation of secondary WasteWater use systems extend far beyond technical aspects. Legal inconsistencies, societal resistance, urban infrastructure constraints, economic limitations are the key issues in the development of secondary use of WasteWater. The report by the World Health Organization (WHO, 2017) highlights the need for better governance frameworks to manage WasteWater reuse, particularly in developing countries. The report emphasizes that strong institutional structures, capable of coordinating the efforts of diverse actors, are essential for the successful implementation of WasteWater reuse initiatives. To overcome the obstacles, governments, policymakers, and stakeholders must focus on developing clear legal frameworks, increasing public awareness, addressing financial barriers, and improving urban planning and governance structures. Only by addressing these challenges holistically can secondary WasteWater reuse become a viable solution for sustainable water management in an increasingly water-scarce world.

1.3 Previous Studies

Research on secondary WasteWater use and the implementation of secondary WasteWater systems has expanded significantly in recent decades, driven by increasing concerns about water scarcity, environmental degradation, and the need for sustainable water management. The studies on the matter examine various aspects, including technological innovations, environmental impacts, economic feasibility, and public perception. Several studies have been particularly influential, shaping the way we understand the potential and challenges of secondary WasteWater reuse.

Jiménez (2006) conducted a seminal study on *secondary WasteWater reuse in developing countries, particularly for agriculture*, highlighting that treated WasteWater could alleviate pressure on freshwater resources when proper monitoring is in place to maintain public health and environmental quality. This work has provided a foundation for safe and efficient WasteWater reuse, especially in water-scarce regions. Secondary WasteWater treatment, which primarily involves biological processes that reduce dissolved and suspended organic matter after primary treatment, is a critical step in producing water suitable for reuse in non-potable applications. These applications include agricultural irrigation, industrial uses, and urban landscaping.

Agricultural irrigation, one of the most important uses of secondary treated WasteWater, has been widely discussed in the literature. Researches, such as by Hashem and Qi (2021) into the use of treated WasteWater for irrigation has shown that *secondary WasteWater can serve as a reliable, nutrient-rich water source*, particularly valuable in arid and semi-arid regions. However, challenges remain, notably the need to manage soil salinity and prevent the accumulation of heavy metals, both of which can impact long-term soil health and agricultural productivity. These issues are central to ensuring the sustainability of WasteWater reuse in agriculture, guiding best practices in water-stressed regions.

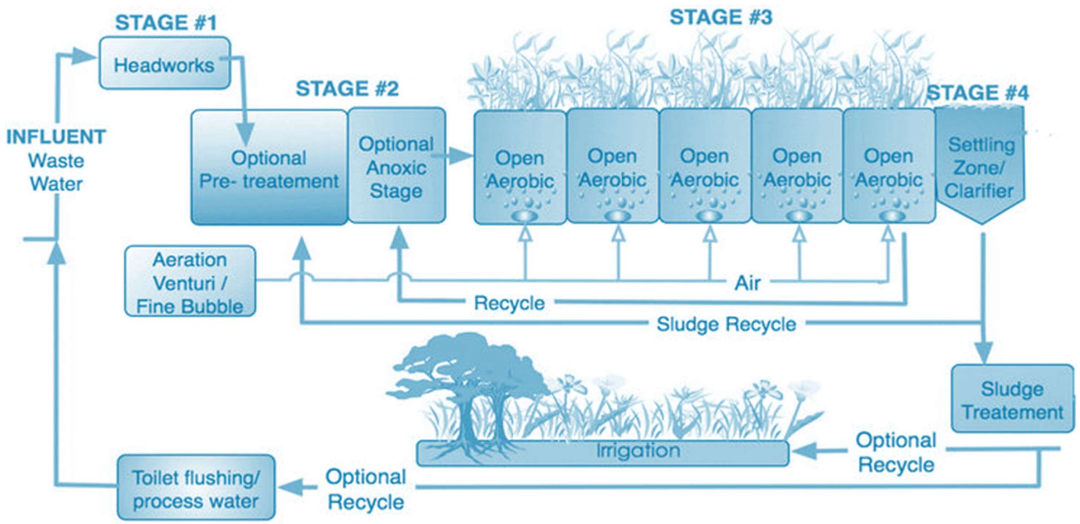

Figure 11. Ecological sewage treatment of WasteWater for the following use in agricultural irrigation (Khan, 2018).

Technological advancements have also been a major focus of research. Secondary WasteWater treatment is energy-intensive, and studies like those by Verstraete and Vlaeminck (2011) have examined how emerging technologies such as membrane bioreactors and anaerobic digestion can improve both the energy efficiency and sustainability of these systems. Their findings showed that innovative treatment methods can reduce the carbon footprint and operational costs of WasteWater reuse systems while maintaining water quality standards necessary for safe reuse. This work underscores the importance of technological innovation in scaling secondary WasteWater reuse systems, particularly in urban and industrial contexts.

Despite technological advancements, one of the greatest barriers to the widespread adoption of secondary WasteWater reuse remains *public perception*. Research by Dolnicar and Schäfer (2009) revealed that *psychological resistance* is often a more significant obstacle than technological limitations, particularly when treated WasteWater is considered for potable uses. Many people express concerns about potential health risks, even when there is ample scientific evidence supporting the safety of treated WasteWater. This study has been crucial in highlighting the need for *public education* and *transparent communication* to foster greater acceptance of WasteWater reuse, emphasizing that social acceptance is as important as technical feasibility in ensuring the success of these programs.

Another key area of research is the *regulatory and infrastructural frameworks* necessary to implement secondary WasteWater systems effectively. Asano et al. (2008) conducted a comprehensive international survey on water reuse practices, detailing the legal, institutional, and infrastructural requirements for implementing WasteWater reuse on a large scale. Their research underscores that successful implementation depends not only on technical solutions but also on clear regulatory frameworks and strong governance to ensure the safety and sustainability of these systems. Case studies from regions like California and Israel show how regulatory support and public engagement have been instrumental in reducing reliance on freshwater sources through the reuse of treated WasteWater.

Ecological and environmental benefits are another critical focus in this field. For instance, the paper “Responsible Water Reuse Needs an Interdisciplinary Approach to Balance Risks and Benefits” (Dingemans et al., 2020) explores how WasteWater reuse can offer significant those benefits. The authors emphasize that reusing treated WasteWater helps *alleviate the pressure on freshwater resources*, especially in water-scarce regions, by providing an *alternative source* for agricultural irrigation, industrial processes, and urban landscaping. This practice reduces the need to extract water from natural ecosystems, thereby preserving aquatic habitats and biodiversity.

Additionally, the paper highlights how WasteWater reuse can reduce the environmental impacts associated with WasteWater disposal, such as nutrient pollution and contamination of water bodies. By promoting more sustainable water management practices, the paper advocates for integrating WasteWater reuse into broader environmental strategies to address global water scarcity and enhance ecosystem resilience. However, the authors also stress that these ecological benefits must be balanced with careful management to avoid potential risks like the accumulation of contaminants in reused water, requiring an interdisciplinary approach that includes health, engineering, and environmental sciences.

The topic of secondary WasteWaters is a multidisciplinary one: the research questions vary from technological to social, from environmental to legal, studying not only how to create the Secondary WasteWater Use Systems, but also how to implement them in cities and how to make people use these systems.

1.4 Personal Experiences

When studying such topics as WasteWater, it is important to consider that it is an issue [not always perceived as such, but still] that we are exposed to in our everyday lives. That means that the perception of the topic is not only defined by the academic research, but also personal experiences that could define individual positioning on the topic.

For this study specifically, of extreme relevance in shaping the perception of the topic were the recent site visits of Florence and Bologna in Italy[2], highlighting two different realities.

On one hand, Florence, with the Arno River as its lifeline, showcases a well-maintained and historically conscious approach to water and WasteWater management. The city's infrastructure reflects centuries of adaptation to hydrological challenges, particularly in flood control and WasteWater treatment – the devastating 1966 flood, which submerged much of the historic center, led to the development of improved

[2] The cities have been visited throughout 2024, however specifically for this study site visits were conducted on 21st January 2025 for Florence and 10th February 2025 for Bologna, including a meeting with the Ecological Transition Sector and Climate Office, Soil and Water System Unit of Bologna (Settore Transizione Ecologica ed Ufficio Clima, UI Suolo e Sistema delle Acque).

hydrological defenses, including upstream reservoirs, enhanced riverbank fortifications, and flood diversion channels (EPA Catchments Unit, 2019). Historically, besides the flooding in 1966, the Medici family also played a crucial role in shaping Florence's urban water management. Under their rule, significant infrastructural projects improved the city's sanitation and water supply: Cosimo I de' Medici initiated the construction of aqueducts to provide clean drinking water to Florence, while later Medici rulers supported the development of drainage systems to reduce disease outbreaks associated with stagnant water (Veen, 2006).

The city's embankments, reinforced with modern engineering techniques, blend seamlessly with the historic urban fabric. Moreover, the city's relatively compact urban layout, with preserved green spaces along the river, may help absorb excess rainfall and reduce surface runoff into the Arno. Observing the clean waters of the river and seeing Florence's emphasis on public drinking fountains – providing high-quality potable water from local sources – demonstrates an enduring commitment to sustainable water use and reducing bottled water dependency, as well as inspires to introduce sustainable solution in historic and modern contexts. And the city's structure along the river Arno with immediate, but organic elevation offers interesting insights on how the urban fabric can naturally be redeveloped and remain human-centered[3].

In contrast to Florence's efficiency, Bologna seems to be a city in the process of rediscovering and rehabilitating its lost hydrological identity: though having a clear idea in urban development in matters of water management, as referred by the corresponding office, the city still struggles during heavy rainfalls and periods of aridity. The city's topography and hydrology have significantly influenced its water management challenges. Bologna, located in the Po Valley, was once renowned for its intricate canal network – comparable to Venice in complexity –gradually covered many of its waterways, including sealing off natural waterways, in the 19th and 20th centuries due to industrialization and urban growth (Foodie's Delight Tour Bologna, 2024; Gruppo di Studi Pianura del Reno, 2021).

[3] In this context human-centered is meant as a design that favors citizens' comfort [though in case of Florence there are some accessibility issues that however will not be covered in this work] as human-centered design in a general sense contradicts the ideas developed and presented later in this study.

The exploration of the city and the meeting of the Water Unit of Bologna revealed an ongoing effort to unearth and reintegrate these canals into the urban landscape. While walking through the city, the restored canal viewpoints that offer glimpses into the watercourses that once powered the city's mills and factories are visible. This effort symbolizes a shift towards

recognizing water as a cultural and environmental asset rather than merely an urban obstacle.

Still, the city has recently faced many water-related crises. For example, in September 2024, Bologna and the Emilia-Romagna region experienced catastrophic flooding due to extreme rainfall (Reuters, 2024). The events served as a wake-up call for further integration of climate adaptation strategies into urban planning. Furthermore, Bologna's WasteWater management is undergoing significant improvements[4]. The city is expanding its WasteWater treatment capacity, addressing long-standing pollution concerns in the Reno River, and new policies promoting decentralized WasteWater treatment systems in new developments reflect a growing awareness of sustainable water management practices. Additionally, the city is investing in green infrastructure solutions, such as rain gardens and bioswales, to counteract the increased risk of urban flooding.

Beholding these interventions firsthand reinforce the understanding of the delicate balance between historical preservation and contemporary urban adaptation. And while Florence felt like a masterpiece of old masters who managed to create ingenious solutions with the limited technologies they had by just making nature and humans work together, Bologna painfully showcased how the human hand twisted nature for the mankind to benefit, only to forget about it, seal it, until the damage become so critical, it could not be ignored. These observations helped lay the foundations of the practical side of this research, raising doubts about the approach to use – nature- or human-centered – for the actions to propose. Bologna's case specifically accentuated the lack of focus in research on the natural structure of a city, arising the idea to reinforce the hydrological structure of a city and to put it in the focus for future urban development, prioritizing water as the base resource for the existence and flourishing of homo sapiens and for homo urbanus.

[4] The information provided below is based on personal notes from meetings with Ecological Transition Sector and Climate Office, Bologna Soil and Water System Unit (it. Settore Transizione Ecologica ed Ufficio Clima, UI Suolo e Sistema delle Acque di Bologna) (10.02.2025) and Daniele Ara, Councilor for Agriculture, Agri-food and Water Networks in Bologna (12.02.2025).

1.5 Summary

In outline, research on secondary WasteWater use and systems implementation is diverse, spanning technological innovations, environmental applications, public perception, and regulatory frameworks. Seminal studies have contributed significantly to our understanding of how secondary WasteWater can be reused to address water scarcity and promote environmental sustainability. Although the field has made considerable progress, ongoing research continues to explore how to optimize WasteWater reuse systems in terms of both efficiency, legal frameworks, and societal acceptance.

Europe and China are interesting cases to confront in this matter as they represent two different contexts in secondary WasteWater use, each shaped by their regulatory frameworks, water scarcity challenges, and societal acceptance. In Europe, the approach is more harmonized and driven by stringent EU directives, with countries like Spain and Italy demonstrating leadership in agricultural reuse. The focus in Europe is on creating a circular economy for water, where secondary WasteWater use is an integral part of sustainable development.

In China, water reuse is a necessity driven by acute water shortages, especially in urban areas and northern regions. China's efforts are part of a larger national strategy to improve water management and reduce pollution, with urban WasteWater reuse being critical to the survival of its megacities. While technical progress is evident, social barriers and uneven regional implementation remain challenges to overcome.

Nevertheless, water management includes many areas of study, specifically confronting the issue of water shortage. In the last years, a lot of studies have focused on rainwater collection for the development of sustainable urban environment through the concept of sponge cities. And while it is a concept worth developing, its primary focus is on new water sources, while the urban development nowadays should focus on the 3 Rs principle (reduce, reuse, recycle) (3R Initiative, n.d.), already shifting to the 5 Rs (refuse, reduce, reuse, repurpose and finally, recycle) (Circle Waste, 2020). Wastewater treatment and secondary WasteWater use lays along those principles, but to better understand the benefits of prioritizing[5] WasteWater treatment and reuse of rainwater collection for urban development it is necessary to first understand the relationship between water and urban environment, and how water as a resource can

[5] Prioritizing, but not excluding, as ideally those projects alongside others should be implemented together in an ideal sustainable future city.

allow cities and its citizens to prosper for the years to come.

It is important to recognize that there are a lot of technical, social, economic, environmental and other solutions that address the water issue. However, it is rare that those solutions are implemented or studied together, something that is necessary to address all aspects of the water issue. Thus, this study attempts to cover this gap by trying to provide a proposal of how multiple water solutions can be combined together in an urban environment on the case of secondary WasteWater use in residential areas.

1.6 Brief Explanation of Contents

To study and illustrate the opportunities and challenges of secondary use of WasteWater in urban areas and the implementation of systems for it, this research will try to give a general overview on water management by describing the relationship between water and the city with a focus the various water cultures and the possibilities to gain urban prosperity through water. More specifically the matter of urban prosperity is linked to the issue of circularity which is a broader topic that includes treatment and reuse of WasteWater, where reuse is not limited to one more use post treatment of WasteWater – as is the focus of this study which aims to illustrate at least one more circle in the general water management cycle – but an infinite loop circle with multiple applications of water and WasteWater as limited natural resources.

Once the general understanding of the water-city relation is defined with a focus on sustainability and circularity, the study aims to outline an analytical framework for WasteWater management through the consumption model with consideration of climate change as a major challenge that optimized WasteWater management can mitigate against. By analyzing via multi-impact risk assessment, the spatial context of the selected study case areas in Italy and China, as a final output this study offers two distinct scenarios of SWWUS implementation with opportunities and challenges encompassed in them.

This work aims to be an illustration of how WasteWater management can be conducted within the contemporary sustainable development of cities, slowly introducing the idea of shifting focus in urban design from human- to nature-centered

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Figure 12. Neptune's fountain in Piazza Della Signoria in Florence (Zbrodko, n.d.).

Chapter 2
Water and the City

Water has profoundly shaped the development of cities throughout history. As a vital resource for drinking, sanitation, agriculture, and trade, water has been integral to urban growth and the formation of settlements. The relationship between cities and water has evolved over time, reflecting advances in technology, urbanization, and changing environmental conditions. Water has been both a resource to be managed and a powerful force that has influenced urbanization patterns and economic activities, with cities emerging and growing around water bodies for practical, economic, and symbolic reasons.

2.1 Historical Relationship between Water and City

The earliest urban centers across ancient civilizations such as Mesopotamia, Egypt, and the Indus Valley were strategically located near rivers, which played a crucial role in supporting settlement and societal development. These rivers provided water for agriculture, transportation, and trade, enabling urbanization to flourish. In Mesopotamia, for instance, the Tigris and Euphrates rivers were vital for irrigation, allowing agriculture to thrive in the region's otherwise arid environment. This irrigation system was essential not only for sustaining the population but also for fostering the growth of cities like Ur. Water management systems, such as canals and reservoirs, were developed in these ancient civilizations to manage seasonal flooding and ensure a steady water supply for agriculture, contributing to urban sustainability (Spurlock Museum of World Cultures, n.d.).

In ancient Rome, water engineering reached new heights with the construction of aqueducts, which supplied the city with drinking water, supported public baths, and irrigated agricultural lands. These aqueducts, extending for hundreds of miles, were a cornerstone of Roman urban expansion, with some estimates suggesting Rome's aqueducts could deliver nearly 1 million cubic meters of water daily at their peak (Hodge, 2002; Serrao-Neumann et al., 2019). The Roman sewage systems, particularly the Cloaca Maxima, also played a critical role in maintaining urban sanitation and public health, underscoring the advanced engineering techniques employed to support a population of over a million (UNRV, n.d.).

During the medieval and early modern periods, water remained integral to urban growth and identity, using in some regions the legacy of the Roman water systems. In Southern Europe, cities like Venice, Florence, and Genoa grew around waterways that not only supported commerce but also contributed to the cultural landscape. Venice, for example, was established on a lagoon and utilized canals for trade, connecting Europe to the Middle East and North Africa, thus making water central to its economy and cultural heritage (Lane, 1973).

Figure 13. Fragment of Marco Polo's departure to the East. Johannes, late 14th century (LorenzaInquisizia, 2015).

In Florence, water-powered mills enabled industrial production, while fountains and water features in Renaissance gardens served as symbols of wealth and political power, reflecting how water influenced both economic and cultural dimensions (Hibbert, 1994).

The Industrial Revolution marked a shift in water's role in cities, as rapid urbanization created new demands for water and sanitation. So, initially, water as a resource was necessary to create urban settlements and allow basic survival of humans, as people cannot survive without water which is a basic necessity. With time water become a resource to improve the quality of life in a stable environment through agriculture and then also commerce, connecting the various settlings and allowing exchange of goods. And afterwards, water became an instrument for urban expansion and also sanitation that was fundamental for maintaining the growing population within the urban growth. Thus, it is possible to observe a cyclic behavior within the water-city relation. First water is an instrument to create or expand an urban settling, by guaranteeing the basic needs such as potable water and health to its inhabitants; then water is being used to stabilize the urban environment and make the population prosper, before once again returning to the growth. So, it is a cycle of growth-development-growth. Currently modern cities should start shifting from the growth towards the stable development, hence the focus of this study on how this development or at least an aspect of it should be managed.

Back to the Industrial Revolution and specific cases, in Western European cities like London and Paris developed extensive water infrastructure, including reservoirs and sewer systems, to address public health needs amid increasing populations. The cholera outbreaks in London highlighted the need for clean water and effective waste management, leading to significant improvements in urban water systems (Hamlin, 2009; Serrao-Neumann et al., 2019). As cities grew, flood management also became a priority, with engineering projects like dams, levees, and embankments constructed to protect urban populations from seasonal flooding and support expansion into previously uninhabitable areas (Carson, 2002).

Ancient Chinese cities along the Yangtze and Yellow Rivers depended on these waterways for trade, flood control, and agriculture. The Grand Canal, a monumental engineering achievement, linked the northern and southern regions, facilitating the transport of goods and fostering urban growth along its route (Cotterell, 2007)[6].

Moreover, in cities like Huaiyang, water elements were incorporated into urban design, reflecting the cultural significance of water in Chinese society (Zhang & Kondolf, 2024). Situated in the lower Yellow River floodplain, Huaiyang historically utilized interconnected ponds and wetlands to manage floodwaters effectively, regulate water flow, and reduce flood risks. These systems not only provided practical flood control but also supported local agriculture, sustained biodiversity, and shaped the region's cultural identity (Zhang & Kondolf, 2024). Huaiyang's traditional practices demonstrate a sustainable, nature-based approach to flood management, offering valuable lessons for contemporary urban planning such as the preservation and restoration of such traditional landscapes to address modern challenges, emphasizing their potential to enhance urban flood resilience while maintaining ecological and social benefits.

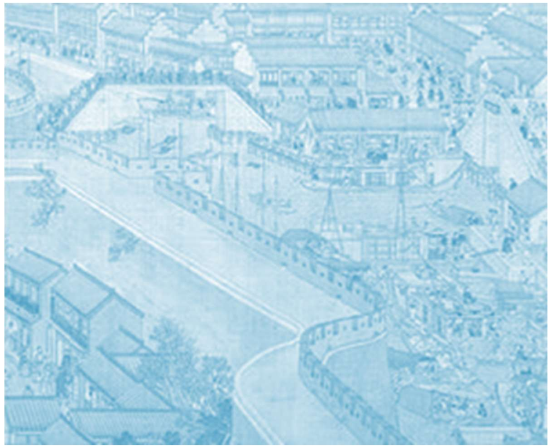

Figure 14. Grand Canal in Suzhou (Hays, n.d.).

So, from the aqueducts of Rome to the canals of Venice and the flood control systems in China, water has been part of the urban development throughout history. However, the constant expansion of urban areas and the challenges of urban sprawl have posed novel issues and challenges in management.

[6] The Grand Canal was formed by linking smaller regional canals, designed to transport troops, move food from southern farmlands to northern cities, and provide merchants a safer alternative to sea routes plagued by typhoons and pirates. The 10th-century Chinese invention of the pound lock system improved travel by enabling control of water levels along the canal. (Hays, n.d.)

2.2 Urban Growth and Water

The 20th and 21st centuries were highlighted by rapid urbanization and urban sprawl: as cities expanded, the demand for water grew posing new challenges and issues. These issues, that both Western and Chinese cities are facing, underscore the need for sustainable approaches to water resource management, especially given the environmental impacts of urban growth. Importantly, when discussing the relationship between water and urban development, the terms "urban growth" and "urban sprawl" are often used interchangeably, yet they represent distinct concepts. *Urban growth*, as a bigger umbrella term that "refers to the increase in urbanized land cover, which can occur through urban extension or spontaneous development known as urban sprawl" (ScienceDirect, n.d.). *Urban sprawl* is characterized as "the spreading of urban developments (such as houses, dense multifamily apartments, office buildings and shopping centers) on undeveloped land near a more or less densely populated city" (Merriam-Webster, n.d.; Remillard, 2023).

The pressures of urban growth on water resources are particularly visible in rapidly urbanizing regions like China. Cities such as Běijīng, located in a semi-arid region, faces significant water scarcity challenges, exacerbated by rapid population growth, urbanization, and industrial expansion. Addressing these issues, the South-North Water Diversion Project (SNWTP) exemplifies a large-scale intervention designed to supply water to northern cities like Běijīng by diverting water from the Yangtze River in the south. This project is one of the world's largest infrastructure undertakings, involving extensive canals and reservoirs to move water over vast distances (Kattel et al., 2019).

In Western cities, urban growth, though limited by historical heritage[7], has also led to water sustainability concerns, prompting a focus on technological innovations and sustainable water management practices. The proliferation of impervious surfaces due to urban sprawl, including roads, buildings, and parking lots, limits natural water absorption, causing increased stormwater runoff, which can lead to flooding and pollution (Serrao-Neumann et al., 2019). As urban areas expand, infrastructure systems are stretched thin, complicating efficient water distribution and water extraction, which among other things causes groundwater over-extraction and thinning of this resource.

Groundwater over-extraction has become a major issue as cities deplete this

[7] Whilst the heritage limits the urban growth and partially the urban sprawl in many European cities, it also creates challenges and limitations for innovating the water management system in those cities.

resource at unsustainable rates. In arid regions, reliance on groundwater for expanding urban populations, combined with climate change impacts like altered rainfall patterns and severe droughts, exacerbates water scarcity. Cities such as Cape Town (South Africa) and São Paulo (Brazil) have experienced severe water shortages as population growth has outpaced water resource management, highlighting the need for improved water resilience in urban planning (Fell & Carden, 2022; Ribeiro, 2018).

The over-consumption of the resources, growing water demand, cultural and historical heritage in cities, preservation of landscape and climate change [as well as many other challenges] are rendering traditional systems insufficient, emphasizing the need for updated, climate-resilient water infrastructure. In response to these challenges, many cities are adopting sustainable water management practices. The concept of "water-sensitive cities", prominent in cities such as Melbourne (Australia) and Vancouver (Canada), incorporates green infrastructure – rain gardens, permeable pavements, and green roofs – to mimic natural hydrological processes, reduce runoff, and improve water quality (Serrao-Neumann et al., 2019). These strategies aim to mitigate urbanization's environmental impact by capturing rainwater, increasing permeability, and reducing the likelihood of flooding. However, the implementation of these practices demands investment in infrastructure and public education to integrate sustainable water management into urban life (Shemie & McDonald, 2014).

2.3 Current Water Frontiers

Water management is an increasingly critical frontier as challenges of scarcity, quality degradation, and climate change start to pose a serious threat to humankind on Earth. The current state of water issues emphasizes a pressing need for sustainable approaches to address both physical and economic water scarcity and to ensure equitable access globally.

2.3.1 Issues

Water scarcity is a pressing global issue, exacerbated by climate change, population growth, and insufficient infrastructure. Over a billion people worldwide face physical water scarcity, where demand exceeds the available local supply. This is particularly acute in arid regions like parts of the Middle East and North Africa, where rainfall is limited and demand is high. (Klobucista & Robinson, 2023). And economic water scarcity affects around 1.6 billion people, even in regions with adequate natural

water resources. This scarcity is driven by poor infrastructure, inadequate management, and elevated levels of water pollution. For instance, in places like Mexico City, despite receiving abundant rainfall, water is lost due to aging infrastructure, contamination, and inefficient use (Petruzzello, 2024). Mismanagement also contributes to water stress in areas with large agricultural sectors, where excessive water use for irrigation depletes vital resources.

UN states that climate change compounds these challenges by making water supplies more unpredictable. Shifting precipitation patterns lead to more intense floods and droughts, while melting glaciers reduce the supply of meltwater that feeds many major rivers. Moreover, rising sea levels increase the risk of saltwater intrusion into freshwater resources, while extreme weather events, such as wildfires and floods, damage water treatment infrastructure. The United Nations estimates that by 2050, up to 3.2 billion people could face severe water scarcity (UN-Water, n.d.).

These factors combined not only stress water resources but also undermine public health, economic development, and food security, underscoring the urgent need for improved water management and climate adaptation strategies.

2.3.2 Opportunities

Urban areas can implement green infrastructure, such as rain gardens and permeable pavements, to manage stormwater sustainably, thereby reducing the risk of urban flooding while promoting aquifer replenishment. Managed Aquifer Recharge (MAR) involves intentionally recharging aquifers to store water for future use, and it can help address seasonal or interannual water imbalances, especially in regions that face water scarcity. (Dillon & International Association of Hydrogeologists, 2022). Nature-based solutions (NbS), such as MAR or restoring wetlands, provide multiple ecosystem services and help filter pollutants, presenting a viable alternative to traditional infrastructure

Grey nature-based solutions can also offer many opportunities. Grey nature-based solutions, such as advanced WasteWater treatment systems for reintroduction in waterbodies or a secondary consumption of waters, offer significant opportunities in addressing the challenges posed by urban waterfronts. Implementing grey nature-based solutions, like constructed wetlands or biofiltration systems, can help cities manage WasteWater more sustainably while enhancing environmental quality. These solutions bridge the gap between hard infrastructure (like traditional treatment plants) and nature-based approaches by utilizing engineered systems that mimic natural processes. For waterfront cities, this approach provides a dual benefit: it improves water quality, ensuring that public water bodies are cleaner and more resilient to pollution, and reduces the environmental footprint of urban growth.

Addressing water management through an integrative approach, which combines environmental, economic, and social perspectives will support adaptive, resilient urban water systems. This approach, often referred to as *Integrated Urban Water Management* (IUWM), emphasizes a comprehensive view of the entire water cycle, from sourcing and consumption to WasteWater and stormwater management. The goal is to ensure that water resources are used efficiently and equitably, considering all water users—including agriculture, industry, households, and ecosystems. Such systems aim to adapt to climate change while meeting the growing demands of urban populations. (Kirshen et al., 2018).

2.3.3 Future Perspectives

Future water management requires systemic changes, including more inclusive governance models, interdisciplinary planning, and climate-resilient infrastructure investments. Integrating water resources modeling with social and cultural considerations could lead to more sustainable urban planning and equitable distribution of resources (Shemie & McDonald, 2014). Furthermore, supporting communities in co-designing water systems tailored to local needs can foster more equitable and adaptable systems that can respond to rapid climate shifts.

Current water frontier strategies must prioritize sustainability and equity by leveraging technological advancements and traditional knowledge, fostering community engagement, and ensuring policies are adaptive to local and global pressures. Focusing on water and putting at the center of current urban development is key to achieving a secure and sustainable water future.

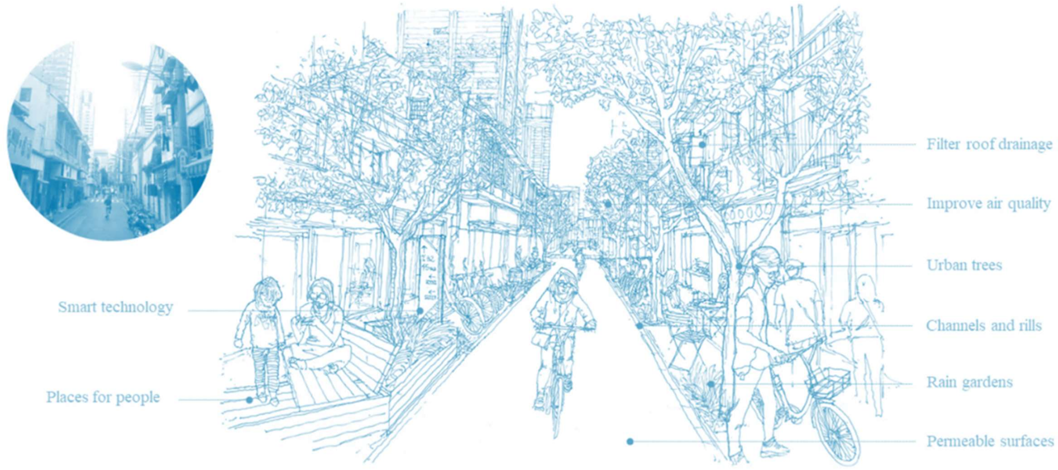

Figure 15. Shànghǎi's vision for 2030 of urban drainage masterplan (CIWEM, n.d.).

2.4 Conclusions on Water-City Relationship

The historical relationship between water and cities has shaped urban growth and infrastructure development in profound ways. From ancient water management systems in Mesopotamia, Rome, and China, to modern megaprojects like the South-North Water Diversion Project in China and the green infrastructure initiatives in Western cities, water has consistently influenced the form and functionality of urban environments. Ancient cities thrived by adapting their designs to natural water sources, while modern cities face complex challenges from urban sprawl and climate-induced water scarcity, requiring more innovative approaches to sustainability (Du et al., 2019; Serrao-Neumann et al., 2019) that could be inspired by ancient nature-adaptive and nature-centered designs.

Today's water-sensitive cities, such as Bangkok, demonstrate the need for integrated water management that considers not only physical infrastructure but also environmental and cultural dimensions. As cities continue to expand, sustainable practices like rainwater harvesting, water recycling, and permeable surface designs are vital to reduce resource strain and environmental impact (Shemie & McDonald, 2014). These strategies reflect a broader shift towards embedding water-centered principles into the urban fabric, which is crucial to building resilience in the face of growing urban populations and climate variability.

So, as explained in this section, without access to water and sanitation, urban development becomes nearly impossible. Water is the lifeblood of cities, supporting public health, economic growth, and social stability. Urbanization hinges on the availability of clean water for drinking, sanitation, and industrial use, which are foundational to thriving communities. Sanitation, linked to water infrastructure, ensures that waste is responsibly managed, reducing disease and fostering a healthier, more productive population. Without these systems, cities would struggle with overcrowding, disease outbreaks, and environmental degradation, stunting their growth and prosperity. Water is not only essential for basic survival but also for the social life of citizens – enabling agriculture, powering industries, supporting infrastructure, and improving the quality of life for all urban dwellers. Thus, water is not just a resource; it is the key to unlocking the potential of cities to grow, thrive, and adapt to future challenges.

Hence, the next section explores water culture, the evolving symbolic and social roles of water in urban life. Historically, water has not only supported urban survival and growth but has also held significant cultural, spiritual, and social value. From Venice's canals to Chinese water gardens, water has been a medium through which cities express identity, power, and connection with the natural world. By examining water culture, it will be possible to see how these intangible aspects of water-city interactions shape our perceptions and use of water, ultimately influencing the future of sustainable urban planning.

Figure 16. Dujiangyan Irrigation System in 2017 (Price, 2019).

Chapter 3 Water Culture

Water has always held profound symbolic and social significance across culture: in cities, water has shaped both the physical landscape – through rivers, canals, and reservoirs – and the social fabric, influencing the development of public spaces, cultural practices, and community rituals. As urbanization accelerates and the effects of climate change become more apparent, water's role is expanding beyond its practical function to become a central element in discussions of sustainability, resilience, and social equity.

3.1 European Water Culture

European water culture has deep historical roots and played a pivotal role in shaping societies, especially in terms of daily practices, religious beliefs, and technological advancements. Traditionally, Europeans regarded water as both a life-giving force and a source of spirituality. Rivers, springs, and wells were often linked to religious practices; many were believed to have healing properties and were associated with saints or deities. However, the perspective on water shifted with the rise of Christianity in Europe. As Christian doctrines supplanted pagan beliefs, water's symbolic and spiritual roles underwent transformation. Christian theology kept water’s role in purification, epitomized by the sacrament of baptism, by so replacing older pagan rituals tied to the healing properties of water.

As urban centers grew, European societies faced the challenge of managing water in both quality and quantity. In cities like London and Paris, clean drinking water became an essential commodity, leading to complex systems of aqueducts and reservoirs as early as the Roman period, later modernized in the 19th century in response to public health concerns. The cholera outbreaks of the 1800s, for example, spurred significant reforms in water infrastructure, marking a turning point when water began to be understood as a potential vector for disease (Hamlin, 2009). These health crises led to innovations in sanitation, including WasteWater removal and filtering systems, which transformed European cities and improved public health (We Are Water, 2021).

Water in sanitation is central not only to health, but also to European social life, from the Terme in ancient Rome as a place for social gatherings where a lot of political decisions were made to the public bathhouses and later spa towns such as Bath in England and Vichy in France becoming popular gathering places. These locales, celebrated for their mineral-rich waters, attracted people from various social classes who believed in the therapeutic qualities of the waters. The social significance of water-based leisure activities shaped European lifestyle and economy by promoting tourism and fostering cultural exchanges making water and water-centered places a luxury and a symbol of status with a clear distinction between people of various classes and backgrounds.

And whilst through the sanitation perspective water become a cause of social segregation in European communities, agriculturally water management practices, especially in Southern Europe. In rural communities, the management of water resources was often shared, with irrigation channels and wells serving as common goods. This necessity for cooperation strengthened social ties and created systems of local governance that ensured equitable access to water.

3.1.1 Italy and Water

The relationship between Italians and water dates back to ancient times, particularly with the Romans, who built sophisticated aqueducts to bring water to their cities, making Italy, thus, an interesting case for studies on water management and its evolution. The legacy of Roman water management systems played a role in the establishment Italy's major cities as powerful cultural and economic centers.

Throughout the Renaissance and beyond, water continued to be vital in Italy, especially in cities such as Venice, Rome, and Florence[8], where aqueducts, fountains, and canals became symbols of civic pride and public health, both signs of prosperity. Venice's Magistrato alle Acque, created in 1501, is an example of Italy's long history of water management and protection (ERC, n.d.). During the 19th century, public health concerns, especially after the cholera epidemics, prompted significant reforms in Italy's water supply and sanitation systems. These reforms led to the construction of modern sewage and drinking water infrastructure that continue to serve for many cities even today (Boccaletti, 2021).

Culturally, water holds a special place in Italian traditions. The use of thermal springs in Tuscany and other regions for health and leisure dates back to ancient Roman times and became particularly important during the Renaissance. The idea that therapeutic waters in Italy historically promoted well-being and functioned as venues for social and intellectual exchange, particularly among the elite, is well-documented. During the Renaissance and early modern period, thermal springs and spa towns

[8] It is important to mention that until 1861 there was a united kingdom of Italy, but first independent city-states and then separate kingdoms and republics, such as the Most Serene Republic of Venice, the Republic of Florence and the States of the Church.

became destinations for healing and leisure. Prominent Italian spa locations like Abano Terme and the Euganean Hills were especially renowned for their mineral-rich waters, attracting aristocracy and intellectuals who sought both physical rejuvenation and opportunities for discourse in these tranquil environments (ERC, n.d.; Sheeba Magazine, 2023). Those and other locations remain a popular destination to this day for relaxation and health benefits.

However, in terms of sanitation and modern water use, Italy has faced challenges with water management. Despite the country's advanced infrastructure in some areas, several cities have struggled to meet EU WasteWater treatment standards[9], leading to legal actions and the implementation of reforms (We Are Water, 2021).

This has highlighted the ongoing importance of effective water management, especially as Italy grapples with the effects of climate change and water scarcity, particularly in southern regions like Sicily and Sardinia (ClimateChangePost, n.d.). Sardinia, for instance, has seen water reserves drop below 50% capacity, and extensive investment is being directed to reduce water loss through outdated infrastructure (P. Koh & Robotti, 2022). In Sicily, extreme weather patterns have led to significant agricultural and economic disruptions, with projections indicating that water scarcity will persist into the future (Williams, 2024).

Furthermore, Italians are among the world's top consumers of bottled water, averaging 194 liters per person annually (Barry, 2010). In 2012, the country withdrew 9.5 billion cubic meters of water for municipal supply, accounting for 18% of total water withdrawals. However, after treatment losses, only 8.4 billion cubic meters entered distribution networks. Further inefficiencies, including non-revenue water (water lost before reaching consumers), reduced the amount delivered to users to 5.2 billion cubic meters, or 241 liters per person per day (Istat, 2012).

These figures reflect critical issues in both water conservation and infrastructure management of different scales from the city sewerage system to public fountains, especially in historic cities like Rome, serving not only as cultural landmarks, but also as functional sources of water and instrument to reduce heat in the urban context.

In conclusion, water in Italy is both a resource and a cultural symbol, woven into the fabric of daily life, infrastructure, and tradition. The cultural importance of water as

[9] The European Union WasteWater treatment standards are primarily governed by the Urban WasteWater Treatment Directive 91/271/EEC, which sets requirements for collecting, treating, and discharging urban WasteWater and certain industrial effluents to protect water environments across member states. While not explained fully, these standards will be mentioned more in detail later on in the work.

both a natural resource and a social bond continues to shape the water management strategies of Southern European countries today, where both traditional and modern systems work side by side to preserve scarce water resources. For example, its impact on Italy's development, from ancient Rome to modern cities, is undeniable, shaping both the physical landscape and the social fabric of the nation.

3.2 Asian Water Culture

The cultural role of water in East Asia has profoundly shaped societal development, influencing everything from infrastructure and health practices to spiritual and communal life. In China, Japan, and Southeast Asia, water is tied to both practical and symbolic aspects of life. This connection often manifests in societal practices and beliefs that emphasize the balance between humans and nature, deeply rooted in cultural and philosophical traditions.

The emphasis on water's cultural significance continues to inform modern policies across Asia. These policies often blend traditional knowledge with contemporary sustainability practices, enhancing resilience against challenges like climate change and water scarcity. As the Asia Development Bank emphasizes, recognizing these cultural dimensions is essential for effective and inclusive water management (ADB, 2024).

In China specifically, water is associated with the yin aspect of the yin-yang philosophy, symbolizing flexibility, receptivity, and strength through softness. These qualities have historically encouraged a harmonious approach to natural resource management, as seen in practices like feng shui, which designs spaces around water's natural flow to maximize harmony and balance. This influence extended to architecture and city planning, where many structures incorporated water features to align with philosophical ideas of natural balance (Salguero, n.d.).

3.2.1 China and Water

Water has played a significant role in shaping Chinese culture, society, and city development. The river's annual floods created fertile lands, enabling the growth of agriculture, and served as essential routes for trade and transportation (HistoryVista, 2024). Chinese philosophy and traditional belief systems, especially Confucianism and Daoism, have long emphasized the harmonious balance with nature, often highlighting water as a central, life-giving force. In Daoism, water represents adaptability and

strength through yielding, embodying the principles of Wu Wei, or "effortless action". Confucianism, however, influenced a more structured approach to water, seen in extensive, state-directed projects aimed at controlling rivers and ensuring agricultural productivity (Boccaletti, 2021).

China's water management efforts have historically centered on controlling the Yellow River, often called *China's Sorrow* due to its frequent, devastating floods. To mitigate these challenges, ancient Chinese rulers undertook massive hydraulic projects, including the Dujiangyan irrigation system, built in the 3rd century BCE and still functional today. This ingenious system redirected the river's flow to irrigate vast areas of farmland in Sichuan Province (Boccaletti, 2021), allowing for reliable water supply to farmland, enabling multiple crop cycles per year, which was essential for sustaining large urban populations and bolstering economic stability (Needham & Gwei-Djen, 1971).

Agriculture in China, especially in northern and central regions, has always been heavily dependent on efficient water management. The ancient Chinese recognized the necessity of controlling water not only to prevent flooding but also to support rice and wheat cultivation, the staples of Chinese agriculture. In addition to controlling rivers, ancient Chinese agricultural practices included the construction of terrace fields in hilly regions and sophisticated canal networks, particularly in the Yangtze River Basin. The Grand Canal, built in stages starting in the 5th century BCE, connected the Yellow and Yangtze Rivers, providing a critical waterway that supported agriculture, trade, and military movements. This infrastructure exemplifies how water management was intertwined with agriculture, facilitating crop transportation and helping local economies flourish (Elvin, 2004). The Chinese state thus played a crucial role in water management, as these large-scale projects often required imperial support and labor. The development of water-centered agriculture became a foundation for economic strength, fostering social cohesion and reinforcing centralized power through its impact on food security and population stability.

Water also played a significant role in city planning and sanitation. Ancient Chinese cities, such as those built along the Yellow and Yangtze Rivers, incorporated water systems that featured moats, canals, and elaborate drainage networks to control flooding and prevent disease. The spatial design of cities reflected both utilitarian and symbolic functions, with water bodies sometimes central in planning, included for irrigation, sanitation, and aesthetic value, often within gardens and temples (Ghisleni & Simões, 2024; More et al., 2022).

Cultural practices and traditions associated with water reflect its symbolic power in Chinese society. Water festivals, like the annual *Duanwu Festival* (Dragon Boat Festival), are celebrated to honor historical figures like the poet *Qu Yuan* and to pay respect to water deities. Festivals like Duanwu reinforce the importance of waterways in urban life, encouraging communities to keep rivers clean and functional, which indirectly supports urban planning efforts centered on rivers and canals. Mythology also reinforces water's cultural significance, with figures such as the dragon symbolizing power over rain and rivers, and legends like that of *Da Yu*, the Great Yu, who heroically controlled floods to protect his people, setting a model of selflessness and leadership. Da Yu, known for controlling the floods of the Yellow River, set an early cultural standard for effective water management. His legend emphasizes selflessness and leadership in tackling water issues, inspiring the construction of levees, dams, and irrigation canals as urban populations grew. This cultural reverence for water heroes and deities encouraged cities to develop their water infrastructure thoughtfully, integrating natural waterways and engineered solutions (Elvin, 2004; Needham & Gwei-Djen, 1971).

These myths and festivities underscore water's revered status and contribute to a communal ethos that prioritizes respect for natural water bodies within urban development. As Chinese cities continue to grow, these ancient beliefs influence modern planning practices by emphasizing the harmony between urban spaces and water resources.

Harmony is often associated with a general sense of well-being and *prosperity* – a state of flourishing, of thriving development, of great well-being, especially economic well-being (Treccani, n.d.). And in the current capitalist society, where economic well-being sometimes is even more important than physical and mental well-being, prosperity is something that is desired by all in any form.

