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Tale of Two Cities: How Nature-Based Solutions Help Create Adaptive and Resilient Urban Water Management Practices in Singapore and Lisbon

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Abstract: Nature-based solutions (NbS) are increasingly recognized as viable tools for sustainable urban water management. This article explores the implementation of NbS in two distinct cities, Singapore and Lisbon, to demonstrate that NbS can work in very different contexts and spark new thoughts on the urban–nature relationship and to identify commonalities that drive and enable the implementation of NbS in different context. Literature review-based research was conducted to examine the types of NbS implemented, the common drivers, the governance model, and the plural functionalities of the solutions. The research shows that, despite the differences, the two cities shared common drivers (including water supply, flood control, and resident demand for green space) and goals, such as improving water quality and overall quality of life, through the deployment of NbS. With rapid urban expansion, water use increase, and the impacts of climate change, NbS can be effective tools to deliver integrated benefits and improve the liveability of cities.

Keywords: biodiversity; nature-based solutions; pluralism; water management; blue-green infrastructure; whole of government approach

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1. Introduction

Global water use has increased by a factor of six over the past 100 years and continues to grow steadily at a rate of about 1.8% per year [1]. According to the United Nations, 55% of the global population lives in cities today. This will increase to 68%, or 6.7 billion people, in 2050. New research suggests that 190 million people currently occupy global land below projected high tide lines for 2100 under the low carbon emissions scenario. Under a high emissions scenario, the number increases to 630 million people [2]. This means that water management in urban areas is one of the top priorities for a prosperous future for cities.

Under the threat of climate change, increasing population, sinking ground due to the overuse of underground water, loss of biodiversity, stress-induced mental health issues, and many other immediate issues cities face today, many have turned to nature for inspirations and solutions.

Nature-based solutions (NbS) are defined by the European Commission as "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions". The International Union for Conservation of Nature (IUCN) is also a strong advocate for NbS and launched the Global Standard for NbS in 2020. IUCN defines NbS as "actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits. They are underpinned by benefits that flow from healthy ecosystems and target major challenges like climate change, disaster risk reduction, food and water security, health and are critical to economic development". Both definitions stress the importance of recognizing the need to deliver mutual benefits for people and the ecosystem.

NbS can play a particularly important role in urban water management (UWM). In the 2018 UN World Water Development Report [3], the authors highlighted three main areas to which NbS can contribute:

- Increase water availability through managing precipitation, humidity, and water storage, infiltration, and transmission;
- Improve water quality through source water protection—forests, wetlands, and grasslands—regulating water quality by reducing sediment loadings, capturing and retaining pollutants, and recycling nutrients;
- Reduce water-related risks through water retention to reduce exposure to floods and droughts.

Furthermore, NbS can help form efficient strategies for mitigating problems arising from growing urbanization, particularly in terms of flood risks, climate regulation (the capacity of water bodies to regulate the micro-climate, mitigating urban heat islands (UHIs) and heatwaves), while promoting the effective incorporation of socio-cultural services, including recreational opportunities, and focusing on aesthetics, human well-being, and social cohesion principles [4–9].

This paper aims to provide an overview of NbS for urban water management in two distinctively different contexts to compare the implementations of NbS and identify common drivers, enablers, and approaches. The paper also aims to generally determine the effectiveness and benefits of the adoption of NbS in different urban contexts, namely Singapore and Lisbon, as a proof of the adaptability and versatility of NbS, allowing these tools to be more widely applied in the future.

2. Materials and Methods

2.1. Overview of Common Nature-Based Solutions for Urban Water Management

Urban water management-related NbS may be categorized and evaluated accordingly to different perspectives, including the categorization proposed by Ramírez-Agudelo et al. [4]. These authors outlined the following 10 categories of NbS, based on data extracted from 66 references: wetlands, including natural and constructed wetlands; sustainable drainage systems (SUDS); green roofs/walls; river parks; agroforestry; parks; permeable pavement; phytorid wastewater treatment; rain gardens; and bioswales. In this paper, we focused on wetlands, SUDS, and river parks, due to the relevance of these types of solutions in Singapore and Lisbon.

2.1.1. Wetlands

Wetlands are often considered to be NbS that can provide a multitude of services of great social, economic, and environmental value to humankind. It is widely acknowledged that wetlands provide a variety of ecosystem services including carbon sequestration, water quality protection, coastal protection, ground water level and soil moisture regulation, flood regulation, and habitats for biodiversity [10–12]. Based on the NbS case review [4], wetlands are particularly effective for flood risk reduction, water pollution reduction, and water purification. Coastal wetlands act as a buffer for sea level rise and flooding, while urban wetlands are constructed or adapted to reduce urban water pollution. Constructed wetlands are most commonly used in cities for the purpose of rainwater treatment, combined sewer overflow treatment, and the treatment of the outflow from existing wastewater treatment plants, including for the treatment of contaminants of emerging concern [11].