However, prosperity can be defined in multiple ways and thus be achieved by different means with different end goals. The Institute for Global Prosperity is one of the institutions that focuses on the studies of prosperity in an urban context with a community-centered approach. And considering how water has been intertwined with society in both functional and symbolic ways, influencing agricultural practices, urban planning, and social customs that have shaped cities' development throughout their history, understanding how urban prosperity can be fostered through water is a fundamental part of a study on water in cities.

Figure 17. Houses Hammarby Sjöstad in Stockholm, Sweden (AdobeStock).

Chapter 4 Fostering Urban Prosperity through Water

Urban prosperity in a general sense refers to the well-being and overall quality of life in cities, encompassing social, economic, and environmental dimensions. The Institute for Global Prosperity (IGP) at University College London (UCL) emphasizes a broader concept of prosperity that goes beyond GDP, including secure livelihoods, social cohesion, *access to resources*, and *environmental sustainability* (IGP, n.d.; UCL, 2016). It seeks to balance growth with inclusivity, aiming to reduce inequality and enhance residents' ability to thrive economically, socially, and ecologically (Chan, 2023; World Bank, 2012).

4.1 Value of Water

If river basin studies are so important, what is the value of water for urban prosperity and urban development?

First of all, it is important to understand what is “value”. In economic terms, *value* represents the worth of a resource, service, or asset, often assessed through frameworks such as market value, labor value, or intrinsic worth (The Editors of Encyclopaedia Britannica, n.d.). Traditional definitions often prioritize over any other type the exchange value – what something can sell for – determined by factors like supply and demand. For example, neoclassical economics emphasizes value based on the price something would fetch in a competitive market, while classical economic theories consider the amount of labor or effort involved in its creation (CFI Team, n.d.).

However, IGP expands this definition, suggesting value should encompass more than market metrics like GDP. IGP proposes a more holistic perspective, evaluating value based on factors like social equity, environmental sustainability, and community well-being. By redefining value in this way, IGP promotes a framework for prosperity that values not only economic gains but also long-term societal health and ecological resilience (IGP, n.d.).

Still, modern cities are centered around the consumption culture and, thus, the exchange value of anything urban. The traditional logic of increasing exchange value in cities revolves around enhancing land and property values to drive economic growth. This approach often prioritizes rising property prices and rents to attract investment, which can lead to gentrification and the displacement of residents, particularly in lower-income neighborhoods. While this boosts certain economic indicators in a short-term perspective, it can reduce access to affordable housing, disrupt communities, and ultimately decrease social equity, besides thinning natural resources, leading to bigger issues in a long-term perspective.

IGP advocates a model that goes beyond rising exchange values, promoting urban prosperity through equitable access to essential resources and services that enhance quality of life and foster inclusive growth (IGP, n.d.; UCL, 2016). For IGP, an economy that values metrics beyond GDP, as mentioned above, includes measurements of social cohesion, environmental integrity, and equitable access to resources. IGP critiques traditional GDP-focused assessments, arguing that they often mask issues such as *environmental degradation* and *social inequality*.

IGP highlights that pathways to prosperity must consider both human and ecological well-being. Recognizing that human prosperity is interlinked with the health of ecosystems, IGP emphasizes that sustainable well-being requires preserving natural resources like clean air, water, and biodiversity. This integrated approach to well-being supports a balanced relationship between humans and the environment, promoting sustainability and equity for future generations. By valuing more-than-human entities, society can foster both ecological resilience and human prosperity (Chan, 2023; IGP, n.d.). To do so, a broader approach is required. IGP's research proposes using these metrics in a *whole-system approach* to shape policies that address societal needs while fostering environmental sustainability and resilience (UCL, 2016).

A whole-system approach considers how interconnected elements (e.g., housing, transportation, health services, and ecological preservation) impact urban life. Among the most important – not only environmentally, but also economically, culturally and socially – resources, suffering from scarcity and pollution, as explained before, is *water*.

Water is essential to human life, playing a critical role in hydration, sanitation, agriculture, and industrial activities. Reliable access to water affects every aspect of daily life and is a key determinant of public health and social equity. Ensuring water access, especially in urban environments, is a universal basic service and is fundamental for a society's overall well-being, as it reflects a society's commitment to meeting its population's basic needs in a sustainable way.

The *value of water* [in urban prosperity] extends beyond its economic worth to its critical role in enhancing the quality of life, reducing inequality, and enabling urban resilience. In dense urban environments, water access impacts public health, sanitation, and economic opportunities, as well as social cohesion. For cities, valuing water as a resource is key to supporting sustainable and inclusive development, making it a dominant factor in building resilient and prosperous urban spaces (CFI Team, n.d.).

4.2 Urban Future

When talking about the future of cities, as urban populations grow and cities become more polycentric, water is increasingly recognized as a central element in urban design and development: the European Green Deal and other sustainability frameworks recognize the value of water elements for improving the social and environmental quality of urban spaces (Schulze et al., 2024). And while water's re-integration into urban planning as a key stakeholder can yield significant benefits, it also presents challenges that need to be addressed through thoughtful planning, inclusivity, and sustainability (Langie et al., 2022).

Water plays a multifaceted role in architecture and urban planning, providing not only aesthetic appeal but also practical value in terms of environmental resilience, urban cooling, and recreational spaces. Water elements in urban spaces are recognized for their ability to enhance environmental resilience, support urban cooling, and provide recreational opportunities. These elements, ranging from natural water bodies to constructed features like fountains or wetland parks, contribute to aesthetics and functionality while addressing climate-related challenges like heat mitigation (Langie et al., 2022). Waterfront areas and water-centric urban designs are desirable for high-density developments due to their scenic beauty, ability to support tourism, and integration into sustainable living environments. Projects like *Singapore's Park Connector Network* and *Hammarby Sjöstad in Stockholm* showcase how integrating water with urban development fosters biodiversity, stormwater management, and high-quality public spaces (Chadha, 2024; Muller, 2018).

However, the integration of water into urban design raises concerns related to exclusivity and socio-economic inequality. Waterfront areas often see gentrification, where rising property values push out low-income residents, even when development projects claim to be inclusive or offer "public" spaces. While these areas may appear accessible, the underlying economic mechanisms often result in exclusionary practices, undermining the social equity that water-centered development could promote (Cook, 2004).

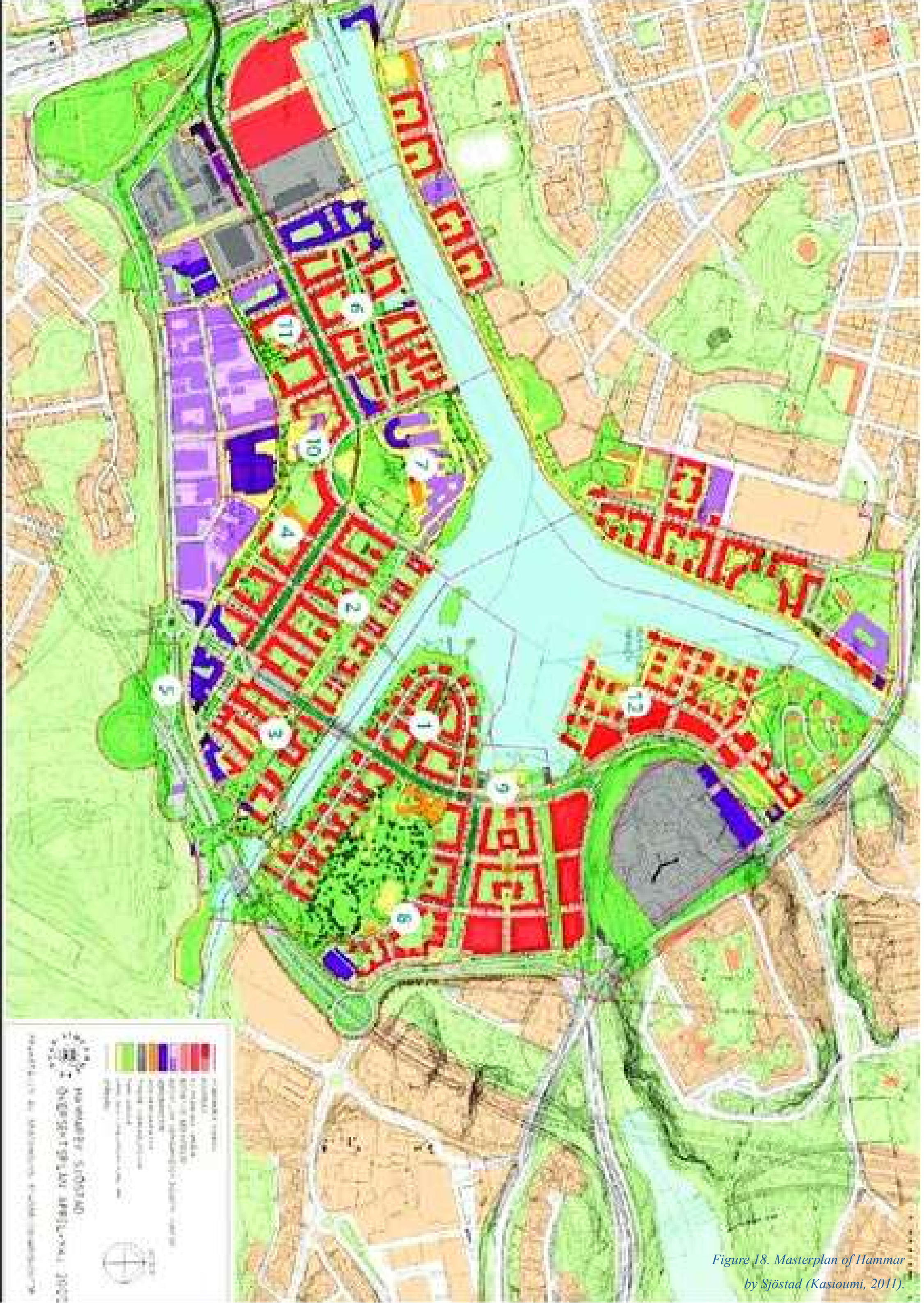

Figure 18. Masterplan of Hammar by Sjöstad (Kasioumi, 2011).

Additionally, water-related challenges, such as flooding, storm surges, and rising sea levels, are becoming more pronounced with climate change. Cities like Miami and New Orleans face growing threats from climate-induced flooding, pushing urban planners to design adaptive infrastructure that can withstand these risks (City of Miami, n.d.; Reynier, 2024).

Still, building near water provides several benefits, such as enhanced density, reduced urban sprawl, and better use of natural resources (Langie et al., 2022; Schulze et al., 2024). Such redevelopment can revitalize neglected urban areas, create employment opportunities, and preserve architectural heritage, all while boosting the economy of the surrounding region, developing cities to be more circular through co-designed systems.

For example, co-designed water systems, such as the use of wetlands for WasteWater treatment or the implementation of community-managed water storage systems, contribute to a more sustainable urban fabric. These systems in some designs could also create green public spaces that foster community engagement and provide recreational areas. In water-centered cities, such initiatives help address both the challenges of climate resilience and urban social inequalities, by ensuring that water management benefits all city dwellers, not just those in more affluent areas (Schulze et al., 2024).

Nevertheless, how to implement those systems in polycentric growing cities? Actually, as cities become more polycentric, with multiple urban centers and diverse districts, water bodies can form the focal points around which different areas are organized. A polycentric structure helps reduce congestion and spreads economic and social opportunities more equitably across a city. The presence of water bodies – whether large rivers or smaller canals – can define the hierarchy of city centers (Roth et al., 2011; Zhou et al., 2022). Larger bodies of water often serve as central hubs, attracting more significant commercial and cultural developments, while smaller bodies support local, district-level needs (Ahlfeldt & Wendland, 2013).

In cities like Paris and Venice, water serves not only as a physical boundary but also as a central organizing principle for spatial and economic development. These hierarchies help structure the city's growth, promoting more decentralized forms of development that can enhance connectivity and reduce the pressure on traditional city centers (OECD, 2019). When planned thoughtfully, water-centered urban hierarchies can support sustainable growth, foster social interaction, and address both human and environmental needs in a more balanced way.

Thus, the future of urban development revolves around integrating water into city planning. Water-centered cities leverage waterfronts, rivers, lakes, and other water bodies as key spaces for economic, environmental, and social vitality. As cities grow and become more polycentric, enhancing water as a resource for enhancing urban livability, sustainability, and social equity becomes crucial.

However, the development of the new concept of water-centered city must be approached with caution to avoid the exclusionary effects that often accompany water-centered developments.

Through circular city principles, co-design practices, and a focus on the hierarchy of water bodies, water-centered cities can promote resilience, inclusivity, and environmental sustainability, ensuring that urban growth benefits all inhabitants and respects ecological limits. The elaboration of methodology in shaping a concept is a fundamental part for the development of a new concept as it allows to summarize in the end synthetically all the key elements to then apply them on real life cases.

Figure 19. A WasteWater Treatment Plant (AdobeStock).

Chapter 5 Circularity & WasteWater

One of the most prominent modern approaches to urban planning, when discussing the future of cities, revolves around the concept of circularity. While at the moment a precise definition of a circular city is lacking in the academic world (Paiho et al., 2020), generally a circular city is seen as a city that puts building circular economy cornerstones into its urban network, by favoring sustainable methodologies over climate-damaging consumption, such as reuse and repurposing over demolition and disposability (Sweco UK, 2024). In urban settings, this approach guides sustainable urban planning, waste management, energy systems, and overall city design, aiming to create resilient, resource-efficient cities while reducing environmental impact.

Being based on the basis of the circular economy, a circular city has both economic and environmental principles [that, of course, interlink among themselves]. Among the more economic aspects of a circular city is *the sharing and collaborative economy*. Circular cities embrace the concept of shared resources, which reduce individual consumption and lower environmental impact. Collaborative spaces or *spaces of multiple uses* such as co-working hubs, shared housing, and community kitchens encourage the sharing of resources, fostering a culture of sustainability and community engagement. Circular cities also advocate for *localizing production and consumption*. By promoting local manufacturing and the use of locally sourced materials, cities can reduce transportation costs, and the carbon footprint associated with moving goods over long distances. This principle also encourages the development of circular supply chains, where businesses design products using sustainable materials that can be easily recycled or reused at the end of their life cycle, keeping resources within the local economy. Additionally, circular cities place a strong emphasis on *economic and social inclusion*. By creating green jobs in sectors such as recycling, repair, and sustainable construction, circular cities help support local economies and provide employment opportunities. Furthermore, urban design is aimed at ensuring that *the benefits of a circular economy are accessible to all residents, especially those in underserved or disadvantaged communities*. This includes access to sustainable services, affordable housing, and green spaces.

As a consequence, *smart and efficient urban planning* is essential for circular cities. Digital technology and data-driven solutions help optimize the management of resources such as energy, water, and waste. Smart grids enable the efficient distribution of energy, while *sensors track real-time resource consumption*, allowing cities to identify inefficiencies and optimize systems for better sustainability. Digital platforms that facilitate the sharing of resources support circular practices and reduce the demand for new goods and infrastructure.

On a more environmental side of things, in circular cities, *climate resilience* is of the critical focuses. Such cities are designed to be adaptable to climate change, with infrastructure that can withstand extreme weather events such as heavy rain, floods, and heatwaves. Consequently, circular cities also prioritize *sustainable blue and green infrastructure*. This includes integrating green spaces like parks, forests, and green roofs into urban design to enhance the ecological, economic, and social benefits of the city. Green roofs and walls, for example, help reduce the urban heat island effect, improve air quality, and promote biodiversity. Moreover, natural ecosystems are integrated into urban planning to absorb excess rainwater, mitigate flooding, and function as carbon sinks, thus contributing to climate resilience.

All of these principles can be grouped under the core principles of circular cities which are *waste reduction and resource efficiency*. This involves designing systems that use resources as efficiently as possible and reduce the generation of waste. Urban infrastructure, buildings, and products are designed to last longer and can be easily repaired, refurbished, or reused. By minimizing consumption, circular cities encourage sustainable practices that reduce reliance on raw materials. In this context, zero-waste strategies are implemented, promoting systems that prevent waste by encouraging the recycling, reusing, and upcycling of various materials across all sectors of the city.

The idea of recycling, reusing and upcycling also aligns with the *waste-to-resource systems* that are in focus for circular cities. In this case, waste is not simply discarded but rather treated and transformed into valuable resources. For example, organic waste such as food scraps and yard waste is often composted or converted into biogas for energy production. Additionally, recycling and upcycling practices are central to urban waste management, ensuring that materials remain in circulation for as long as possible.

Furthermore, waste-to-resource systems principle often mirrors the *closed-loop systems* approach that is also a principle for the development of a circular city. This principle ensures that resources are continuously reused within the city, reducing the need for new inputs and minimizing waste. Water recycling is a key example of this; treated WasteWater is reused for non-potable applications such as irrigation, industrial processes, and toilet flushing. This reduces water consumption and relieves pressure on natural water resources. Similarly, circular cities often emphasize the use of renewable energy sources like solar, wind, and geothermal energy, coupled with energy storage solutions, to create energy loops that ensure the efficient and sustainable use of energy within the city.

To put it briefly, circular cities aim to redesign urban spaces with sustainability at their core. Through principles of waste reduction, resource efficiency, closed-loop systems, and green infrastructure, circular cities strive to minimize their environmental impact and create resilient, sustainable environments. By leveraging smart technologies, sharing economies, and ensuring economic and social inclusion, circular cities offer a model for how urban areas can thrive in a future that balances economic growth with environmental stewardship.

5.1 Types of Wastewaters

A lot of focus in a circular city is on the reuse and recycling of the resources that have already entered the urban ecosystem [in a broader sense than environmental], such as water that becomes WasteWater, but that can still be reused, before exiting the system. However, it is important to consider that "WasteWater is any water that has been adversely affected in quality by anthropogenic influence and comprises liquid waste" (The Caribbean Environment Programme, n.d.). That means, it contains various pollutants, including organic matter, chemicals, and pathogens, depending on its origin; based on the provenience WasteWater can be categorized for a more effective management; effective management and treatment of WasteWater are essential for environmental protection, public health, and the conservation of water resources.

So, WasteWater can be classified into several categories based on its source and characteristics[10]:

- *Domestic Wastewater*.

  Originating from households and residential areas, this category includes:

  - *Black Water*. Sewage from toilets, containing fecal matter and urine. It is rich in pathogens and organic pollutants.
  - *Grey Water*. Generated from showers, washing basins, kitchens, and laundry activities. Grey water contains fewer pathogens than black water, so it is easier to reuse, but may still harbor soaps, detergents, and food residues.

- *Commercial Wastewater*.

  Produced by commercial establishments such as markets, restaurants, banks, schools, and hospitals. This WasteWater often contains organic matter, oils, greases, and cleaning agents.

- *Industrial Wastewater*.

  Emitted from industrial processes, the composition of this WasteWater depends on the specific industry. It may contain heavy metals, toxic chemicals, and hazardous substances. According to Alaa Fahad (2019), industries such as textile manufacturing and chemical production contribute significantly to this category.

  - *Leachate*.

    Generated from landfills, leachate is the liquid that percolates through waste materials, extracting soluble or suspended contaminants.

  - *Thermal Wastewater*.

    Produced by industries that use water for cooling purposes, such as power plants. Elevated temperatures in this WasteWater can adversely affect aquatic ecosystems.

[10] The presented classification was developed specifically for this study, taking as a the categorization illustrated in the in the article "Wastewater and its Treatment Techniques: An Ample Review" (Fahad et al., 2019).

  - *Radioactive Wastewater*.

    Originating from nuclear power plants, medical facilities, and research institutions, this type contains radioactive substances that require stringent handling and treatment protocols.

  - *Mining Wastewater*.

    Generated during mining operations, it often contains high concentrations of metals, suspended solids, and acids, posing significant environmental challenges.

At this juncture it is important to note, firstly, that a combination of domestic, commercial, and industrial WasteWater collected in sewer systems and treated at centralized facilities could be combined under one umbrella term: Municipal Wastewater[11], commonly referred to as sewage. Municipal Wastewater is understood as WasteWater that is collected from mainly residential, but also [more recently in some cases] commercial and industrial [as in small industries] sources within a municipality (a city, town, or local community) and transported through a sewer system to a treatment facility (Thomas & Thomas, 2022; US EPA, 2015). This category accounts for approximately 380 billion cubic meters annually worldwide according to a study in 2020. The same study calculated projections, indicating that municipal WasteWater production could increase by 24% by 2030 and 51% by 2050 (Qadir et al., 2020).

Secondly, it is also important to note that while leachate, thermal, radioactive and mining WasteWater can be considered as part of the industrial WasteWater, they can also be seen as separate from industrial categories. In this case they are not necessarily understood as part of Municipal WasteWater[12].

[11] Furthermore, it is important to note that this amalgamation is not only in terminological terms, but also de facto since the division of spaces as it is traditionally understood is slowly disappearing, the functions of spaces are un-separating and mixing up, especially with the changes to the habits and the general life of the society brought by technologies and COVID-19 pandemic. This topic is explained in a more detailed fashion further in the work in chapters 6.2.3 The Impact of Remote Work on Water Consumption and 8.1.1 Un-separation of Functions.

[12] The specific definition and inclusion of these categories of WasteWater should be case-to-case based, depending on the location of the source, the affiliation to a sewer system, legal registration, etc. Together with the agricultural WasteWater those WasteWaters are not considered as part of Municipal or Urban WasteWaters [in the context of this study] as they can be outside of the dense urban fabric (though still being part of the municipality, as a larger term) and so their management diverts.

- *Agricultural Wastewater.*

  Resulting from farming activities, this WasteWater often carries fertilizers, pesticides, sediments, and animal waste, contributing to nutrient pollution in water bodies. Agriculture is a major source of WasteWater, primarily through runoff that carries fertilizers, pesticides, and sediments into water bodies. Quantifying this on a global scale is complex due to differing agricultural practices and reporting standards.
- *Meteorological Wastewater*

  Refers to water generated from meteorological events (such as rain, snow, hail, or sleet) that enters WasteWater systems or becomes part of the water management infrastructure, including:
  - *Water from flooding or heavy precipitation*, so the excess water, which overwhelms drainage systems and enters sewers or WasteWater treatment facilities.
  - *Stormwater Runoff*. Water from rain or melting snow (snowmelt) that flows over surfaces (like roads, rooftops, and pavements) does not soak into the ground. It can pick up pollutants like oil, chemicals, and debris as it flows, which can impact water quality when it enters rivers, lakes, or oceans.

While sometimes confused, meteorological WasteWater and stormwater runoff should not be confused, especially in terms of water treatment as stormwater runoff is often managed separately from sewage systems, whereas meteorological WasteWater might mix with sewage in combined sewer systems during heavy rainfall, leading to overflows.

Together with the Municipal WasteWater the meteorological WasteWater (usually referring to stormwater runoff specifically) is referred to as Urban Wastewater. WasteWater generated in urban areas that enters the sewer systems, encompassing domestic WasteWater or the mixture of domestic WasteWater with other WasteWaters (Council Directive 91/271/EEC of 21 May 1991 Concerning Urban Waste-Water Treatment, 1991). The WasteWater that enters the sewer system can be returned to a water body immediately or could be treated before being returned or reused.

5.2 WasteWater Treatment

The treatment process of WasteWater varies depending on its origin and the specific contaminants it contains. In case of urban WasteWater, domestic and commercial WasteWaters undergo a structured and well-established multi-stage treatment process, which we will explore in detail below.

Industrial WasteWater requires more customized treatment systems to manage toxic chemicals, heavy metals, and organic pollutants. Advanced methods such as chemical precipitation, membrane separation, and advanced oxidation processes (AOPs) are often used (Water & Wastewater, n.d.). The treated effluent can be reused for cooling processes or as feed for non-critical industrial applications (Badruzzaman et al., 2022; US EPA, 2023).

Meteorological WasteWater and, more specifically, stormwater runoff typically requires minimal treatment beyond sedimentation and filtration to remove physical debris, depending on contamination levels. That is why usually it is the preferred type of WasteWater to be treated in a developing circular city. However, while offering a number of opportunities, meteorological WasteWater reuse depends on weather conditions. On the contrary, municipal WasteWater is [mostly] independent from weather events and as such offer more stable opportunities for reuse. However, as mentioned above, industrial WasteWater treatment is a difficult process that encompasses more risks, making domestic and commercial WasteWaters the optimal for year-round reuse[13].

The treatment of domestic WasteWater is commonly divided into four stages: preliminary, primary, secondary, and tertiary treatment. Each stage plays a critical role in transforming raw sewage into water suitable for safe disposal or reuse.

[13] The term "optimal" in this context should be considered as relative. From a technical perspective it may appear as optimal, but there is a problem with who maintains [pays for] the infrastructure, the collection, the purification. All WasteWater is collected, delivered, purified, discharged either into a reservoir or to the consumer if reused. And someone always pays for all this. For example, in the Russian Federation, the same structure who is responsible for the infrastructure is also responsible for roads since the infrastructure is located along the roads, but they have no reason to purify the water and, accordingly, pay as this is not their profile (Министерство Транспорта Российской Федерации, n.d.; Росводоканал, n.d.). Another example, are yard areas of building complexes [where there are also puddles] are practically not serviced by anyone, as observed from personal experience.

For the Preliminary Treatment, the first step focuses on the removal of large solid materials such as rags, plastics, and grit to prevent damage to subsequent treatment equipment. Techniques used include screening, when bar screens and fine screens capture large objects, and grit removal when settling chambers or vortex separators remove heavy inorganic materials like sand.

Water at this stage is unsuitable for any direct use but is prepared for effective downstream processing.

Afterwards come the Primary Treatment. In this stage, the WasteWater is directed into sedimentation tanks, where suspended solids settle at the bottom, forming sludge. Floating material is skimmed from the surface and clarifiers are employed to enhance settling efficiency as part of sedimentation[14]. After this treatment, the water can be considered as partially treated water may be used in industrial processes where high-quality water is unnecessary, such as dust suppression; while sludge from primary treatment can be processed into biogas through anaerobic digestion.

After the Primary Treatment comes the Secondary, also known as Biological, Treatment. This kind of treatment removes dissolved and suspended organic matter using microbial processes such as: activated sludge system, when air is pumped into aeration tanks to promote the growth of microorganisms that consume organic pollutants; trickling filters, so when WasteWater flows over a bed of stones or plastic media coated with biofilm, where microbes break down the pollutants; and sequencing batch reactors (SBRs) that provide a time-sequenced batch treatment process that combines aeration and settling in one tank. After secondary treatment, effluent can be used for landscape irrigation and non-potable industrial processes. The biomass produced can be stabilized and converted into fertilizers.

The last treatment step is Tertiary or also known as Advanced Treatment. Tertiary treatment aims to remove residual contaminants, nutrients (nitrogen and phosphorus), and pathogens to produce water of a quality suitable for high-end applications. This kind of treatment is done through filtration, when sand filters or membrane systems remove fine particles; chemical treatment where coagulation and flocculation help remove phosphates; and disinfection with chlorination, ultraviolet (UV) irradiation, or ozonation to eliminate pathogens.

[14] "process of deposition of a solid material from a state of suspension or solution in a fluid (usually air or water)" (The Editors of Encyclopaedia Britannica, 2022).

Effluent from tertiary treatment can be reused for agricultural irrigation, industrial processes, and even as a source for potable water after advanced purification steps like reverse osmosis. Treated sludge from advanced systems may be processed into biofertilizers.

Speaking about sludge, there is a separate management for it when sludge generated at various treatment stages is stabilized and dewatered using methods such as anaerobic digestion that produces biogas, which can be used as an energy source and centrifugation and celt pressing that is used to reduce the water content in sludge for easier handling. Treated sludge can be applied to agricultural lands as a nutrient-rich soil conditioner, provided it meets safety standards.

The benefits of treating and reusing domestic WasteWater are that both black and grey water reuse reduce WasteWater discharge into the environment, lowering pollution risks(Fane, 2013): grey water reuse can significantly reduce household water demand from 26% to 50%, depending on the reuse system and household practices (Penn et al., 2012).

Of course there are also limitations, as black water reuse for agriculture must be carefully managed to prevent contamination of crops and soil; while grey water reuse is limited by local regulations and public perception concerns. Both black and grey water reuse require monitoring and compliance with water quality standards.

The SWOT analysis[15] below highlights the need for tailored approaches to domestic WasteWater treatment and reuse, considering the differences between black and grey water. By leveraging technological advancements and fostering public awareness, communities can harness the full potential of sustainable WasteWater management.

[15] While the Strengths and Weakness differentiate among the Black Water and grey Water Treatment, they both share same preliminary Opportunities and Threats.

Table 1. SWOT Analysis of Domestic Wastewater Treatment and Reuse: Black Water vs. Grey Water

	Strengths	Weaknesses	Opportunities	Threats
Black Water Treatment	Effective treatment removes harmful pathogens, ensuring public health safety. Sludge from black water can be processed into biogas, providing an additional renewable energy source. High nutrient content (nitrogen and phosphorus) in treated effluent can support agricultural applications.	High operational and maintenance costs due to the need for robust pathogen removal processes. Potential odor and sludge management challenges. Complex centralized treatment infrastructure is typically required.	Technological Innovations: Advances in membrane filtration, ultraviolet disinfection, and biological treatment systems improve efficiency and reduce costs. Development of compact, on-site grey water treatment systems for residential applications. Resource Recovery: Energy recovery through anaerobic digestion of black water sludge.	Health and Safety Risks: Inadequate treatment of black water poses significant public health hazards. Grey water misuse or improper treatment can lead to biofilm formation and pathogen outbreaks. Environmental Risks: Mismanagement of treated black water can lead to nutrient pollution and eutrophication in water bodies. Grey water with excessive chemical content can harm soil health and plant growth.
Grey Water Treatment	Contains fewer pathogens compared to black water, making it simpler and less costly to treat. Suitable for decentralized treatment systems, reducing the burden on municipal WasteWater plants. Treated grey water is ideal for landscape irrigation and toilet flushing, reducing freshwater consumption.	Risk of cross-contamination if black and grey water streams are not carefully separated. Accumulation of surfactants and chemicals (e.g., detergents) can be challenging to manage for reuse.	Nutrient recovery for agricultural fertilizers. Grey water can be reused for non-potable purposes, reducing pressure on freshwater sources. Policy and Regulation: Growing support for circular economy models in water management. Incentives for water conservation and reuse programs can accelerate adoption.	Public Perception and Acceptance: Negative perceptions of black water reuse, even when fully treated, can hinder adoption. Grey water reuse may be viewed skeptically due to concerns about hygiene. Regulatory Barriers: Stringent regulations and compliance requirements can slow down the implementation of reuse systems. Variability in water reuse standards across regions creates challenges for widespread adoption.

5.3 Secondary WasteWater Use and Policies for Implementation

As mentioned above, the reuse of treated WasteWater has a lot of benefits as it presents a sustainable approach to water resource management, especially in arid regions facing water scarcity. Applications of reclaimed water include:

- Agricultural Irrigation. Provides a reliable water source for crops, reducing the demand on freshwater supplies. However, careful management is required to prevent soil salinization and crop contamination.
- Industrial Processes. Industries can utilize reclaimed water for cooling systems, boiler feed, or process water, thereby conserving potable water.
- Landscape Irrigation. Urban landscapes, parks, and golf courses can be irrigated with treated WasteWater, promoting urban water conservation.
- Groundwater Recharge. Replenishing aquifers with treated effluent helps maintain groundwater levels and prevents saltwater intrusion in coastal areas.

The implementation of WasteWater reuse is governed by stringent regulations to ensure public health and environmental safety (Shoushtarian & Negahban-Azar, 2020). Policies typically define treatment standards, monitoring requirements, and permissible uses of reclaimed water. Public acceptance and awareness are also critical factors influencing the success of WasteWater reuse programs. Still, such programs exist, and their number is growing across the globe with an estimated 52% of WasteWater being treated globally (Jones et al., 2021)[16].

[16] Though treatment levels range significantly between different levels of income groups as can be seen in Figure 20 (Jones et al., 2021). Furthermore, with the increasing number of treatment facilities, the global reuse capacity is less than 250 million m^3 per day, which corresponds to only 8% of total freshwater withdrawals for domestic and industrial use (B. Koh et al., 2025).

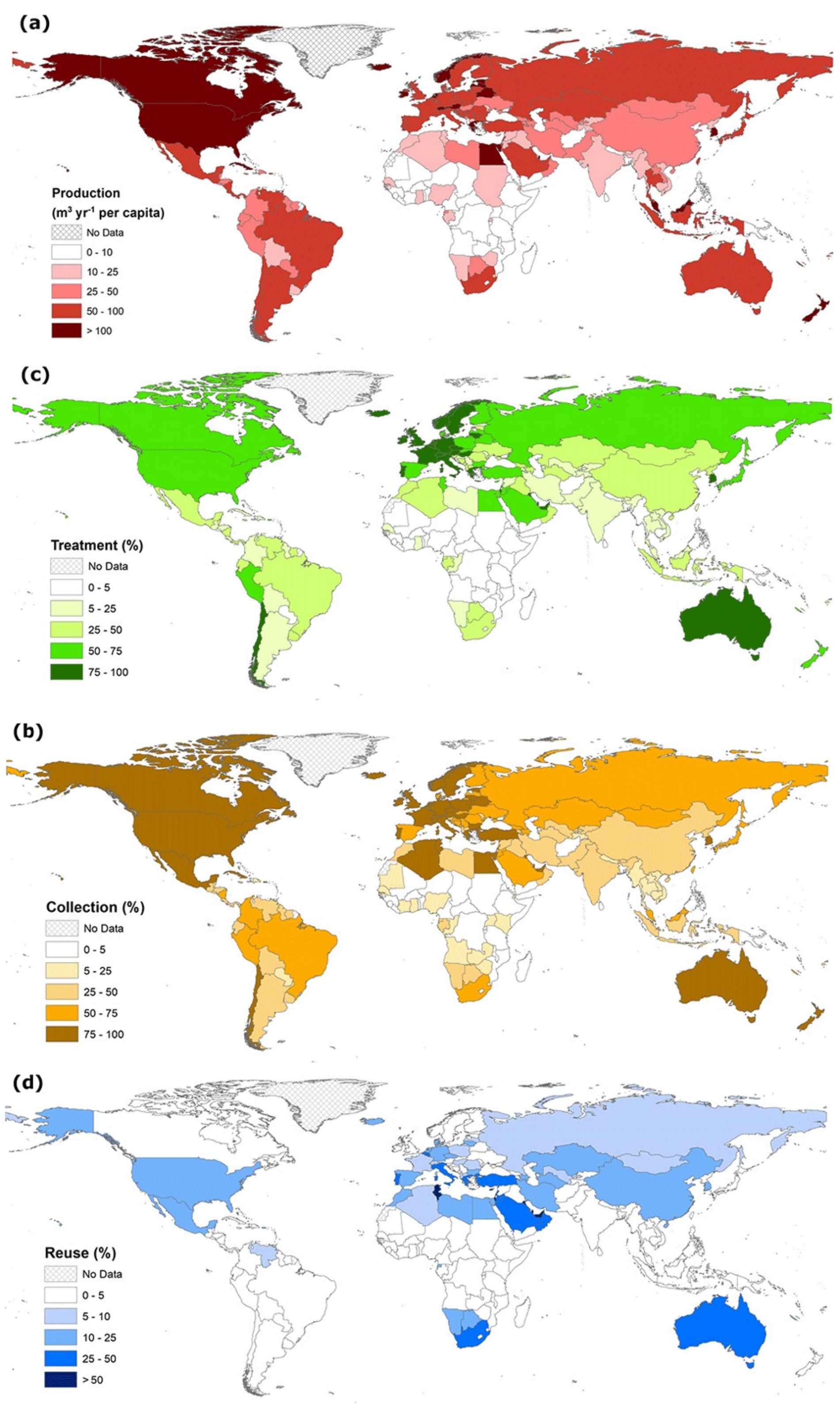

Figure 20. Wastewater production (m3 yr−1 per capita) (a), collection (%) (b), treatment (%) (c) and reuse (%) (d) at the country scale (Jones et al., 2021).

Among such projects is NEWater in Singapore (Singapore's National Water Agency, 2024). Singapore, a city-state with limited natural water resources, has pioneered the use of treated WasteWater for non-potable and potable purposes through its NEWater program. NEWater is treated through advanced processes, including microfiltration, reverse osmosis, and ultraviolet disinfection. It is primarily used for industrial purposes such as cooling in power plants and in wafer fabrication, as well as for potable use through further purification processes. The Singapore government has made it a national policy to incorporate NEWater into the water supply network, aiming for 55% of its water demand to be met by reclaimed water by 2060 (Tang, 2015). The program includes a comprehensive public outreach effort to enhance acceptance, with public events, information campaigns, and media dissemination about the safety and benefits of treated WasteWater. As an outcome, Singapore has successfully implemented WasteWater reuse on a large scale, decreasing dependence on imported water and enhancing water security. The city's robust policies ensure high standards for treated water quality, which have gained public trust. The country aims to expand this initiative to more industries and even residential areas in the future.

Another great example is Western Australia's Water Recycling Projects (Western Australian Government, 2023). Western Australia has long been prone to water scarcity, and the state has implemented various water recycling initiatives, especially in its urban areas. In Perth, the state's capital, treated WasteWater is reused in irrigation, parks, and public spaces. The groundwater replenishment project has treated WasteWater infiltrated back into aquifers to augment freshwater supplies. The policy also includes WasteWater treatment and reuse for toilet flushing in commercial buildings and public amenities.

Western Australian's government has set clear regulations and incentives for water recycling. The Department of Water and Environmental Regulation in Western Australia has created comprehensive guidelines for WasteWater reuse, focusing on both environmental protection and public health. This includes treatment standards and the establishment of appropriate infrastructure.

These projects have significantly reduced pressure on local freshwater resources and enhanced drought resilience. The policy encourages the use of treated WasteWater for urban landscaping, promoting sustainability and water conservation in the region.

Another project about groundwaters is in Orange County, California, United States, Groundwater Replenishment System. There, water scarcity and over-extraction of groundwater have been ongoing challenges. The region introduced a pioneering WasteWater reuse project to restore and augment local water supplies.

The Groundwater Replenishment System (GWRS) (Orange County Water District, n.d.) in Orange County treats WasteWater using microfiltration, reverse osmosis, and ultraviolet light to produce high-quality, purified water. This water is then injected into local aquifers, recharging the groundwater supply.

Local and state regulations encourage water recycling and support efforts to use treated WasteWater for potable purposes. The project's success has been underpinned by strong collaboration between local utilities, state regulators, and the public. Orange County Water District has implemented extensive public education campaigns to explain the safety and benefits of water recycling, alleviating concerns and building trust in the program.

As a result, GWRS currently produces up to 130 million gallons of purified water per day, which is injected back into the local aquifers, providing around 35% of the county's drinking water needs (Orange County Water District, n.d.)[17]. This system has significantly reduced reliance on imported water, promoting a more sustainable water supply strategy.

Europe is following this trend, and one of these cases is the Spanish Water Reuse Program (Zarzo, 2021). Spain has faced significant water scarcity issues, particularly in the southern and eastern regions. So with the Royal Decree 1620/2007 (Real Decreto Nº 1620/2007 - Régimen Jurídico de La Reutilización de Las Aguas Depuradas. Texto Consolidado., 2007), which permits reclaimed water use in urban, agricultural, industrial, recreational, and environmental applications, setting specific quality standards for each. This framework was a pioneering effort in Europe, positioning Spain as a leader in water reuse technologies and contributing to its national Circular Economy Strategy. More recently, Spain's reuse efforts are also guided by the broader EU Regulation 2020/741 (Regulation - 2020/741 - EN - EUR-Lex, 2020), which focuses on agricultural reuse and further promotes sustainable water management across the region (Zarza & González-Cebrián, 2024).

[17] Numbers provided according to the official data on GWRS website on 25.08.2025.

Wastewater from domestic sources is treated and reused for irrigation, cooling in power plants, and urban landscaping. The southern regions, particularly Andalusia, have adopted these systems to ensure consistent water supply during dry seasons. Spain has developed a legal framework for water reuse, which includes specific guidelines for treatment processes, water quality, and permissible uses. This framework has been integrated into broader water conservation and management strategies. The government provides financial incentives for municipalities to develop water recycling infrastructure.

As a consequence, about 13% of Spain's total WasteWater volume is reused today (Drechsel et al., 2018). The policy has proven effective in helping Spain address water scarcity while enhancing the sustainability of agricultural practices.

When speaking about European countries, it is important to remember that in terms of WasteWater management they operate not only according to their own programs but also under the European Union regulations on the matter. The EU over the years has established a comprehensive regulatory framework to govern the reuse of treated urban WasteWater, particularly focusing on agricultural irrigation. This initiative aims to mitigate water scarcity, promote sustainable water management, and ensure public health and environmental safety (European Commission, 2025; European Council, 2020).

A cornerstone of the EU's approach is Regulation (EU) 2020/741 (Regulation - 2020/741 - EN - EUR-Lex, 2020) on Minimum Requirements for Water Reuse, which sets harmonized minimum water quality requirements for the safe reuse of treated urban WasteWater in agricultural irrigation. Adopted on May 25, 2020, and effective from June 26, 2023, this regulation aims to stimulate and facilitate water reuse across member states. It outlines minimum water quality standards, risk management provisions, monitoring and transparency.

Firstly, for the quality standards, it establishes four classes of reclaimed water quality (A, B, C, D) based on intended agricultural use and irrigation methods. Each class specifies parameters such as E. coli levels, biochemical oxygen demand (BOD_5), and total suspended solids (TSS). For instance, Class A, suitable for food crops consumed raw, requires additional filtration and stringent monitoring.

Secondly, this regulation mandates comprehensive risk assessments to identify potential health and environmental risks, leading to the implementation of appropriate mitigation measures. Furthermore, it requires regular monitoring of reclaimed water quality and public disclosure of relevant information to ensure transparency and public confidence.

Of course, member states have the discretion to decide against the practice of water reuse in certain areas based on specific geographic and climatic conditions, pressures on water resources, or environmental and resource costs. Such decisions must be justified and communicated to the European Commission.

So, the possibility to divert from this and other regulations is present. As a consequence, to ensure coherence with broader water management strategies, the EU has provided guidelines on integrating water reuse into water planning and management within the context of the Water Framework Directive (WFD). These guidelines assist member states in incorporating water reuse practices into river basin management plans, emphasizing the role of reclaimed water in achieving the WFD's environmental objectives (European Environment Agency, n.d.).

Additionally, recently in April 2024, the European Parliament adopted revisions to the Urban Wastewater Treatment Directive to enhance WasteWater treatment standards and promote water reuse (European Parliament, 2024; Horton & Niranjan, 2024). Key provisions of the revision include enhanced treatment standards, Extended Producer Responsibility (EPR) and promotion of water reuse.

The enhanced treatment standards are necessary to achieve that by *2035 urban WasteWater must undergo secondary treatment in all agglomerations of 1,000 population equivalent or more.* Tertiary treatment for nitrogen and phosphorus removal is mandated for larger treatment plants by 2039, with quaternary treatment for micro-pollutant removal required by 2045 (European Parliament, 2024). And with EPR, producers of pharmaceuticals and cosmetics are required to finance at least 80% of the costs associated with quaternary treatment to remove micro-pollutants from urban WasteWater (European Parliament, 2024). And, of course, the revision highlights that member states must also “individually” encourage the reuse of treated WasteWater, particularly in water-stressed areas, to alleviate water scarcity and promote sustainable water management practices.

To support the effective implementation of these regulations, the European Commission has published guidelines to assist member states and stakeholders in applying the rules on safe water reuse. These guidelines provide practical examples and technical specifications to ensure compliance and facilitate the uptake of water reuse practices. Furthermore, technical guidance documents, such as those developed by the Joint Research Centre (JRC), offer detailed methodologies for risk management in water reuse projects, ensuring that reclaimed water meets safety standards for agricultural irrigation.

The EU continues to focus on enhancing water resilience and sustainability. Member states are encouraged to integrate water reuse practices into water management plans, especially in water-stressed regions. Additionally, the EU is investing in improving water infrastructure to address challenges such as leakage and inefficiencies in water distribution systems. For instance, Spain is seeking approval to reallocate over a billion euros from post-pandemic recovery funds to enhance Valencia's climate resilience following catastrophic floods (Pons et al., 2025).

While EU provides regulations only for the Member States, WasteWater reuse is a critical component of global water management strategies, so various international organizations establish guidelines and policies that influence national and regional regulations on WasteWater treatment and reuse. While no single institution enforces binding global rules, frameworks from the *United Nations*, the *World Health Organization*, the *Food and Agriculture Organization*, the *International Organization for Standardization*, and *the World Bank* shape policies worldwide, including in Italy and China.