2.1.2. Sustainable Drainage Systems

SUDS are a collection of water management practices that aim to align modern drainage systems with natural water processes, including control structures and strategies designed to efficiently and sustainably drain surface water, while minimizing pollution and managing the impact on the water quality of local water bodies [13]. SUDS often use built components that mimic natural features in order to reduce flooding (due to attenuation and infiltration), improve water quality, promote biodiversity (wildlife and plants), and provide amenity, therefore constituting an environmentally beneficial approach. Examples generally accepted as components in a SUD system include bioswale, permeable pavements, detention basins, infiltration trenches, and green roofs.

Sustainable drainage approaches emphasize moving away from the traditional concept of designing only to manage flood risk, where runoff is regarded as a nuisance, to a philosophy where surface water is a valuable resource and should be managed for maximum benefit [13].

2.1.3. River Parks

River parks work similarly to wetlands. They deliver numerous ecosystem services including supporting biodiversity, climate regulation, flood control, and water purification and supply. They also bring significant benefits to people through improving the environment and increasing green space for sports and activities. Europe is leading in the urban river restoration process to build more resilient cities [14].

2.2. Study Areas

The research was undertaken in Singapore, a tropical island city state, and Lisbon city, the capital of Portugal and the European Green Capital 2020. The two cities have significantly different backgrounds and conditions (namely in terms of culture, physical characteristics, and climate) and thus serve as good examples of how NbS is not limited to any particular type of cities.

2.2.1. Singapore

Singapore (1.3521° N, 103.8198° E) has a total land area of 725.7 square km and a water area of 10 square km (2019). With a population of 5.68 million (2020), it is considered one of the most densely populated countries and cities in the world. Singapore has urbanized rapidly since the 1950s. However, with an ambitious greening strategy since the 1960s, close to 50% of its land area is now covered by natural and managed vegetation, making it a unique city state island [15].

Singapore is located at the southern tip of the Malay Peninsula, 137 km north of the Equator. Due to its location, Singapore has a tropical climate with two monsoon seasons characterized by uniformly high temperatures (monthly mean 26.4–28.3 °C) and nearly constant precipitation (monthly mean 112.8–318.6 mm) throughout the year [16].

Singapore became independent from Malaysia in 1965 and subsequently became one of the world’s most prosperous countries with strong international trading links and high per capita GDP at 59,819 USD (2020). However, Singapore faces several challenges with regard to water management. First, Singapore is an island country with no freshwater resources. The water supply has always been one of the biggest existential challenges that the country has faced since its independence. Furthermore, with the continued expansion of the country through land reclamation, coupled with sea level rise, coastal Singapore faces erosion and flooding risks. Finally, storms in Singapore have become more intense and frequent in the past 20 years, resulting in more flash floods [17].

2.2.2. Lisbon

Lisbon (38.7223° N, 9.1393° W) is one of the oldest cities in the world, founded around 3000 years ago. It is the capital of Portugal and its largest city, with a population of over 500,000 (inner city) and of 2.8 million people (overall city). Lisbon, with its “seven hills”, sits at the mouth of the River Tagus and is the country's main port and its political and commercial centre. The old city is served by combined sewers systems, while the more recent neighbourhoods include separate sewer systems.

Portugal's geographical location in the southwest of Europe leads to a Mediterranean type of climate: the summers are warm and dry and the winters cool and wet [18]. Almost half of the annual precipitation falls during winter, with only 7% during summer [18]. The last decades have shown a decrease in total annual precipitation and an increase in extreme weather events, such as heat waves, droughts, and heavy rains [18]. Seven out of the 10 hottest summers in continental Portugal occurred in the 21st century, and the trend of even hotter and drier summers is expected to continue in the future [19].

Lisbon was nominated as the European Green Capital 2020 due to the continued commitment to sustainability that started during an economic crisis, demonstrating that sustainability and economic growth may go hand in hand. The city's sustainable measures are centred in urban area development and water efficiency and management [20]. The municipality of Lisbon (Câmara Municipal de Lisboa, CML) has expanded its public transport and bicycle path network, invested in energy-efficient traffic lights, and transformed the waste management system.

Lisbon has been cleaning up the Tagus Estuary mainly since 2008 with the aid of EU Cohesion and Structural Funds. The resulting increase in biodiversity has seen dolphins return after a 50 year absence. Currently, 2% of Lisbon's treated wastewater is reused for the treatment process and street cleaning, but CML aims to decrease its freshwater demand in the future by building an urban recycled water distribution network through the city, with three wastewater treatment plants (WWTP) as a water source.

In mitigating and preparing for climate change, Lisbon has developed 13% more green areas under a consistent ecological network based on green corridors and tree-planting. These actions do not only increase green spaces and biodiversity; they also mitigate pollution and provide land for urban farming. There are now 850 organic allotment gardens using compost organic waste and, in some locations, collected rainwater. In addition, natural drainage solutions to prevent or reduce damage from floods have been implemented or planned, and 16 rainwater design locations now provide natural rainwater retention and/or infiltration.

2.3. Methods

The research focused on comparing the approaches (main drivers, climate and social context, implementation, and results) of nature-based solutions for urban water management in Singapore and Lisbon (Portugal).

In both cities, the history and experience of NbS were qualitatively analyzed, presenting results that are related to water supply (either domestic water supply or wastewater reuse for compatible uses), flood control (and related climate change aspects, including coastal erosion prevention), and the construction of green and recreational areas.

The implementation of NbS projects in Lisbon and Singapore was compared against different site-specific factors, namely location, climate, natural water resources, total population and population density, and per capita GDP, as well as governance models and cultural and social aspects. The number of people with adequate close-to-home recreational opportunities was also considered, particularly in Lisbon. Furthermore, it was examined whether new green projects were used to rehabilitate industrial/degraded areas or were built in former natural areas. In some situations, the flood mitigation impact was illustrated through the dynamic modelling (1D/2D) of the city drainage system considering precipitation events with different return periods and scenarios regarding climate change projections.

Our discussion aims at stressing out how these two cities, which are so different from historical, climatic, economic, and cultural perspectives, have shifted from concrete and engineering-based water solutions to NbS. The common drivers, enablers, and approaches are identified, and the need for pluralism in spatial planning is highlighted, evidencing the mindset shift in both cities among citizens and policy-makers.

3. Results

3.1. The Experience of NbS in Singapore

The use of the term "nature-based solutions" became common in Singapore in the past one to three years (Figure 1). In 2018, the National Research Foundation Singapore funded a three-year collaborative research project "Natural Capital Singapore" that aims to "assess the current status and health of Singapore's major ecosystems and quantify their economic and societal value" [21]. The quantification of the benefits that people obtain from ecosystems, which are usually referred to as "ecosystem services", including flood control and UHI reduction, highlighted the importance of NbS. In 2020, the National University of Singapore established the "NUS Centre for Nature-based Climate Solutions", which is the first research organization in Singapore to focus on the research and development of NbS for climate change mitigation through an interdisciplinary approach [22]. The term "nature-based solutions" was also later used in the Singapore Green Plan 2030 in 2021 [23]. However, this recognition and readiness to adopt NbS as important urban solutions could probably be attributed to a few milestones in Singapore's history; in particular, the history of tree-planting in Singapore, which began in the 1960s with the Garden City vision as part of nation building; the evolution of the vision to transform Singapore into a City in a Garden; and more recently, the vision of a City in Nature in 2018. Figure 1 below illustrates the timeline of some selected milestones.

Figure 1. Selected milestones of the emergence of NbS in Singapore.

3.1.1. Integrated Planning for Water Supply

Singapore's water supply came from Malaysia before its independence in 1965. Today, imported water from Malaysia accounts for about 30% of Singapore's water demand. In order to meet the island country's 430 million gallons of water demand on a daily basis [24], Singapore has developed a comprehensive water management strategy that combines technology and nature.

Because of the water constraints, Singapore developed an integrated water strategy early on, under the Public Utilities Board, Singapore's National Water Agency. The water strategy plans for four water sources, also known as the four national taps: water from local catchments, imported waters, NEWater (recycled greywater), and desalinated water [25]. Currently, 45% of Singapore's water demand comes from domestic use and 55% from non-domestic use. NEWater provides up to 40% of total water demand, while desalinated water accounts for 30%. Water demand is projected to double by 2060, by which time NEWater will supply 55% while desalinated water will make up 30% of the total water supply [25].

The four national taps are built on two key pillars: water technologies and integrated planning and water management. The country invested heavily in desalinization and water purification technologies to ensure two of the national taps would run smoothly; at the same time, the state embarked on integrated planning from the beginning to leverage nature for rainwater collection and storage. In total, 40% of the land-scarce island country is devoted to green space and water catchment. There are 17 constructed and natural water catchment areas on the island, as shown in the map below (Figure 2).