The United Nations plays a central role in setting overarching policy objectives through its 2030 Agenda for Sustainable Development. Sustainable Development Goal 6 (United Nations, 2015a), which focuses on clean water and sanitation, specifically addresses WasteWater management. The sub-target 6.3 emphasizes the need to improve water quality by reducing pollution, minimizing hazardous chemicals, and increasing WasteWater treatment and reuse (United Nations, 2015b)(United Nations, 2015). UN-Water, a coordinating body that brings together multiple UN agencies, monitors global progress on WasteWater management and promotes the integration of reuse strategies into national policies (UN Water, 2021). While the UN does not issue binding legal requirements, its sustainability goals influence legislative frameworks worldwide. The European Union aligns its WasteWater policies with SDG 6, while China has incorporated SDG indicators into its water governance strategy[18].

[18] Although implementation remains uneven due to variations in infrastructure and regulatory enforcement.

Besides UN, the World Health Organization also provides international guidelines that are health-based to ensure that WasteWater reuse does not pose risks to public health. One of its most significant contributions is the WHO Guidelines for the Safe Use of Wastewater, Excreta, and Greywater, first published in 2006 and updated in 2022 (WHO, 2022). These guidelines establish microbiological and chemical safety standards for WasteWater reuse in agriculture, urban settings, and industrial processes. Additionally, the WHO Drinking-Water Quality Guidelines, which were most recently updated in 2022, set threshold limits for contaminants in water sources, indirectly affecting WasteWater reuse regulations (WHO, 2022). These standards are widely referenced in national legislation, influencing both the European Union’s Water Reuse Regulation (Regulation - 2020/741 - EN - EUR-Lex, 2020) and China’s National Standards for Drinking Water Quality (China’s National Standards for Drinking Water Quality - GB 5749-2022, 2023). The EU generally imposes more stringent limits than WHO recommendations, while China adjusts its regulatory approach based on local conditions and available treatment technologies.

Besides direct potable consumption treated WasteWater can be used for urban or agricultural irrigation. For that the International Organization for Standardization publishes technical specifications that are widely adopted by national and regional regulatory bodies. Among the most relevant standards are ISO 16075, a four-part series on treated WasteWater use in irrigation, which was originally published in 2015 and regularly updated. Another crucial standard is ISO 20760, which sets out requirements for water reuse in urban areas, ensuring that treated WasteWater meets quality benchmarks before being used for municipal and industrial applications. Additionally, ISO 24521 provides guidelines for decentralized domestic WasteWater management, particularly in rural and peri-urban settings.

However, all the actions proposed or required by these guidelines require not only legal, but also economic support. The World Bank plays a crucial role in financing large-scale WasteWater treatment and reuse projects, particularly in water-stressed regions. While it does not issue regulatory requirements, its lending conditions and technical assistance programs encourage countries to adopt international best practices. For example, the World Bank’s Water Global Practice initiative funds urban WasteWater recycling projects, supporting infrastructure development and policy reform (World Bank, 2022). Additionally, the 2030 Water Resources Group, a public-private partnership hosted by the World Bank, promotes sustainable water use and WasteWater recycling (World Bank, 2024). The financial and technical incentives provided by the World Bank often lead to regulatory improvements, as recipient countries must meet environmental and governance criteria to access funding.

So, although no single international institution enforces legally binding WasteWater reuse regulations on a global scale, international guidelines and frameworks significantly shape national and regional policies. The European Union tends to adopt stricter regulatory approaches for its Member States, incorporating high safety standards and extensive monitoring requirements. In contrast, China adapts global guidelines to its local context, balancing economic development with environmental protection. As water scarcity intensifies worldwide, greater international cooperation and policy harmonization will be essential to ensure safe and efficient WasteWater reuse practices.

5.3.1 Secondary WasteWater Use and Policies for Implementation in Italy

Italy, a country that experiences water stress, particularly in the southern regions, has been increasingly turning to WasteWater recycling as part of its broader water management strategies. Regions such as Lazio, Sicily, Sardinia, and Lombardy have developed specific WasteWater reuse projects, with Milan being a key example.

In Italy, treated WasteWater is widely used for agricultural irrigation. One significant example is the Latina WasteWater treatment plant in the Lazio region, which treats WasteWater and uses it to irrigate agricultural land, including crops like grapes, tomatoes, and olives. Similarly, in Sardinia, treated water is used in agriculture to maintain crops during the dry season.

In urban areas, treated WasteWater is used for non-potable purposes such as irrigation of public parks, green spaces, and municipal cleaning. These applications help alleviate the demand for freshwater, particularly in regions where water conservation is a priority.

Milan's Nosedo Wastewater Treatment Plant, one of the most advanced in Italy, is an important example of how urban WasteWater is treated and reused. The plant, which has been operational since 2016, treats the WasteWater of approximately 1.4 million people. The Nosedo plant employs advanced treatment technologies, including biological treatment, tertiary filtration, and UV disinfection, to ensure that the treated water meets safety standards for non-potable uses.

The treated water from the Nosedo plant is primarily reused for irrigating public parks, urban green spaces, and even sports fields in Milan. This helps reduce the city’s demand for potable water, which would otherwise be used for these non-potable applications.

Milan's local government strongly supports WasteWater reuse as part of its urban water management strategy. The Nosedo plant is aligned with Italy's national water reuse regulations and the European Union's Water Framework Directive, which encourages water recycling and sustainable use. The Nosedo plant is an integral part of Milan's strategy to address water scarcity. It contributes to the reduction of water withdrawals from freshwater sources for non-potable uses. In addition to urban irrigation, the plant’s treated WasteWater also serves to cool industrial facilities and support non-potable demands in the city. The plant helps Milan save approximately 10 million cubic meters of freshwater per year, reducing the city's environmental footprint and promoting sustainability.

In southern Italy, regions like Sicily and Sardinia have also adopted WasteWater reuse in agriculture. The treated WasteWater is used for irrigating crops like fruit trees, vineyards, and vegetables, particularly during dry spells when natural water resources are scarce. These regions are among the first in Italy to adopt water reuse technologies due to their exposure to periodic droughts.

The Italian government has set out clear guidelines for the treatment and reuse of WasteWater. These guidelines focus on the safe use of reclaimed water for both agricultural and urban purposes, ensuring that treated water meets strict safety and quality standards. The government has also provided incentives for municipalities and private companies to invest in WasteWater treatment and recycling technologies. Financial support is available for projects that enhance water conservation and reduce the environmental impact of WasteWater discharge.

When talking about the policies and the legal procedure for SWWUS implementation, it is also important to understand the legal procedure in the sense of the administrative structure for WasteWater management. Wastewater management in Italy operates within a multi-tiered administrative framework that involves national, regional, and municipal authorities, alongside public and private service providers. The governance structure is shaped by EU directives, national legislation, and regional regulations, which collectively ensure compliance with environmental and public health standards. This system reflects Italy’s decentralized governance model, where local authorities play a significant role in service management and implementation.

At the national level, WasteWater management falls under the responsibility of the Ministry of Ecological Transition (Ministero della Transizione Ecologica, MiTE), which oversees policy development, coordination, and compliance with EU regulations, such as Directive 91/271/EEC on Urban Wastewater Treatment (Council Directive of 21 May 1991 Concerning Urban Waste Water Treatment (91/271/EEC), 2014). The MiTE collaborates with the Italian Institute for Environmental Protection and Research (Istituto Superiore per la Protezione e la Ricerca Ambientale, ISPRA), which conducts environmental monitoring and provides technical guidance. Additionally, the Italian Regulatory Authority for Energy, Networks and Environment (Autorità di Regolazione per Energia Reti e Ambiente, ARERA) plays a crucial role in regulating the economic aspects of water services, including tariffs and service standards, ensuring financial sustainability and efficiency in WasteWater management.

At the regional level, WasteWater management is governed by Regional Environmental Protection Agencies (Agenzie Regionali per la Protezione dell'Ambiente, ARPA), which monitor water quality, enforce regulations, and issue permits for WasteWater discharge. Each region has significant autonomy in implementing national policies and adapting them to local conditions. For example, the Veneto Region has its own water protection plans, aligning with national and EU directives while addressing specific regional concerns (Regione del Veneto, n.d.). Additionally, regional governments have Departments responsible for environmental policies, such as the Department of the Environment (Assessorato all'Ambiente), which manages water resource planning, pollution control, and coordination with ARPA and ATOs (Optimal Territorial Areas, it. Ambiti Territoriali Ottimali).

Municipalities and local water utilities, organized into ATOs, are responsible for the actual management and operation of WasteWater treatment plants, sewer systems, and water reuse initiatives. These ATOs are overseen by governing bodies that coordinate among municipalities to ensure efficiency and compliance with regulatory standards. In some cases, WasteWater services are provided by private or semi-public companies through concessions, operating under strict regulations set by ARERA and regional authorities. The local Assessorato all'Ambiente within municipalities plays a crucial role in overseeing the implementation of WasteWater policies, issuing local ordinances, and managing relationships with utility companies.

A concrete example of this structure in practice can be observed in Venice, where WasteWater management is particularly complex due to the city's historical infrastructure and lagoon environment. The WasteWater system in Venice is managed

by Veritas S.p.A., a multi-utility company responsible for water supply, sewage, and waste treatment across the metropolitan area. Additionally in Venice there is also the Consorzio di Bonifica Acque Risorgive (Reclamation Consortium of Spring Waters). This organization is a consortium responsible for water management and land reclamation in the Venice region, particularly focusing on the areas of the Veneto region affected by waterlogged or flooded land. It works on tasks related to the drainage of excess water, flood prevention, irrigation systems, and maintaining water balance in agricultural and urban areas. The consortium manages the reclamation and environmental preservation of wetlands and other sensitive ecosystems, contributing to the protection of the Venice Lagoon and surrounding areas (Consorzio di Bonifica, 2025).

Given the city's unique challenges, WasteWater treatment in Venice involves a decentralized approach, utilizing small-scale purification plants and separate sewer networks to minimize pollution in the lagoon (Comune di Venezia, 2025). Furthermore, the Special Law for Venice (Legge Speciale per Venezia) grants additional administrative powers to local and regional authorities to protect the delicate ecosystem of the lagoon, integrating WasteWater management with broader environmental conservation efforts. The Environmental section of the Department of Urban Planning, Private Construction and Environment of Venice collaborates with Veritas S.p.A. and the regional government to ensure compliance with both national and local WasteWater policies while addressing the unique environmental concerns of the lagoon.

5.3.2 Secondary WasteWater Use and Policies for Implementation in China

China, a country with significant water scarcity challenges, particularly in its northern and arid regions, has been investing heavily in WasteWater treatment and reuse. The country has been working towards integrating WasteWater recycling into urban water management and industrial processes.

China has adopted various WasteWater reuse programs, especially in large urban areas such as Běijīng, Tiānjīn, and Shànghǎi. The primary focus of these programs is to use treated WasteWater for non-potable purposes, such as industrial cooling, irrigation, and landscape watering. In some cities, treated water is even used in toilet flushing and for municipal cleaning.

China's national policies have strongly encouraged the reuse of treated WasteWater. The "Water Pollution Prevention and Control Action Plan" (also known as the "Water Ten Plan") mandates the treatment and recycling of WasteWater in large cities and industrial zones. The government has also established specific standards and regulations regarding WasteWater reuse in both urban and industrial sectors. Local governments are incentivized to adopt WasteWater treatment technologies through financial subsidies and investments.

The Shànghǎi Municipal Water Reclamation Plant treats and reuses WasteWater for cooling systems in power plants and industrial operations. The city's WasteWater reuse policy has helped reduce pressure on freshwater sources. Industrial applications make up a significant portion of WasteWater reuse in China. The Tiānjīn Industrial Wastewater Treatment Plant treats industrial WasteWater and reuses it for cooling and processing water, reducing freshwater consumption for industrial purposes.

These projects in China are managed rather differently opposed to Italy, because WasteWater management in China is structured within a centralized governance system that integrates national policies, regional authorities, and municipal administrations contrary to the decentralized Italian one. The system is shaped by national laws, five-year plans, and regulatory frameworks set by the central government, with implementation at the provincial and local levels.

At the national level, the Ministry of Ecology and Environment (MEE) is the primary authority responsible for formulating policies, monitoring environmental compliance, and enforcing WasteWater discharge standards. MEE establishes nationwide pollution control targets, issues discharge permits, and sets emission limits for industries and municipalities. The National Development and Reform Commission (NDRC) also plays a significant role by overseeing infrastructure development and funding large-scale WasteWater treatment projects, ensuring alignment with broader economic and environmental policies. Additionally, the Ministry of Housing and Urban-Rural Development (MOHURD) provides technical guidelines and supervises urban WasteWater treatment facility construction, playing a key role in integrating WasteWater treatment into city planning and sustainable development initiatives.

China's WasteWater governance follows a hierarchical model where provincial governments translate national policies into local regulations and oversee their enforcement. Each province has an environmental protection department responsible for coordinating municipal-level WasteWater management, ensuring compliance with both national and regional water quality standards. Municipal governments, such as the

Shànghǎi Municipal Government, are responsible for implementing WasteWater treatment policies, monitoring compliance, and investing in sewage infrastructure. Shànghǎi's Environmental Protection Bureau (EPB) is the key regulatory body ensuring that WasteWater treatment plants operate within the standards set by the central government.

Shànghǎi's WasteWater management, as an example, is among the most advanced in China, featuring an extensive network of treatment plants and an integrated monitoring system that ensures high compliance with national standards. The city has adopted a multi-layered approach to WasteWater treatment, incorporating centralized treatment facilities, decentralized small-scale plants, and eco-friendly water reclamation projects. Major WasteWater treatment plants in Shànghǎi include the Báilónggǎng, for example, treatment facilities, which collectively process millions of cubic meters of WasteWater daily. The municipal government also promotes water reclamation and reuse projects, aligning with national sustainability goals outlined in China's 14th Five-Year Plan, which emphasizes circular water resource management and reducing industrial water consumption (Shanghai Municipal Development and Reform Commission, n.d.).

Within Shànghǎi, the district of Qīngpǔ serves as a specific example of localized WasteWater governance as a city within a city. Qīngpǔ, which is part of the Yangtze River Delta region, is a crucial area for water resource management due to its proximity to key water bodies, including Dianshan Lake. The Qīngpǔ District Water Authority oversees local WasteWater treatment plants, ensuring compliance with Shànghǎi's environmental regulations while implementing innovative water reuse programs. One of the major initiatives in Qīngpǔ is the integration of WasteWater treatment with ecological restoration projects, aimed at improving water quality in natural water bodies. This includes the construction of wetland-based treatment facilities, which use natural vegetation and microbial processes to filter pollutants before treated water is reintroduced into the environment.

As a matter of fact, the Yangtze River plays a crucial role on the topic, having its own plan: the Yangtze River Delta Water Governance Plan refers to a series of coordinated policies and actions aimed at improving water quality, managing resources, and promoting sustainable development across the Yangtze River Delta region in China (Liu et al., 2022). This area, encompassing major cities like Shànghǎi, Hángzhōu, and Nánjīng, is vital to China's economy and has faced significant environmental challenges due to rapid industrialization and urbanization.

Three-Year Action Plan (2024-2026), Eco-Green Integrated Demonstration Zone and Yangtze River Protection Law (YRPL). This last one specifically was enacted to resolve coordination issues among various water-related sectors, aiming to integrate efforts in water environment protection, water ecology restoration, and water resource management, promoting a unified approach to safeguarding the river's health (R. Li & Jin, 2023).

China's WasteWater management system, particularly in urban areas like Shànghǎi and Qīngpǔ, demonstrates a well-organized administrative structure that balances central oversight with regional and local implementation. The national government sets strict regulatory frameworks, while municipal and district-level authorities execute and adapt these policies based on local environmental conditions. This structured approach allows for effective WasteWater treatment, pollution control, and water resource conservation, ensuring sustainable urban development. Ongoing initiatives, such as the development of smart water management systems and increased investment in WasteWater recycling, further highlight China's commitment to improving WasteWater governance and environmental sustainability.

5.4 Conclusive thoughts on WasteWater

Effective WasteWater management is integral to sustainable development, encompassing environmental protection, public health, and resource conservation. Advancements in treatment technologies have enhanced the ability to reclaim and reuse water, offering viable solutions to address challenges of water scarcity. The development of eco-innovative technologies for WasteWater treatment and reuse is essential for sustainable water resource management. Continued research, supportive policies, and public engagement are vital to optimize WasteWater treatment processes and expand reuse applications, thereby contributing to a more sustainable and resilient water future. Though approaches in prioritization may vary as China at the moment is mainly driven by economic development so the government has to balance economic and sustainable development, while in Italy and Europe sustainable development is the main priority currently.

Source: AdobeStock

Chapter 6
Analytical Framework for WasteWater Management

Ancient times often serve as inspiration, but often the context is overlooked. Modern cities are part of the contemporary capitalistic world – which with its opportunities and issues is a fundamental part of the development of our society – and thus are also operating on the concept of demand-supply to satisfy the needs of consumers. And while the idea of modern water-centered city, inspired by the ancient traditions of focusing on the main resource for human survival, may be tempting, it is almost impossible to reintroduce the symbolic value of water to contemporary urban dwellers, considering that the ancient symbolic value was strictly linked to the value of agriculture in the ancient societies – something that is not valuable to the modern urban society. Nowadays water is seen as a good to be consumed[19] and in the context of urban planning the development of a new concept should firstly address the supply chain of a resource, trying to design how it can be modified to both satisfy the demand and achieve sustainability goals. Addressing the supply matter is fundamental – specifically in long-term perspective –, as re-designing the supply chain can help changing the [consumption] behavior of individuals and, as a consequence, change the demand [for a good or a service], and thus the society, shaping it accordingly to the available resources.

So, methodologically speaking, to design a water-centered city from an urban planning perspective with an effective water management system one of the necessary steps is to define the supply of water in a city and, consequently, it is fundamental to understand the water demand first.

6.1 Water Demand

Water demand is defined as total water required by the residents of city for different purposes is included in water demand. Broadly speaking, water demand can be categorized into six types, ranging from domestic and industrial needs to agricultural and recreational uses (Neha, 2023)[20]:

[19] From here on, unless said otherwise, the statements refer to the ideology of urban societies in "developed" countries.

[20] The categorization of types of WasteWaters is partially linked to the categorization of water demand as the first is the outcome of the second one through the process consumption, the need(s) that is being satisfied through the act of consumption and the function of space of consumption.

1. *Domestic Water Demand.*

Water used for everyday needs such as drinking, bathing, cleaning, gardening, and other household activities.

2. *Industrial Water Demand.*

Estimated based on the type, size, and water usage of industrial operations per unit of production.

3. *Institutional and Commercial Water Demand.*

Covers water used by institutions and businesses like hospitals, offices, schools, and restaurants.

4. *Water Demand for Public or Civic Uses.*

Water that is used for public services such as street cleaning, park maintenance, and public toilets.

5. *Fire Demand of Water.*

Water allocated for fire emergencies, calculated using various formulas.

6. *Water Required to Compensate Losses in Thefts and Wastes.*

Accounts for losses due to leaks and theft.

Of these, domestic water use typically makes up the largest proportion of overall water demand, accounting for approximately 50-60% of the total (Gleick, 2000). Industrial water use is the second-largest contributor, with additional water demands arising from agricultural and other sectors.

As domestic water consumption rises, managing demand becomes an urgent issue for municipalities and water suppliers. It is essential to reassess water distribution strategies and infrastructure to meet the increasing needs of a population spending more time at home. Municipalities may need to implement policies that promote water efficiency, such as encouraging the use of low-flow fixtures, incentivizing water recycling, or promoting rainwater harvesting (Bakker, 2010a).

Recent shifts in lifestyle – particularly the rise of remote work after the COVID-19 pandemic and the increasing time people spend at home (NBER, 2021) – have had significant impacts on water consumption patterns, particularly at the household level. As more people transition to home-based working, water demand increases due to a variety of factors, from basic hygiene to leisure activities. The question arises: how do these changes affect both water consumption and the underlying water management?

6.2 Water Consumption

Water consumption is deeply intertwined with the spectrum of human needs, which expand and transform alongside societal development. As communities evolve – from subsistence to over consumption – the ways in which water is valued, used, and managed also undergo significant change. Understanding these patterns requires not only quantitative analysis of water demand but also a qualitative interpretation of the motivations that drive its use.

To analyze this complexity, two complementary conceptual frameworks prove particularly insightful: Maslow’s Hierarchy of Needs and the subsequential Hierarchy of Water Requirements. The first explains the psychological progression of human needs, from essential survival to self-fulfillment, while the second translates those needs into practical categories of water use, linking quality and purpose. Together, they illuminate how water use evolves from the most basic functions of sustaining life to more sophisticated expressions of comfort, identity, and social distinction.

These frameworks are not static: they also help explain how external can permanently or temporarily alter established consumption patterns. The COVID-19 pandemic serves as a recent and profound example of how human-water relationships can shift rapidly under exceptional circumstances, revealing the elasticity of both behavior and infrastructure in response to crisis.

6.2.1 Maslow's Hierarchy of Needs and Water Consumption

Water consumption can be analyzed through the lens of human motivation, and one of the most influential frameworks for understanding human behavior remains Abraham Maslow’s Hierarchy of Needs. Introduced in 1943 and later expanded in his 1954 work Motivation and Personality, Maslow’s model proposes that human actions are driven by the progressive satisfaction of needs organized in a hierarchical structure – ranging from physiological survival to self-actualization (Maslow, 2013). Applying this psychological framework to water allows for a deeper understanding of how human-water relationships evolve as societies develop economically, socially, and technologically.

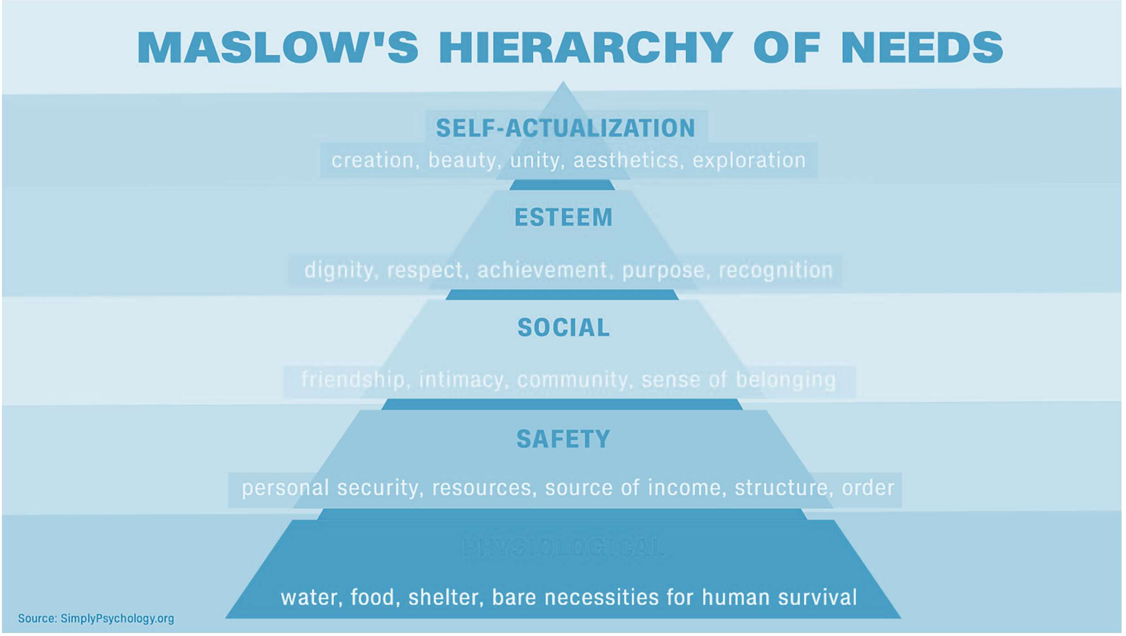

Figure 21. Explanation of Maslow's pyramid of needs (Willingham, 2023).

At the base of Maslow's hierarchy lie the physiological needs, essential for survival. Water, as a fundamental biological necessity, occupies a central position at this level. Access to safe and sufficient drinking water is indispensable for human life and health. The World Health Organization (WHO) estimates that a minimum of 20 to 50 liters per person per day is required to meet basic drinking, cooking, and hygiene (WHO, 2017). At this stage, water use is primarily utilitarian – directed toward biological and domestic needs, including hydration, food preparation, and basic sanitation. Any disruption in this access leads directly to threats to survival and public health.

Once these basic needs are met, individuals and societies move toward the safety and security level. Here, water is linked to stability and protection. It supports sanitation systems, firefighting, disease prevention, and disaster resilience. The availability of reliable water infrastructure ensures not only individual safety but also collective well-being, reflecting the societal capacity to prevent health crises and maintain a sense of security. In urban contexts, this manifests through regulated water distribution systems, water quality control, and flood management strategies that reduce vulnerabilities and enhance resilience against climate risks. Thus, at this level, water's value extends beyond the individual body to the collective structure of society.

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The next levels – social belonging and esteem – reflect the increasing social and cultural significance of water. As basic and safety needs are satisfied, water becomes a medium of social interaction and identity. Access to clean, aesthetically pleasant, and abundant water reflects social inclusion and status. Shared water spaces – such as public fountains, spas, or urban green areas with water features – symbolize community, cohesion, and collective identity; spaces for socialization and collective decision-making processes. Historically, societies have used water to represent power and prestige: from the fountains of Renaissance Italy to the grand canals of imperial China, water was not merely a resource but a social statement.

At the highest level of Maslow's hierarchy – self-actualization – water consumption becomes symbolic and expressive of individual or societal aspiration. It extends into domains of comfort, creativity, and environmental consciousness. The pursuit of sustainable water management, ecological restoration, or participation in water-saving initiatives may represent self-actualization at a collective level, where the goal is not only personal well-being but harmony with the environment. Water use at this level is often less about necessity and more about meaning: it reflects cultural maturity, ethical responsibility, and a long-term vision for sustainable coexistence.

Therefore, by examining water consumption through Maslow's hierarchy, it becomes evident that water demand evolves not only quantitatively but qualitatively. As societies advance economically, water use tends to expand from essential survival toward comfort, leisure, and symbolic expression. This expansion, however, introduces complexity and potential imbalance: *as higher-order water uses grow, the challenge becomes ensuring that basic needs remain equitably met*. Recognizing this progression provides a valuable framework for understanding contemporary water crises – where abundance in one sector can coexist with deprivation in another.

This psychological interpretation of water consumption sets the foundation for the next section, which operationalizes these motivational principles into a tangible structure – the Hierarchy of Water Requirements. This subsequent model translates human needs into specific categories of water use, revealing how different qualities and quantities of water correspond to different levels of necessity, and how this understanding can inform sustainable water management practices.

6.2.2 The Hierarchy of Water Requirements

Building directly upon the theoretical foundation of Maslow's hierarchy, the Hierarchy of Water Requirements provides a practical model that translates psychological needs into the physical realm of water management. Developed in applied water studies (Alukwe, 2016; Reed, n.d.), this hierarchy organizes water uses according to their degree of necessity, quality, and societal priority. It serves as a bridge between human-centered motivation theory and resource-oriented sustainability frameworks, offering a holistic understanding of how water demand can be managed across different social and environmental contexts.

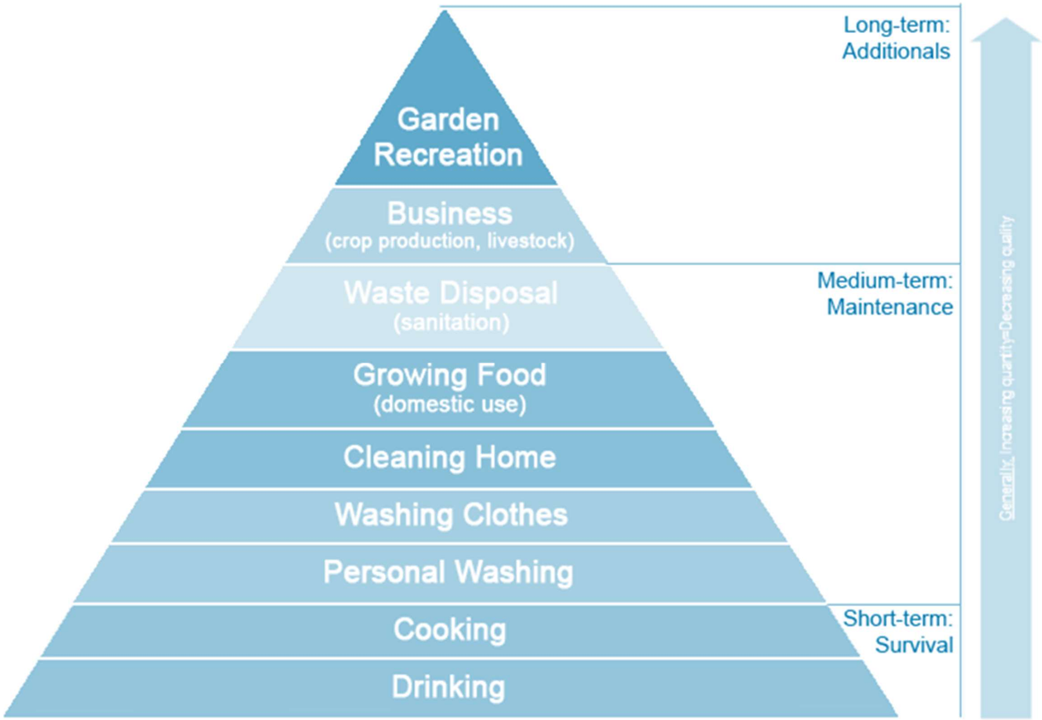

Figure 22. Hierarchy of water requirements for domestic use
(inspired by Abraham Maslow's (1908-1970) hierarchy of needs) (based on Reed, n.d.).

At its base, the hierarchy emphasizes the minimum water requirements for survival – those linked to drinking, cooking, and basic hygiene. These uses demand the highest water quality and are non-negotiable in terms of access. They correspond to Maslow's physiological needs and represent the fundamental human right to water, as recognized by the United Nations General Assembly in 2010 (The Human Right to Water and Sanitation : Resolution Adopted by the General Assembly, 2010). Without satisfying this level, no higher forms of societal development can occur. The primary concern at this stage is the quantity and purity of water: availability of safe drinking water and basic sanitation facilities remains the defining measure of human welfare.

The second level, health and security needs, extends beyond immediate survival to include water for sanitation, food preparation, disease prevention, and urban resilience. Here, the focus shifts from individual consumption to collective well-being – mirroring Maslow's safety stage. The management of WasteWater, stormwater, and emergency supply systems becomes essential to protect communities against epidemics, droughts, and floods. In this sense, water management transitions from personal necessity to institutional responsibility, requiring planning, policy frameworks, and infrastructure capable of ensuring reliability and safety for all.

Comfort and social uses represent the application of water to improve quality of life. Activities such as bathing, cleaning, gardening, maintaining green urban spaces correspond to Maslow's levels of belonging and esteem, reflecting both social and psychological dimensions of well-being. The quality of water required for these uses is typically lower than that for drinking or cooking, making them prime opportunities for reuse and recycling within urban systems. Greywater and reclaimed water, for instance, can satisfy these mid-level needs efficiently, thus supporting the circular economy principles discussed in previous chapters. This reinforces the idea that sustainability is not only an environmental goal but also a behavioral and cultural transformation.

At the top of the hierarchy lie aesthetic and symbolic uses – activities that express human creativity, status, and environmental ethics. These include water features, recreational landscapes, pools, and cultural events centered around water. Though these uses may appear non-essential, they play an important social role in shaping identity, civic pride, and environmental awareness. Nevertheless, they should be supported primarily through non-potable and recycled water sources to minimize strain on freshwater reserves, especially in times of severe climate conditions such as drought. In doing so, urban water systems can maintain cultural and social richness while aligning with sustainability objectives.

The interdependence between Maslow's hierarchy and the Hierarchy of Water Requirements reveals a critical insight: as human societies progress through higher stages of development, their water use diversifies and intensifies, but the ethical obligation remains to prioritize access for basic human needs. Higher levels of water consumption – associated with comfort, leisure, and symbolic value – must therefore be regulated within the boundaries set by ecological sustainability and social equity.

In this way, the Hierarchy of Water Requirements not only complements Maslow's psychological framework but also provides a policy-oriented instrument for water governance. It encourages decision-makers to allocate resources rationally according to need, water quality, and purpose, ensuring that luxury or discretionary uses do not compromise access to essential water for survival and safety. The combined interpretation of these two hierarchies thus offers a multidimensional understanding of water demand – one that integrates human psychology, social development, and environmental responsibility.

6.2.3 The Impact of Remote Work on Water Consumption

The COVID-19 pandemic profoundly altered daily routines, lifestyles, and patterns of work, with remote and hybrid arrangements becoming a new norm for millions worldwide (Cranfield University, 2021). This behavioral shift had a marked impact on water consumption patterns, particularly at the household level. As people spent more time at home for work, education, and recreation, domestic water use surged, while consumption in commercial and institutional buildings declined sharply (Cranfield University, 2021; Lüdtke et al., 2021).

Empirical data confirm this transformation. In the United Kingdom, household water consumption increased by up to 46% during the peak of the May 2020 lockdown, compared to pre-pandemic levels. This rise was accompanied by a redistribution of demand, with multiple smaller peaks across the day rather than the traditional single morning surge (Cranfield University, 2021). Similarly, in Germany, residential water use rose by approximately 14.3% during the first lockdown, largely due to enhanced hygiene practices and the extended presence of individuals at home (Lüdtke et al., 2021). From a demand perspective, this pattern blurred the conventional distinction between residential, commercial, and institutional water use, indicating a merging of categories under new social conditions.

In addition to quantitative increases, qualitative changes in domestic water use were observed. Remote work and extended home occupancy stimulated higher usage of appliances such as dishwashers and washing machines. Studies in the United States indicated more frequent laundry and dishwashing cycles, associated with increased meal preparation at home and heightened hygiene awareness (Beach, 2020; Water Science School, 2018). The result was not merely a growth in total water use but also a transformation in the types of water consumption linked to domestic life.

Temporal patterns also shifted. Whereas typical residential demand peaks in the early morning and late evening, remote work produced a more even distribution throughout the day. Individuals engaged in meal preparation, cleaning, and self-care during working hours, resulting in higher midday water usage. For utilities, this posed operational challenges: supply schedules, pressure management, and treatment capacities had to be recalibrated to accommodate flatter, more continuous demand curves.

The increase in household demand placed additional pressure on urban water systems, many of which were designed to accommodate high daytime consumption in commercial districts and lower residential use. With offices and schools closed, the inversion of these patterns exposed vulnerabilities in network design. Some utilities reported significant reductions in water use from commercial customers, while simultaneously facing stress on residential supply systems (Moglia & Nygaard, 2024).

Moreover, this period reaffirmed the psychological and social dimensions of water use identified in Maslow's framework. At the physiological and safety levels, water regained its visibility as a fundamental component of public health – handwashing and sanitation became the most critical global health interventions. At higher levels, water provided comfort and psychological relief through gardening, cooking, or personal rituals that fostered stability and emotional well-being amid uncertainty.

With remote work likely to persist in many sectors, its long-term influence on water consumption patterns may be significant. Experts predict that permanent increases in residential demand will require new strategies for water efficiency and infrastructure resilience (Castelo, 2020). Smart water management technologies – such as household metering systems, real-time monitoring, and leak detection – can play a crucial role in optimizing consumption. Complementary policies promoting water-efficient appliances, public education, and behavioral change will be essential to sustain resource balance in a future where home-based lifestyles remain prevalent (Valero et al., 2023).

In this context, the pandemic serves as a revealing case study of how sudden societal shifts can restructure the hierarchy of water needs. It temporarily elevated water's role as both a survival necessity and a symbol of security and comfort. Consequently, it reinforced the imperative of circular and adaptive urban water management – one that recognizes behavioral flexibility, promotes resource efficiency, and integrates human well-being with sustainable infrastructure planning.

6.3 Focus of the Study

The water matter during COVID-19 pandemic and increasing drastic climate events arise the question of the whole urban water system and what can be done to it in matters of circularity and sustainability, as the main direction of urban [and not only] development nowadays.

This trend also aligns with the topic of urban prosperity, which has three main types of values: historic cultural value, interrelated architectural value, and socio-ecological value. The last one can be achieved through the study of river-city or river basins, for example, to foster urban prosperity through water, as explained above. And one of the types of urban water is WasteWater that can still be reused for various water demands, by maximizing the output of the resources that are already in the urban water system and give it a "second life". As such, secondary WasteWater use covers both the sustainability goals of city and fostering urban prosperity to guarantee the flourishing of people in cities [and related environments].

Withal as a consequence of case to case specificities with overall relevance and universality of the issue, the **primary goal** of this work is to develop an illustrative example of methodological approach for the identification of various priority area for the implementation of secondary WasteWater use systems on a local level in an urban development. It does not mean developing a technical approach on specific engineering solutions, but a policy and urban design visualization of possibilities in the already existing urban realities [with the consideration of the existing local historical cultural heritage].

Thus, considering the analyses of water and importance of preservation of water as a resource with an increasing demand for it, the **main research** question that will be addressed in this study is:

How the implementation of secondary WasteWater use in public spaces can be beneficial for the urban environment?

This question is designed to explore the strategies to integrate secondary WasteWater use systems in various urban areas within a circular water economy for the development of a sustainable urban environment initially on a local level to be then [with necessary corrections] applied on a bigger scale in future projects.

While having this as the main research question, there are also **other questions** on the topic of secondary WasteWater use to address to understand better:

1. What are the key challenges that hinder the implementation of secondary WasteWater reuse systems in different geographical contexts?
2. What strategies can be used to enhance public acceptance and awareness of secondary WasteWater reuse in both developed and developing countries?
3. How does secondary WasteWater use contribute to a circular water economy in urban environments?
4. What are the potential synergies between WasteWater reuse and other urban sustainability strategies (e.g., green infrastructure, water-sensitive design)?
5. How can secondary WasteWater use enhance urban resilience against climate change and water scarcity?

These questions allow to study more in-depths the relationship between the city and the WasteWaters, the opportunities offered by secondary use of WasteWaters in various urban contexts.

In relation to the research questions, in addition to the main goal, the **objectives** for this study are:

1. Describe the possibilities for spatial planning interventions;
2. Identify the legal and regulatory barriers;
3. Illustrate different contextual scenarios of SWWUS implementation.

The current **premise** is that the reuse of WasteWater can help with developing BGI in cities that will help not only mitigate the damaging effects of climate change but will also enhance urban livability; additionally, SWWUS implementation will stimulate the development of WasteWater treatment to potable reuse to mitigate water scarcity globally.

6.4 Methodology

In order to develop effective strategies for the implementation of SWWUS, it is essential to undertake a comprehensive spatial and contextual analysis of the area of intervention. Such analysis enables the identification of locations where implementation would yield the highest environmental and social impact, as well as the prioritization of interventions within a long-term planning timeline. A spatially informed understanding of the urban context is necessary not only to determine the technical feasibility of reuse systems but also to align them with existing infrastructures, social dynamics, and policy frameworks.

The planning and implementation of SWWUS require a collaborative approach that involves the expertise of urban planners, architects, engineers, and policymakers, as well as the cooperation of local and national governments. This is because water reuse interventions are inherently multi-scalar – they involve both local actions (such as retrofitting buildings or introducing small-scale decentralized systems) and larger infrastructural transformations (such as integrating blue-green networks and WasteWater treatment facilities). These interventions should also be accompanied by new policy instruments that support the development, financing, and long-term maintenance of reuse systems, ensuring their integration into broader sustainability strategies.

This study aims to illustrate a methodological framework for identifying priority areas for SWWUS implementation through the integration of spatial multi-impact risk assessment, contextual literature review and policy analysis, all supported by site overview documented through SWOT analysis. The combination of these methods allows for both quantitative and qualitative understanding of the urban environment. The literature and policy analysis provided the theoretical and institutional foundation for the research, while site visits in the selected cities of Venice and Shanghai offered direct observation of spatial conditions, existing water infrastructures, and local behavioral patterns related to water use.

The information gathered through site visiting and SWOT analysis provided practical insight into how local realities intersect with theoretical concepts of water reuse and resilience. This grounded understanding was crucial for adapting the spatial risk analysis to each context and for interpreting the results in light of governance structures, infrastructural conditions, and socio-spatial dynamics.

The core analytical component of this work is the spatial multi-impact risk assessment, conducted in QGIS. This method allows for the visualization and quantification of environmental vulnerabilities by overlapping multiple datasets representing distinct but interrelated urban stressors. It follows the logic of multi-criteria decision analysis and spatial vulnerability mapping commonly applied in climate resilience studies (Ahern, 2011; Cutter et al., 2003; Elmqvist et al., 2019). Through this approach, spatial layers representing different risk factors are integrated into composite maps that identify areas of high environmental stress and, consequently, areas where SWWUS implementation would be most beneficial. Besides risk map visualization, vulnerability as a step in the analysis process will also be spatially visualized; while risk maps are more informative as they include the data from vulnerability maps, it is important to look at vulnerability maps separately to be able to see not only where the potential for damage is the highest, but also where people and places are more susceptible to harm.

The purpose of this analytical procedure is methodological rather than prescriptive: it demonstrates how spatial data can inform strategic planning and how overlapping risk factors can guide the prioritization of interventions. While the results are limited by data availability, they establish a replicable framework that can be refined when more granular information becomes accessible. For instance, incorporating datasets such as household-level water consumption, detailed sewer network maps, or microclimatic temperature data – when and if available for future studies – could significantly enhance the model’s accuracy. However, privacy regulations and institutional data fragmentation often limit access to these variables.

The theoretical justification for this method is grounded in systems thinking and urban socio-ecological resilience theory, which conceptualize cities as interdependent systems where environmental and social processes interact dynamically (McPhearson et al., 2015; Meerow, 2016). Within this framework, environmental risks such as flooding and urban heat are seen as mutually reinforcing stressors. Consequently, an integrated spatial assessment that considers multiple impacts simultaneously allows for the identification of synergistic intervention zones – areas where a single set of actions, such as the implementation of SWWUS, can address several vulnerabilities at once.

The choice of Urban Heat Island (UHI) and Flooding Risk as the two key parameters in the multi-impact assessment reflects both their prevalence in the selected case study cities and their direct relevance to the potential benefits of WasteWater reuse. UHI is a widespread phenomenon in dense urban environments, caused by heat absorption from impervious materials, lack of vegetation, and anthropogenic heat emissions (Santamouris, 2015, 2018). It contributes to higher energy consumption, health risks, and reduced urban comfort. SWWUS can directly mitigate UHI through the use of treated WasteWater for irrigating vegetation, maintaining green roofs, or feeding evaporative cooling systems. These interventions promote evapotranspiration and create microclimatic regulation, thereby reducing localized temperatures (Bowler et al., 2010; Gunawardena et al., 2017).

Flooding, in turn, is a critical challenge in many coastal and riverine cities, exacerbated by impervious surfaces, heavy rainfall, and inadequate drainage networks. Climate change projections indicate that flooding will intensify due to rising sea levels and more frequent extreme precipitation events (UN-Habitat, 2011). SWWUS can contribute to flood mitigation through various design and infrastructure measures – such as permeable pavements, rain gardens, bioswales, and retention tanks—that capture, store, and reuse excess water (Ellis & Lundy, 2016; Fletcher et al., 2014). These solutions reduce stormwater runoff and relieve pressure on municipal drainage systems, while simultaneously providing reclaimed water for non-potable uses.

Analyzing UHI and flooding risk together through a multi-impact lens makes it possible to locate spatial intersections where both phenomena occur simultaneously. These "co-vulnerability zones" are strategic for SWWUS implementation because interventions here would yield multiple benefits – reducing thermal stress, improving water management, and contributing to urban biodiversity and comfort. The approach thus promotes a synergistic understanding of circular urban water management, where WasteWater reuse is integrated not only as a technical measure but also as part of a spatial and ecological regeneration strategy.

This methodological framework demonstrates how spatial tools can bridge the gap between urban theory and practice, linking resilience thinking within circular economy principles. It situates SWWUS within a broader paradigm of nature-based and resource-recovery solutions, emphasizing that water reuse systems are not isolated infrastructures but part of a living network of interdependent ecological and social processes.

While the analysis remains limited by the granularity of available data, its value lies in providing a scalable, adaptable, and interdisciplinary model. The integration of site-based observation, policy review, and spatial risk mapping enables both a grounded and a systemic understanding of urban water challenges. Future research can build upon this foundation by incorporating additional datasets – such as per capita household

water use, building typologies, or more social vulnerability indices – to further refine the precision and policy relevance of the model.

In summary, the multi-impact spatial analysis used in this research serves as a demonstration of how SWWUS can be strategically planned and spatially prioritized in response to overlapping urban challenges. The approach reinforces the need for spatially informed decision-making that connects water reuse, climate adaptation, and urban design within an integrated resilience framework.

6.4.1 Creating Flood Vulnerability and Flood Risk Maps

A flooding vulnerability map highlights the areas within a city or region that are most likely to suffer severe impacts if a flood occurs. It doesn't predict where floods will happen, but rather shows which areas are least prepared to cope with them. This kind of map focuses on inherent weaknesses in the urban or natural environment. For example, areas with little vegetation, lots of impervious surfaces like concrete, or those located in low-lying zones with poor drainage are typically more vulnerable. In some cases, social and economic conditions are also considered – neighborhoods with lower incomes, older populations, or less robust infrastructure may be especially susceptible.

In contrast, a flooding risk map takes the concept a step further. It combines vulnerability and exposure – the number of people, buildings, or critical infrastructure located in each area – to show where actual damage from flooding is most likely to occur. This is the map most often used by urban planners, emergency responders, and policymakers to determine where action is most urgently needed, as it creates a fuller picture of danger: not just who is susceptible, but also where flooding is both likely and impactful. In essence, vulnerability maps show who or what is sensitive, while risk maps show where damage is most probable and severe, considering not just sensitivity but also the likelihood of the hazard and the value of what's exposed.

Flood vulnerability and risk maps are valuable tools for urban planners, especially when developing strategies for implementing secondary WasteWater use systems. These maps provide crucial insights that can guide the planning, design, and placement of WasteWater infrastructure for:

- Understanding Site Suitability and System Safety;
- Identifying Priority Areas for Green Infrastructure and Wastewater Reuse;
- Supporting Equitable and Resilient Planning;
- Optimizing Siting for Efficiency and Safety;
- Aligning with Integrated Water Management Goals.

Flood vulnerability maps are also helpful for identifying areas with low natural water infiltration and poor drainage, which are often highly vulnerable to flooding. These areas are prime candidates for integrating green infrastructure solutions that both manage stormwater and support WasteWater reuse.

For example, treated WasteWater can be used to irrigate parks, green roofs, or urban forests, which serve to absorb stormwater, reduce urban heat islands, and enhance public spaces. This not only helps to reduce flood vulnerability but also creates an integrated, sustainable solution where green spaces benefit from treated WasteWater, thereby increasing urban resilience and improving local water management practices.

Furthermore, flood risk maps help planners identify safe, efficient locations for WasteWater reuse infrastructure, such as storage basins, small-scale treatment plants, or constructed wetlands. These locations can be strategically placed outside of high-risk flood zones, yet still close enough to serve areas with high water demand or limited supply.

Flood mitigation and WasteWater reuse are both essential components of Integrated Urban Water Management (IUWM). Flood vulnerability and risk maps allow planners to see how stormwater, treated effluent, and urban design interact across space. This helps guide planning for:

- Dual-purpose systems, such as wetlands that treat WasteWater while also managing runoff.
- Multi-functional landscapes, which provide both environmental and recreational benefits.
- Circular water systems, where treated WasteWater is used repeatedly within neighborhoods or districts.

By using flood maps in conjunction with WasteWater reuse plans, urban planners can ensure that flood mitigation, water reuse, and urban development work in harmony, increasing the city's resilience to both flooding and water scarcity.

Thus, flood vulnerability and risk maps are essential decision-support tools for urban planners, enabling them to identify areas where WasteWater reuse systems can be safely and efficiently implemented. These maps help avoid placing critical infrastructure in high-risk areas, target vulnerable communities for equitable interventions, and design multi-functional landscapes that contribute to both flood control and WasteWater reuse, hence the use of those in this study.

Creating the Flood Vulnerability Map

The flood vulnerability map identifies areas that are more physically susceptible to flooding, primarily based on their lack of vegetative cover. Vegetation plays a critical role in absorbing rainwater and reducing runoff, so areas with minimal vegetation are generally more vulnerable.

The process begins by correcting the Digital Terrain Model (DTM) to remove topographic depressions that could misrepresent water flow. Topographic depressions are small pits or low-lying areas in elevation data that do not naturally drain and can artificially trap water in hydrological models, leading to inaccurate watershed delineation. Using the GRASS `r.fill.dir` tool in QGIS, a terrain preprocessing tool that fills these depressions and calculates drainage direction, a new "depressionless DTM" is created, ensuring accurate hydrological flow modeling.

Next, sub-watersheds are delineated using the GRASS `r.watershed` tool. This function divides the terrain into drainage basins based on a chosen threshold size. The resulting raster, in which each cell is assigned to a unique watershed, is then converted to a polygon vector layer. Each polygon now represents a distinct watershed and serves as the unit of analysis for subsequent steps.

To assess vegetation coverage, a binary NDVI raster is used, where 1 represents vegetated pixels and 0 represents non-vegetated pixels. Using the Zonal Statistics tool, the number of vegetated pixels within each watershed polygon is calculated. This pixel count is then multiplied by the pixel area (in this case 100 m² for the used Sentinel data) to determine the total *vegetated area* per watershed.

Next, the *total area* of each watershed polygon is computed using the `$area` function. Following, the percentage of non-vegetated area is then calculated using the formula:

```
1 - (Vegetated Area / Total Area)
```

This percentage becomes the watershed's *flood vulnerability indicator*. Higher values indicate greater vulnerability due to reduced water absorption capacity. This value provides a spatially explicit, quantitative representation of where natural landscape conditions are likely to worsen flooding impacts – specifically, areas with limited vegetation cover are less capable of absorbing rainfall, leading to higher surface runoff and greater potential for flash floods or water accumulation during storm events.

Assessing Exposure Indicators

Before computing the flood risk, it is necessary to do an exposure assessment to identify elements within each watershed that are potentially affected by flooding – namely, buildings and public amenities.

For building exposure, building footprints are first converted from polygons to centroid points. A spatial index is created to improve the performance of spatial queries. Then, using the `Join Attributes by Location (Summary)` tool, the number of building points within each watershed polygon is counted. This count is normalized using a min-max normalization formula to produce a 0–1 scale, allowing for comparison across watersheds. Any NULL values are replaced with zeros using the `coalesce` function, a function in QGIS that substitutes NULL (missing) values with a specified default value, ensuring complete and consistent datasets for calculations. The normalized values are stored in a new field.

A similar process is followed for amenities. Amenity data[21] are downloaded from OpenStreetMap and merged into a single shapefile. After creating a spatial index, amenities are counted within each watershed using the same spatial join method. These counts are also normalized and stored in a new field, again using `coalesce` to manage missing values.

The normalized building and amenity indicators are then averaged to compute a composite *exposure index* – a single metric that combines multiple exposure factors into one, allowing for a more holistic representation of the elements at risk. This is done using the formula:

```
(Normalized Buildings + Normalized Amenities) / 2
```

This result quantifies the relative degree of physical and infrastructural exposure to flooding for each watershed. Higher values reflect watersheds with more infrastructure and public services potentially at risk.

[21] Within this study the following amenities were included in the calculation: schools, universities, hospitals, childcare facilities, clinics, social facilities, colleges, kindergartens, banks, doctors, pharmacies, water points, drinking water points and watering places.

Computing the Flood Risk Index

The final step integrates the vulnerability and exposure components to produce a comprehensive *flood risk index*. This is done through a simple multiplication of the two indicators:

```
Urban Flood Vulnerability * Urban Flood Exposure
```

Each value reflects the combined impact of physical susceptibility (low vegetation) and the presence of valuable infrastructure (buildings and amenities). Higher values identify the watersheds most at risk of flood-related damage and disruption.

This index provides a data-driven basis for identifying priority areas for flood mitigation interventions. It allows planners to focus on zones where both the likelihood and potential consequences of flooding are highest.

This integrated approach – grounded in geospatial data, remote sensing, and spatial analysis – offers a replicable, scalable method for urban flood risk assessment that supports climate-resilient planning and infrastructure development. Generally, for this approach all data is publicly available and there are no data limitations for the calculations.

6.4.2 Creating Urban Heat Vulnerability and Risk Maps

Urban Heat Vulnerability and Risk Maps are essential planning tools that identify areas within a city that are most susceptible to the harmful effects of extreme heat. These maps are typically created by combining land surface temperature data from satellite imagery with vegetation indices and socio-demographic indicators, such as age, income, or housing type. Vulnerability maps highlight the sensitivity of populations to heat, while risk maps integrate vulnerability with actual exposure to high temperatures and population density to show where the greatest impacts are likely to occur.

These maps are highly relevant in the planning and implementation of secondary WasteWater use systems – systems that recycle treated WasteWater for non-potable uses such as irrigation, street cleaning, or cooling urban infrastructure. One of their primary benefits is their ability to guide the placement of these systems in areas where heat stress is both severe and socially significant. For instance, neighborhoods identified as heat hotspots – areas that experience high temperatures and contain vulnerable populations – can be prioritized for cooling interventions. Secondary WasteWater can be used to irrigate parks, green corridors, and street trees in these areas, reducing surface and air temperatures through evapotranspiration while conserving potable water.

Moreover, in densely populated, low-income neighborhoods – where vulnerability to heat is compounded by limited access to cooling systems or green space – WasteWater reuse infrastructure can serve a dual purpose. It can support the development of green public spaces that offer both environmental relief and social benefit. By connecting WasteWater reuse with urban heat adaptation, cities can ensure that infrastructure investments support not only environmental sustainability but also social equity.

Urban Heat Risk Maps also inform more strategic land use and zoning decisions. For example, planners can use them to justify the integration of WasteWater reuse infrastructure into developments located in high-risk zones or to advocate for policies that encourage green, water-reliant cooling solutions in urban redevelopment plans. The maps help determine where cooling demand – and thus recycled water demand – is likely to be highest, allowing for more efficient system sizing and placement.

Ultimately, these maps enable urban planners to align secondary WasteWater use systems with broader climate resilience strategies. They ensure that interventions are targeted where they are most needed, and that reused water is applied in ways that reduce urban heat risks while conserving resources. This integrated approach not only enhances system efficiency and long-term sustainability but also contributes to more just and climate-resilient cities.

Calculating Urban Heat Vulnerability

The vulnerability map reflects how susceptible different areas are to heat-related impacts. It incorporates environmental and socio-demographic indicators to identify where populations may experience the most severe consequences of heat events.

The first step is to prepare a dataset that includes the mean surface temperature (LST) for each census unit. These values are typically derived from thermal satellite bands, such as Band 10 from Landsat 8, which captures thermal infrared radiation and is used to estimate Land Surface Temperature (LST) by detecting emitted heat energy from the Earth's surface, for summer and spring periods.

To create a standardized vulnerability indicator from the raw LST, which represents the radiative skin temperature of the land surface as measured from space – normalization is applied. This involves transforming values to a 0–1 scale using the formula:

```
(X - Xmin) / (Xmax - Xmin)
```


Where `X` is the surface temperature for a given census unit, `Xmin` is the minimum observed temperature, and `Xmax` is the maximum. This produces a normalized surface temperature, stored in a new field. Higher values correspond to higher thermal stress. Normalization ensures comparability across units and scales the variable to be used in further composite calculations. This step is done twice for summer and spring periods. The UHI Vulnerability for the two seasons is then merged into an average UHI Vulnerability over the two seasons to be used in future calculations.

Spring and summer are chosen because they represent periods of increasing and peak temperatures in temperate climates like Venice[22]. These seasons capture the most relevant changes in heat exposure and vegetation stress before and during the peak risk period, making them particularly useful for urban heat assessment. Autumn and winter, by contrast, present minimal heat-related health risks and are therefore less critical for heat vulnerability studies. By calculating the mean values in summer and spring temperatures maps, planners can identify consistent hot spots, to form more nuanced climate adaptation strategies.

Additionally, the age of buildings can also be included in the UHI Vulnerability[23]. The first step would be the preparation of data: with only the year of construction available the age of the buildings is calculated by subtracting from the current year (2025) the year of construction. Afterwards this information is joined in the layer with the normalized surface temperature using the `Join attributes by Location (Summary)` function and computing the minimum, maximum and mean values as the age of buildings is in the buildings layer (which is presented as individual buildings and later centroids) while the surface temperature is aggregated according to the census districts, so multiple values of age need to be computed to get the average age for each district. The mean age value is then normalized using the formula from before. With the normalized values it is possible to compute the UHI Vulnerability using the following formula:

```
Normalized LST * 0.8 + Normalized Age of Buildings * 0.2,
```

[22] And for Shanghai. However, in order to compare Shanghai and Venice the same year was chosen (2021) and the available satellite shots for Shanghai in that year over spring and summer in good quality were available for April 29th – in all the other available dates in that period there was a significant number of clouds which would make calculations faulty if not impossible.

[23] This step was done only for Shanghai as there was no spatial information available at the moment of the study for mainland Venice.

where the weighting reflects the assumption that surface temperature plays a stronger role (80%) in shaping UHI vulnerability than the decay of buildings (20%), because heat exposure directly affects the entire population's health and urban livability, while structural decay mainly influences localized adaptive capacity.

Table 1
Indicators in constructing HV/Rs.

Category			Amount of studies	Explanation
	Socio-economic status and cultural background			
	Age		50	% of elderly and young population
	Poverty, income		37	% of population below poverty line
	Education		32	% of population without high school diploma/never attended schools/only attended pre-elementary
	Living alone/in group		31	% of people (or elderly) live alone, elderly live alone;
	Ethnic minority		19	% of non-white/Hispanic/black/Asian
	Population density		18	Density of inhabitant per living block/per square mile
	Employment		15	% of unemployment
	Language barrier		14	% of illiterate population/speaking a non-official language
	Born in foreign/immigration		8	% of population born in foreign country/immigrated
	Home ownership		7	% of rented household
	Gender		6	Female ratio
	Family structure		6	% of population of: single, widowed, divorced, separated, or single parent with children under 18
	Job specification		5	% of: labor workers, agricultural workers, craft and related trade workers, plant and machine operators and assemblers
	Vehicle ownership		4	% of household without any vehicle
	Settlement/homeless		2	% of population with different residences from 5 years/homeless people
	Urban population		1	% of urban population
	Social class		1	% of population of scheduled castes and tribes
Climate	Land surface temperature		26	Satellite image of Landsat TM/ETM+/MODIS
	Air temperature (Ta)	Daily Ta	14	Daily maximum/minimum Ta
		Night Ta	2	Night maximum/minimum Ta
		Heat wave days	4	Number of days that daily maximum Ta exceeds a certain degree
	WBGT		1	Measure heat stress by considering temperature, humidity, wind and solar radiation
	Humidex		3	Describe how hot the weather perceived by person by considering heat and humidity
	Air quality		4	Average of PM2.5 concentration; maximum recorded ozone level
Urban environment	Street incoming solar radiation		1	Potential solar radiation incoming for street surface
	Roofs incoming solar radiation		1	Potential solar radiation incoming for roof surface
	Land use/land cover	Vegetation cover	26	NDVI; % of green space/water body area; Enhanced Vegetation Index (EVI)
		developed land cover	15	% of impervious land cover; normalized difference built-up index (NDBI)
	Accessibility/proximity	Proximity to parks/green space	3	% of population with limited park accessibility; number of woody pixels around each pixel
		Proximity to water bodies	4	Distance to major water bodies; Number of water body pixel around each pixel
		Proximity to cool shelters (community centers, homeless shelters, libraries)	5	Number of cooling facilities; distance to cooling facilities
		Proximity to public transportation/major road	3	% of population that does not live near transit station/major roads
		Proximity to hospitals	6	Distance to the nearest health care center; number of hospitals; % of area within a certain buffer to a public hospital to the total area
		Proximity to city center	1	Distance to city center
	Urban density	Building density	5	% land with high building intensity areas
		Paved road density	6	Paved road density
	Landform/elevation		4	Digital Elevation Model (DEM) data
	Sky view factor		2	% of the amount of sky hemisphere visible from ground level
	Urbanization rate		1	Urbanization rate

Figure 23. Vulnerability metrics (Cheng et al., 2021).

Chapter 6 Analytical Framework for WasteWater Management

Next, several population vulnerability metrics are calculated using census data. For this study following metrics were included[24]:

- Percentage of children (under 15 or under 17[25]) and elderly (over 65), because both age groups are physiologically more susceptible to extreme heat due to reduced thermoregulation, limited mobility, and higher dependence on care or external support during heatwaves.
- Percentage of female population, because women may experience greater vulnerability to extreme heat due to physiological differences in heat tolerance, higher prevalence of certain health conditions, and social factors such as caregiving responsibilities and unequal access to resources.

Each of these indicators is also normalized using the same formula from above.

Once all individual indicators are normalized, they are averaged to produce a social population vulnerability score:

`(V1_norm + V2_norm) / 2`

This generates a composite vulnerability index, *population vulnerability*, which quantifies the relative socio-demographic sensitivity of each area.

Finally, environmental vulnerability (from LST) is averaged with population vulnerability to create an overall heat vulnerability index:

`(UHI Vulnerability + Population Vulnerability) / 2`

This Overall *UHI Vulnerability index* provides a balanced measure that accounts for both physical heat intensity and population sensitivity where higher values indicate greater vulnerability to heat related harm.

---

24 Both variables were used for the Venice case study, while for Shanghai due to lack of data only the age variable was calculated within the population vulnerability.

25 Generally, for UHI vulnerability, within the age metric are taken children younger than 15 as they are considered because they are physiologically more sensitive to heat stress, with less efficient thermoregulation and higher dependency on caregivers, making them disproportionately vulnerable during extreme heat events. And for Venice study case within this variable are taken children younger than 15, but for the Shanghai census the age range starts with "younger than 17" hence the difference.

Assessing Exposure to Heat

The next step is to evaluate exposure – essentially, how many people or structures are present in areas vulnerable to heat. For the assessment of the exposure in this case were taken into consideration the proximity to any kind of water body and the population density[26]: calculated as total population divided by the area of each census unit. The population density is normalized using the same min-max formula to produce comparable exposure scores. Again, `coalesce` is applied to avoid NULL values interfering with calculations.

The water proximity indicator identifies how exposure to urban heat is influenced by the distance of buildings from water bodies. Proximity to water generally reduces the intensity of urban heat due to the cooling effect of evaporation and microclimatic regulation. Therefore, in the context of UHI exposure, buildings located closer to water are considered less exposed, while those farther away are considered more exposed.

To compute the *Water Proximity Index*, the process begins with the preparation of building geometries. If the building layer is in polygon format, each footprint is converted to a centroid point using the Centroids tool. This ensures that the subsequent analysis uses a single representative point per building. The water bodies layer, originally provided as polygons, is prepared by converting to boundaries (lines), so to calculate the distance to the border of a water body and not its center, providing more accurate data.

Next, the distance from each building centroid to the nearest water body is calculated using the `Distance to Nearest Hub (line to hub)` tool. In this analysis, the building centroids serve as the input points, while the water body boundaries or centroids serve as the hubs. The tool produces the Distance to Water, containing the calculated distance values in meters. This value represents the straight-line distance from each building to the closest [border of] water body.

Subsequently, these building-level values are aggregated to the census polygons using the `Join attributes by location (summary)` tool, with the statistic set to `mean`. This step assigns each census area an average value of water proximity, representing the overall accessibility of buildings in that area to water-related cooling.

[26] Total population can be used alternatively, however, density reflects how concentrated people are where heat occurs and it's comparable across units of different size (districts, hexes, pixels); while total population is sensitive to area size: big polygons look "more exposed" just because they're big.

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The Distance to Water is also normalized to avoid bias from differing units of measurement, but inverted with the following formula:

```
1 – ((X - Xmin) / (Xmax - Xmin)),
```

where `X` is the Distance to Water, `Xmin` and `Xmax` are the minimum and maximum distance from a building to the closest [border of] water body. The values resulting from this calculation vary from 1, meaning that a building is very close to water which is good to 0, meaning that a building is far from water, which in context of this analysis is bad.

Finally, the *UHI exposure index* is calculated as a weighted combination of the two normalized indicators:

```
0.6 * Normalized Water Proximity Index +
0.4 * Normalized Population Density
```

Exposure fields represent the extent to which people are located in areas affected by heat. Higher values suggest greater exposure to thermal hazards. The weighting reflects the assumption that biophysical factors (water proximity) play a slightly stronger role (60%) in shaping UHI exposure than demographic concentration (40%), since cooling from water affects the baseline physical intensity of heat, while population density influences the scale of impact on people. The resulting score provides a spatially explicit measure of UHI exposure per census area, capturing both the environmental buffering effect of water and the social concentration of residents.

Calculating the Urban Heat Risk Index

To compute the *Urban Heat Risk Index*, vulnerability is combined with exposure:

```
Overall UHI Vulnerability Index × UHI Exposure Index
```

This index reflects both how severe the impact of heat is likely to be (vulnerability) and how many people it will affect (exposure). Areas with high risk scores are those where high temperatures intersect with socially sensitive, densely populated communities.

This integrated heat risk assessment method supports data-driven urban planning, targeting interventions such as tree planting, green infrastructure, and social services toward areas most in need. It combines remote sensing and demographic data into a comprehensive framework for urban resilience.

6.4.3 Creating a Multi-Risk Map for Urban Heat and Flooding

The final output of this technical analysis on QGIS is a Multi-Risk Map that integrates two separate spatial layers – one representing Urban Heat Risk and the other Urban Flood Risk – into a single composite index. This approach helps identify areas that are simultaneously vulnerable to both climate-related hazards, offering a more comprehensive view of risk distribution.

To begin, both the Urban Heat Risk and Urban Flood Risk layers should be in raster format and projected in the same coordinate reference system. In this case the flood risk layer needs to be adjusted: it can be rasterized using the `Rasterize (vector to raster)` tool in QGIS, with the pixel size matching the resolution of the UHI raster (10 meters). The extent and resolution settings must also match the UHI raster to ensure spatial alignment. Following, `Zonal Statistics (summary)` tool is used on the Urban Flood Risk layer the administrative boundaries layer from the census file to calculate the mean, minimum, and maximum risk values within each unit. The result is a vector layer where each census tract contains statistical summaries of urban flood risk exposure, allowing for more accurate comparison across neighborhoods with the UHI risk exposure.

Once both layers are available in raster format and are spatially aligned, the *Multi-Risk Index* can be calculated. The expression simply averages the two risk layers as they share the same weight (meaning they have the same value and are equally important in the context of this study) by summing them and dividing by two:

```
(UHI Risk Index + Urban Flooding Risk Index) / 2
```

As a result, each pixel contains a value between 0 and 1, with higher values indicating locations that are more exposed to both heat and flood risks. These are the areas where interventions are most urgently needed, and where urban planning strategies – such as the implementation of secondary WasteWater use systems – can have the greatest impact. For instance, treated WasteWater can be used to irrigate green infrastructure in areas with high heat risk, helping to reduce temperatures, while also supporting flood mitigation by maintaining permeable, vegetated surfaces. These insights directly support the strategic siting of secondary WasteWater use systems by ensuring that reused water is distributed where it can help mitigate both urban heat and flooding, enhancing the overall resilience and sustainability of urban neighborhoods. This information can then inform the siting of cooling infrastructure, green space expansion, stormwater management systems, and other integrated adaptation strategies.

6.4.4 Limitations

Such research route was chosen because of difficulties of obtaining detailed data of China for a foreigner not affiliated with the Chinese government, as well as privacy reasons. The privacy issues are linked to data of water consumption. Ideally, with the support of hydraulic and civil engineers, the specific amount of per capita consumed water and per capita produced WasteWater, including the typology of the said WasteWater, should be included in the territory analysis, to understand and address the specific needs of the different areas of the city, as well as propose more customized solutions based on the defined needs and the available resources. However, such data is connected to individual consumption patterns and behavior which undermines a citizen's privacy and could possibly impair personal safety. Thereupon, such data was not available for the purposes of this research and was not included in the methodology.

Furthermore, for the Chinese study case the same demographic and land use data as used for the Italian case study is not available or is not available on the same small scale as for the Italian, hence the results are less accurate and cannot be fully compared. Nonetheless, representative illustrative and practical results were achieved with the available data and resources.

6.5 Case Study Selection

The selection of case studies for this comparative study on WasteWater secondary use in the context of waterfront urban planning focuses on cities that provide diverse perspectives on integrating SWWUS within different urban and peri-urban contexts. This research emphasizes a Sino-Italian scenario confrontation to gain insights into the unique strategies and policies that each region employs. By studying the areas of Venice in Italy alongside the Qīngpǔ district in Shànghǎi, China, this study aims to explore the interplay between WasteWater management and urban planning in settings with distinct historical, social, and regulatory backgrounds.

Venice and Qīngpǔ represent cities with an explicit and intrinsic relationship with water. Venice, as a historic Italian city shaped by its canals, exemplifies the challenges of WasteWater management within a waterfront urban landscape where preserving the delicate ecosystem is paramount even on the mainland territory. This city's infrastructure is interwoven with its water systems, making it an ideal case for studying how secondary WasteWater can help mitigate the risks imposed by climate change on a city with such delicate urban ecosystem.

Similarly, Shànghǎi's Qīngpǔ district, which combines urban and agricultural functions, offers a unique perspective on WasteWater use for peri-urban settings. Qīngpǔ's growing infrastructure and proximity to agricultural areas provide an opportunity to examine WasteWater reuse for agriculture and urban landscape irrigation. In this context, Qīngpǔ serves as a model for understanding how WasteWater can be a prevention instrument with the growing urbanization of peri-urban areas of developing cities that suffer in the historical parts the damaging effects of climate change.

Of course, it is hard to compare Italian and Chinese cities not only because of the historical and social contexts, but also because of the various scales of the cities and population densities, the various approaches to urban design, which makes it harder to compare the case studies from an urban planning perspective.

But ultimately, these case studies were chosen because they represent different scales and types of urbanization, and by studying these contrasting settings, the research captures the challenges of WasteWater reuse across different urban planning frameworks, regulatory requirements, and public perceptions. Insights from Italy's experience with circular economy models and stringent EU regulations on WasteWater reuse may provide lessons applicable to China, while Shànghǎi's experience with rapid urban development and high-density solutions offers valuable considerations for future

Italian projects. These cases will highlight the distinct legal, social, and infrastructural challenges each region faces in implementing WasteWater reuse. This comparative approach provides a comprehensive view of best practices and obstacles in secondary WasteWater use, offering guidance for future projects on water-centered cities in both China and Italy.

6.6 Expected Outcomes

Considering that the previous studies on this topic do not specifically focus on comparing various circumstances worldwide to gain knowledge from shared experiences in different historical and cultural contexts and also work on a bigger scale, this study provides a new view on local interventions within different socio-legal contexts on how to implement secondary WasteWater use systems for local governments from city to district administration.

To specify, this research illustrates a structuralized approach on how to study and what are the possible strategies for the effective implementation of secondary WasteWater use systems in urban residential areas in public spaces, particularly focusing on NbS and Blue-Green Infrastructure (BGI) which offer sustainable inclusive design choices. The study aims to offer practical insights and recommendations for local governments to promote the implementation of sustainable WasteWater management.

These results will be obtained through drafts of urban design projects of the selected areas for the implementation of SWWUS, that will. be conceptualized for some areas within the selected study cases to illustrate more specifically the proposed actions and their benefits. All the visual results will be followed by the result of the analysis conducted of the study case areas to highlight the future opportunities and issue for the development of water-centered cities as a concept that should offer a theoretical solution to the water issue on a bigger scale within the existing legal framework, combining all the existing separated solutions that address parts of the bigger issue.

In the end, the idea is to envision the city of the future that is resilient and sustainable, but also comfortable and responding to needs of its inhabitants.

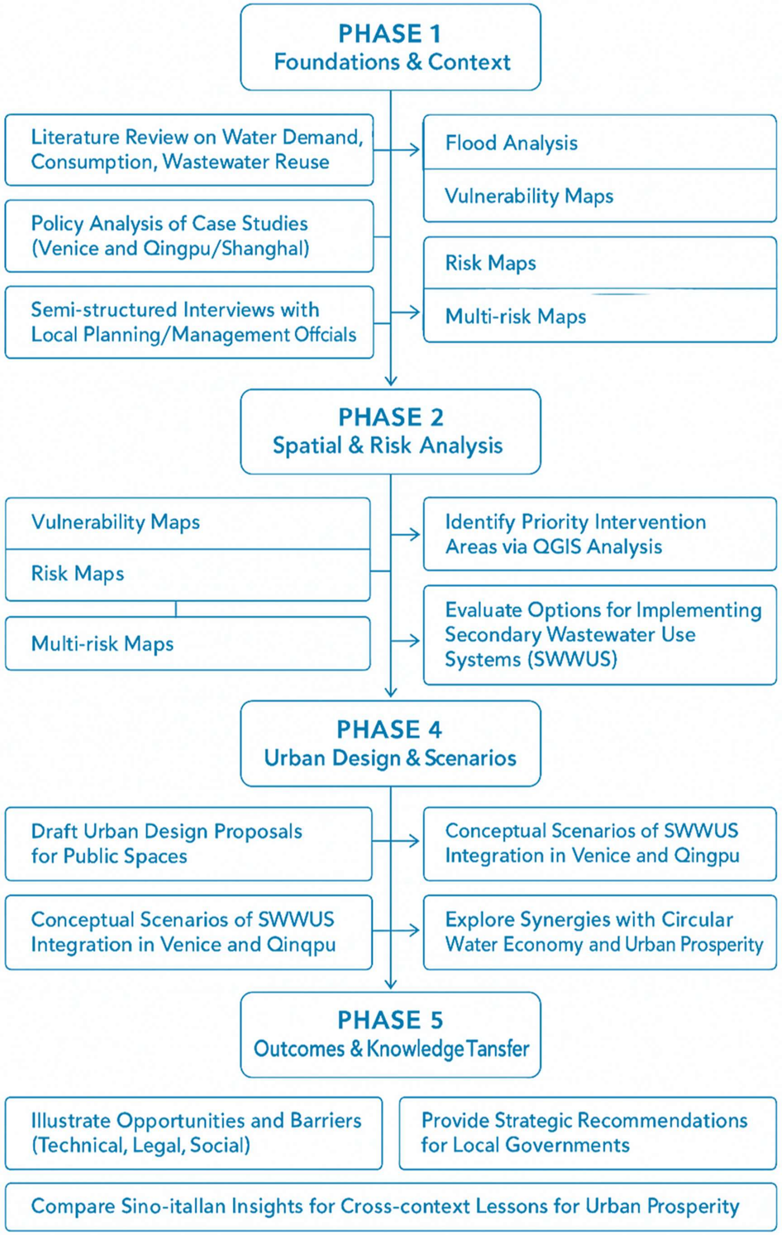
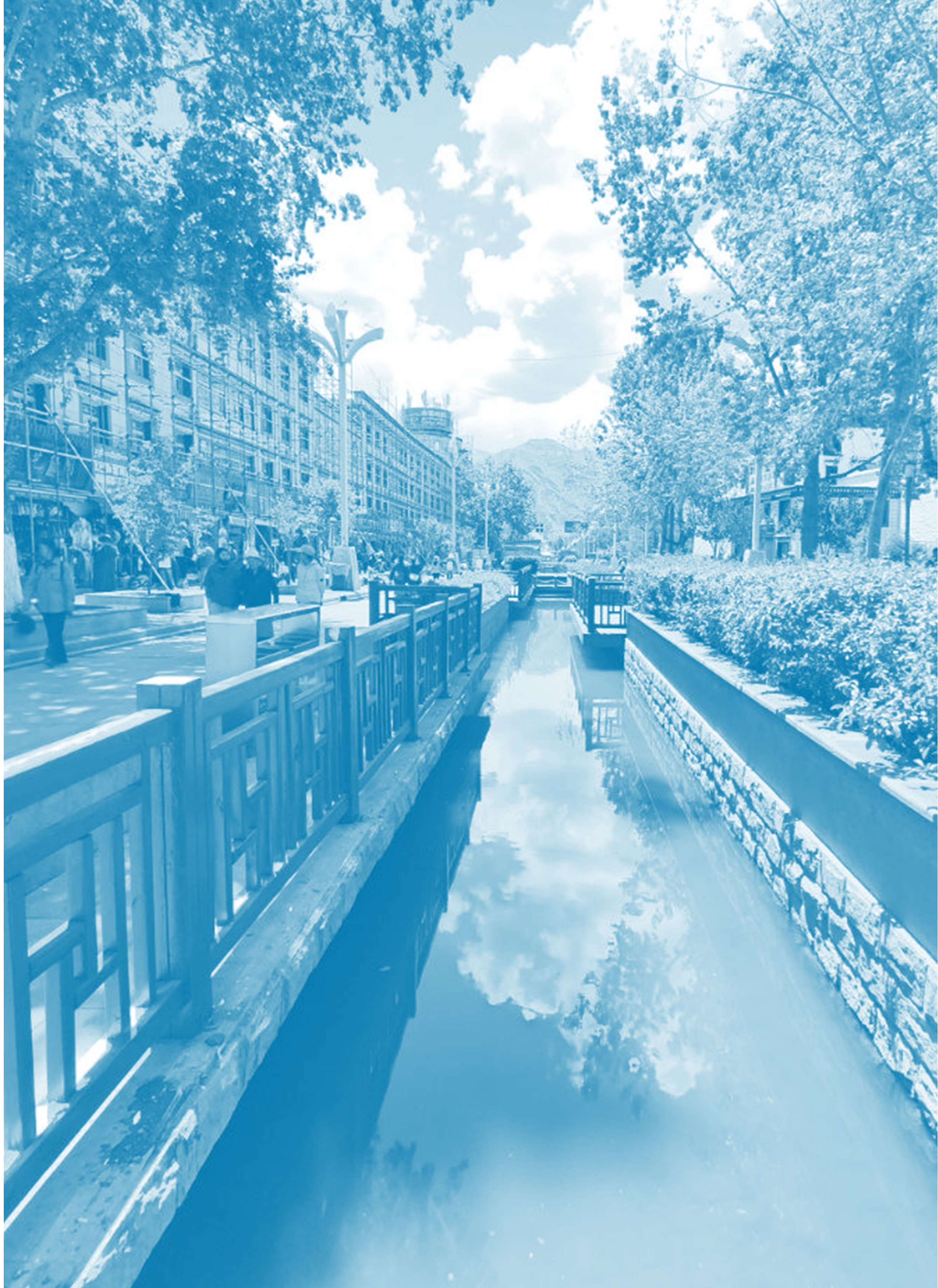


Figure 24. Research route scheme developed for this study.



Lhasa Urban Landscape (Photo by author).

Chapter 7 Integrated Urban Analysis for WasteWater Reuse Planning

While a literature review can give a great general understanding of a city and allows to explore different dimensions, any written (or in any other way structuralized) information about a city is an interpretation of reality given by somebody else. And no good urban design should be based on other's experience and interpretation of the urban space. For a good and effective urban design, it is important to analyze the territory and the current territorial planning in order to obtain a cognitive framework of the regulatory aspects, at the level of organization and management of the territory, falling on the municipal area and in the bordering areas.

Building upon the multi-impact risk assessment developed in previous chapter, the following spatial analyses translate the analytical findings into planning interpretation. The vulnerability and exposure maps produced through the combined flood- and heat-risk indicators provided a first layer of territorial diagnosis, identifying areas where climatic pressures and infrastructural deficits converge. These patterns of overlap were not viewed merely as environmental weaknesses but as opportunities for spatial intervention, revealing where secondary wastewater use systems (SWWUS) could deliver the highest multi-benefit impact. Consequently, the selection of reference sites in Venice and Shànghǎi was guided by the degree of composite risk identified through the GIS-based model: in both cases, zones of high urban density and limited green coverage corresponded with elevated flood susceptibility, making them strategic for testing integrated blue-green and reclaimed-water strategies. The ensuing case-study analyses therefore translate the analytical results into urban-planning propositions, examining how different morphological, social, and governance conditions shape the feasibility and form of SWWUS implementation.

7.1 Venice

7.1.1 Urban and Policy Framework of Water management in Venice

As mentioned before, this study aims to understand how to implement secondary WasteWater use from an urban planning perspective, but it is important to understand that the implementation approach may vary based on the urban context.

One of the urban contexts studied in this research is Venice, often referred to as the "Floating City" and characterized by its intricate relationship with water. The city's urban structure is divided into several distinct yet interconnected areas: the *laguna* (lagoon), the *isole* (islands), the *città antica* (historic city), and the *terraferma* (mainland), including settlements of Mestre and Marghera.

The environmental challenges facing Venice are deeply tied to its hydrological context. Venice's relationship with water is not only defined by its iconic canals and lagoon but also by the complex challenges of managing WasteWater and ensuring sustainable water use. While the lagoon itself is a fragile ecosystem, the primary issue stems from the sediment and pollutants transported by rivers flowing from the Alps and Apennines into the lagoon. These rivers carry not only silt, which contributes to the lagoon's siltation, but also agricultural runoff, industrial waste, and urban WasteWater. This influx of pollutants threatens the lagoon's water quality and biodiversity, exacerbating issues such as eutrophication and habitat degradation (Bendoricchio & Baschieri, 1997; Zonta et al., 2024). Consequently, the management of municipal WasteWaters and stormwater runoff is critical to preserve the city's long-term sustainability. The city's WasteWater treatment infrastructure and water management strategies are critical to preserving its delicate ecosystem, particularly in the face of pollution, urbanization, and climate change.

Venice's WasteWater treatment system is divided between the historic city and the mainland. The historic city, due to its unique structure and preservation requirements, relies on a decentralized network of septic tanks and small-scale treatment systems. (Archinfo, 2023; Mehrotra, 2025)These systems are designed to oversee the limited capacity of the islands and to avoid disrupting the city's architectural heritage. However, this decentralized approach poses challenges in terms of efficiency, maintenance, and environmental impact, as untreated or partially treated WasteWater can sometimes enter the lagoon.

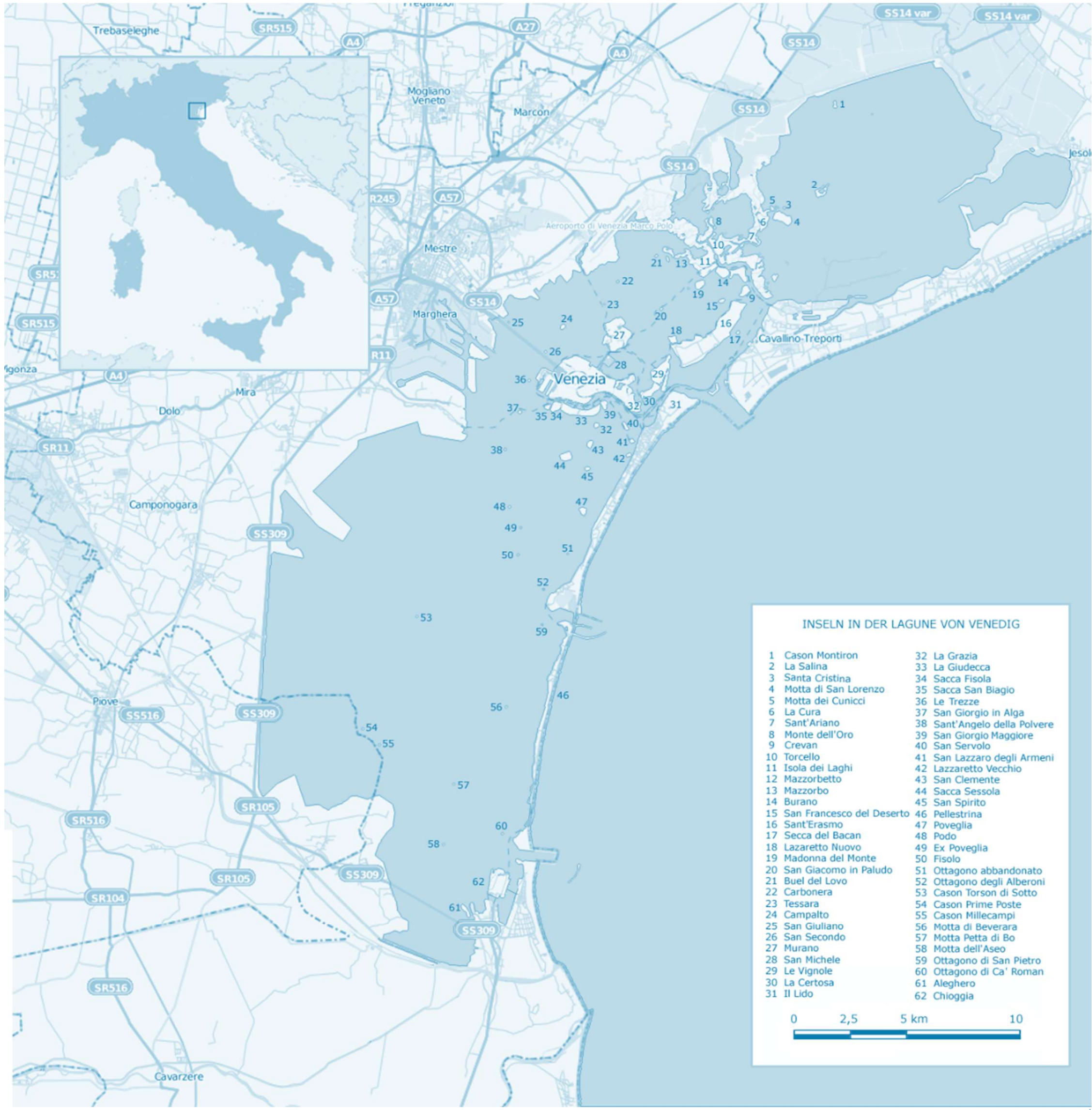


Figure 25. Map of Islands of Venetian Lagoon (based on OpenStreetMap by Nikater, 2011).

On the mainland, Mestre and Marghera are served by more conventional WasteWater treatment plants. The primary treatment facility for the area is the *Depuratore di Fusina*, located near Marghera. This plant treats WasteWater from both residential and industrial sources, playing a crucial role in reducing pollution in the lagoon (Martin, 2022).

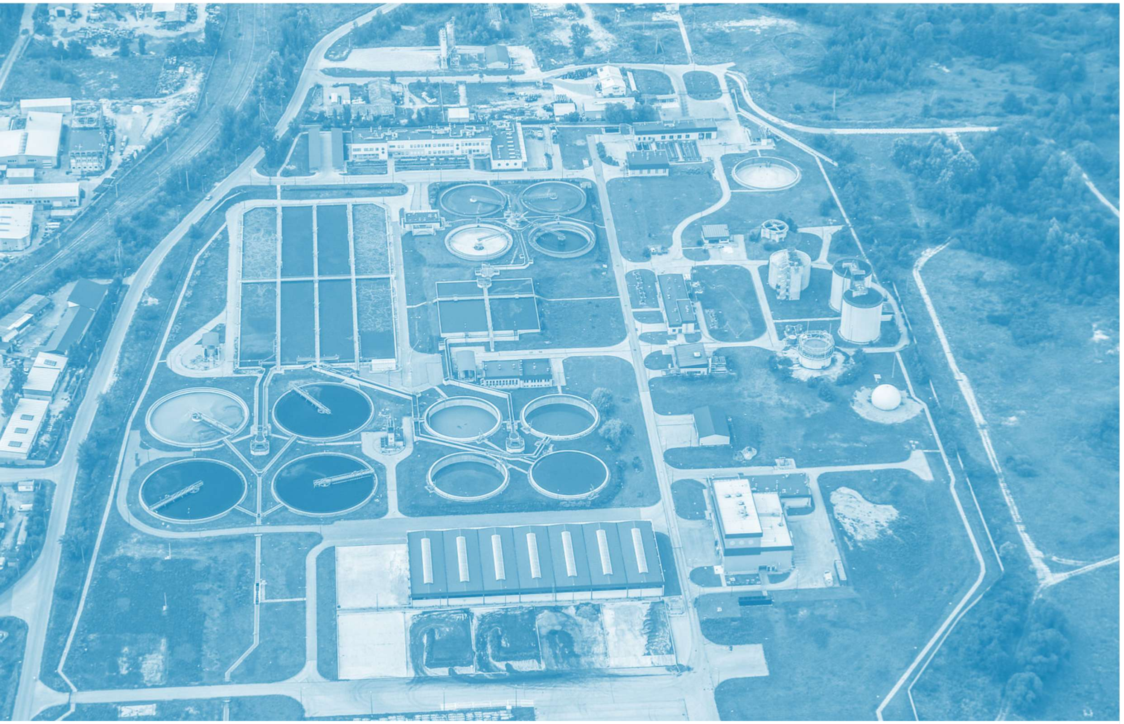


Figure 26. Depuratore di Fusina, Marghera, Venice (Martin, 2022).

The Fusina plant uses advanced treatment processes to remove contaminants, including organic matter, nutrients, and heavy metals, before discharging the treated water into the lagoon or reusing it for industrial purposes. Despite its capacity, the plant faces challenges related to aging infrastructure and the need to accommodate increasing urban and industrial demands. Still, in Marghera, treated WasteWater from the Fusina plant is increasingly being reused for industrial processes, reducing the demand for freshwater and minimizing the environmental impact of industrial activities (Sistema Integrato Fusina Ambiente, n.d.).

Wastewater reuse is an emerging priority in Venice, particularly in the context of sustainable resource management. This practice aligns with broader regional and national efforts to promote circular water management, where WasteWater is treated and reused rather than discharged into natural water bodies. In addition to WasteWater reuse, several water management projects are underway to address Venice's environmental challenges.

Venice's water management challenges are addressed through several strategic plans and projects, One notable initiative is the *MOSE* (Modulo Sperimentale Elettromeccanico) system, a series of mobile flood barriers designed to protect the city from *acqua alta* (high tides) and rising sea levels. While the MOSE system primarily addresses tidal flooding, it also has implications for water quality, as it helps prevent saltwater intrusion into the lagoon and reduces the risk of contamination from industrial and urban runoff. For all that, one of the most significant projects is the *Piano delle Acque del Comune di Venezia* (Water Management Plan of the Municipality of Venice) (Comune di Venezia, 2022). This plan, updated by the Municipality of Venice in 2020, was developed in response to the growing need for a comprehensive and integrated approach to water management in the city. The plan was designed to address the multifaceted water-related issues facing Venice, including flooding, *WasteWater treatment*, and the preservation of the lagoon ecosystem, while also aligning with broader regional and national environmental goals. For example, while the MOSE system addresses tidal flooding from the Adriatic Sea, the Piano delle Acque focuses on managing rainfall-induced flooding and surface water runoff in urban areas, particularly in Mestre and Marghera. This includes improving *drainage systems*, increasing the *permeability* of urban surfaces, and creating *retention basins* to manage stormwater. Furthermore, the plan emphasizes reducing pollution in the lagoon and its tributaries by *upgrading WasteWater treatment infrastructure*, controlling industrial discharges, and promoting sustainable agricultural practices in the surrounding areas. The maintenance of water quality is also linked to ecosystem restoration aspect of the plan, since natural habitats in the lagoon, such as salt marshes and seagrass beds, play a crucial role in maintaining water quality and biodiversity.

However, as explained above, Venice consists of many different areas and the Piano delle Acque includes a range of projects and interventions tailored to the specific needs of different areas within the municipality. In *Mestre*, the plan focuses on upgrading the urban drainage network to reduce flooding during heavy rainfall events. This includes the construction of new stormwater retention basins and the rehabilitation of existing drainage channels. In *Marghera*, the emphasis is on managing industrial WasteWater and reducing pollution from port activities. The plan supports the expansion and modernization of the Fusina WasteWater treatment plant, as well as the implementation of green infrastructure to filter runoff from industrial sites. In the *lagoon*, the plan promotes the restoration of natural habitats, such as salt marshes and mudflats, which function as natural filters for pollutants and provide habitat for wildlife.

It is important to note here that while the Piano delle Acque addresses the whole municipality of the city of Venice, as it should, Marghera and Mestre should be seen separately from the historical city center, especially in the context of WasteWater management. The historic city of Venice, while iconic, presents unique challenges that limit its applicability as a study case for broader urban and environmental issues. The flooding in the historic city, known as *acqua alta*, is primarily caused by tidal surges from the Adriatic Sea, rather than rainfall or surface runoff. This means that traditional stormwater management strategies, such as increasing permeability or constructing retention basins, are largely ineffective in this context, besides the fact that historic city's reliance on canals for transportation and its lack of a centralized sewer system make WasteWater treatment and reuse systems highly specialized and difficult to generalize. Moreover, the historic city's status as a UNESCO World Heritage Site imposes strict limitations on urban interventions. Preservation of its cultural and architectural heritage is a top priority, which often restricts the implementation of modern infrastructure or large-scale environmental projects. For example, the installation of advanced WasteWater treatment systems or green infrastructure may conflict with preservation goals, making it challenging to balance sustainability with heritage conservation.

In contrast, Marghera and Mestre offer greater flexibility for implementing and studying innovative solutions, as they are not subject to the same level of restrictions. Marghera and Mestre, located on the terraferma, are integral parts of the broader Venetian metropolitan area. Unlike the historic city, which is built on a network of islands and canals, these areas are characterized by more conventional and "typical" urban and industrial landscapes. Such characteristics make these areas of Venice also more comparable with other cities of the Pianura Padana (for example, Padua, Verona, Bologna) in matters of urban and environmental challenges.

In fact, distinctive feature of the Piano delle Acque is its emphasis on community engagement and stakeholder collaboration. The plan recognizes that effective water management requires the involvement of local residents, businesses, and government

agencies. Public consultations and participatory planning processes are integral to the implementation of the plan, ensuring that the needs and perspectives of all stakeholders are considered. This collaborative approach not only enhances the effectiveness of water management interventions but also fosters a sense of ownership and responsibility among the community.

The collaboration approach is not limited to only to the involvement of citizens, In fact, the Piano delle Acque is closely aligned with broader regional and national water management strategies, such as the Legge Regionale del Veneto 4 aprile 2019, n. 14, which provides incentives for sustainable urban development and environmental restoration. In the future such approach should be expanded to cooperate with other cities, regions and even countries (with the legal support of national and EU laws and projects). As a matter of fact, despite its comprehensive approach, the Piano delle Acque faces several challenges, including funding constraints, bureaucratic complexities, and the need to balance competing priorities. Nevertheless, the plan represents a significant step forward in addressing Venice's water management challenges, providing a roadmap for sustainable and resilient urban development.

As a matter of fact, the Piano delle Acque, though it has been issued almost 10 years ago, is still relevant, according to Venice's Councilor for Urban Planning, Private Construction, Environment Massimiliano De Martin[27].

According to the Councilor, as an engineer and a venetian, the main hydraulic challenge in Venice is to connect ever larger parts of the city to the sewer system, obviously considering the urban planning difficulties and architectural constraints to which the city is subject. Currently, between purification plants serving relatively new areas (Sacca Fisola and Sacca San Girolamo), mini-purification plants to which hotels, large structures and communities are connected, and condominium tanks or those of single apartments or businesses, over 50% of the city is connected to some form of purification. Such spread of purificators through the urban fabric can help the implementation of secondary WasteWater reuse systems. And though at the moment in the Municipality of Venice there are no specific policies or incentives dedicated to promoting the collection and reuse of rainwater in urban and private areas, at the regional level, the Veneto Regional Law of 4 April 2019, n. 14, provides volumetric incentives for building interventions that include rainwater recovery systems. In

[27] The presented below information are details provided by Venice's Councilor for Urban Planning, Private Construction, Environment, Massimiliano De Martin and his office on February 13th, 2025.

particular, for residential extensions, a 5% increase in volume is foreseen for the adoption of such systems. Furthermore, the management of water resources in the Venetian territory is coordinated by the "Laguna di Venezia" Basin Council, which deals with the planning and management of the Integrated Water Service. The Council's Area Plan, adopted with resolution no. 19 of 13 December 2018, defines the objectives and strategies for efficient, effective and economic management of water resources, in line with regional and national regulations. These planning tools aim to ensure sustainable management of water resources in the Municipality of Venice, addressing both urban development needs and environmental protection.

Another important measure of a purely urban planning nature was Variant no. 90 to the Intervention Plan of the Municipality of Venice, approved with City Council Resolution no. 66 of 14 November 2024, which introduced new urban planning regulations for the areas of planned transformation (which lapsed pursuant to art. 18, paragraph 7, of Regional Law no. 11/2004) and drastically reduced approximately 280 hectares of building areas that would have allowed the development of approximately 2,000,000 cubic meters, depriving them of any building capacity. These areas have therefore become agricultural areas[28] whose possible development must be defined through a public and/or private agreement, a tool that allows the Municipal Administration to evaluate, case by case, whether or not it is worth "consuming land" after having carefully evaluated the intervention proposed by the interested parties. Such approach, in addition to reducing land consumption in line with regional policies, provides for the improvement of the existing building fabric and the construction of new buildings that meet current eco-sustainable construction standards, and promote quality architectural interventions, all while respecting existing and future natural areas, in order to achieve the quality and resilience objectives capable of counteracting the negative phenomena resulting from climate change.

Besides having a regional support and local regulations, the Municipality of Venice is taking part in many initiatives of urban planning nature to mitigate the effects of climate change, which includes storm water management. Among such initiatives there are such projects as STREAM (2020-2022) for the development of strategies for flood management[29], and HYPERION (2019-2022) for the development of a decision

[28] While maintaining the building potential defined by the PAT, as such making it easier to redevelop the area when and if necessary.

[29] It is important to note, however, that this initiative's actions are developed in particular to address coastal risk and not stormwater.

support system based on innovative sensors and modelling tools to improve the resilience and sustainable reconstruction of historic areas[30] and cope with climate change and extreme events. Furthermore, the Municipality is committed to providing strategic responses to the issue of climate change by joining the Mayors' Covenant for Energy and Climate with City Council Resolution no. 29/2020, gathering the experience of international projects and local initiatives.

Among the various initiatives, as Councilor, De Martin underlined, the Municipality of Venice there are definitely those aimed at reducing the impacts of drought and the adaptation of the existing building heritage (and the updating of regulations on the matter) for water saving through interventions of separation of networks and dual systems, treatment and reuse on site, collection of rainwater for non-potable uses (e.g. agriculture), the circular use of water used in industrial processes, etc. At the moment, in fact, there are now consolidated methods for designing and evaluating projects of retention basins, urban drainage systems in car parks, in areas with trees, in road environments, as well as urban forests. The increase in urban greenery, for example, has among its main objectives that of contributing to the attenuation of the effects of urban overheating and of increasing the time of flow of rainwater in sewage disposal plants.

However, while the perspective for secondary WasteWater reuse and the implementation of the necessary systems for it seems positive, it is more complicated.

Councilor De Martin highlights that one of the crucial issues related to water waste and the correct use of the resource is linked to the reuse of purified water: the water that comes out of the purifiers and, after being treated, is to be released into nature. For example, the purified water that comes out of the Fusina plant – 36 million cubic meters/year, 44% of the entire production of Veritas[31] – goes to the Adriatic, 10 km from the coast of the Lido. To resolve this issue, PIF – Progetto Integrato Fusina (Fusina Integrated Project) – was born. In addition to removing waste from the Venice Lagoon, the system is designed to maximize water resource recovery by separately collecting and treating industrial, domestic, rainwater, and groundwater from the Marghera basin,

[30] Whilst the initiative focuses in case of Venice more on the historical part of the city, the technologies developed and used within the initiative can be beneficial for projects in any other city.

[31] Veritas refers to Azienda Veneziana della Mobilità (Venetian Mobility Company), the public utility company responsible for water and WasteWater services besides other services. It plays a central role in managing the city's water systems, including both drinking water distribution and WasteWater treatment (Gruppo Veritas, n.d.).

which are then used for industrial purposes or irrigation. As of February 13th, 2025, all the works have been completed, but the system has not yet been activated.

Another issue is that there are no specific regulations that encourage sustainable solutions for WasteWater management in new construction and building renovations. However, the principle of hydraulic invariance[32] is always foreseen, specifically, during the release phase of all the enabling titles, the maximum limit of WasteWater to be discharged into the collection networks is set to prevent further deterioration of the receiving bodies. Additionally, there are supporting measures that can be of use in matters of WasteWater reuse. Among those, the Municipality of Venice pursues every useful path to maximize the reuse of water. One of the interventions to which it gives greatest support is the completion of PIF, as a strategic technological asset for the treatment and purification of drainage water from the permanent safety margins of the industrial area of Porto Marghera, water from industrial processes, surface runoff and municipal WasteWater from the mainland.

The PIF plant is connected to the open sea by a 160 cm diameter discharge pipeline for approximately 20 km in length which, starting from Fusina, crosses the Lagoon and the Lido of Venice, delivering the purified and non-reused WasteWater into the open sea at a distance of approximately 10 km from the coast and at a bathymetry of -20 meters.

And when asked if Venice is considering nature-based solutions, such as phytoremediation systems[33] or multifunctional green areas, to improve water management, Councilor De Martin pointed out that all the works in the areas managed by the Consorzio di Bonifica Acque Risorgive go towards this objective. Parco di Malcontenta, Parco del Lusore., Parco del Marzenego and other projects are all interventions that deal with water regulation, flood management, phytoremediation and increasing biodiversity. Furthermore, a phytoremediation plant is also planned in the Fusina area where part of the purified water will be conveyed into a distribution network capable of guaranteeing the supply of reused water to the cooling systems of the

[32] The principle of hydraulic invariance states that the hydraulic properties of a system (such as flow and pressure) remain consistent when scaled proportionally, meaning that the relationship between flow, velocity, and cross-sectional area remains unchanged as long as the scaling factors are applied uniformly (Fox & McDonald, 1998).

[33] Phytoremediation systems refer to the use of plants to remove, degrade, or stabilize contaminants from the environment, particularly from soil, water, or air. This process utilizes the natural abilities of plants to absorb, transform, or sequester pollutants, making it an eco-friendly method for environmental cleanup (Furlong & Evans, 2010).

industrial activities located within the perimeter of the Venice's Site of National Interest - Porto Marghera.

So, it is possible to claim that future efforts in Venice in matters WasteWater treatment and secondary use will need to focus on securing long-term funding, enhancing interagency coordination, and leveraging new technologies and innovations to improve water management outcomes.

Such opinion is supported by Councilor De Martin, who reminds that Venice, but also its mainland, is a city of water before being a city on water. The relationship of the territory with this element must be fully recovered after years in which one part has prevailed over the other: renaturalizing the waterways where possible, expanding the green areas [but also maintaining high attention on the multiple functions of the Venice lagoon].

Figure 27. Lusore, the hydraulic system project (ANBI Veneto, n.d.).

Figure 29. Marzenego River Park (VeneziaToday, 2020).

Figure 30. Malcontenta Basin Park Plan-2 (VeneziaToday, 2023).

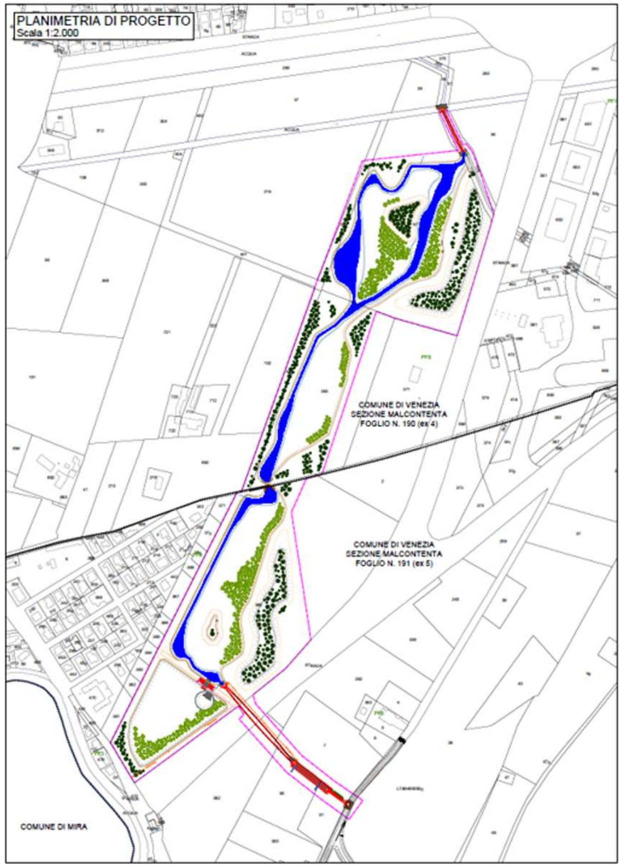
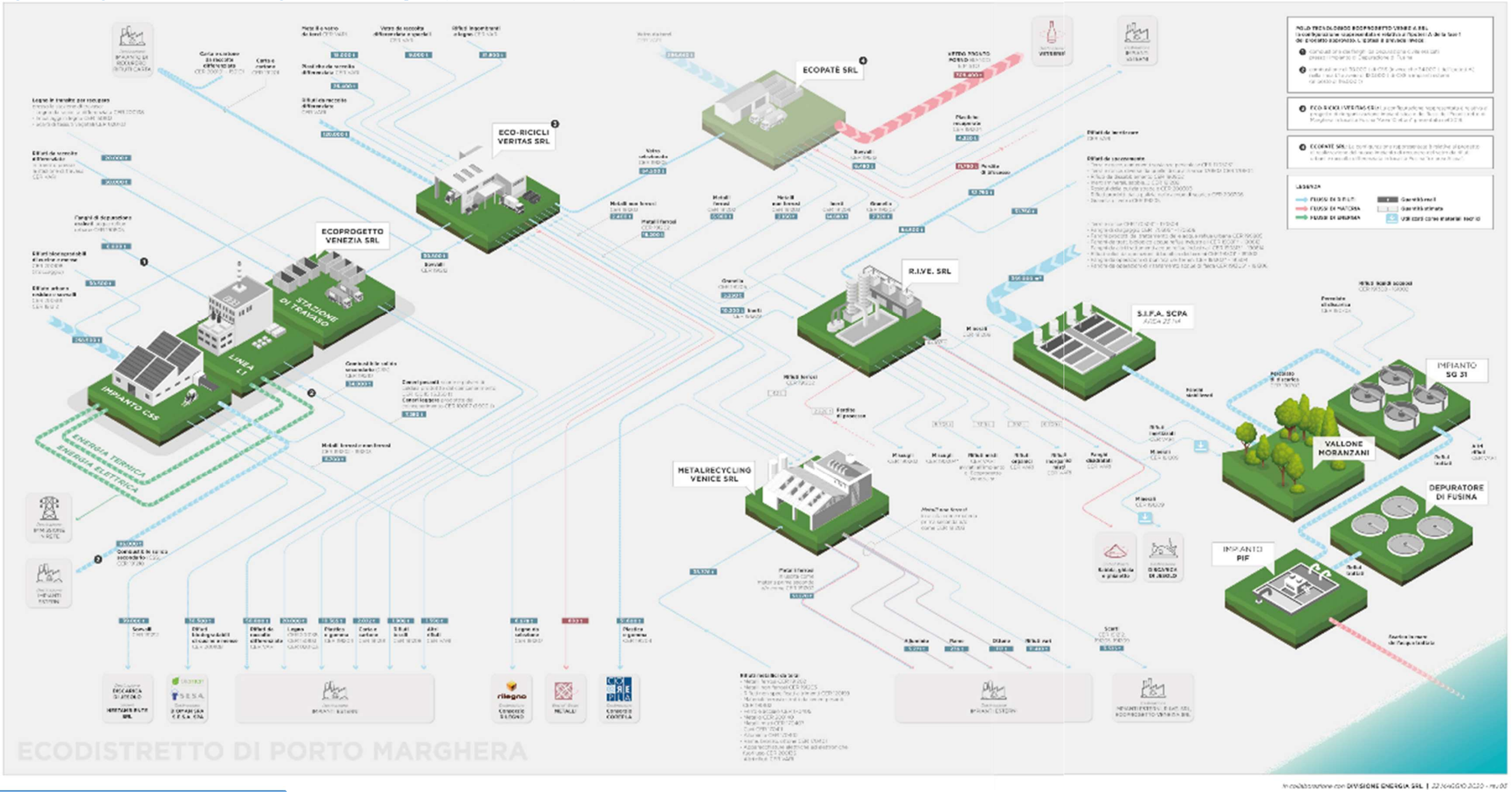


Figure 28. Marghera eco-district, including Fusina treatment plant (Razzini et al., 2020).



7.1.2 Spatial Analysis of Mainland Venice[34]

Besides understanding the legal framework within which a project will be developed, it is also important to understand that a project cannot (and sometimes should not) be implemented immediately on a city-level, so it is important to identify the priority areas of intervention. That can be done with multiple techniques, for SWWUS one of the best approaches is a spatial analysis through a multi-risk index that combines urban flooding – as SWWUS aims to collect and redirect the excessive waters that cause flooding thus preventing it – and UHI – the effects of which can be mitigated thanks to the various implementations of the reuse of treated WasteWater without using more water resources and thus without escalating water scarcity that also enhances the effects of urban heat in cities and not only.

The process of creation and visualization of a multi-risk index (as explained in section 6.4 Methodology,) includes the creation of vulnerability maps that are used for the development of risk maps which in their turn are combined result in a multi-risk map that allows to identify the priority areas for intervention.

The map in Figure 31 presents the flood vulnerability index for watershed basins of mainland Venice[35]. The vulnerability values are classified into five categories, ranging from very low (0 – 0.12) to very high (0.81 – 1), represented in progressively darker shades of blue. The visualization shows how vulnerability varies spatially across the territory, reflecting the interplay between topography, urbanization, and proximity to the lagoon.

[34] The outcomes presented in this section are based on the 2021 available data for this area.

[35] The historical island part of the city has been excluded for reasons explained in the previous section.

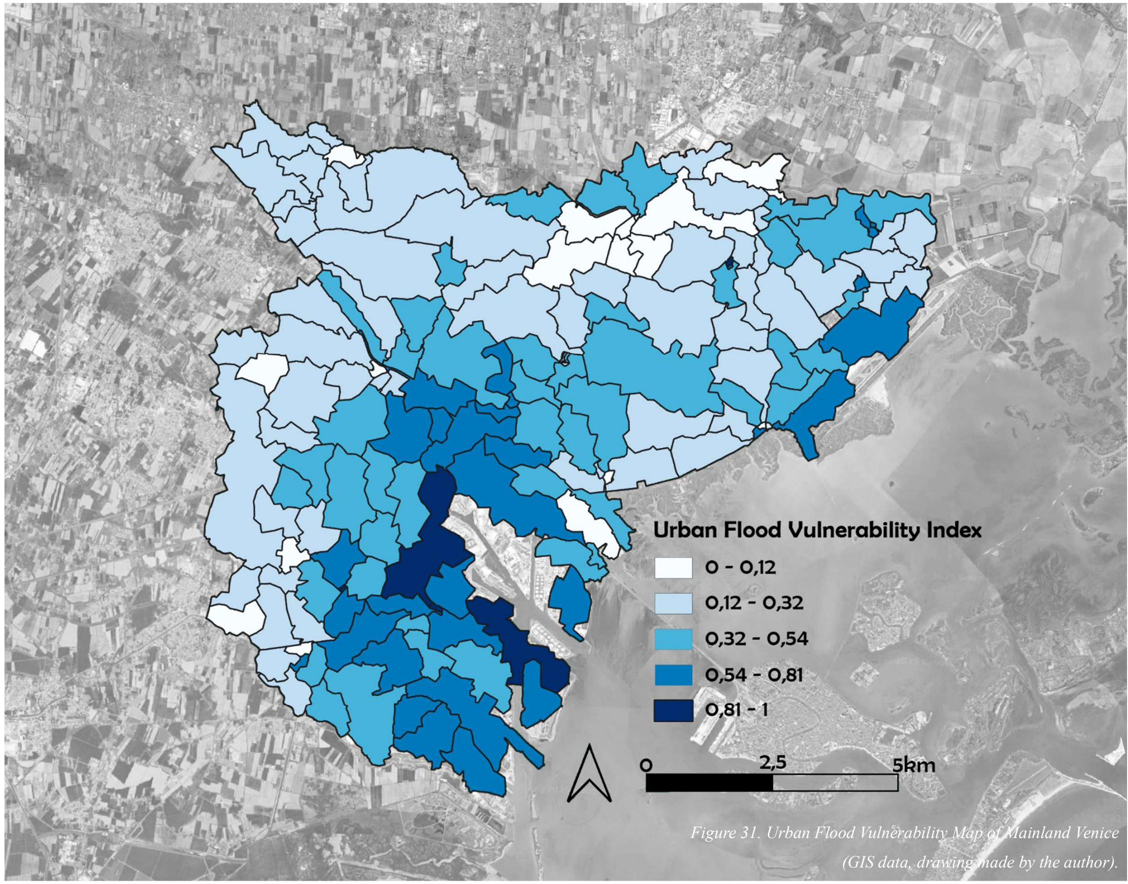


Figure 31. Urban Flood Vulnerability Map of Mainland Venice (GIS data, drawing made by the author).

A flood vulnerability map primarily shows where would the effects be the most damaging if a flood happens, and in case of mainland Venice the high-vulnerability zones, indicated with the darkest blue shade on the map (values 0.81 – 1), are concentrated around Venice's industrial port area (Marghera) and parts of the southern mainland coast, adjacent to lagoon waters. These areas face greater exposure because of their low elevation, ongoing land subsidence, and immediate proximity to tidal inlets and canals[36]. Furthermore, the presence of reclaimed land and heavy industrial

[36] Though this aspect can be considered only in case of when those water bodies overfill due to heavy rainfall, and not in case of high tide. So, while generally it is a high risk zone area, it is important to consider that a part of reasons of why it is such is not directly relevant for the case of this study.

infrastructure magnifies risks, as flooding here can cause both economic and environmental impacts.

A wide band of southern and central areas, particularly those bordering the lagoon, falls within the moderate to high vulnerability range (0.32 – 0.81). These zones combine dense urban settlements, critical infrastructure (transport, utilities), and hydrological connectivity to lagoon waters. Even if not the lowest lying, their urban density and socio-economic activities increase potential damage and disruption.

While the northern and inland territories, shown in the lightest shades of blue, are the lowest vulnerability zones, with the index variating between 0 – 0.32. These areas lie at higher elevations and are further from the lagoon and the bigger water bodies. They also tend to have lower urban density, which reduces exposure in case of flooding.

Thus, a distinct north-to-south gradient emerges: inland areas remain less exposed, while vulnerability intensifies closer to the lagoon edge and industrial port zones. This reflects the combination of geographic position, hydrological risks, and urban development pressures. This vulnerability mapping underscores the urgent need for targeted flood protection measures in high-risk districts such as southern Marghera. Consequently, the new urban expansion in these zones should be strictly regulated, as the existing industrial hub and transport corridors near the lagoon are highly exposed. Reinforcing flood defenses, drainage systems, and adaptive building design, as it will be proposed later in the study more in detail, will be essential to safeguard economic activity and reduce disruption. Additionally, vulnerable populations in dense, lower-income neighborhoods may face disproportionate impacts. So, social resilience strategies – such as community engagement that is already taking place – are as important as physical protections. And with projected sea-level rise, stronger storm surges, and intensifying extreme rainfall, the vulnerability of lagoon-edge communities will increase. The MOSE barrier system offers crucial temporary protection, but it must be integrated with local-scale adaptation, such as elevating buildings and improving natural buffers.

However, while showing useful insights, a vulnerability map is not sufficient to offer a proper identification of risks connected to urban flooding. While the vulnerability map asks where damage would be worst if flooding occurred, the risk map asks where is flooding most likely to cause serious harm, given who and what is in harm's way.

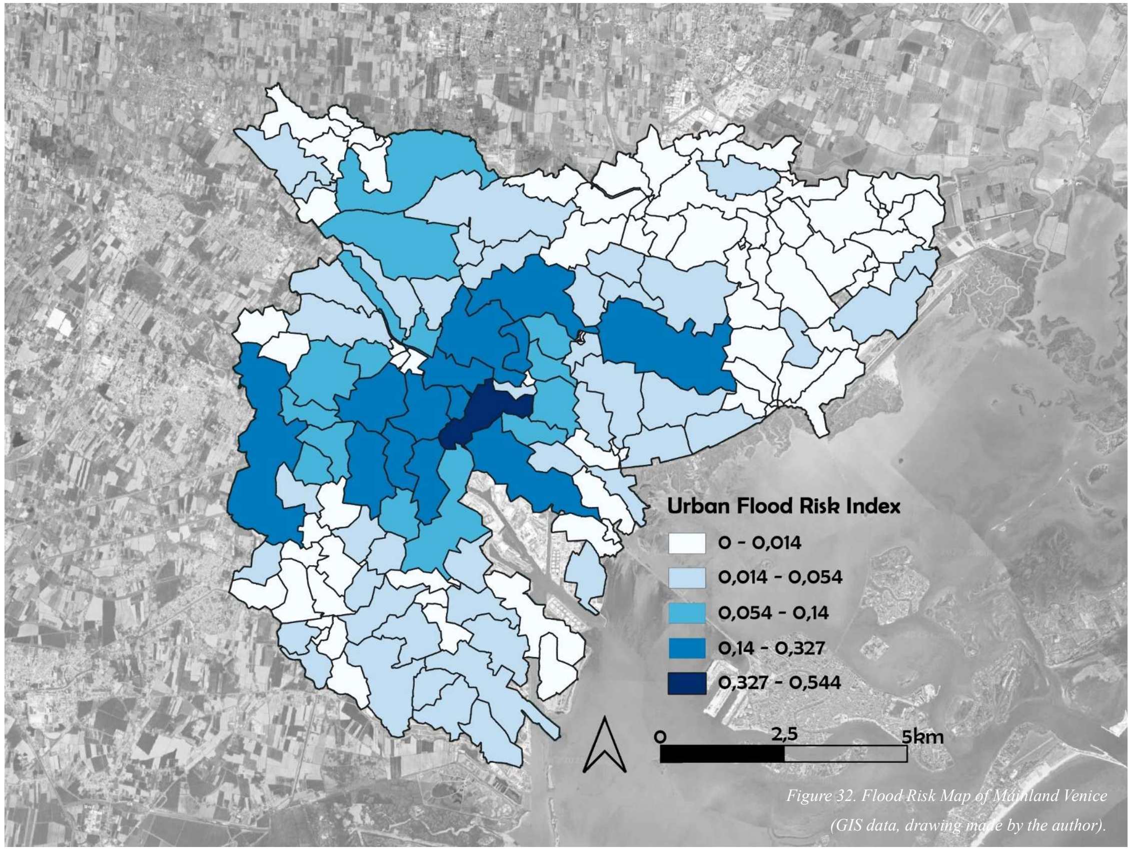


Figure 32. Flood Risk Map of Mainland Venice (GIS data, drawing made by the author).

The map from Figure 32 illustrates the flood risk index for mainland Venice, where the index values are grouped once again into five categories, ranging from very low (0 – 0.014) to moderately high (0.327 – 0.544), represented in increasingly darker shades of blue. Unlike vulnerability, which reflects sensitivity and adaptive capacity, this map integrates probability of flooding and potential exposure, offering a clearer picture of where actual flood events are more likely to occur.

In the flood risk map the higher-risk areas (values range 0.327 – 0.544), indicated in the darkest blue, are concentrated in the central part of the mainland, extending from districts near Marghera and Mestre inland toward surrounding urbanized neighborhoods. These areas are relatively low-lying, with high population and infrastructure density, and a strong hydrological connection to lagoonal waters and canal systems. The central concentration suggests not only lagoon influence but also challenges with urban drainage and stormwater accumulation.

At the same time, a large portion of the southern and western mainland zones fall into the moderate risk band (0.14 – 0.327). These zones are subject to periodic tidal flooding (which is less relevant in this context, but still important to include), heavy rainfall events, and surface water drainage issues, with significant exposure due to residential and industrial land use. While not as critical as the previously mentioned areas, they remain vulnerable to disruptive flood events.

The northern and northeastern grounds generally show lower values (0 – 0.14), with light blue and near-white shading. These areas are situated at slightly higher elevations and further away from direct lagoon influence. Lower urban density also contributes to reduced exposure, though localized risks (e.g., flash floods from intense rainfall) may still occur.

Unlike the previous vulnerability map that showed a clear north-to-south gradient, this risk map emphasizes a central cluster of higher flood risk, surrounded by more moderate to low-risk peripheries. This reflects both urban topography (low-lying basins in the central mainland) and the concentration of critical infrastructures that are more exposed to flooding. Furthermore, this map highlights that central-southern districts face the highest risks, making them priority targets for drainage improvements and flood-resilient design interventions. New developments should be discouraged in medium-to-high risk areas, while existing neighborhoods require adaptive retrofitting and protective infrastructure.

To summarize the urban flood risk aspect of the analysis, both maps identify southern and western portions of the mainland as moderate-to-high concern zones. However, in the vulnerability map, these zones appear more extensive, as it captures socio-economic exposure across a broader area; while in the risk map, the distribution is narrower and more clustered, pointing to specific physical flood-prone basins.

The northern and northeastern districts consistently show lower values in both maps, as these areas are at higher elevation, further from the lagoon, and less densely urbanized. These zones benefit from both reduced flood exposure and lower socio-economic fragility.

However, some lagoon-edge zones show high vulnerability but only moderate risk. This suggests they may not flood as often, but when they do, the consequences are severe (due to fragile infrastructure or socio-economic exposure). Conversely, central inland areas show moderate-to-high risk but lower vulnerability, meaning floods are more likely here, but adaptive capacity or reduced socio-economic fragility mitigates the overall impact.

Based on the outcomes of urban flood analysis it is possible to outline a draft categorization of priority areas:

- **Priority 1.** Zones that are both high vulnerability and high risk (southern Marghera, coastal fringe) that require immediate, integrated adaptation (structural defenses, industrial safeguards, emergency preparedness).
- **Priority 2.** Zones with high risk but moderate vulnerability (central inland clusters) that require focus on drainage improvements, green infrastructure, and water-sensitive urban design.
- **Priority 3.** Zones with high vulnerability but moderate risk (lagoon-facing residential zones) should strengthen social resilience, insurance coverage, and building retrofits, even if floods are less frequent.
- **Lower Priority but Still Relevant.** Northern and east inland zones should maintain monitoring, as climate change may expand flood exposure into currently safer areas.

While these insights are useful, it is not correct to finalize the priority of interventions list without taking into consideration the UHI index.

The map below presents the UHI vulnerability index for census districts of mainland Venice in 2021. The index is based on vegetation cover (NDVI), surface temperature (LST) from spring and summer (02/03/2021 and 09/08/2021 respectively), and socio-demographic variables (age and gender) for a social vulnerability indicator. These values are classified into five categories, from very low (0 – 0.44) to very high (0.547 – 0.909), represented in progressively darker shades of red. This visualization highlights how the lack of green spaces and other factors contribute to the distribution of heat-related vulnerabilities across the territory.

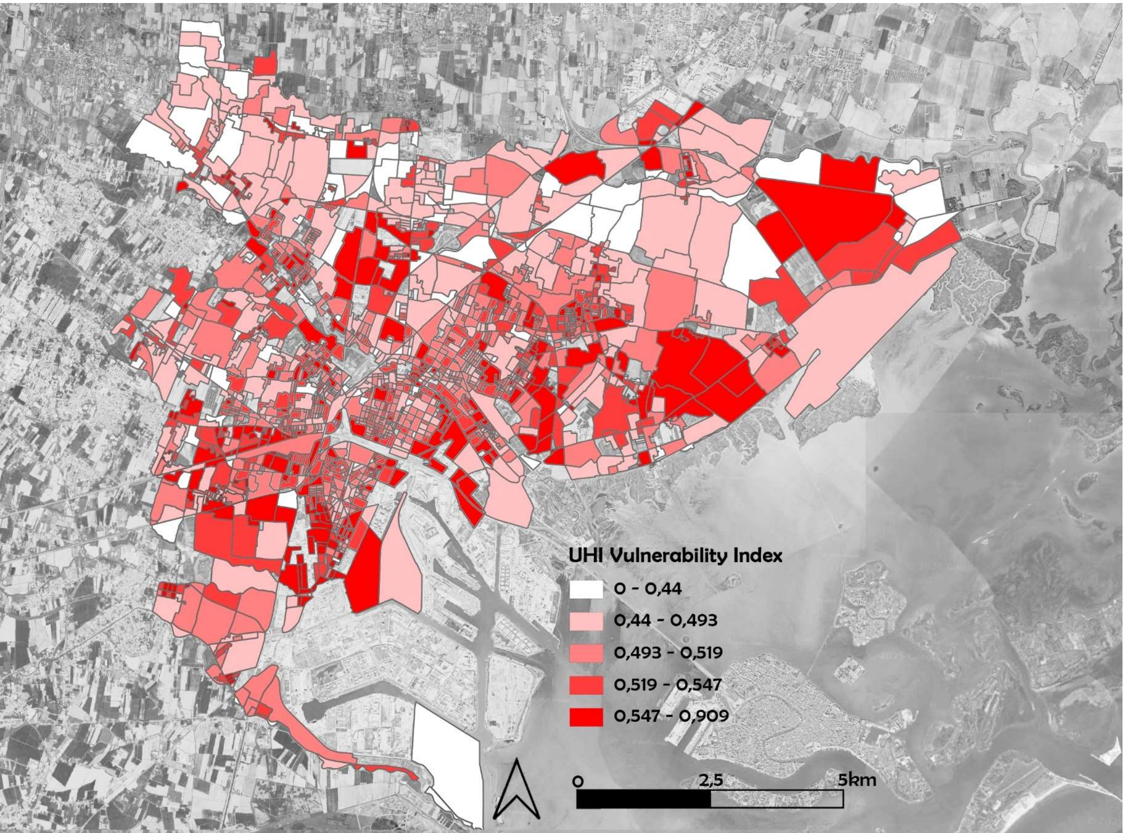


Figure 3233. UHI Vulnerability Map of Mainland Venice (GIS data, drawing made by the author).

High UHI vulnerability zones (0.547 – 0.909), displayed in the darkest red color, are concentrated in the densely urbanized central districts of Mestre, extending toward surrounding neighborhoods. These zones are characterized by dense built-up fabric, limited vegetation, extensive impervious surfaces (asphalt, concrete), and reduced ventilation, which amplify heat retention. The industrial port areas of Marghera also show notable heat vulnerability, as reclaimed land and industrial infrastructure create heat-trapping environments with little natural cover.

A wide swath of residential and mixed-use neighborhoods around Mestre and western residential areas in the industrial area of Marghera are of moderate to high vulnerability (0.493 – 0.547). These districts have patchy green infrastructure, meaning heat mitigation exists but remains insufficient against rising summer temperatures.

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The northern and eastern, peri-urban, and agricultural areas are lower vulnerability zones (0 – 0.493), shown in lighter shades (pale pink to white). These zones benefit from greater vegetation cover, open spaces, and lower building density, which reduce heat accumulation. However, even some of these areas risk increasing UHI vulnerability if urban expansion reduces vegetated land.

Thus, a relatively strong center–periphery gradient emerges where core urban zones (Mestre, Marghera) are of highest vulnerability, the transitional residential belts are moderate vulnerability, and rural and semi-natural northern edges are of lowest vulnerability. This reflects the classical UHI phenomenon, where densely urbanized centers are heat hotspots compared to greener, less developed surroundings. Areas with high UHI vulnerability overlap with densely populated neighborhoods, where elderly residents, children, and low-income groups may face elevated heat stress during summer heatwaves.

Mitigation should prioritize green roofs, tree-lined streets, urban parks, and permeable surfaces in the most heat-exposed districts of Mestre and Marghera. Expanding vegetation corridors could help break up heat-retaining surfaces. However, the heat burden in Marghera requires not only vegetation but also cooling technologies, reflective materials, and sustainable redesign of large paved and industrial zones, especially since with increasing frequency of extreme heat events in Northern Italy, UHI impacts will intensify without adaptation. And to see the possible risks of UHI impacts a UHI risk map could be useful, that, by creating an overlap between heat intensity and population exposure, shows where people are most at risk of suffering from heat stress, particularly in dense residential districts.

The map in Figure 34 presents the UHI risk index for census districts of mainland Venice in 2021. Unlike vulnerability (which focuses on sensitivity), the risk index integrates probability and intensity of UHI effects with population exposure and proximity to water, identifying where heat stress is most likely to occur and cause harm. The map once again uses a five-class scale ranging from very low (0 – 0.036, blue) to relatively high (0.21 – 0.391, red). The colors show a distinction between the urban core and peri-urban areas, highlighting how urbanization patterns can shape local climate risks.

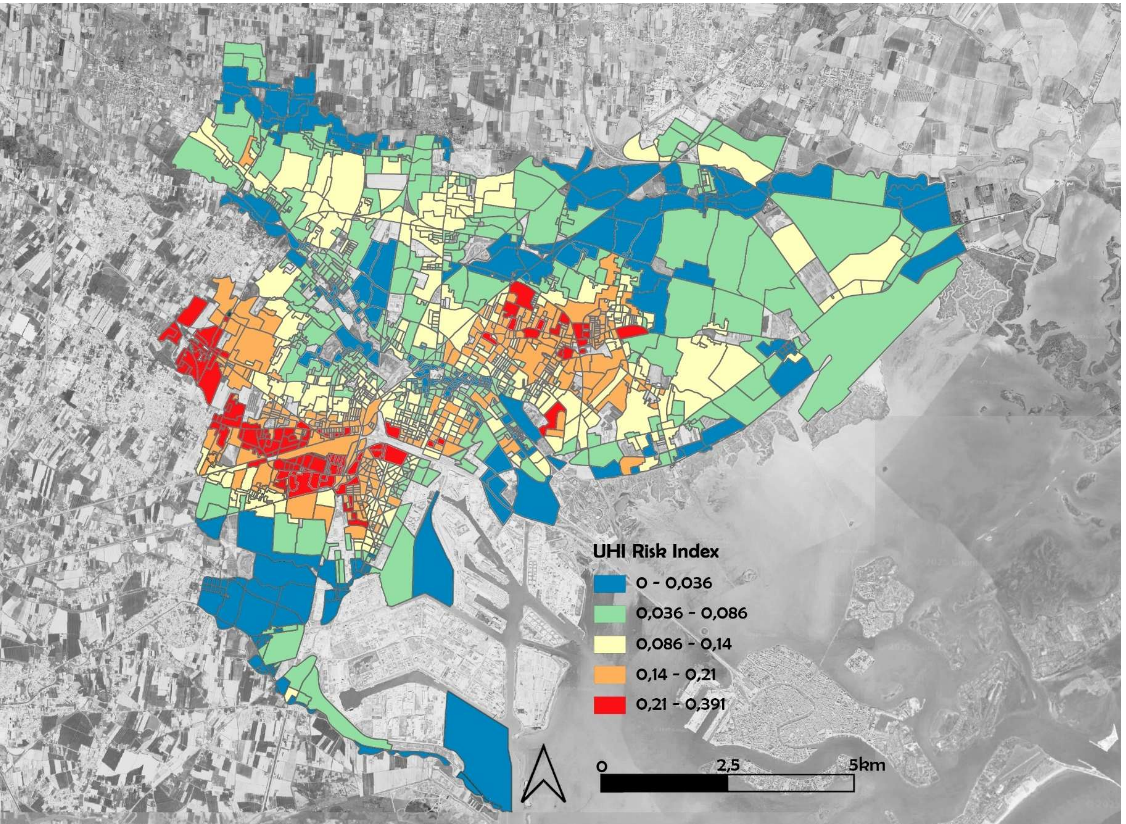

Figure 3244. UHI Risk Map of Mainland Venice (GIS data, drawing made by the author).

Some dense residential neighborhoods to the west and east of the mainland are high UHI risk zones (0.21 – 0.391, red). These areas combine high population density, extensive impervious surfaces, low vegetation cover, and intense urban activity, which exacerbate heat accumulation. Social exposure is particularly high here, meaning large numbers of people may experience severe heat stress during heatwaves.

Moderate to high risk values (0.14 – 0.21), displayed in orange, can be associated with transition zones around the urban core, extending toward suburban districts, as well as parts of the mainland city center. These areas face considerable heat stress risks, though slightly mitigated by partial green spaces and lower density compared to the inner city. Similarly, low to moderate risk values (0.036 – 0.14) in green and light yellow are typical of semi-urban and peri-urban belts, where built-up areas are interspersed with vegetation and open land. Risk is lower because vegetation helps cool the environment, but exposure can still occur during extreme heat. And the lowest risk values (0 – 0.036, blue) are concentrated in northern rural areas and industrial-port complexes with less residential exposure. And although some industrial zones have large impervious areas, low population density reduces human risk, which explains their classification as low UHI risk zones.

Thus, anew, a clear core-to-periphery gradient emerges with central Mestre and dense residential clusters being of highest risk, suburban belts of moderate risk and rural northern and lagoon-edge districts the lowest risk. This aligns with the typical UHI phenomenon where densely built, populated centers function as heat hotspots, while green and open areas at the periphery remain cooler. High-risk areas overlap with densely populated, residential neighborhoods, where vulnerable populations (elderly, children, women) face elevated heat-related health risks and require more urgent adaptation. Such adaptation should prioritize high-risk districts through urban greening (parks, tree canopies, vegetation corridors), reflective pavements and surfaces, increased ventilation in urban design.

Those areas – the urban core of Mestre and some parts of Marghera's industrial-port areas – stand out in both vulnerability and risk maps. These zones have low vegetation, high impervious surfaces, and reduced adaptive capacity, making them structurally prone to overheating. More specifically the urban core of Mestre remains the hotspot, but industrial areas appear less risky despite being vulnerable.

Residential belts around Mestre and coastal edges show moderate to high vulnerability and risk, reflecting fragmented green cover and dense housing. Northern and rural fringe districts appear less vulnerable and show low risk, thanks to stronger vegetation cover and open land, but also due to being less populated.

The UHI vulnerability map highlights where the urban fabric is structurally prone to overheating, while the UHI risk map shows where heat exposure and population overlap most strongly. The two maps converge on Mestre's dense urban core as the critical hotspot but diverge in industrial-port zones (highly vulnerable but less risky) and outer residential belts (moderately vulnerable but at higher risk due to dense populations). Together, they provide a complementary framework for prioritizing climate adaptation, balancing both structural heat risks and human exposure.

Hence, just like in the case of urban flooding, it is possible to draft a priority of intervention list based on the outcomes of UHI risk assessment.

- **Priority 1.** Central Mestre neighborhoods have both high vulnerability and high risk and require urgent greening, shading, and cooling interventions as well as social safety measures.
- **Priority 2.** Residential belts with high risk but moderate vulnerability should focus on people-oriented strategies.
- **Priority 3.** Industrial areas with high vulnerability but low risk, so interventions should protect workers and industrial operations, but broader public health concerns are lower.
- **Low-priority zones.** Northern rural and peri-urban areas, where both risk and vulnerability remain low, though urban expansion should be carefully monitored to avoid future UHI escalation.

Both Urban Flood and UHI assessments offer useful insights to prioritize area of intervention for SWWUS implementation and once combine into one multi-risk index, a finalized categorization can be outlined.

This map (Figure 35) presents a multi-risk index for 2021 census districts of mainland Venice, integrating two major climate-related hazards: flood and UHI risks. The index values are classified into five categories, from very low (0 – 0.037, pale yellow) to moderate high (0.25 – 0.386, brown). This integrated view highlights where combined climate risks overlap, producing compounded vulnerabilities for people and infrastructure.

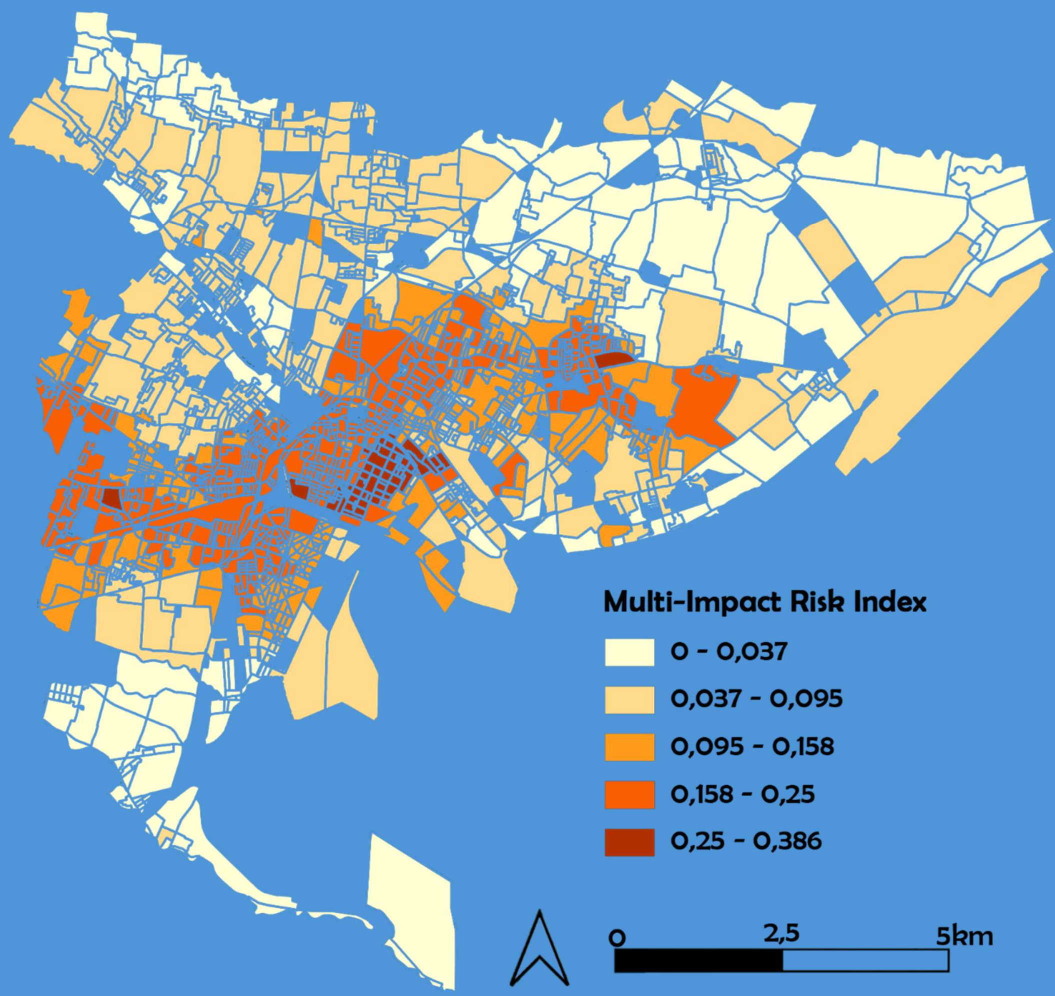

Figure 3255. Multi-impact Risk Map of Mainland Venice (GIS data, drawing made by the author).

The high multi-risk areas (0.25 – 0.386, brown) are concentrated in the central urban core of Mestre These areas are simultaneously highly exposed to flooding (low-lying basins, dense drainage networks) and intense UHI effects (dense built-up zones, scarce vegetation). The convergence of risks here magnifies potential health, infrastructural, and socio-economic impacts.

Moderately high multi-risk values (0.158 – 0.25), displayed in medium orange tones, can be associated with residential area to the west of Mestre and the area along the eastern urban corridor toward the lagoon. These areas face either moderate flooding risk combined with significant UHI risk, or vice versa. They represent important transition zones where multiple hazards overlap at medium intensity.

The moderate risk levels (0.095 – 0.158, light orange) are typical of northern semi-urban and suburban areas where one hazard (flooding or UHI) is present but not both at high intensity. And low to very low multi-risk values (0 – 0.095) highlighted in pale yellow are concentrated in the eastern rural districts and parts of the industrial-port areas (Marghera). In rural zones, risk is low due to vegetation cover, higher elevation, and lower population density. In industrial areas, while UHI vulnerability is structurally high, low residential exposure reduces overall risk in the combined index.

Looking at this map, a core-to-periphery gradient is evident, and it reflects how urban density amplifies both flooding and heat impacts simultaneously, whereas peri-urban and rural areas benefit from natural buffers. Critical hotspots in central Mestre require integrated adaptation measures: flood-proofing infrastructure, WasteWater management, expansion of BGI, and heat mitigation (urban greening, cool roofs, shading), besides social protection policies for vulnerable populations facing compounding hazards. Moderate-risk Transition zones are priority areas for preventive planning, as they may escalate into high-risk zones under climate change. Targeted investments in green corridors, water-sensitive urban design, and sustainable mobility can buffer both flood and heat impacts. And low-risk areas should be preserved and developed as climate buffers (agricultural land, vegetated peripheries). Careful regulation is needed to avoid urban expansion into these currently safer areas, which could raise future risk.

7.1.3 Priority Areas for SWWUS implementation in Mainland Venice

The integrated analysis of flood-related risks and UHI-related risks shows that while these hazards are distributed unevenly, they converge strongly in certain areas, creating multi-risk hotspots where climate impacts are most severe. And while the values generally are not extremely high, which means that the policies and projects in action are being efficient, further action is needed, in certain areas more urgently than others.

The neighborhoods of central Mestre and residential Marghera stand out as the highest climate risk hotspots of mainland Venice, facing both severe flood exposure and extreme UHI stress. Surrounding residential belts (east and west) form a second ring of concern, while northern and rural districts remain relatively safer. If looking more in detail, the following **priority of intervention categorization** can be outlined:

1. **Priority 1. Core High-Risk Hotspots.** These neighborhoods consistently emerge as high in both vulnerability and risk, making them the most critical intervention zones.
    a. *Central Mestre* (historic and dense residential districts):
        i. High flood risk due to low-lying basin topography and drainage limitations;
        ii. Severe UHI vulnerability and risk due to dense built-up fabric, impervious surfaces, and limited vegetation;
        iii. Significant part of population consists of vulnerable groups (elderly, children, women).
    b. *Marghera* residential and industrial fringe (southern mainland near the port):
        i. High flood vulnerability due to reclaimed land, subsidence, and lagoon proximity;
        ii. High UHI vulnerability (heat-trapping industrial zones, low vegetation), though overall risk is slightly moderated in purely industrial tracts because of lower population density;
        iii. Residential pockets within Marghera remain double high-risk zones.

2. **Priority 2. Secondary High-Risk Zones.** These areas are not as critical as Mestre's core, but they show significant combined risks and may worsen under climate change.
    a. *Eastern Mestre* corridor toward the lagoon (Carpenedo, Favaro Veneto, Campalto area):
        i. Moderate flooding risk (surface water challenges);
        ii. Elevated UHI risk due to suburban expansion with fragmented green infrastructure.
    b. *Western Mestre* residential belts (Chirignago and surrounding neighborhoods):
        i. Pluvial flood exposure from basin-like topography;
        ii. Moderate-to-high UHI risk from dense residential development and reduced vegetation.
3. **Priority 3. Low to Moderate Risk Areas.**
    a. *Northern mainland districts* (Zelarino, parts of Favaro Veneto):
        i. Higher elevation, stronger vegetation cover, and lower population density reduce both flood and UHI risks;
        ii. These zones function as climate buffers and should remain protected from urban expansion and developed as buffer zones.
    b. *Industrial-port core of Marghera*:
        i. Structurally highly vulnerable to UHI but lower direct human risk due to limited residential exposure;
        ii. Still critical for economic resilience and worker protection.

These findings provide a spatial priority framework for Venice's climate adaptation strategy within the existing Piano delle Acque with minor legal changes and moderate to significant architectural and spatial updates. The general framework of this climate adaptation strategy for Venice with a focus on mainland area includes urgent interventions in central Mestre and Marghera with a *focus on infrastructure* and social protection; *preventive adaptation* in transitional belts to stop escalation; *preservation* of rural northern buffers to maintain resilience.

A more detailed on-site examination of central Mestre, as a high-priority for SWWUS implementation area, reveals a complex territorial condition that combines infrastructural potential with significant socio-spatial and governance challenges. Specifically, the area surrounding the train station, extending along Corso del Popolo toward Piazza XXVII Ottobre, presents one of the most dynamic yet environmentally stressed urban zones within the Venetian mainland. From a spatial and planning perspective, this portion of the city illustrates both the opportunities and the limits for the integration of secondary wastewater use systems within an established urban fabric.

If structuring the findings from site-visiting and the previous research in a SWOT analysis structure, the **strengths** of the area derive primarily from its existing infrastructural density and strategic urban position. Mestre serves as the functional and residential counterweight to the historic islands of Venice, with a relatively modern and adaptable sewage and drainage system compared to the lagoon core. The district's compact urban form and mixed-use typology provide favorable conditions for decentralized interventions such as greywater recovery, dual-pipe retrofits, and the integration of retention or infiltration systems within public spaces. Moreover, its designation within municipal planning instruments – notably the Piano degli Interventi and the Piano delle Acque – as a priority zone for drainage improvement and public-space regeneration creates institutional support for experimental infrastructure. Site observation confirms the presence of wide road corridors and civic squares that can be reimagined as multifunctional blue-green infrastructure, capable of accommodating stormwater retention, shading, and the reuse of reclaimed water for irrigation.

However, several **weaknesses** constrain the feasibility of implementation. The existing sewer network, though relatively modernized, remains functionally integrated with older systems serving peripheral zones, limiting the capacity for selective diversion and reuse without costly retrofitting. Governance fragmentation persists between municipal technical offices, Veritas S.p.A., and regional agencies, complicating project coordination and long-term maintenance. Socially, the area around the train station faces ongoing challenges of social marginalization and transient population patterns, which can hinder community engagement and public acceptance of infrastructural experiments perceived as disruptive. Economic pressures related to commercial turnover and real estate speculation further complicate the allocation of public funds for infrastructural retrofits that do not yield immediate visible benefits.

The **opportunities** for SWWUS implementation are nonetheless significant. Mestre's role as a testing ground for innovation within the Municipality of Venice positions it to pioneer integrated urban-water strategies at the mainland scale. The availability of EU funding for climate adaptation and circular-economy initiatives – particularly under the NextGenerationEU and LIFE programs – provides potential financial instruments for pilot projects combining wastewater reuse, green infrastructure, and urban regeneration. The area's ongoing public-space redesign initiatives, particularly along Corso del Popolo, align closely with the principles of water-sensitive urban design, offering an opportunity to integrate technical infrastructure within visible and socially meaningful interventions. Moreover, site observations suggest an emerging civic interest in environmental quality, evidenced by the recent greening and pedestrianization efforts, which could facilitate public support for sustainable water initiatives.

At the same time, several **threats** must be acknowledged. Climatic stressors, particularly pluvial flooding and rising temperatures, are projected to intensify, placing additional strain on existing infrastructure. Without coordinated action, isolated SWWUS interventions risk underperformance if not integrated within the broader hydraulic management system of the Venetian mainland. Policy uncertainty also remains a threat: while the Piano delle Acque supports innovative water management, national-level regulations on water reuse (D.M. 185/2003) still impose stringent quality and monitoring requirements that increase operational costs. Furthermore, cultural perceptions of wastewater – often associated with risk or contamination – persist among residents and local stakeholders, creating potential resistance to visible reuse applications in public spaces.

Overall, the analysis of central Mestre identifies the area as a strategic yet sensitive laboratory for the application of SWWUS in a dense urban context. The proximity of institutional attention, the adaptability of the urban fabric, and the availability of EU and municipal policy frameworks create favorable conditions for pilot implementation. Yet, success will depend on overcoming governance fragmentation, addressing public perceptions, and ensuring that technical innovations are embedded within a coherent long-term vision of circular urban development. As field observations revealed, the visible transformation of streets and squares into multifunctional, blue-green spaces could serve not only as infrastructural improvements but as symbolic gestures of a broader transition toward an environmentally regenerative urban identity.

7.2 Shànghǎi

7.2.1 Urban and Policy Framework of Water management in Shànghǎi

Shànghǎi is located on the Yangtze River Delta, and its low-lying, alluvial plain topography, with an average elevation of only four meters above sea level, makes it highly vulnerable to water-related challenges such as flooding, stormwater management, and sea-level rise. It is bordered by the East China Sea to the east and is crisscrossed by the Huángpǔ River and numerous canals, which play a critical role in water management.

Being one of China's biggest cities, Shànghǎi is divided into 16 administrative districts – that could be seen as cities inside a city –, each facing unique challenges and implementing different water management strategies, in accordance to their local strategies. For example, Pǔdōng New Area, a financial and commercial hub, has invested in large-scale WasteWater treatment facilities and flood defense infrastructure; Huángpǔ District, the historical center, where modernizing aging water infrastructure while preserving heritage sites is a key challenge; Qīngpǔ District, home to water towns like Zhūjiājiǎo[37], prioritizes ecological preservation and decentralized WasteWater treatment; Chóngmíng District is a key area for ecological conservation, with wetland restoration projects supporting sustainable water management.

Having such different zones on a big geographical area, the city's policy framework is complicated and multi-leveled, incorporating national programs, local strategies, and international collaboration. But generally speaking, Shànghǎi's approach to water and WasteWater management has evolved in the last years, prioritizing both the challenges of urbanization and climate change.

For example, Shànghǎi is a key participant in China's Sponge City Program, launched in 2015 to enhance urban resilience against flooding and promote water conservation (Tong et al., 2022). The initiative integrates green infrastructure solutions, such as *permeable pavements, bioswales, and green roofs to reduce surface runoff*, as well as *retention ponds and urban wetlands to enhance natural water filtration*. The goal is to achieve 80% of urban area coverage with sponge infrastructure by 2030 And

[37] Shanghai's water towns, such as Zhūjiājiǎo, are sometimes compared to Venice due to their canal-based transportation and historic significance. However, these water towns differ significantly in scale and integration within the broader urban landscape, not sharing the same water (and WasteWater) management issues as Venice [not because of the topography, at least].

a case study indicates that already across major cities – including Shànghǎi – annual urban runoff control rates reached approximately 85% through sponge-city interventions (W12Blueprint, n.d.). These projects aim to transform the city into a resilient and water-sensitive urban environment.

This and other nature-based solutions have been "in trend" for Shànghǎi, which, by embracing those, has invested in developing constructed wetlands and restoring natural waterways to enhance water quality and biodiversity. The Qīngpǔ Loop Waterside Park, covering nearly 150 hectares, functions as a vital ecological buffer by enhancing wetland habitats and filtering stormwater runoff, thereby improving local water quality. At the same time, it provides extensive recreational areas and riverfront spaces for residents. As part of Shànghǎi's wider strategy to develop multifunctional green infrastructure, the park demonstrates how ecological restoration can be integrated with social and economic benefits, strengthening both community well-being and environmental resilience (Better Future Awards, n.d.).

Additionally, wetland restoration projects in Chóngmíng Island and Jiading District help mitigate flood risks, improve biodiversity, and function as flood buffers, integrating ecological goals with urban planning (Ding, 2025; Landezine, 2020).

Furthermore, Shànghǎi has made significant strides in improving its WasteWater treatment infrastructure. With a treatment rate exceeding 90%, the city has established large-scale facilities such as the Báilónggǎng Wastewater Treatment Plant (WWTP), which processes over 2.8 million cubic meters per day (ABB, 2021; J. Gao, 2020).

In terms of WasteWater reuse, Shànghǎi emphasizes industrial applications, particularly in zones such as Pǔdōng, where treated WasteWater is reused for cooling and other non-potable purposes. And while at the national level China's 14th Five-Year Plan (2021–2025) set a target for 25% of urban WasteWater to be recycled in water-scarce cities by 2025, reflecting the country's broader circular water management strategy (Fujian Provincial People's Government, 2021), Shànghǎi' has already achieved a WasteWater treatment rate above 90% (Sing, 2018). Thus, future development and expansion of reuse aligns with national and international sustainability goals.

Figure 36. Báilónggǎng Wastewater Treatment Plant, Shànghǎi (Qin, 2019).

Figure 3727. Shànghǎi Qīngpǔ Loop Waterside Park (Better Future Awards, n.d.).

Figure 38. Surroundings of Báilónggǎng Wastewater Treatment Plant, Shànghǎi (Qin, 2019).

In order to achieve such results, public awareness programs are key. For example, there is China Water Week – an annual national initiative, organized by China's Ministry of Water Resources and promotes public awareness of water safety and conservation (上海水务海洋, 2025). Besides national programs, there are also more local actions: public engagement is a cornerstone of Shànghǎi's water management strategy: these programs focus on integrating water sustainability into school curricula and encouraging local businesses to adopt water-saving technologies (International Services Shanghai, 2020). However, cultural resistance remains a challenge, particularly regarding the safety and quality of reused WasteWater for drinking purposes.

All of these actions are integrated into the latest Shànghǎi Master Plan. The Shànghǎi Master Plan 2017-2035 (Shànghǎi Urban Planning and Land Resource Administration Bureau, 2018)outlines key strategies for improving water management, with the three main focus topics being:

- *Reducing flood risks* in low-lying districts like Baoshan and Pǔdōng through expanded retention basins and updated drainage systems.
- *Improving water quality* by enforcing stricter industrial WasteWater discharge standards.
- *Developing blue-green corridors* along major waterways like Suzhou Creek, which integrate ecological restoration with urban development.

This plan aligns with the Yangtze River Delta Water Governance Plan, ensuring that regional cooperation is part of Shànghǎi's broader water sustainability framework.

Besides, to the Shànghǎi Master Plan 2017-2035 and Yangtze River Delta Water Governance Plan, another important document for urban planning and WasteWater management in Shànghǎi is the Climate Action Plan 2024-2035, that sets a target to achieving 80% Sponge City coverage in urban built-up areas by 2030 (Shànghǎi Municipal Leading Group Office of Ecological Civilization Construction, 2024). The Sponge City initiative aims to optimize rainwater management. To assist with it and the general water management, China is actively promoting digital twin technologies in the water sector. These systems provide real-time digital representations of water infrastructure and bodies—which support resilience, planning, and resource management (W. Li et al., 2024).

This line of actions has been confirmed by Tian Feng, Deputy Director of the Rural Division of the Shànghǎi Municipal Planning and Natural Resources Bureau on March 2025. The following are extracts of responses he received when he asked the

relevant technical staff of the Qīngpǔ District Planning and Natural Resources.

The Resources Office has confirmed that at present, Shànghǎi has several artificial wetland projects, which are supported by central government funds, to treat agricultural diffuse pollution runoff. This is a project that uses multi-tiered artificial wetlands (e.g., planting aquatic plants with strong decontamination ability) to naturally restore water quality through plants to improve river water quality. At the same time, WasteWater from new buildings and building renovations is generally disposed of by sedimentation in three-stage sedimentation tanks and then reused, for example, during events that promote WasteWater reuse among citizens. An example of such reuse at present, is the popular check-in point of Qīngpǔ Xújīng Pánlóng Tiāndì, that uses the water treated by the sewage treatment plant to enter small and medium-sized rivers to improve the water quality and water ecology problems caused by insufficient water dynamics in regional rivers.

Speaking of Qīngpǔ – one of the largest districts of Shànghǎi – in terms of WasteWater management, the district's landscape is dominated by waterways, including rivers, canals, and lakes, with its proximity to Lake Dianshan and the Yangtze River Delta providing both opportunities and challenges for water management. And, as mentioned above, Qīngpǔ is also home to water towns like Zhūjiājiǎo – sometimes referred to as the "Venice of Shànghǎi" –, which is known for its historical canal systems and traditional water-based culture.

The district's low-lying topography and extensive water systems make it particularly vulnerable to flooding and water pollution, but they also provide a foundation for innovative water management solutions, including nature-based solutions and decentralized WasteWater treatment strategies. As such, Qīngpǔ is a relevant case study area for WasteWater research in urban planning due to its blend of historical urban areas, modern residential developments, and ecological conservation efforts. Currently, the sewage system there is mainly rural domestic sewage, farmland tailwater[38] and aquaculture tailwater, according to Qīngpǔ District Planning and Natural Resources.

[38] Tailwater refers to the runoff or return flow of water that has been used for irrigation or other agricultural activities, typically discharged from fields or irrigation systems into nearby water bodies. It often contains dissolved nutrients, pesticides, or sediments, potentially contributing to water pollution if not properly managed (Waller & Yitayew, 2015).

In some suburban villages, due to the high cost of laying and operating pipe networks, it is impossible to collect and send them to urban centralized sewage treatment plants. Currently, rural areas primarily use on-site treatment facilities for rural domestic sewage, and after treatment, the effluent meets the standards for discharge into water bodies.

Currently, Qīngpǔ District, according to Qīngpǔ District Planning and Natural Resources, has 10 urban sewage treatment plants to collect and treat industrial WasteWater and domestic sewage. Due to the high collection and treatment rates of industrial and urban domestic sewage, the water quality of surface water in the entire district has now reached the standard of Class III water. Class III is characterized by moderate levels of pollutants, but the water still meets specific criteria for safe use in most non-drinking applications, according to the classification is part of the "Environmental Quality Standards for Surface Water" (GB 3838-2002), which sets five classes (I-V) based on parameters like oxygen content, pH, and pollutants. These classes are used to assess the suitability of water for different uses, including drinking, irrigation, industrial, and recreational purposes:

- Class I (Best quality). Suitable for the protection of aquatic life, as well as for potable water after minimal treatment.
- Class II. Suitable for drinking water (after treatment), aquatic life protection, and general industrial use.
- Class III. Suitable for agricultural irrigation and general industrial use, as well as for some recreational activities like swimming (but not drinking).
- Class IV. Suitable only for agricultural irrigation or industrial uses that do not require high water quality. Not suitable for swimming or drinking.
- Class V (Worst quality). Only suitable for very limited industrial purposes (e.g., cooling water) and irrigation of non-food crops.

Shànghǎi has already issued emission standards for aquaculture tailwater and requires the establishment of tailwater treatment facilities for treatment and discharge in compliance with standards.

Furthermore, Qīngpǔ has been an active participant in Shànghǎi's broader Sponge City Program, specifically working on permeable pavements and green roofs to absorb rainwater and reduce runoff, retention ponds and wetlands as natural filtration systems, and rain gardens and bioswales to absorb excess water and improve water quality.

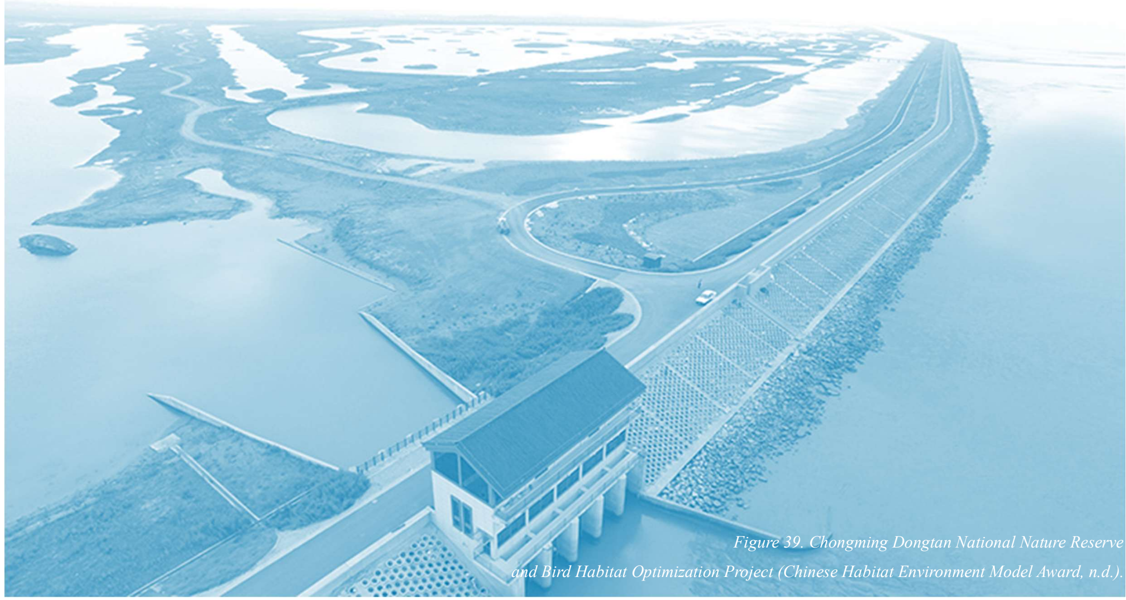

Figure 39. Chongming Dongtan National Nature Reserve and Bird Habitat Optimization Project (Chinese Habitat Environment Model Award, n.d.).

As part of this action plan, Qīngpǔ has adopted a robust set of nature-based solutions to improve water quality and mitigate the impacts of climate change. These solutions focus on ecological restoration, including the restoration of natural wetlands and the creation of green corridors that connect urban areas with natural spaces. Within such projects there are the Chóngmíng Dongtan Wetland Restoration, a Ramsar-listed wetland site, which provides essential flood control and biodiversity conservation, and ecological riverbank restoration along the Zhūjiājiǎo canals, where natural vegetation is used to filter pollutants and reduce erosion. These projects highlight Qīngpǔ's focus on integrating nature into urban planning, improving water quality, and enhancing the district's resilience to environmental changes (IW:LEARN, 2014; Ramsar Sites Information Service, 2017).

However, the integration of some projects can be complicated, as, due to its unique geography, Qīngpǔ has been using decentralized WasteWater treatment systems. Generally, such systems complement the district's larger-scale infrastructure, but in suburban areas and smaller water towns like Zhūjiājiǎo, small-scale treatment plants have been established to provide more efficient localized WasteWater treatment. These systems utilize constructed wetlands and bio-filtration techniques to treat WasteWater before releasing it back into the environment (IW:LEARN, 2014).

And, in addition to decentralized treatment, the district also integrates rainwater harvesting systems to reduce the demand for potable water. Residential areas and public buildings are encouraged to collect and store rainwater for non-potable uses such as irrigation and landscape maintenance, reducing pressure on the municipal water supply and WasteWater systems.

All these initiatives align with the water management objectives included in the Shànghǎi Master Plan 2017-2035. Being one of the largest districts in the city, Qīngpǔ plays a significant role in achieving those objectives through such actions as *flood risk reduction* through improved drainage systems and expanded retention basins in low-lying areas like Zhūjiājiǎo and other parts of Qīngpǔ. Additionally, a big goal is *the development of blue-green corridors* along major waterways like Zhūjiājiǎo canals to enhance water management while fostering community engagement and ecological preservation.

By working towards these targets, the surface water quality in Qīngpǔ District has improved significantly over the past 20 years, according to Qīngpǔ District Planning and Natural Resources. At present, the surface water quality has been completely eliminated from black and smelly and inferior V-class water, and the water quality of the main rivers has basically reached the Class III water standard. According to Dr. Tian, with Shànghǎi's ongoing efforts to remediate sewage outlets into rivers and address mixed rainwater and sewage, this initiative is expected to be fully completed by 2026, while also accelerating the development of beautiful rivers and lakes: the water environment has shifted **from pursuing physical and chemical indicators to ecological indicators**.

7.2.2 Spatial Analysis of Shànghǎi

Contrary to Venice, the spatial analysis for Shànghǎi cannot be used to identify priority areas for SWWUS implementation due to data limitations. One of the core datasets necessary for this analysis is the census data that for Shànghǎi is available only on the district level which – in case of such big city as Shànghǎi – gives overly generalized information. Nevertheless, this information can still offer interesting insights on the different areas of the city. However, it is possible to presume that the areas that would result most at risk would be the historical city center due to its higher number of inhabitants, population density and vicinity to the Huángpǔ river. Furthermore, interventions in that area would include working with historical and cultural heritage – similarly to Venice's island historic city center – which would complicate the implementation of treatment and reuse systems. Hence, districts from Shànghǎi city center (Huángpǔ, Xúhuì, Jìng'ān, Hóngkǒu, Yángpǔ, Pǔtuó and Chángníng) have been excluded from the final analysis: while there will be for each step present a map of the whole area of Shànghǎi, the analysis will be done based on the map where those districts are excluded. Additionally, Chongming district located on islands the north of the city is also excluded as it is [mainly] a natural reserve area that is under protection from urban development, thus SWWUS implementation is neither urgent nor possible there in the context defined by this study.

With the increasing urban development of Shànghǎi urban and rural areas, this analysis will focus on districts with higher redevelopment and development pressures. Specifically, Qīngpǔ, while not being of the central and more populated districts of Shànghǎi, with its vast green areas, canals and its proximity to the Dianshan lake which can in the future become an important reservoir of potable water for Shànghǎi. Furthermore, Qīngpǔ can be an interesting area of focus for preservation actions, in contrast to the mitigation actions more suitable for the Venice case study.

Figure 4280. Shànghǎi administrative structure (Master en Comercio y Finanzas Internacionales, 2009).

Chapter 7 Integrated Urban Analysis for WasteWater Reuse Planning

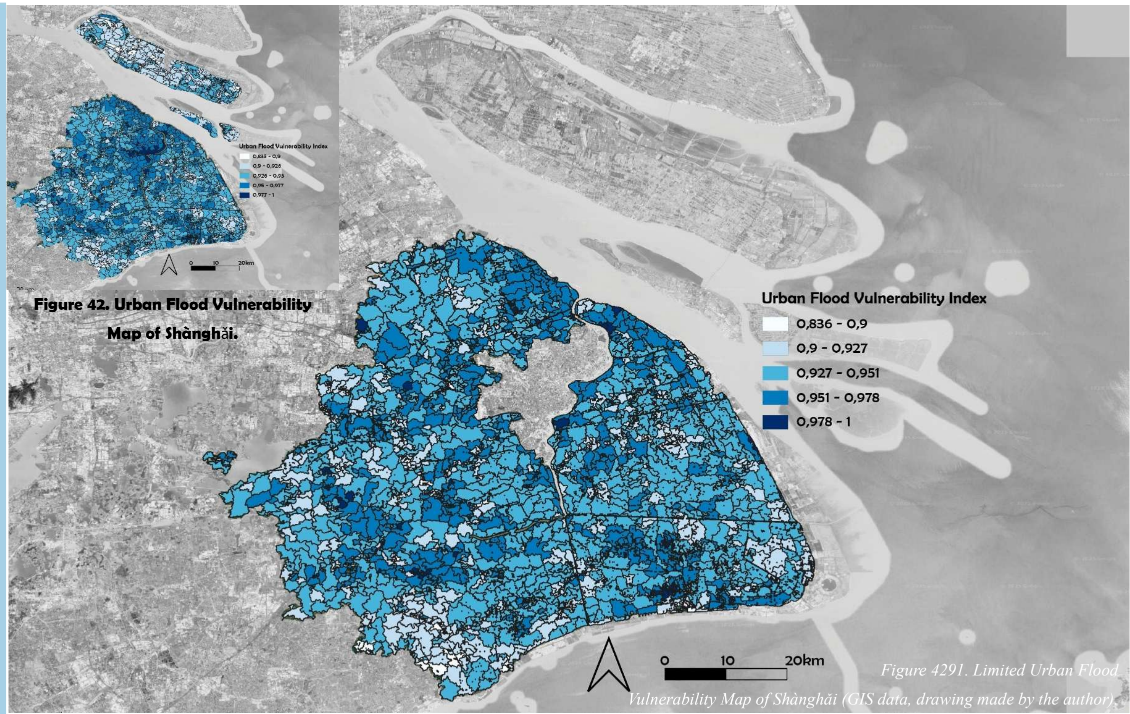

Figure 4291. Limited Urban Flood Vulnerability Map of Shànghǎi (GIS data, drawing made by the author).

The map in Figure 41 illustrates the urban flood vulnerability index for Shànghǎi, broken down into watershed basins units. Vulnerability measures the potential severity of damage if flooding occurs, considering factors such as land elevation, drainage capacity, urban density, and the sensitivity of local populations. For this Shànghǎi's flooding vulnerability index values range from lower vulnerability (0.836–0.9, white and light blue) to very high vulnerability (0.978–1, dark blue). The distribution highlights how vulnerability is unevenly spread across Shànghǎi, shaped by geography, urban development patterns, and exposure to hydrological pressures.

High to very high vulnerability (0.951–1) areas in medium to dark blue are dispersed mainly in central, northern, and southeastern territories, particularly along the Huángpǔ River and near low-lying inland basins. These areas are densely urbanized, low-lying, and (for the central and northern districts) heavily populated, meaning that floods would cause widespread disruption and potentially severe damage. Vulnerability is also probably amplified by the aging drainage systems and limited green and permeable surfaces, which reduce flood absorption.

Moderate vulnerability areas (0.9–0.951, light to medium blue) are spread across much of southern and eastern Shànghǎi, covering large suburban districts. These areas face significant exposure but retain some buffering capacity through more open land, slightly higher ground in some areas, or newer infrastructure. However, vulnerability could escalate with continued urban expansion and climate change-driven rainfall increases.

Lower vulnerability values (0.836–0.9, white to very pale blue) are concentrated in the southwestern and some western peripheries of Shànghǎi. These areas benefit from higher elevations, greater vegetation, and less intense urbanization, which reduce sensitivity to flooding. Additionally, these areas historically have a widespread network of canals which have flood-preventing construction and the urban development in these areas has been done by taking that into consideration.

There is no evident spatial gradient of flood vulnerability, but some implications are still possible, such as southern areas from east to west are emerging problem areas, so proactive adaptation (e.g., BGI, permeable surfaces, water-sensitive design) is needed to prevent escalation. Furthermore, they should be preserved at least partially as climate buffers, protecting open land and green areas to maintain flood resilience. Especially considering that more intense typhoons and extreme rainfall events will likely push more areas of the city into higher vulnerability categories. Building integrated water management systems (linking flood control, WasteWater reuse, and urban cooling) is essential to future-proof the city.

This map below (Figure 43) presents the urban flood risk index for Shànghǎi. Unlike vulnerability (which reflects the potential damage if flooding occurs), the risk map identifies where flooding is most likely to cause harm, combining hazard probability (likelihood of flooding) with exposure (e.g., amenities, buildings). The index values are grouped into five classes, from very low risk (0–0.019, white) to relatively high risk (0.249–0.477, dark blue). This highlights how risk is not evenly distributed but instead clusters around specific urban cores and drainage basins.

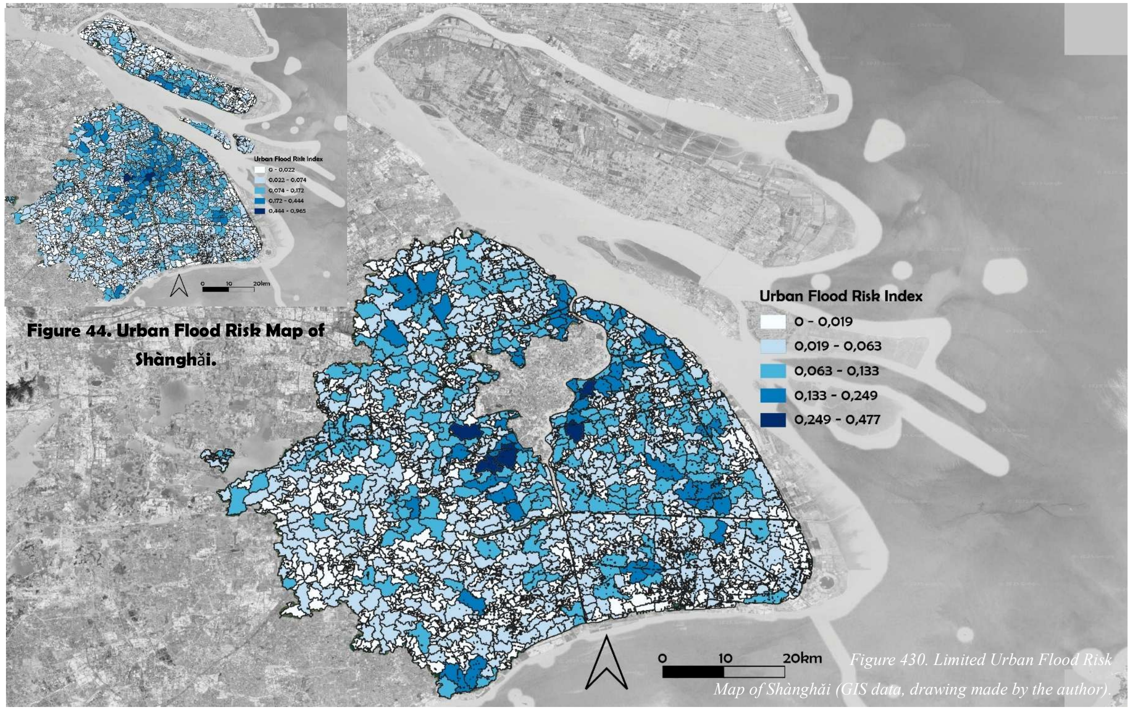

Figure 44. Urban Flood Risk Map of Shànghǎi.

Figure 430. Limited Urban Flood Risk Map of Shànghǎi (GIS data, drawing made by the author).

More high risk zones (0.133–0.477, medium to dark blue) are concentrated around central Shànghǎi; several inland urban basins emerge as dark blue hotspots, reflecting drainage bottlenecks and high population density. These areas are not necessarily the lowest-lying (like the eastern coast) but are pluvial flood hotspots, where heavy rainfall frequently overwhelms stormwater systems.

Moderate risk areas (0.063–0.133) in light blue can be found across large portions of eastern and northwestern Shànghǎi. These zones face a medium likelihood of flooding, typically due to growing urbanization, partial drainage capacity, and dense but not maximum exposure. They function as transitional belts between the high-risk inner core and lower-risk peripheries. Those low risk areas (0–0.063, white to pale blue) are concentrated southwestern to southeastern peripheries. These territories remain relatively safer because of higher elevation, more vegetation, and lower urban density, which reduce both flood probability and exposure. They currently function as buffers, though unchecked urban expansion could erode this resilience.

The map reveals a central-northern concentration of risk, rather than a simple coastal-to-inland gradient. River-adjacent zones (Huángpǔ corridor) and urban basins in central districts would be the most critical hotspots. Moderate risk transitional zones should be targeted with preventive measures – such as permeable pavements, BGI, and adaptive land-use planning – to avoid escalation into higher risk categories and to enforce the buffer area around the more critical and prone to flooding urban core.

Interestingly, both urban flood vulnerability and risk maps show broad transitional belts of moderate values in southern and eastern Shànghǎi. On the vulnerability map, these areas appear sensitive because of rapid urbanization and reduced green cover. On the risk map, they register frequent moderate flooding likelihood, especially during heavy rainfall, due to higher urban development and density, followed by a more elevated number of amenities, which are affected by sudden flooding. Additionally, eastern coastal districts appear more vulnerable, but less risky, as flood probability inland from tidal surges is lower compared to rainfall-driven flooding. This means catastrophic events here are less frequent but more damaging, which is why when talking about flooding risk it is important to differentiate the reasons behind flooding: while rainfall-driven flooding as a one-time occurrence may be less damaging the cumulative effect of it can become comparable to tidal catastrophic flooding, especially for the inland pluvial basins with drainage blockage. In those cases, drainage infrastructure upgrades, stormwater retention basins, and WasteWater reuse systems to reduce both flood frequency and damage potential must be prioritized.

This map in Figure 45 illustrates the UHI vulnerability index for Shànghǎi, aggregated at the district level by 2021 census[39]. Vulnerability here refers to the sensitivity of urban areas and populations to the damaging effects of extreme heat, including vegetation cover and the age of buildings. Values of the index range from very low vulnerability (0.12–0.147, white to light pink) to moderately high vulnerability (0.554–0.628, red).

[39] While data for the following years is available, for comparability reasons, the same year as for the Venice data was chosen for the analysis framework of Shanghai.

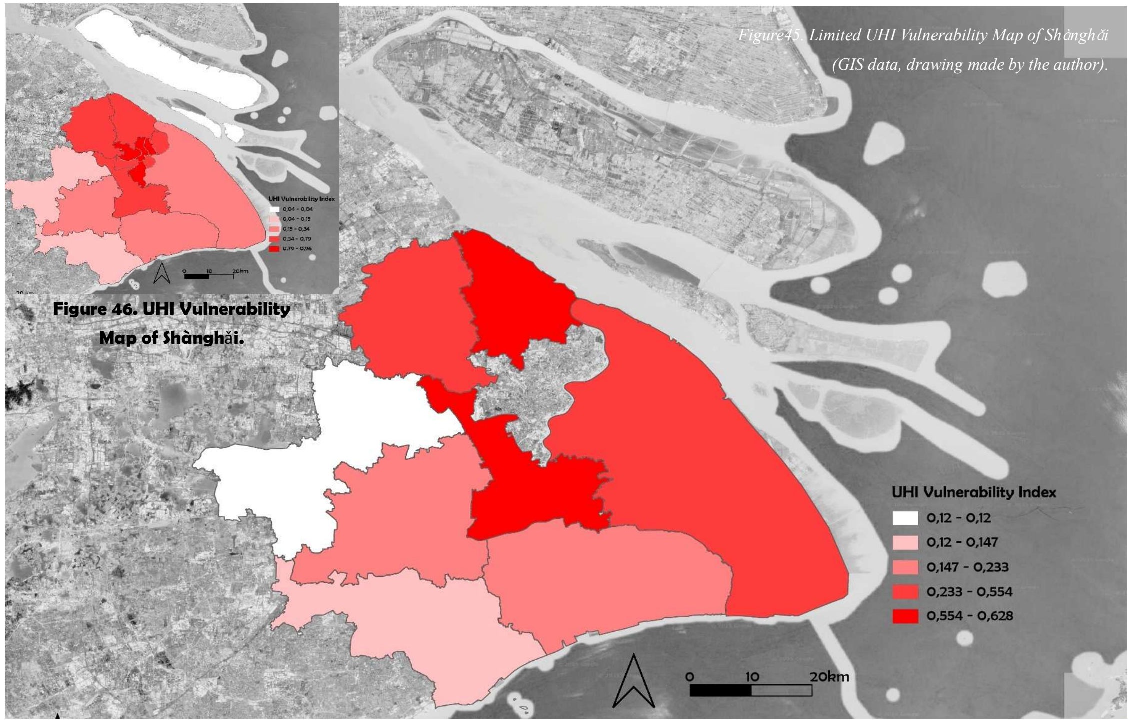

Figure 46. UHI Vulnerability Map of Shànghǎi.

Figure45. Limited UHI Vulnerability Map of Shànghǎi (GIS data, drawing made by the author).

Higher vulnerability values (0.233–0.628) in the more intense red shades are concentrated in northern, central, and eastern districts. These areas are characterized by dense urbanization, continuing urban development, extensive impervious surfaces, and limited to only certain areas vegetation, which amplify the UHI effect. High population densities increase exposure, making heat impacts on public health, energy demand, and infrastructure stress particularly acute.

Lower vulnerability values (0.12–0.233, pink to light red) can be found in southern and southeastern districts surrounding from bellow the high-vulnerability core. These areas show mixed land uses, combining urban development with partial green and open spaces, which reduces vulnerability compared to the core but leaves them sensitive to intensifying heatwaves. And the lowest vulnerability values (0.12, white) are in the western peripheries. These areas benefit from greater vegetation and water network cover, lower urban density, and more open land, providing natural cooling and buffering capacity. They currently represent low-exposure zones but may face increasing vulnerability if urban expansion continues.

The spatial distribution shows a clear concentration of heat vulnerability in the northern, central, and eastern urban districts, while peripheral western and southwestern areas appear less exposed. This reflects Shànghǎi's UHI profile, where the most intense impacts concentrate in the dense built-up heart of the metropolis and decline outward. This underlines the need for expansion of parks, tree-lined streets, and green corridors, which need more water capacity for irrigation. Furthermore, vulnerable districts face higher risks of electricity demand surges during extreme heat. Investments in cool roofing, reflective pavements, and water-sensitive design will help reduce system stress, which will only increase if no action is taken with rising global temperatures.

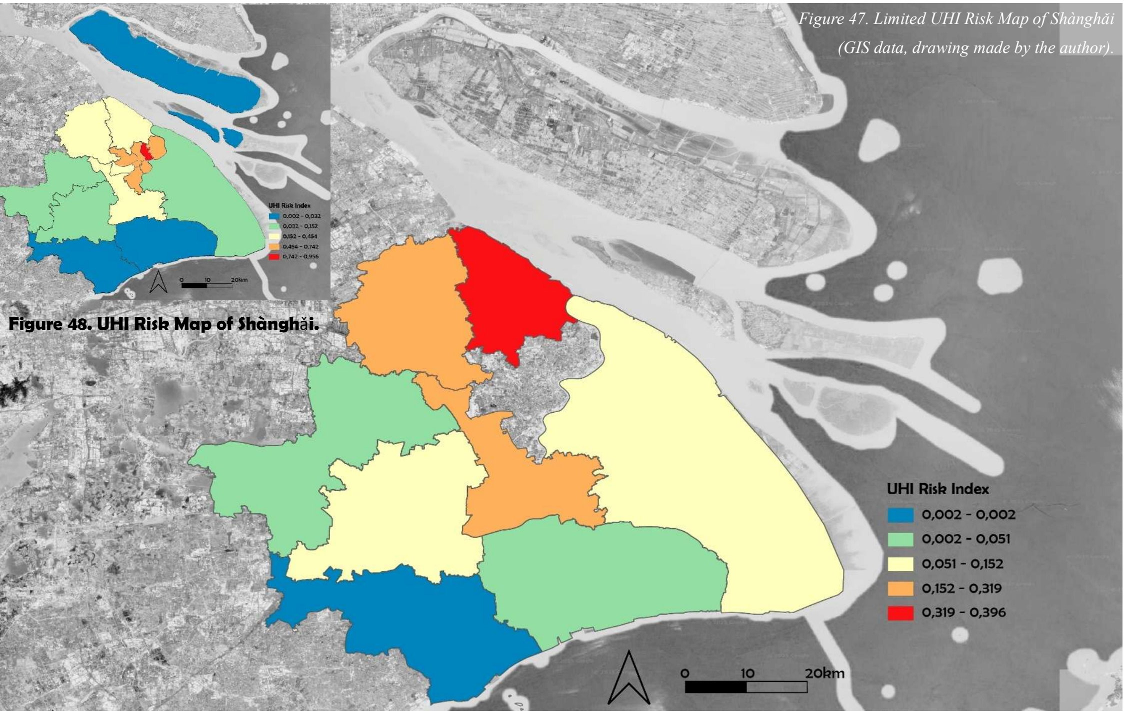

Figure 47. Limited UHI Risk Map of Shànghǎi (GIS data, drawing made by the author).

Figure 48. UHI Risk Map of Shànghǎi.

The map under Figure 47 presents the UHI risk index at the district level across Shànghǎi. Risk, unlike vulnerability, integrates both the intensity of the heat island effect and the exposure of populations and proximity to water. The values range from very low risk (0.002–0.051, blue to green) to higher risk (0.319–0.396, red). This allows to distinguish areas where UHI intensity overlaps critically with population exposure.

The higher risk areas (0.152–0.396, orange to red) are concentrated in the northern and central districts of Shànghǎi, with the highest risk (red) in the far north urban zone. These areas combine dense populations, heavy urbanization, and limited vegetation, amplifying both heat intensity and exposure even though having water bodies of significant size in proximity. The central-northern belt with the second highest values present in orange reflects the clustering of residents in older, densely built neighborhoods with lower adaptive capacity.

Central-western and east districts, extending to urban periphery, are considered moderate risk Areas (0.051–0.152, yellow). These zones experience significant UHI intensity, but somewhat lower exposure levels compared to the northern core due to lower levels of urbanization, compared to higher risk areas. They represent transitional belts, where rapid urbanization may increase future risk without proactive adaptation. Neighboring them are the low to very low risk areas (0.002–0.051, blue and green), in the southern and southwestern districts. These areas have greater vegetation cover, more open water bodies, lower density, and more open land, reducing both heat accumulation and exposure. They currently serve as natural climate buffers, helping regulate citywide temperatures.

In fact, a north–south gradient is noticeable, with northern districts having both intense UHI effects and dense population exposure; and southern districts having lower risk, thanks to vegetation and lower density. This distribution shows that risk is not only where the UHI effect is strongest but also where exposure is greatest, explaining why northern areas rank higher than some central and eastern zones. As such high-risk northern districts must be prioritized for heatwave response systems, cooling centers, and medical preparedness. Nevertheless, investments should be made into the southern and southwestern districts that function as ecological buffers. Preventing unchecked urban sprawl here will be crucial to maintaining resilience for the whole city. Supporting this evidence is the fact that southern and southwestern districts consistently rank lowest in both vulnerability and risk which underlines their role and importance as climate buffers.

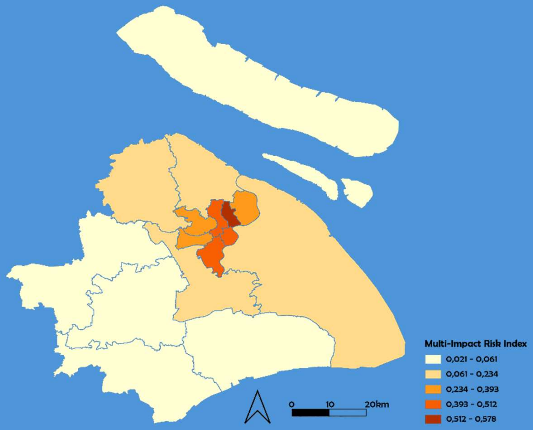

Figure 50. Multi-impact Risk Map of Shànghǎi.

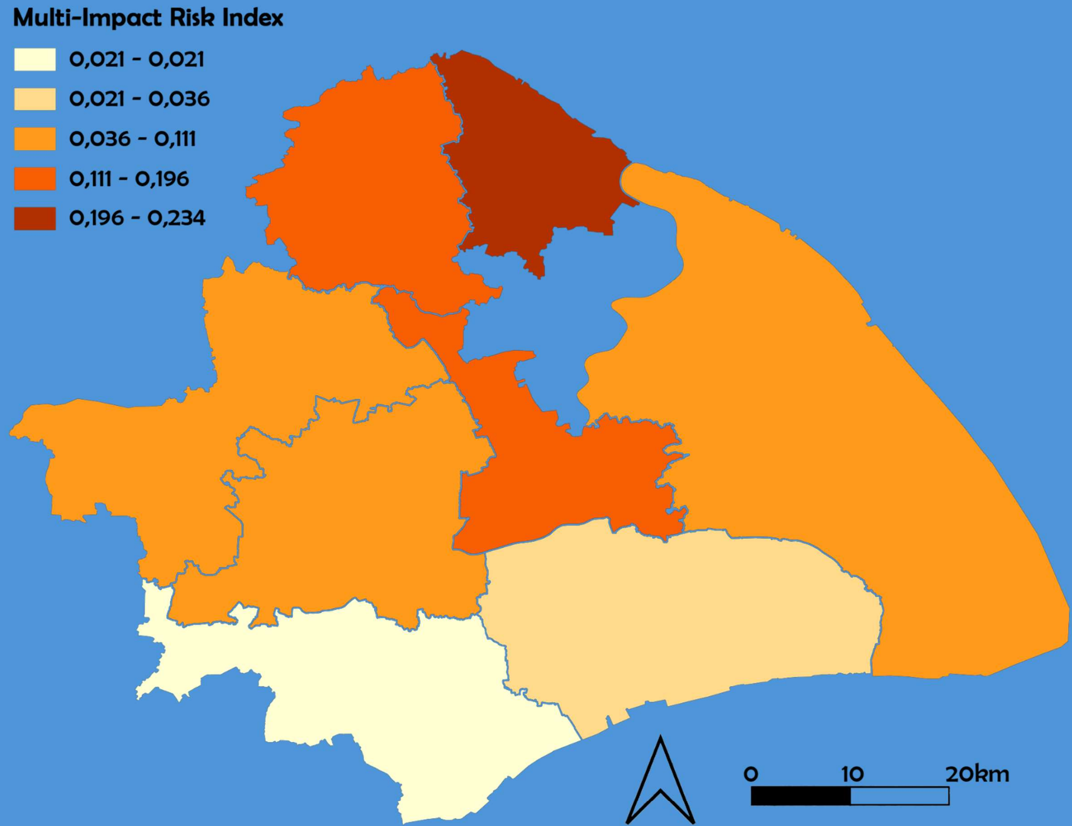

Figure 49. Limited Multi-impact Risk Map of Shànghǎi (GIS data, drawing made by the author).

Figure 49 illustrates a map that shows the combined multi-impact risk index for Shànghǎi, reflecting where flooding and heat hazards overlap and where their combined effects are likely to cause the greatest harm to people, infrastructure, and the urban system. The index ranges from very low risk (0.021–0.036, light yellow) to moderately high risk (0.196–0.234, dark brown). The map highlights that risks are not evenly distributed but cluster strongly in the northern and central urban districts, while the east southern and southern periphery remains relatively resilient.

So, the northern and the northern-central urban core districts have moderate high risk levels (0.111–0.234, dark orange to dark brown) within the multi-impact index. These areas combine high UHI exposure (due to dense, impervious built environments and low vegetation) with high flood risk (drainage bottlenecks, low-lying terrain, and population exposure). The dark brown northern district is the main hotspot, where both flooding and heat stresses converge at their most intense levels, creating severe threats to public health, infrastructure resilience, and social equity.

Moderate levels of the multi-impact risk index (0.036–0.111, orange) can be found in western and eastern Shànghǎi. These zones have structural vulnerability to heat and floods, but exposure and hazard intensity are not as extreme as in the northern core. They function as transitional belts, where rapid urbanization and population growth could escalate risks if adaptation measures are not implemented. While the lowest values (0.021–0.036, light yellow) are concentrated in the southern and southeastern districts. These areas remain comparatively resilient, benefiting from greater vegetation, lower population density, and reduced exposure to both hazards. They currently function as climate buffers, but uncontrolled urban expansion could erode this resilience.

Once again, a north-to-south risk gradient is apparent, aligning with Shànghǎi's broader urban form: dense, heat- and flood-prone cores to the north and center versus more open, greener, and resilient peripheries to the south. But besides the general implications of urgent interventions in the northern districts and preservation actions in the intact southern districts, a highlight appears: even though on the separate risk maps the western districts of Qīngpǔ and Songjiang did not show elevated levels, once combined together, those territories show how from buffer areas they could become under risk of serious damage to their inhabitants and the infrastructure. Strategies including secondary WasteWater reuse systems are perfect not only for mitigation, but also prevention., by enhancing drainage, urban cooling networks, and green cover to prevent escalation into high-risk categories. As urban growth continues, these areas risk shifting into hotspot status without proactive planning. And while a list of priority areas for intervention similar to the Venice case study is not possible with the existent data limitations and the used scale, a target area for action is visible for Shànghǎi.

The Qīngpǔ District, located on the western edge of Shànghǎi's metropolitan area, presents a distinctive territorial condition in which rapid urbanization, ecological preservation, and cultural heritage coexist within a single planning framework. As one of the city's designated demonstration zones for ecological civilization and sponge-city development, Qīngpǔ encapsulates both the potential and complexity of implementing secondary wastewater use systems (SWWUS) in a transitional urban landscape where peri-urban expansion meets historic settlement, contrasting with the critical conditions central Mestre in Italy from the previous case.

When studying this area specifically, it becomes evident with the support of previous literature and policy analysis that among the district's **strengths** are its advanced institutional integration and strong policy alignment with national and municipal directives on water management. The Shànghǎi Master Plan 2017–2035, combined with the Sponge City initiative and the Yangtze River Protection Law, provides a clear governance structure for sustainable water practices. Qīngpǔ benefits from its inclusion in the Shànghǎi Water Ecological Security Plan, which promotes integrated stormwater management, flood control, and reuse-oriented infrastructure. The district's existing network of canals, lakes, and wetlands – including Dianshan Lake and the smaller interconnected water bodies that traverse historic settlements such as Zhūjiājiǎo – offers natural hydrological systems that can be adapted to support decentralized reuse and infiltration. Site observations indicate that newly developed areas, particularly around the Huawei Lianqiu Lake R&D Center in Jīnzé, already incorporate elements of water-sensitive design, such as vegetated buffers, permeable surfaces, and local retention ponds, which create a solid technical foundation for the introduction of reclaimed-water networks.

However, certain **weaknesses** persist, reflecting the spatial and administrative duality of the district. The coexistence of traditional water towns and new high-tech developments has generated uneven infrastructural quality and management capacity. While new urban zones possess modern sewage treatment facilities, older settlements often rely on smaller-scale or outdated systems, leading to variable water quality and treatment efficiency across the district. Moreover, the reuse of treated wastewater for non-potable purposes remains limited by the absence of localized distribution infrastructure and by the prioritization of flood control over reuse in existing plans.

Institutional compartmentalization between planning, environmental protection, and water bureaus can further delay project implementation, despite the district's overall administrative coherence. From a socio-cultural perspective, the perception of wastewater reuse remains cautious; public understanding tends to emphasize sanitation and control rather than resource circulation, indicating the need for communication and demonstration projects to foster awareness.

Nevertheless, Qīngpǔ offers numerous **opportunities** for expanding SWWUS as part of its ongoing ecological transformation. The district's role as a pilot area for green development under both municipal and national strategies makes it eligible for targeted funding and technical assistance. Its strong industrial and research base – illustrated by technology clusters such as those near Lianqiu Lake – creates the potential for partnerships that combine innovation, monitoring, and implementation. Furthermore, the continuing restoration of historical canals and public-space redevelopment in water towns like Zhūjiājiǎo demonstrate the capacity to integrate hydraulic, ecological, and cultural values within a single design vision. The growing emphasis on tourism, recreation, and livability provides a social and economic rationale for visible reuse infrastructure, such as reclaimed-water-fed ponds, irrigation systems for green corridors, and artificial wetlands designed for public education. Site impressions indicate that local authorities are increasingly aware of the multifunctional potential of these spaces, viewing them not only as flood-control elements but as nodes of environmental identity.

Still, several **threats** could undermine long-term sustainability if not managed carefully. Rapid urban expansion continues to encroach upon agricultural and wetland areas, intensifying land-use pressures and altering the district's hydrological balance. While the Sponge City framework has improved surface drainage and infiltration, the pace of development risks outstripping infrastructural adaptation, particularly under extreme weather conditions. Climate change is expected to exacerbate these pressures through heavier rainfall and higher temperatures, increasing both flooding and energy demand for treatment systems. Additionally, the concentration of planning authority in higher administrative levels can limit local flexibility and experimentation, while strict performance metrics tied to short-term output may discourage more holistic, community-based reuse initiatives. The challenge lies in reconciling the district's rapid modernization with its ecological and cultural heritage — ensuring that progress does not result in homogenization or environmental degradation.

Taken together, the complex analysis positions Qīngpǔ as a strategic testing ground for integrating SWWUS within a mature sponge-city framework. Its strengths in governance, infrastructure, and ecological planning create a favorable institutional environment, while its spatial diversity and cultural landscape demand context-sensitive design approaches. The combination of high-tech innovation zones and historic water towns offers a unique opportunity to demonstrate how wastewater reuse can serve both advanced industries and traditional communities. However, realizing this potential will require coordinated governance, adaptive management, and the cultivation of public awareness – transforming wastewater reuse from a technical afterthought into an emblem of Shànghǎi's broader ecological civilization agenda.

7.3 Cross-City Analysis: Policy Divergence and Methodological Boundaries

Venice and Shànghǎi provide two distinct yet complementary perspectives on the integration of secondary wastewater use systems within urban governance. Both are cities historically defined by water, yet their institutional settings, policy instruments, and urban forms produce divergent pathways toward sustainability. Examining their policy frameworks helps to understand not only how wastewater reuse and water management are embedded in local planning but also why a direct methodological comparison between the two cases is ultimately constrained by structural and data asymmetries.

In the European context, and particularly in Italy, wastewater management and reuse are guided by a complex multi-level regulatory system. At the supranational level, the European Union sets the legislative foundation through the Water Framework Directive (2000/60/EC), the Urban Wastewater Treatment Directive (91/271/EEC, recast 2022), and, most recently, Regulation (EU) 2020/741 on minimum requirements for water reuse. These instruments collectively establish quality standards, monitoring obligations, and risk-management protocols to ensure that reclaimed water use aligns with human health and environmental protection goals. Italy has transposed these principles through national decrees and standards (such as Decreto Ministeriale 185/2003), while regions and municipalities hold executive authority for local implementation.

Within this framework, Venice's governance model is further shaped by the Legge Speciale per Venezia (Special Law for Venice, 1973 and subsequent amendments), which prioritizes the ecological integrity of the lagoon system. This legislation, combined with the Piano delle Acque (Water Plan) and the Piano degli Interventi,

constrains infrastructural modifications that could alter hydrodynamic balances or visual integrity in the historic core. Wastewater reuse and flood-management measures are therefore pursued through cautious, small-scale strategies – such as upgrading sewer connections, installing minor retention basins, or integrating low-impact green infrastructures in the mainland and peripheral islands. These actions reflect a preservation-oriented planning culture, where innovation is bounded by environmental protection and heritage regulation.

In contrast, China's policy landscape positions water management as a central pillar of its environmental modernization agenda. The 2015 Water Pollution Prevention and Control Action Plan (the "Water Ten Plan") and the Yangtze River Protection Law (2020) establish mandatory targets for wastewater treatment and reuse, coupled with strict discharge controls. National programs such as the Sponge City Initiative explicitly promote the integration of water reuse, rainwater harvesting, and blue-green infrastructure to mitigate flooding and improve microclimates. These frameworks are operationalized through five-year municipal plans, giving cities like Shànghǎi a clear mandate to embed circular-water practices into urban design. Within Shànghǎi, the Qīngpǔ District Planning and Natural Resources Bureau plays a crucial role in translating national directives into local spatial policy, often combining reuse infrastructure with land-use zoning, ecological corridors, and public-space redevelopment. The governance model is centralized and performance-oriented, favoring rapid implementation through hierarchical coordination and state-financed pilot projects.

Comparing these two policy systems reveals a fundamental difference in governance logic. Venice operates within a polycentric regulatory environment, where European, national, regional, and municipal authorities share overlapping responsibilities and where consensus and environmental safeguards slow innovation but ensure accountability and transparency. Shànghǎi, by contrast, reflects a vertical governance structure, where strategic goals are cascaded from central ministries to municipal and district levels, enabling swift mobilization of resources and large-scale experimentation. The result is that while Venice advances incrementally through adaptive retrofitting and environmental caution, Shànghǎi advances rapidly through proactive, state-driven transformation. Both models carry strengths and weaknesses: Venice's ensures strong ecological stewardship and public participation but often limits technical innovation; Shànghǎi's achieves scale and integration, but risks limited local flexibility and participatory oversight.

These policy divergences have direct methodological implications for this study. Although the same analytical framework – the spatial multi-impact risk assessment combining flooding and urban heat-island indicators – was applied to both contexts, the quality, structure, and accessibility of spatial data differ profoundly. In Venice datasets are relatively transparent and detailed, available through regional and municipal open-data portals, allowing high-resolution mapping; in Shànghăi, most detailed data is restricted due to administrative confidentiality, and the available data is generalized and aggregated at the district level. This disparity makes quantitative cross-case comparison infeasible for the spatial analysis: outputs cannot be directly normalized; vulnerability and risk indices cannot be standardized to a common spatial scale.

Additionally, privacy and data-protection regulations – particularly concerning household-level consumption – prevent the integration of micro-scale data in both cases. Such information would be crucial to estimate per-capita reuse potential and to calibrate local vulnerability models but remains inaccessible due to European GDPR restrictions and Chinese data-governance policies. The absence of these datasets limits the comparability of the analyses to a methodological demonstration in various scenarios rather than a statistically equivalent evaluation.

Beyond data, the cities' hydrological and cultural conditions also inhibit direct comparison. Venice's lagoon system experiences tidal flooding (acqua alta) and saline infiltration, phenomena that differ fundamentally from the pluvial and fluvial flooding in Shànghăi's subtropical delta. Likewise, heritage preservation imperatives in Venice constrain the retrofitting of subterranean systems or the visible introduction of new infrastructure, whereas Shànghăi's expanding urban frontier allows the integration of new technologies at the planning stage. The socio-economic structures differ as well: Venice's small population and dependence on tourism contrast with Shànghăi's dense residential and industrial fabric, which shapes both water demand patterns and policy priorities.

Consequently, the analysis between Venice and Shànghăi can be understood as illustrative rather than equivalent. The parallel use of spatial risk analysis demonstrates how the same methodological tool – integrating flood and UHI data to identify priority zones for secondary wastewater use – can be adapted across governance systems and spatial realities. However, differences in data quality, institutional structure, and environmental context prevent full alignment of results. The value of this comparison thus lies not in producing uniform metrics, but in highlighting how distinct policy frameworks condition the feasibility and form of circular-water interventions.

As such, while both case studies employ the same analytical framework, a direct quantitative comparison between Venice and Shànghăi is methodologically unfeasible. The two contexts differ substantially in institutional structure, data availability, hydrological dynamics, and socio-economic baselines, resulting in divergent scales and levels of precision in spatial assessment. Nevertheless, these limitations do not preclude comparative insight: the contrast between adaptive, heritage-constrained governance in Venice and centralized, performance-oriented planning in Shànghăi allows for thematic parallels that illuminate how institutional capacity and planning culture shape the implementation of secondary wastewater use systems across distinct urban environments.

Ultimately, the juxtaposition of these two cases reveals that methodological transferability depends on policy compatibility. Where institutional capacity, data transparency, and governance coherence are strong – as in Shànghăi – the approach can directly guide large-scale implementation. Where governance is fragmented and highly regulated – as in Venice – the same framework serves primarily as a planning support tool for incremental, small-scale adaptation. Understanding these contextual constraints underscores that comparative research in sustainable urban water systems must remain sensitive to policy regimes, data ecologies, and socio-ecological particularities rather than assume analytical equivalence.

The territorial assessments and SWOT analyses of Mestre and Qīngpŭ reveal how spatial form, governance structures, and socio-cultural dynamics condition the implementation of secondary wastewater use systems. While both areas demonstrate significant potential for circular water integration, their opportunities emerge through contrasting mechanisms: adaptive retrofitting within a historically constrained European urban fabric and systemic planning within a rapidly modernizing Chinese district. These findings underline that the success of SWWUS depends not only on the technical suitability of a site but also on its institutional adaptability, community perception, and policy alignment. The comparative interpretation of these contextual parameters forms the foundation for the next stage of analysis with development from the territorial diagnosis to a methodological synthesis, evaluating how the analytical framework and case-study results can be integrated into a replicable planning approach applicable across diverse urban conditions.

Chapter 8
From Grey to Blue-GreenDesign: SWWUS Implementation

When talking about climate change resilient urban design, generally three main directions of interventions are thought of – adaption, mitigation and prevention, each one of them having different urban design approached. But SWWUS implementation can be used in the design for all of them. Flood mitigation and WasteWater reuse are both essential components of Integrated Urban Water Management (IUWM). Flood vulnerability and risk maps allow planners to see how stormwater, treated effluent, and urban design interact across space. This helps guide planning for:

- Dual-purpose systems, such as wetlands that treat WasteWater while also managing runoff.
- Multi-functional landscapes, which provide both environmental and recreational benefits.
- Circular water systems, where treated WasteWater is used repeatedly within neighborhoods or districts.

Additionally, WasteWater can be used to irrigate parks, green corridors, and street trees in these areas, reducing surface and air temperatures through evapotranspiration while conserving potable water.

For more case-based examples, for Venice, there is an urge to act immediately in Mestre, where risk is already high and impacts are recurrent – mitigation is needed to address urgent existing stress. It can be reduced vulnerability through focus on water design and management which can help directly mitigate the effects of climate change or can create the necessary context for other instruments of mitigation, such as adaptive green infrastructure. Another example could be Qīngpǔ district in Shànghǎi where a preventive focus is necessary to avert escalation into high-risk zones. By prioritizing nature-focused urban planning such as blue and green buffers preservation it will help balance growth and avoid the concentration of risk as seen in the north and center of Shànghǎi.

However, urban planning focused on water – whether waterfront revitalization or SWWUS implementation – requires a multidisciplinary approach that combines urban design, environmental management, transportation planning, and community engagement.

Intrinsically, for each case a specific set of actions should be developed in cooperation between local governments, urban planners and engineers, to take in consideration not only the urban dimension, but also the social, legal, financial and technical dimensions of the matter, as WasteWater requires a multidisciplinary approach. The main consideration was the focus on the **hydraulics** and not hydrology. The terms hydraulic and hydrological are often used interchangeably in discussions of water management, but they refer to distinct areas of study and practice, especially in the context of urban planning, water, and WasteWater management. Although both fields deal with water, they differ in scope, focus, and application, especially when integrated into infrastructure planning.

In urban planning, these two fields complement each other. Hydraulic engineering provides the technical framework for designing and maintaining systems that control water flow, while hydrological analysis informs the broader environmental and sustainability context, helping to guide decisions on stormwater management, flood risk, and water conservation. Together, they contribute to the creation of resilient, efficient, and environmentally responsible water management systems in cities. This study was not conducted by either an engineer or an environmentalist, so the proposed designs will not go into detail for either of the two fields; but, generally, the aim of this work is to present a result that focuses mainly on hydraulics rather than hydrology. However, it is possible to develop an urban design draft project by primarily [though not exclusively] considering the urban and social dimensions, without the immediate contribution of legal and technical expertise.

That being said, another important consideration for the development of the design scenarios was the flow of WasteWater in the system. When working with WasteWater management, the actions should not necessarily address the full cycle of water and, subsequently, WasteWater in the hydraulic system, but can focus on water being brought from, for example, buildings [various users] to the purification facilities [to treatment] or WasteWater being brought **from treatment to users**, not necessarily directly. The focus of the design is on the latter, while also sometimes considering on the full cycle.

For all that, besides the proposed drafts of urban designs with SWWUS implementation, a proposal of actions for future masterplan development is presented. The set of proposed goals, objectives, strategies and actions aims to a complex solution to not only to mitigate the existing issues in terms of water management, but also to prevent future disasters and limit the drastic development of climate change. The illustrated below list of recommended actions for a future masterplan does not only address WasteWater treatment and reuse, but also the supplementary actions necessary to make the whole system work within the framework of sustainability and circularity.

The design principles from the strategic action plan applied for the specific cases of this study are selected directly upon the territorial analyses and SWOT assessments presented previously with the policy and spatial analysis of each area. The insights derived from Mestre and Qīngpǔ serve as interpretive frameworks for understanding how secondary wastewater use systems (SWWUS) can be spatially and institutionally embedded within contrasting urban contexts. In Mestre, the SWOT analysis highlighted the need for integrated multi-functionality – combining water reuse with flood mitigation, public-space regeneration, and social revitalization – while also addressing the challenge of governance fragmentation through coordinated planning instruments and simplified maintenance frameworks. In contrast, the Qīngpǔ case emphasized hybrid governance and ecological continuity as guiding principles: the coexistence of historic water towns and high-tech developments requires adaptive systems that link decentralized reuse infrastructure with the broader ecological and cultural landscape. Together, these case-derived insights inform the methodological propositions that follow, demonstrating how spatial analysis, design reasoning, and policy coordination can converge into a replicable framework for SWWUS implementation.

Strategic Action Plan for SWWUS Implementation

Goals

- Develop Efficient and Scalable Treatment and Reuse
- Integrate Secondary Water Use into Urban Planning and Policy.
- Increase Public and Stakeholder Engagement.

Objectives

1. Develop a distribution network to efficiently deliver treated WasteWater for non-potable uses such as irrigation, industrial cooling, and street cleaning.
2. Implement storage and pumping systems to ensure reliable and cost-effective reuse in different urban areas.
3. Establish regulatory frameworks and incentives to encourage the adoption of secondary WasteWater use in public and private sectors.
4. Require new developments to incorporate greywater recycling and secondary water use systems in their design.
5. Educate communities, industries, and policymakers on the environmental and economic benefits of secondary WasteWater use.
6. Foster collaboration between municipalities, businesses, and research institutions to develop innovative reuse solutions.

Strategies

1. Design Water-Efficient Urban Developments: Require new residential and mixed-use developments to include dedicated infrastructure for greywater collection and reuse (e.g., dual-pipe systems for non-potable water supply).
2. Incorporate Water Reuse into Public Space Design: Ensure parks, green roofs, and urban forests are designed to use treated WasteWater for irrigation and maintenance.
3. Encourage Compact and Mixed-Use Developments: Promote dense urban planning that facilitates shared water reuse infrastructure, reducing the cost and complexity of implementation.
4. Support Nature-based Solutions: Integrate constructed wetlands, rain gardens, and permeable surfaces into public spaces to complement WasteWater reuse efforts and enhance urban resilience.
5. Mandate Water Reuse in Large-Scale Developments: Require major residential and commercial projects to incorporate WasteWater reuse infrastructure as part of zoning and permitting processes.
6. Develop Localized Water Reuse Regulations: Align urban planning policies with water reuse goals by adapting building codes, zoning laws, and municipal ordinances to support secondary WasteWater use.
7. Create Incentive Programs for Residential Adoption: Offer density bonuses, reduced permit fees, or tax incentives for developers who integrate WasteWater reuse systems into residential and public projects.
8. Establish Water Reuse Zones: Identify and designate areas where secondary WasteWater use is a priority, such as new housing developments, industrial zones, or public facilities.
9. Launch Community-Led Water Conservation Initiatives: Engage residents in discussions about water reuse benefits through public forums, local planning committees, and participatory budgeting.
10. Develop Partnerships with Private Developers and Housing Associations: Encourage private sector investment in WasteWater reuse by integrating it into urban development agreements and public-private
11. Strengthen Municipal Coordination Across Sectors: Ensure collaboration between urban planners, environmental agencies, and public health departments to integrate water reuse into broader sustainability goals.
12. Implement Pilot Projects in High-Visibility Urban Areas: Develop demonstration sites in residential districts and public spaces to showcase successful WasteWater reuse strategies and build public confidence.

Actions

- A1. Construct wetlands and ponds for natural filtration and secondary WasteWater reuse before distribution to urban areas.
- A2. Develop BGI (parks, urban forests, wetlands, floodplains) to enhance biodiversity, urban cooling, and water reuse.
- A3. Integrate water features into panoramic walks and cycle paths
- A4. Reuse treated WasteWater for non-potable uses such as irrigation, industrial processes, and urban cooling.
- A5. Optimize water use efficiency in domestic and commercial sectors, by reusing WasteWater before releasing it into the general sewerage network.
- A6. Restore and integrate rivers, canals, wetlands, and floodplains into urban water reuse, ecological corridors.
- A7. Share best practices with neighboring cities and encourage intercity cooperation
- A8. Develop joint infrastructure projects with neighboring cities for water reuse
- A9. Design multifunctional public spaces integrating water-based elements (e.g., parks as stormwater retention basins) to support WasteWater management.
- A10. Update zoning regulations to prioritize water-sensitive planning, including mixed-use development, BGI, and water reuse systems.
- A11. Invest in WasteWater management studies
- A12. Develop detention and retention basins with time-shifted drainage to manage stormwater and peak WasteWater flow efficiently.
- A13. Install advanced WasteWater treatment systems to produce high-quality recycled water for non-potable uses like irrigation, industrial processes, and urban cleaning.
- A14. Install informative signage along panoramic walks & cycle paths explaining water management efforts.
- A15. Incorporate cultural elements into new water infrastructure (e.g., artistic wetlands, heritage trails).
- A16. Establish a single real-time monitoring system for weather, water levels, and network performance, including a single messaging system for real-time updates on water quality, flooding, and system performance.
- A17. Schedule regular cleaning & inspections of drainage systems to prevent blockages.
- A18. Upgrade the sewage system to prevent contamination and ensure sustainable water management.
- A19. Design water-based public spaces, including fountains, ponds, and artificial canals, for leisure and aesthetic value.
- A20. Create panoramic walkways and cycle paths alongside waterways.
- A21. Incorporate historical water infrastructure into urban redevelopment projects.
- A22. Ensure routine and emergency maintenance of WasteWater reuse infrastructure for long-term efficiency and sustainability, with a focus on optimizing system performance.
- A23. Build local storage and reuse reservoirs (e.g., tanks) to regulate network discharge and ensure a reliable treated WasteWater supply
- A24. Develop public education programs on water conservation and on the safe and efficient use of recycled water for urban applications, focusing on households, businesses, and public facilities.
- A25. Promote the installation of dual piping systems in new developments to separate WasteWater for reuse.
- A26. Incorporate secondary WasteWater reuse infrastructure into mixed-use developments, ensuring that residential, commercial, and public spaces benefit from recycled water for non-potable uses like irrigation, toilet flushing, and landscape watering.
- A27. Design dedicated treatment plants for non-potable WasteWater reuse that serve specific urban areas, ensuring scalability and reliability of supply for irrigation, street cleaning, and cooling systems.
- A28. Implement decentralized WasteWater treatment and reuse systems in residential neighborhoods, leveraging modular systems to minimize infrastructure costs and increase flexibility.
- A29. Develop a citywide smart water distribution network that connects WasteWater reuse systems to key urban sectors, ensuring efficient delivery of recycled water to areas with high demand.
- A30. Introduce incentives for developers to integrate secondary WasteWater reuse systems in urban projects, including grants, rebates, zoning allowances, or tax credits.
- A31. Retrofit older residential and commercial buildings with secondary WasteWater reuse systems to ensure existing infrastructure supports modern water efficiency standards.

Venice, Mestre (photo by author).

Shànghǎi, Qīngpǔ, (photo by author).

8.1 Mitigation in Venice: Blue-Green Corridor

In Mestre, the design focuses on mitigating the effects of climate change in mostly residential area of the city center to create livable public spaces by revitalizing the existing waterbodies and bringing them more inside the city; and with the support of those expand the green infrastructure as well. Based on the finding from the analysis, the design proposal will be for the city center of Mestre, near the train station, specifically for areas like Corso del Popolo, Via Cappuccina and Piazza XXVII Ottobre (as a continuation of Via Pepe).

Figure 51. Corso del Popolo current state, fragment (drawing by author).

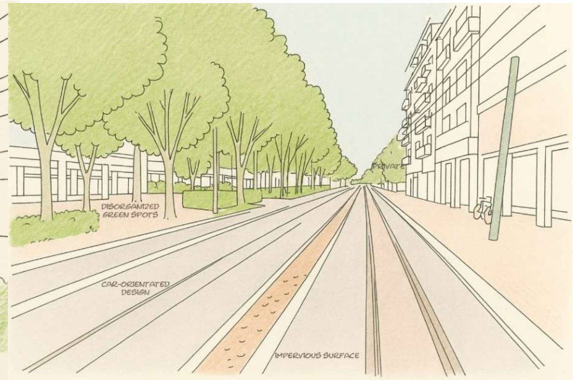

Figure 52. Piazza XXVII Ottobre current state, fragment (drawing by author).

The idea is to start with low-cost, high-impact changes – such as pilot projects, education – before expanding citywide with proved feasibility and updated infrastructure. An important component is to ensure durable sustainability and a long-term impact through regional cooperation, regular professional maintenance and technical modernization.

Therefore, **Phase 1** (years 0–3) focuses on laying the foundations of the project and raising awareness on the topic among citizens to minimize the yuck effect:

- Research & Mapping.
  - Studies on feasibility and WasteWater management (A11);
  - Development of multi-impact risk maps.
- Nature-Based Pilots.
  - Construction of retention ponds (A1, A12);
  - Pilot street canal development along Via Cappuccina or Corso del Popolo for natural filtration.
- Community Awareness.
  - Launch of public education campaigns (A24);
  - Educational advertisement from municipality;
  - Signage explaining new and future water systems (A14).
- Localized Reuse.
  - Manual and automatized irrigation of street trees and small parks with the existing treated WasteWater (A4, A9);
  - Pilot cooling fountains in Piazza XXVII Ottobre.

The Phase 1 should result in a small biodiversity boost, first public exposure to reuse systems, and ideally reduction of flooding in hotspots thanks to the construction of retention basins and creation of natural filtration spots. These actions focus on Meteorological WasteWater instead of Domestic WasteWater for more immediate solutions and creation of infrastructure to each treatment and secondary use of Domestic WasteWater can be connected in the following phase. Supporting actions that focus Meteorological WasteWater management can include permeable paving and change of inclination of streets to facilitate stormwater collection and prevent street flooding.

Figure 53. Corso del Popolo, Phase 1 (drawing by author).

Figure 54. Piazza XXVII Ottobre, Phase 1 (drawing by author).

Phase 2 (years 3–10) steps into the expansion of blue-green corridors by developing the pilots started in the previous phase into visible public-space transformations:

- Urban Corridors.
  - Creation of blue-green corridors along Corso del Popolo and Via Cappuccina through canals and planting of trees (A2, A6, A9).
  - Extension the canal along the Via Forte Marghera along Via Pepe until Piazza XXVII Ottobre and revitalize the surrounding area into a recreational pedestrian boulevard (without completely removing vehicle traffic however).
- Drainage Upgrades.
  - Modernization of the sewage and drainage networks for contamination prevention and connection to treatment facilities (A18);
  - Creation of multi-functional water collection basins integrated into big public green spaces (A12).
- Initial Building Integration.
  - Beginning of retrofitting older buildings with reuse systems (A31);
  - Requirement for dual piping in new developments (A25).

Phase 2 should result in visible city-center transformations that will reduce urban heat and create welcoming public spaces that – with the support of continuing educational advertisement campaigns from Venice municipality and educational programs – will help to grow citizens acceptance towards Wastewater reuse. Additional actions can include the development of cycling and pedestrian paths for accessibility as well as slower perception of surroundings that will help with the acceptance of changes (besides the psychological benefits) as well as development (through incentives, for example) of small recreational businesses to attract citizens in the newly created public spaces.

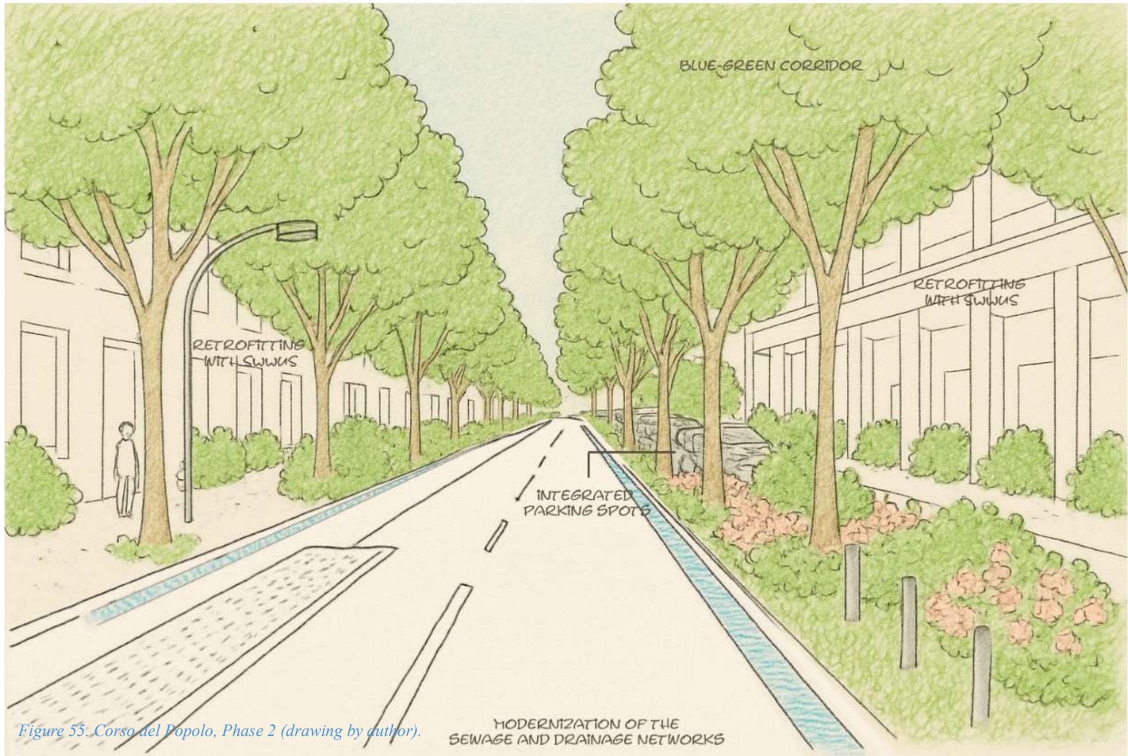

Figure 55. Corso del Popolo, Phase 2 (drawing by author).

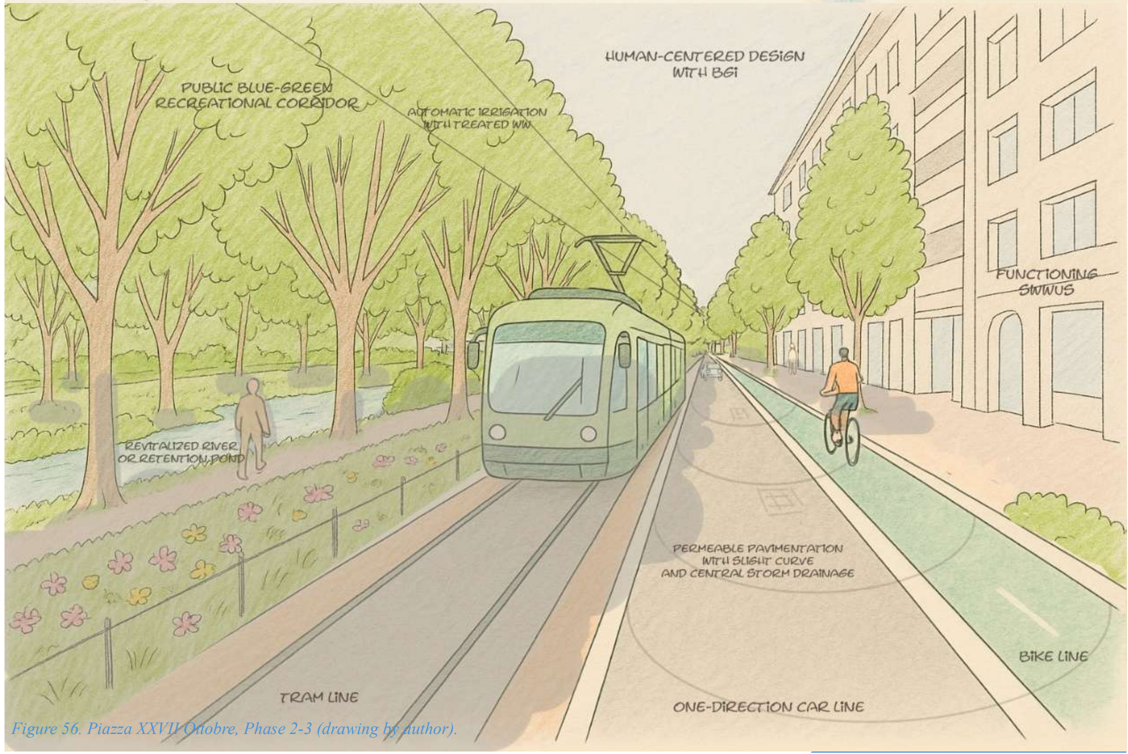

Figure 56. Piazza XXVII Ottobre, Phase 2-3 (drawing by author).

Phase 3 (years 10–20) is more technical and focuses on the infrastructure development as well as installation of smart systems for automatization before full-scale adoption and transition to full-cycle circular water management:

- Storage & Monitoring.
  - Construction of local reservoirs and tanks for treated WasteWater (A23);
  - Installment of real-time monitoring for water quality, flood alerts, and system performance (A16).
- Smart Networks.
  - Pilot smart distribution networks to connect reuse systems (A29);
  - Integration of predictive AI models for demand forecasting and rapid flood response.
- Continuation of Building Integration.
  - Large-scale retrofitting program for existing buildings;
  - Financial incentives for developers and individuals for integration and use of secondary reuse systems (A30).
- Public Realm.
  - Expansion of fountains, wetlands, artistic canals into cultural identity projects (A15, A21).

By the end of this phase a resilient, semi-centralized reuse network should cover most non-potable demand in key districts. It can be supported by legal actions for integration of circular water management model in the local legal framework. Besides these “professional” actions, public actions can also be implemented – public events in the newly created public spaces besides offering the government possibilities for income can also work as a positive reinforcement for citizens to make use of the new developing blue-green spaces and motivate them to want more spaces like this.

Mestre. Phase 3-4

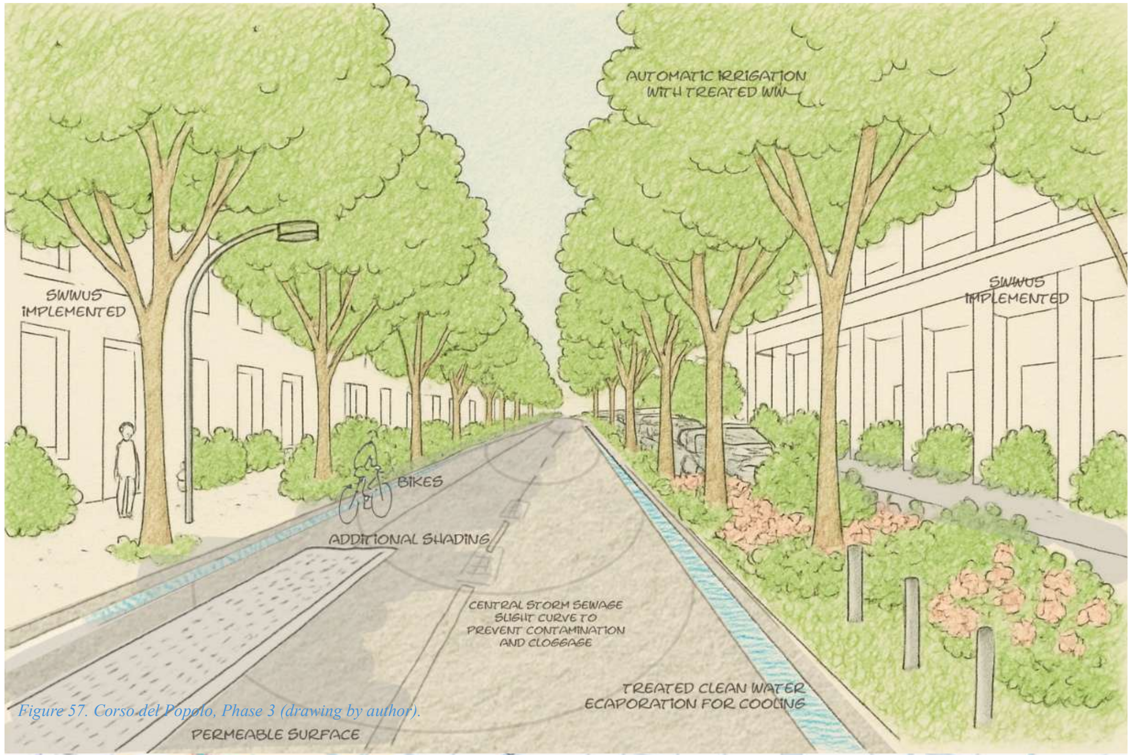

Figure 57. Corso del Popolo, Phase 3 (drawing by author).

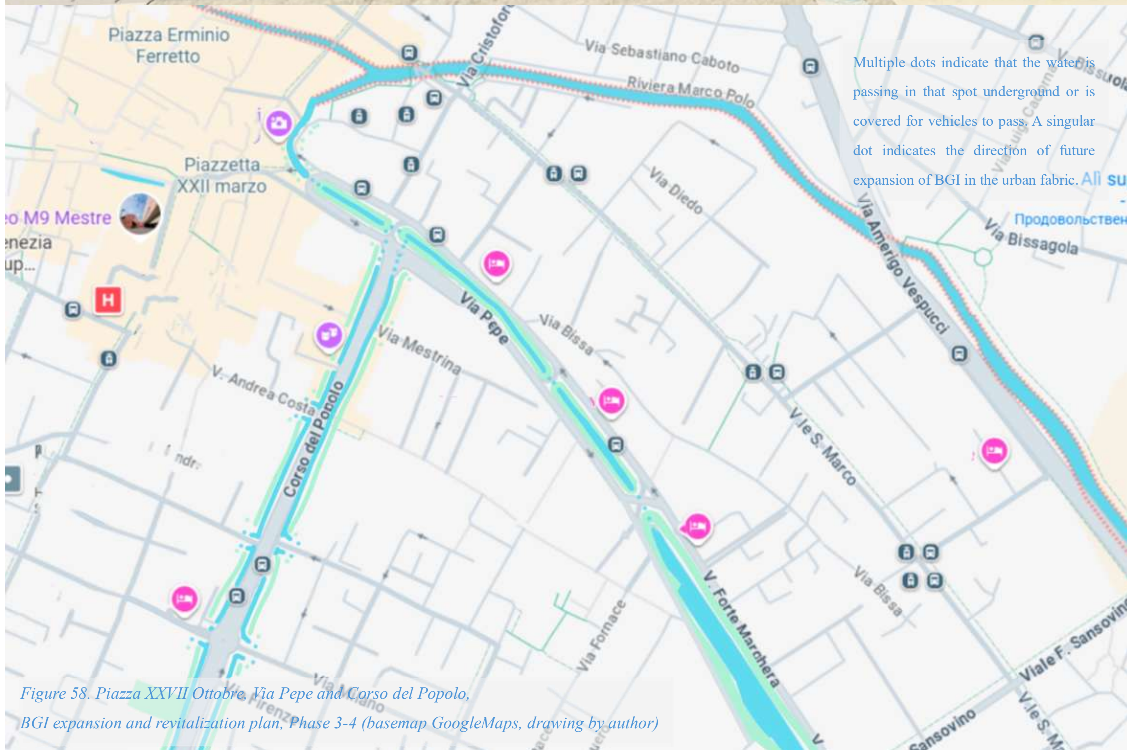

Figure 58. Piazza XXVII Ottobre, Via Pepe and Corso del Popolo,
BGI expansion and revitalization plan, Phase 3-4 (basemap GoogleMaps, drawing by author)

Finally, **Phase 4** (post 20+ years) focuses on maintenance and equity to ensure long-term sustainability while innovating with new technologies. Maintenance should begin immediately with the project, however Phase 4 highlights the completion of the design project by focusing on longevity of the systems:

- Maintenance Systems.
  - Establishing a routine and emergency maintenance framework with the responsible departments and/or institutions (A17, A22);
  - Developing a digital twin of Mestre's water systems for predictive upkeep and international knowledge exchange.
- Innovation.
  - Piloting energy recovery from WasteWater (e.g., biogas, heat pumps);
  - Deployment of modular decentralized treatment in underserved urban and rural areas (A28).
- Equity Focus.
  - Guarantees that WasteWater reuse infrastructure serves social housing and vulnerable neighborhoods, not only new developments.

Active implementation of Phase 4 should guarantee reliable and inclusive reuse infrastructure, as well as reduced operating costs due to efficient maintenance. With these interventions it is possible that Mestre (and Venice generally) evolves into an innovation hub which lead to the next last phase. **Phase 5** (post 30+ years) focuses on positioning first Venice as a reference city for integrated water-sensitive design:

- Regional Cooperation.
  - Joint reuse infrastructure first in Venice and later with other Veneto cities (A7, A8);
  - Cross-city and inter-city water-sensitive planning corridors.
- Cultural & Historical Integration.
  - Blending Mestre's – and following Venice's – historic canals with advanced WasteWater systems into one water network (A21, A23);
  - Positioning public spaces as showcases of past–future coexistence.
- Global Leadership.
  - Sharing Mestre's expertise internationally, hosting conferences and knowledge exchanges;
  - Exporting of technologies and planning know-how.

This urban design project will transform Mestre (and hopefully later the whole city of Venice) into a blue-green corridor city, resilient to climate extremes and globally recognized as a living laboratory of water-sensitive design. Specific spatial interventions include linear canals flanked by trees and double pedestrian and bike paths, with WasteWater-treated irrigation for green corridors. Multifunctional flood basins will be integrated into existing and new plazas with cooling fountains and ponds as smaller public gathering spaces compared to the plazas and boulevards, such as the .Via Pepe to Piazza XXVII Ottobre boulevard redevelopment, transforming Mestre's heart into a water-sensitive livable district.

8.1.1 Technical Summary of Mestre Project

The transformation of Mestre's urban core is conceived as a mitigation strategy against climate-induced flooding and heat stress, with the added objective of revitalizing underutilized public space. The intervention focuses on reconfiguring major corridors such as Corso del Popolo, Via Cappuccina, and Piazza XXVII Ottobre into multifunctional blue-green infrastructures. Technically, this involves the retrofitting of existing carriageways into linear water boulevards, embedding shallow stormwater canals along street edges, introducing permeable paving systems with sub-base storage layers, and planting street trees irrigated through a treated WasteWater distribution network. These interventions are supported by the construction of retention and detention basins within plazas, allowing them to act simultaneously as civic squares in dry conditions and as floodwater storage during extreme rainfall events.

The initial phase prioritizes feasibility studies that integrate hydraulic flow modeling with hydrological catchment analyses, using GIS-based multi-risk mapping to identify priority flood-prone segments and potential discharge points. Pilot projects include the creation of small-scale retention ponds and localized canal interventions, supported by public education campaigns to overcome the "yuck factor" associated with WasteWater reuse. These early measures address surface flooding while establishing public familiarity with water-sensitive infrastructure.

In the medium term, the design expands into continuous blue-green corridors, physically linking different parts of the city center. Sewer and drainage networks are modernized to prevent cross-contamination, while older building stock is progressively retrofitted with secondary water reuse systems. New developments are mandated to install dual-piping networks to enable the direct separation of potable and non-potable flows. Corridors are further enhanced with cycling and pedestrian pathways that align with water infrastructure, reinforcing both resilience and sustainable mobility objectives.

Longer-term interventions introduce advanced systems, including district-level reservoirs, decentralized storage tanks, and real-time monitoring units that track water quality, flow rates, and system performance. AI-driven predictive models are integrated to forecast demand for irrigation and cooling while also serving as early-warning systems for flood risk. Public spaces are equipped with automated irrigation systems and adaptive fountains that double as cooling infrastructure during heat events.

The opportunities presented by this strategy are manifold. Mestre has the potential to position itself as a European model for urban water-sensitive retrofitting, linking cultural identity with engineering innovation. The combination of stormwater control, WasteWater reuse, and urban cooling produces co-benefits that improve livability and environmental performance simultaneously. Moreover, by aligning water infrastructure with pedestrian and cycling routes, the project strengthens the city's transition to sustainable mobility.

Yet the challenges are equally significant. Retrofitting dense urban corridors requires complex underground engineering in constrained environments, with risks of disrupting existing utilities such as gas, telecommunications, and power lines. Hydraulic-hydrological coordination requires sophisticated modeling capacity and real-time monitoring to ensure correct performance under variable rainfall conditions, which increases technical demands on municipal staff. The financial costs of dual-piping retrofits in existing buildings are considerable, and long-term maintenance of decentralized systems requires a dedicated institutional framework and a skilled workforce. Public acceptance of treated WasteWater reuse also requires sustained awareness campaigns and transparent quality monitoring to build trust in the system.

Chapter 8 From Grey to Blue-Green Design: SWWUS Implementation

Figure 59. Zhuhu Road current situation, fragment (drawing by author).

8.2 Preservation in Shànghǎi: Spaces-Transformers

Qīngpǔ's lakes, rivers, green lands and historic water serve as an outer ring of climate buffers for the inner city. Qīngpǔ as part of other western and southwestern districts should be preserved as climate buffers of Shànghǎi: with urban development restricted, multifunctional blue-green spaces will function as flood absorbers, cultural landscapes, and adaptive urban areas. And considering the extreme weather conditions linked to the climatic specificities of Shànghǎi, adaptive spaces-transformers ensure plazas, parks, and public facilities can function as both civic spaces and floodwater buffers, conforming to extreme weather conditions. It is a suitable flexible solution for the water-town region both in existing urban contexts such as Zhūjiājiǎo and recently redeveloped spaces like the Huawei Lianqiu Lake R&D Center in Jīnzé. This strategy is less about retrofitting like Mestre and more about preserving water landscapes while integrating multifunctional BGI to prevent risk escalation.

With the project aimed at preservation prevent risk escalation, **Phase 1** (years 0–2) should implement immediate actions to protect water landscapes as well as preparing the grounds for the implementation of adaptive SWWUSs:

- Research & Policy.
  - Conducting WasteWater and water-cycle management studies (A11);
  - Mapping flood risks & heritage water assets (A6);
  - Updating land zoning to restrict urban sprawl and safeguard existing buffer zones (A10).
- Initial BGI.
  - Construction of additional wetlands and small-scale retention ponds along Zhuhu Road and Huqingping Highway in Zhūjiājiǎo and near Lianqiu Lake in Jīnzé (A1, A12);
  - Restoration of historic canals in Zhūjiājiǎo and Jīnzé and treatment of the waters in those canals (A6).
- Public Engagement.
  - Public emphasis on Qīngpǔ's role as a climate buffer (A24);
  - Installation of signage explaining planned projects and SWWUS (A14).

With sprawl boundaries established, wetlands and canals starting to have filtering water, and public being introduced to reuse benefits that will come with future projects, piloting spaces-transformers in **Phase 2** (years 2–7) becomes possible with the construction of adaptive multifunctional spaces in visible public locations:

- Plazas as Ponds.
  - Creation of different scale sunken plazas in open spaces – including parking and squares – along Zhuhu Road in Zhūjiājiǎo that serve as civic squares in dry times and flood ponds in wet times (A9, A19).
- Parking as Basins.
  - Retrofitting parking near Zhuhu Road, the road itself and walkable ground in Huawei Lianqiu Lake R&D Center with permeable paving to function as stormwater detention (A12).
- Playgrounds & Schoolyards.
  - Transformation of Jīnzé schoolyards and playgrounds[40] into seasonal wetlands for both play and flood control (A9).

[40] This step presumes the increase of number of playgrounds as well as the renovation of the existing ones, making them accessible for all age groups and making them community connection places.

Chapter 8 From Grey to Blue-Green Design: SWWUS Implementation

- Public Realm & Cooling.
  - Utilization of treated WasteWater for irrigation of parks and street greenery (A4, A5);
  - Addition of cultural and artistic wetland features – from artists worldwide, but also from community members during festivities – to strengthen local identity and highlight its connection to water (A15);
  - Develop panoramic walks and cycle paths alongside waterways for locals and tourists (A3, A20).

Figure 60. Zhuhu Road, Phase 2-3 (drawing by author).

The goal of Phase 2 is for daily-used spaces to become visible examples of resilience by involving the residents to experience the multifunctionality of spaces-transformers. This will not only help with the acceptance of SWWUS within the residents but also enhance public spaces in residential areas and strengthen the local community sense.

Phase 3 (years 7–15) focuses on network expansion and infrastructural upgrades to scale pilots in Zhūjiājiǎo and Jīnzé into an interconnected water-sensitive system for later further expansion in all Qīngpǔ:

- Blue-Green Corridors.
  - Connection Jīnzé and Zhūjiājiǎo through blue-green corridors on the surface (e.g., integrated canals, retention plazas, and shaded boulevards) and a unified sewage network for WasteWater collection, treatment and reuse underground (A2, A6, A9).
- Infrastructure Upgrades
  - Modernization of sewage and drainage network to prevent contamination and guarantee automatization of processes (A18);
  - Retrofitting older public and commercial buildings with secondary WasteWater reuse (A31).
- Storage & Monitoring.
  - Development of decentralized water storage reservoirs and tanks for reuse outside of residential urban areas (A23);
  - Installation of real-time smart monitoring of water quality, floods, and system performance (A16).

With Phase 3 completed, Qīngpǔ should obtain a district-wide blue-green adaptive network with heritage canals full of treated clean water, modern plazas, and reuse systems working together to enhance the district's buffer zone function. The developed in Qīngpǔ system should with time expand into other districts of Shànghǎi to develop a network of SWWUS that covers the whole city not only to prevent but also mitigate and adapt to the extreme climate conditions.

Chapter 8 From Grey to Blue-Green Design: SWWUS Implementation

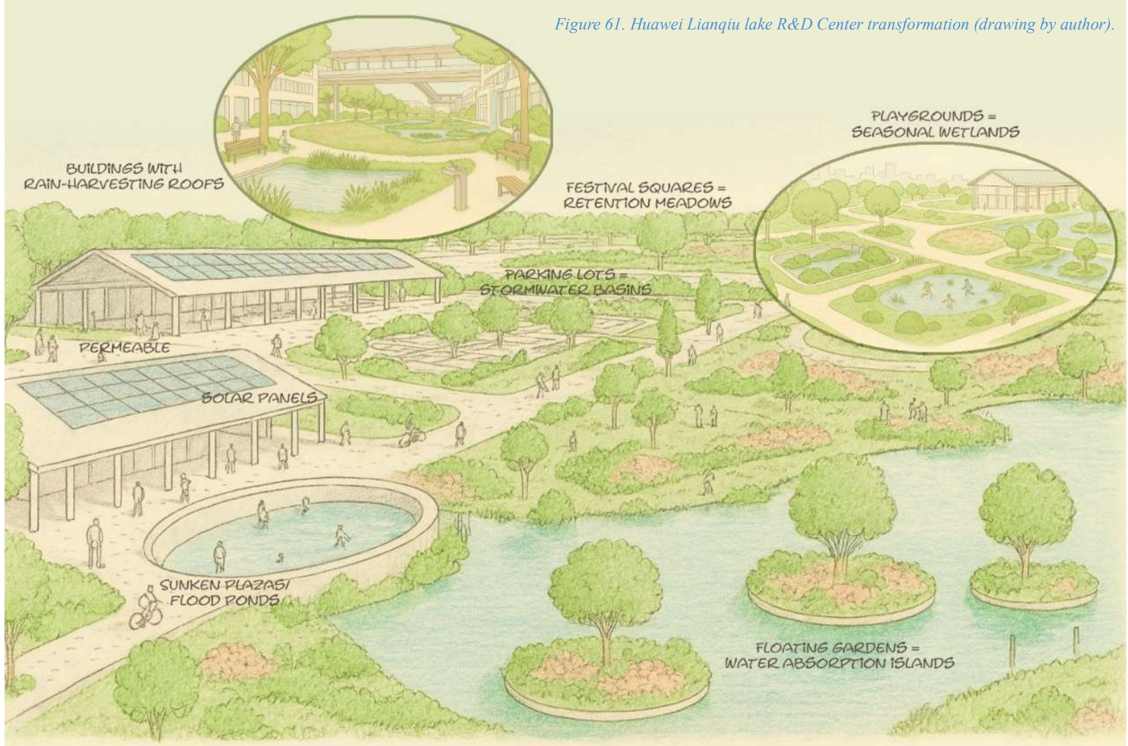

Figure 61. Huawei Lianqiu lake R&D Center transformation (drawing by author).

Consequently, **Phase 4** (years 15+) through maintenance and innovation tasks actions aims to ensure long-term sustainability with expansion of reuse and inclusivity of access:

- Routine Maintenance.
  - Regular inspections and maintenance works, specifically the cleaning of drainage and water reuse infrastructure (A17, A22);
  - Installation of digital systems to predict and optimize maintenance needs in real-time format (A16).
- Innovation in Reuse.
  - Installation of decentralized modular WasteWater reuse systems in residential neighborhoods (A28);
  - Construction of advanced treatment plants for irrigation, cleaning, and cooling (A13, A27);
  - Experimentation with underground cisterns beneath plazas and floating gardens in canals for future development and expansion.

- Equity & Inclusion.
  - Retrofitting community and social housing with reuse systems (A31);
  - Offering incentives for developers to integrate and reinforce water reuse in affordable housing (A30).

With reliable, equitable reuse systems with advanced technology in action, Qīngpǔ's buffer role will be preserved for all residents, not just corporate campuses, serving as a regional and international example for **Phase 5** (25+ years), where Qīngpǔ – and consequently Shànghǎi – evolves into a reference model for water-town climate preservation:

- Regional Cooperation.
  - Joint water reuse infrastructure and programs with neighboring Yangtze Delta cities (A7, A8);
  - Connection of Qīngpǔ's systems with Dianshan Lake and Suzhou's water networks (in case it was not done yet with previous expansions).
- Cultural & Heritage Integration.
  - Blending historic canals and urban architecture with adaptive plazas and blue-green corridors (A21, A23);
  - Transforming Zhūjiājiǎo into a cultural-climate destination for national and international tourism, by showcasing adaptive water-town natural and cultural heritages (A15, A20).
- Global Leadership.
  - Sharing Qīngpǔ's space-transformer model globally and developing international partnerships in developing buffer zones with SWWUS.

The end goal is to maintain Qīngpǔ Shànghǎi's preserved climate buffer, globally recognized for balancing heritage, ecology, and resilience, with a water-centered approach to its continuing urban development, creating from the past cities of the future.

8.2.1 Technical Summary of Qīngpǔ Project

Unlike Mestre, Qīngpǔ is not primarily a site for retrofitting but for preservation and prevention. Situated on the urban periphery of Shànghǎi, it functions as a hydrological buffer for the metropolitan core, with lakes, rivers, and historic canals forming a natural protective system. The planning strategy is to reinforce this buffer role by restricting urban sprawl through strict zoning controls, while embedding adaptive multifunctional spaces – "spaces-transformers" – into the existing urban morphology.

The technical concept of spaces-transformers involves re-engineering civic and public areas such as plazas, schoolyards, and parking lots to serve dual functions. Plazas are designed with sunken profiles and pervious surfaces, allowing them to function as temporary flood basins during extreme rainfall events while functioning as public squares in dry conditions. Schoolyards and playgrounds are converted into seasonal wetlands, combining recreational and ecological functions with water storage capacity. Parking areas are retrofitted with permeable paving and subsurface gravel trenches to absorb and detain runoff before controlled discharge.

The project begins with an intensive diagnostic phase, including hydrological modeling of flood return periods, mapping of heritage water assets, and the delineation of strict growth boundaries to prevent risk escalation. Initial interventions include the restoration of historic canals in Zhūjiājiǎo and Jīnzé, combined with the construction of distributed wetlands and retention ponds along key arterial routes such as Zhuhu Road and Huqingping Highway. These serve as decentralized treatment and storage nodes, integrated into the broader hydrological network of Qīngpǔ.

The medium-term phase prioritizes the development of adaptive civic spaces, with high-visibility projects such as plazas and parking retrofits to demonstrate multifunctionality to the local population. The introduction of treated WasteWater irrigation for public parks and green corridors begins at this stage, supported by decentralized treatment facilities that serve sub-district scale catchments. Cultural features, such as artistic wetlands and panoramic cycle paths, reinforce local identity while enhancing resilience.

In the long term, Qīngpǔ is expanded into a district-wide water-sensitive network. Heritage canals are hydraulically reconnected with newly created adaptive spaces, forming continuous blue-green corridors that integrate ecological and mobility functions. Below ground, a unified sewage and drainage system is constructed, linked to decentralized reservoirs and equipped with smart monitoring devices for real-time water quality assessment and automated flood management. Floating gardens, underground cisterns, and modular decentralized treatment plants are introduced as innovative pilot solutions.

The opportunities presented by Qīngpǔ's approach are substantial. By maintaining its function as a metropolitan climate buffer, the district not only protects central Shànghǎi from escalating flood risks but also positions itself as a cultural-ecological model of water-town resilience. The multifunctional use of public spaces ensures that resilience measures are embedded directly in daily life, fostering acceptance and long-term community support. The distributed nature of interventions also reduces dependence on single mega-infrastructures, spreading risk and increasing redundancy.

Nevertheless, the technical and planning challenges are pronounced. Enforcement of zoning restrictions requires political continuity and robust institutional capacity, especially given the economic pressures for development in peri-urban Shànghǎi. The integration of historic canals into modern hydraulic systems demands careful engineering to avoid damaging heritage assets while ensuring adequate flow, storage, and water quality. The decentralized nature of the interventions introduces high maintenance requirements, including routine cleaning of permeable pavements, dredging of wetlands, and inspection of modular treatment units. Achieving interconnectivity between numerous small systems across a large district requires a sophisticated monitoring framework, likely based on digital twin technology, to predict performance and optimize maintenance scheduling.

Source: AdobeStock

Chapter 9 Replicability and Governance of SWWUS

Urban planning traditions in Italy and China are shaped by profoundly different histories, governance structures, and socio-environmental conditions. In Italy, planning is embedded within a multilevel governance system rooted in European Union directives, national legislation, and municipal plans. Italian planning practices emphasize historical preservation, environmental protection, and the balancing of multiple public interests in compact urban contexts. In Venice specifically, planning is constrained by the unique morphology of the lagoon and the UNESCO heritage designation of the historic islands, which prioritize conservation and limit large-scale infrastructural change. The mainland areas of Mestre and Marghera, however, provide more flexibility for integrating contemporary infrastructure such as wastewater reuse systems.

In China, urban planning follows a markedly different trajectory. It is strongly centralized and directive, with national Five-Year Plans establishing urbanization targets that cascade into provincial and municipal master plans. Shànghǎi exemplifies this model: its 2017–2035 Master Plan outlines ambitious objectives for blue-green corridors, drainage modernization, and the integration of ecological infrastructure within rapid metropolitan expansion. Unlike Venice, Shànghǎi's planning operates at a scale and pace that allows for rapid adoption of innovative systems such as Sponge City initiatives and district-scale wastewater reuse networks.

These divergent traditions have direct implications for wastewater treatment and reuse. In Italy, wastewater management is governed by European directives, such as Regulation (EU) 2020/741 on water reuse, and national instruments that require advanced treatment for effluent quality and risk management. While these rules ensure safety and environmental protection, they also constrain the speed of implementation and often limit experimentation in historic urban cores, as they rarely offer financial support. For some countries, it can even be more convenient to pay fines than to invest in the development and maintenance of new sustainable systems. Conversely, in China, wastewater management is framed as a national development priority under the Water Pollution Prevention and Control Action Plan and the Yangtze River Protection Law. These instruments establish binding targets and empower local governments to implement wastewater reuse projects at scale, particularly in peri-urban and industrial districts, where large state-financed systems can be rapidly deployed.

Comparing Venice and Shànghǎi is thus particularly instructive. Both cities face water management challenges intensified by climate change and urban growth, but they respond within different institutional and planning frameworks. Analyzing their respective approaches provides insights into the replicability of analytical methodologies and design logics for secondary wastewater use systems. Understanding how governance, planning culture, and data environments shape reuse projects is essential for advancing urban water sustainability in diverse global contexts.

From the perspective of methodology, the analytical framework developed in this study demonstrates a high degree of transparency and portability. It is structured as a sequential, tool-agnostic workflow beginning with digital terrain model correction and watershed delineation, proceeding through NDVI-based flood vulnerability assessment and exposure analysis, and resulting in the estimation of flood and heat risk through integration with land surface temperature, vegetation cover, and building characteristics. These elements are combined into a composite multi-risk index that can be directly used in planning interventions. The reliance on standard GIS tools, satellite imagery (e.g., Sentinel), open-source cartographic layers, and demographic data makes the method readily transferable to different urban contexts. Its strength lies not only in technical reproducibility but also in its orientation toward practice: outputs are explicitly designed to inform the siting of small wastewater treatment and reuse systems, green infrastructure, and heat-mitigation interventions.

However, the replicability of the methodology is constrained by several key factors. Data asymmetry remains a major limitation. In Venice and its mainland areas, detailed spatial and demographic datasets are available, allowing fine-grained assessments of vulnerability and exposure. In Shànghǎi, by contrast, much of the publicly accessible data is aggregated at the district level, reducing analytical precision. The same methodological workflow thus produces outputs of differing quality across contexts. Additionally, restrictions on data access further complicate replicability. Critical information on household consumption patterns, wastewater generation, and system capacities is often confidential or unavailable, forcing reliance on proxies and diminishing the reliability of the model.

Beyond data, governance and legal structures shape how results can be operationalized. In Venice, multi-level governance under EU law ensures environmental protection but complicates coordination between agencies responsible for water, heritage, and infrastructure. The Legge Speciale per Venezia and the Piano delle Acque illustrate the city's focus on protection and mitigation, while the Progetto Integrato Fusina (PIF) demonstrates the potential—and the difficulty—of translating circular-water ambitions into functioning systems. Despite its completion, the PIF remains only partially activated due to funding and governance fragmentation,

Chapter 9 Replicability and Governance of SWWUS

reflecting the institutional inertia typical of heritage-constrained European contexts.

Shànghǎi's model, in contrast, benefits from hierarchical coherence. The Water Ten Plan, Yangtze River Protection Law, and Sponge City Program create a vertical governance chain that connects national targets to municipal execution. The Shànghǎi Master Plan 2017–2035 operationalizes these mandates through district-level implementation, enabling large-scale integration of wastewater reuse into ecological corridors, flood basins, and industrial water systems. State financing and institutional capacity support rapid expansion. Yet, this same centralization means that replicability relies on continued political commitment and may not translate easily to more decentralized governance contexts like Venice.

This divergence means that replicability occurs in different forms. In Venice, replicability is adaptive. The methodology can guide incremental improvements compatible with heritage protection and fragmented governance. Here, the focus should be on small-scale, decentralized reuse systems – such as dual-pipe retrofits in public buildings or wastewater-fed irrigation for urban greening – embedded within existing planning instruments. In Shànghǎi, replicability is scalable. The same methodological framework can inform district-level prioritization, integration with digital urban management platforms, and expansion of sponge-city interventions using reclaimed water besides the general update of the urban water infrastructure to a close cycle.

Nevertheless, full comparability between the two cases remains limited. Hydrological conditions differ substantially – Venice's tidal flooding and saline intrusion contrast with Shànghǎi's fluvial flooding and subtropical climate. Cultural and institutional contexts further constrain direct equivalence. Venice's governance model emphasizes deliberation and preservation; Shànghǎi's favors performance and rapid execution. Even with identical analytical procedures, the results must be interpreted through these local filters, meaning that replication does not imply identical outcomes.

For this reason, replicability must be understood as a process of contextual translation rather than mechanical transfer. The spatial analytical framework can be applied in both contexts, but the design and policy outcomes depend on governance capacity, financial structure, and environmental conditions. In Europe, replicability should prioritize open data, interoperability, and cross-sector collaboration to overcome institutional silos. In China, it should focus on adaptive governance and data transparency to strengthen local flexibility within a centralized system. To improve replicability across contexts, targeted strategies can be grouped by regional context, including policy and socio-cultural contexts.

For European cities like Venice:

- Prioritize open-access, interoperable datasets at neighborhood scale to improve vulnerability and exposure mapping;
- Develop incentives under EU funding frameworks (e.g., Horizon Europe, LIFE) to assess SWWUS within heritage-sensitive environments;
- Incorporate circular-water planning instruments within projects and documents like Piano Urbanistico Generale, aligning reuse objectives with flood-resilience and heat-mitigation policies;
- Promote local pilot projects in public spaces and social housing to demonstrate feasibility and public acceptance.

For Chinese cities like Shànghǎi:

- Improve transparency and cross-sector data integration to enable fine-grained analysis without compromising administrative control;
- Strengthen the connection between the Sponge City and wastewater-reuse programs to achieve co-benefits in climate adaptation;
- Introduce adaptive governance mechanisms at district level to balance centralized efficiency with local flexibility;
- Utilize district-scale digital twins and sensor networks to monitor the performance of decentralized reuse systems and enhance replicability within other megacities.

These measures acknowledge that the methodological framework developed here is formally replicable but substantively differentiated. The transparency, openness, and modular structure of the GIS-based multi-risk assessment make it transferable, but its successful application depends on policy alignment and institutional adaptation. And future success of the application of the projects depends on investments and funds for maintenance and adjournment of the treatments and reuse systems.

Ultimately, the comparative analysis of Venice and Shànghǎi demonstrates that replicability is not about reproducing identical results but about reproducing the analytical reasoning – a sequence of data integration, spatial prioritization, and strategic planning adaptable to local governance, morphology, and culture. In this time and context, in Venice, this means integrating wastewater reuse within preservation-oriented frameworks; in Shànghǎi, it means optimizing large-scale systems for ecological and social performance. The key outcome of this research is the demonstration that sustainable water management depends on reconciling universal methodological principles with locally specific governance realities.

By linking technical, spatial, and institutional dimensions, the proposed approach provides a transferable yet adaptable model for circular water management. It shows that while cities differ in scale, structure, and policy regime, they share a common need for integrated planning capable of transforming wastewater from an environmental liability into a spatial and ecological asset.

The comparison (though limited) of Venice and Shànghǎi demonstrates that while the methodological framework for secondary wastewater use systems is universally applicable in structure, its outcomes are deeply conditioned by local realities. Certain principles emerge as universally transferable across contexts: the necessity of integrated policy coordination between planning and water-management agencies, the inclusion of stakeholder participation to build legitimacy and public acceptance, and the importance of transparent, open-access data to ensure replicable analytical processes. However, other determinants remain context-dependent, shaped by each city’s historical trajectory, governance culture, and spatial morphology. In Venice, the constraints of heritage preservation, fragmented competencies, and limited municipal autonomy define a pathway of adaptive and small-scale innovation. In Shànghǎi, the centralized institutional framework and high infrastructural capacity enable systemic and rapid implementation, but often at the expense of local flexibility and participatory engagement. Recognizing these distinctions clarifies that replicability lies not in the duplication of forms but in the translation of shared principles into site-specific strategies – a process through which methodological universality meets contextual specificity in pursuit of circular, water-sensitive urban development. Building on these insights, it is possible to reflect on the urban planning opportunities and challenges that arise from the implementation of SWWUS in diverse governance and spatial settings.

Chapter 10 Conclusions

Municipal WasteWater – collected from predominantly residential, but also increasingly commercial and small industrial sources – represents a critical yet underutilized resource in cities. The implementation of secondary WasteWater use in public spaces through BGI offers multiple benefits for the urban environment, ranging from reduced reliance on freshwater supplies to improved ecological health and resilience. By reusing treated WasteWater for irrigation, landscaping, and other non-potable purposes, cities can not only alleviate growing water scarcity pressures but also close resource loops, thus advancing the principles of circular urban development. The improvement of the urban environment through these instruments includes psychological benefits for the residents and visitors that will enhance the quality of life. Thus, SWWUS implementation does not only address only SDG 6 (Clean Water and Sanitation), but also SDG 3 and 11 (Good Health and Well-being, and Sustainable Cities and Communities, respectively).

The implementation of secondary wastewater use systems (SWWUS) in cities represents one of the most promising yet complex frontiers of contemporary urban planning. This research began from the premise that urban water is not only a technical or environmental issue but also a spatial, social, and governance matter – one that reveals how societies value resources, organize infrastructures, and design the relationship between people and their environments. Throughout the investigation, the study has shown that wastewater reuse, when approached through an integrated planning lens, can function as both a symbol and mechanism of urban transition toward circularity, resilience, and sustainability.

At the conceptual foundation, the study established that water consumption patterns mirror human development needs, as illustrated through Maslow's hierarchy of needs and its adaptation to the hierarchy of water use. Understanding this evolution – from basic survival to comfort and social expression – allows planners to see how water use, and consequently wastewater generation, changes with societal progress. The pandemic-related shifts further confirm that urban water systems are deeply responsive to lifestyle, cultural, and behavioral transformations. This insight frames wastewater reuse not as a static engineering solution, but as a dynamic planning opportunity to reimagine how cities adapt their infrastructures to evolving patterns of human activity.

From a methodological standpoint, the research proposed and evaluated a spatial analytical framework that integrates multi-impact risk assessment with planning interpretation. By combining Urban Heat Island (UHI) intensity and Flooding Risk, the framework identifies where environmental stressors overlap, thus revealing areas where

SWWUS can deliver multiple co-benefits – reducing runoff, cooling urban microclimates, and enhancing ecological networks. This process transforms vulnerability mapping into an opportunity-mapping tool for planners, guiding decisions about where interventions can achieve the greatest social and environmental value. The use of accessible data, open-source GIS tools, and a transparent workflow makes this methodology broadly transferable, providing cities with a replicable process for linking technical analysis to spatial planning priorities.

Yet the research also demonstrates that methodology alone cannot guarantee implementation. The true test of replicability lies in institutional alignment and governance capacity. The comparative analysis of Venice and Shànghǎi revealed that the same analytical process operates very differently depending on policy frameworks, data infrastructures, and planning cultures. In Venice, urban water governance is defined by a multi-layered system of European, national, and municipal regulations. These ensure environmental integrity but often fragment decision-making, creating barriers to integrated projects and slowing the diffusion of innovation. The Legge Speciale per Venezia, while essential to lagoon protection, imposes procedural rigidity that complicates the realization of adaptive water systems. Despite this, Venice also embodies a unique planning opportunity: its heritage-driven identity and ecological vulnerability position it as a laboratory for small-scale, context-sensitive reuse systems that blend historic preservation with contemporary sustainability. Here, the challenge is not to build faster, but to build intelligently – to integrate SWWUS into the city's existing urban fabric through incremental retrofitting, adaptive design, and policy experimentation.

Shànghǎi, in contrast, represents a planning environment where centralization and scale enable rapid innovation. The Water Ten Plan, Yangtze River Protection Law, and Sponge City initiative create a cohesive policy ecosystem that promotes wastewater reuse as both a technological and ecological mandate. The city's capacity for coordinated governance and infrastructural investment makes it fertile ground for district-scale projects, such as those in Qīngpǔ, where water reuse can be integrated into green corridors, flood retention zones, and public spaces. However, this model also exposes an important planning challenge: while vertical governance enables efficiency and speed, it risks limiting local flexibility and participatory engagement. The opportunity lies in using this centralized structure not just for rapid delivery but for adaptive learning – embedding feedback mechanisms, data transparency, and localized experimentation within national-scale initiatives.

Taken together, the two case studies demonstrate that SWWUS implementation occupies a delicate intersection between technological feasibility and institutional adaptability. It is not a question of whether a method can be replicated, but how its logic can be translated into different political and spatial realities. Replicability depends on the relationship between data precision, policy coherence, and governance culture. Venice exemplifies adaptive replicability, where analytical insights guide gradual improvements aligned with existing regulatory systems. Shànghǎi embodies scalable replicability, where state-led integration allows rapid and large-scale application. Both models offer valuable lessons: Venice teaches the importance of cultural sensitivity, interdisciplinary collaboration, and public acceptance; Shànghǎi demonstrates how strategic alignment and infrastructural coherence can accelerate systemic change.

These comparative insights highlight the central role of urban planning in mediating between opportunity and constraint. Urban planners are uniquely positioned to interpret the spatial, technical, and social dimensions of wastewater reuse – to translate data into design, regulation into implementation, and environmental urgency into coherent strategies. Planning for SWWUS requires rethinking the traditional boundaries between engineering and urban design, between environmental protection and development, and between governance and community participation. In this sense, wastewater reuse becomes a planning paradigm rather than a discrete project type – a way of reimagining the city as a living, circular system where water flows, risks, and opportunities are spatially and institutionally interlinked.

However, significant challenges remain. Data asymmetry continues to constrain analysis and decision-making. In Venice, granular consumption data are limited by privacy laws; in Shànghǎi, by administrative restrictions. These gaps hinder the precision of vulnerability assessment and the comparability of results. Moreover, the technical feasibility of SWWUS is often overshadowed by financial and institutional inertia — by fragmented responsibilities, limited coordination, and insufficient long-term maintenance frameworks. Addressing these issues requires not only technological investment but also governance innovation: mechanisms for interdepartmental cooperation, open data policies, and stable funding streams that bridge short-term projects with long-term urban transitions.

The broader contribution of this research lies in demonstrating that SWWUS can serve as both an instrument and indicator of circular urban development. When wastewater is reframed as a spatial and ecological resource, cities gain the ability to link climate adaptation, public space design, and infrastructure planning under a unified vision. The proposed methodology provides the analytical foundation for this transformation, while the comparative cases reveal the political and cultural pathways through which it can occur.

Ultimately, the opportunity is not only to reuse water but to reuse knowledge — to learn from local experimentation, adapt frameworks across governance levels, and embed water circularity within the DNA of urban planning.

In conclusion, the study reaffirms that the future of wastewater reuse in cities depends on the balance between innovation and context. The opportunity lies in the capacity of planners, engineers, and policymakers to integrate environmental intelligence with spatial imagination; the challenge lies in aligning regulatory, financial, and cultural systems to sustain this integration over time. If Venice symbolizes the challenge of adaptation in constrained heritage contexts and Shànghǎi embodies the opportunity of transformation in dynamic metropolitan environments, then together they outline the dual trajectory through which global cities must navigate: from incremental retrofitting to systemic reconfiguration.

The research thus closes with a simple but powerful proposition: wastewater reuse is not only a technical response to scarcity, but a spatial and institutional opportunity to design cities that learn from their own cycles. By merging scientific methodology with planning practice, and by situating innovation within context, SWWUS becomes a lens through which urban planners can address the intertwined challenges of sustainability, resilience, and equity – transforming waste into value, risk into design, and necessity into opportunity.

10.1 Afterthought: Toward a Water-Centered City

The integration of secondary WasteWater reuse and BGI can be seen not only as a pragmatic response to water scarcity but also as the first foundational step toward a broader paradigm shift: the development of water-centered cities. A water-centered city is not one where water is merely managed, but one where water becomes the organizing principle of urban life – shaping public space, guiding infrastructure, and sustaining ecological and social vitality.

By treating WasteWater as a resource and embedding it into urban landscapes through parks, wetlands, permeable surfaces, and multifunctional public areas, cities begin to reframe water from an external challenge into an internal lifeblood. This approach aligns with circular economy principles, closing loops between consumption, treatment, and reuse, and it creates visible, tangible connections between residents and the water systems that sustain them. In doing so, it lays the groundwork for a cultural as well as infrastructural transformation, where water is perceived not as waste to be discarded but as value to be regenerated.

A water-centered city, much like a tree growing from its roots, thrives when its water systems support multiple functions at once: ecological health, flood protection, cooling, recreation, and food production. These multifunctional systems enhance resilience against climate change, foster equity through shared public amenities, and generate economic opportunities by revitalizing underused spaces such as waterfronts. The result is a city that is more livable, adaptive, and just.

As urban populations expand and water shortages intensify, cities can no longer afford to operate in linear, consumption-driven cycles. Secondary WasteWater reuse and BGI represent an accessible entry point into circular urbanism, a first step that demonstrates both feasibility and impact. Embracing them not only alleviates immediate pressures but also orients urban development toward a future where water is at the heart of planning. In such a future, the water-centered city emerges as a model of prosperity, resilience, and harmony – one that is urgently needed in the twenty-first century. This demonstrates that circular water systems can form a basis for sustainable urban transformation.

Building upon these conclusions, it is possible to reflect on the broader implications of this work for urban planning practice and the evolving role of planners in shaping circular and regenerative cities. From a planning-practice perspective, the findings of this research demonstrate that secondary wastewater use systems can serve as tangible instruments for adaptive and regenerative urban development. For urban planners, this means reframing wastewater not as an end-of-pipe concern but as a spatial and design opportunity – a resource to be integrated into public-space renewal, ecological restoration, and community resilience strategies. Implementing SWWUS requires new forms of cross-sectoral collaboration in which planners function as mediators between engineering, policy, and design disciplines, ensuring that infrastructural innovation aligns with social and spatial objectives. In adaptive planning contexts such as Venice, this entails embedding small-scale reuse systems within incremental regeneration projects and flood-mitigation schemes. In more dynamic environments like Shànghǎi, it involves scaling circular-water principles through district-level frameworks that link urban growth with ecological restoration. Ultimately, the role of urban planners is to translate the analytical and policy insights of this research into spatially grounded actions – designing cities where water reuse becomes not only a technical solution to scarcity but a catalyst for systemic transformation toward more resilient, regenerative, and circular urban futures by changing how we see our cities and the resources it needs and offers to its inhabitants.

In essence, the city's relationship with water mirrors the way it manages change: both demand balance, adaptation, and vision. By positioning wastewater reuse as a core principle of circular urbanism, this research reaffirms that the future of sustainable planning lies in cities capable of learning from their own cycles:

transforming constraints into creativity and necessity into opportunity, returning to natural cycles with the support of modern technologies and knowledge.

Source. AdobeStock

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