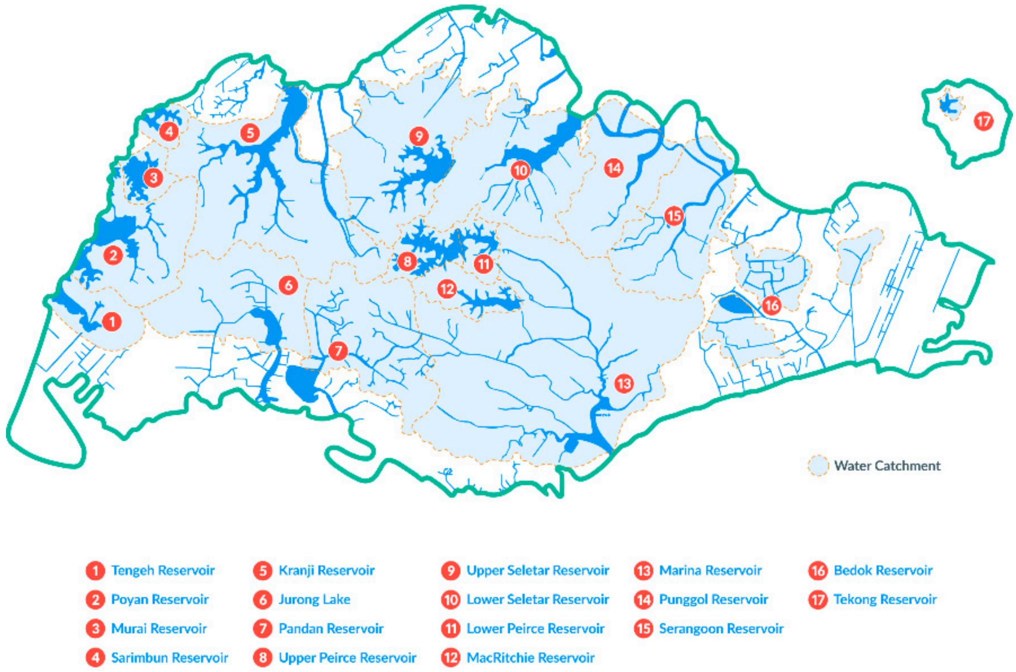

Figure 2. Distribution of Singapore's water catchments. Reproduced with permission from the Public Utilities Board (PUB) [24].

The water catchments integrate a range of NbS including river parks, rain gardens, and permeable pavement to maximize the coverage of the water catchment area. The island's surface is well connected by different waterways and canals to ensure all rainwater is drained into the 17 reservoirs. The planning of these water catchments involved different government agencies to ensure optimal benefit capturing. For example, many of the water catchments are designated within the nature reserves (e.g., Central Catchment Nature Reserves) and parks, which are managed by the National Parks Board (NParks), while tourism activities in the areas that generate economic benefits are managed by the Singapore Tourism Board (STB).

3.1.2. NbS for Flood Control

In 2006, the Public Utilities Board (PUB) launched a new programme called the Active, Beautiful, Clean Waters Programme (ABC Waters) [26]. The ABC Waters Programme aims to apply a water-sensitive urban design approach to water infrastructure, landscaping, and buildings. The ABC Waters Programme in general aims to achieve three goals: (1) create a lively environment for activities, (2) contribute to a more resilient city with better flood control, and (3) provide a natural and effective way to clean the water before it enters the catchments. Between 2010 and 2018, 75 projects were certified under the ABC Waters Programme. According to new research, ABC Waters programme-certified projects can achieve a 33% reduction of peak flow for 10-year design storm [27].

One of the first and the flagship projects of the ABC Waters Programme—Bishan-Ang Mo Kio Park (Figure 3)—is a community park that was developed as a green buffer between Bishan and Ang Mo Kio new towns [28]. The naturalized river, designed based on a flood plain concept, runs across the middle of the park connected to the Kallang River and was once part of a concrete-based storm water drainage system (Figure 4). In 2012, it was transformed into a series of constructed wetlands, rain gardens, and vegetated bioswales, not only for flood regulation, but also for recreational use and to support biodiversity (Figure 4). The park is now used extensively by people in the neighbourhood and also from across the city. Although no wildlife was introduced to the park, a stable and abundant assemblage of fish that highly resembles the upstream reservoir and differs significantly from the downstream unrehabilitated canal was found to have established in the waterway [29]. The greening and rehabilitation of the waterway has also facilitated the use and presence of the smooth-coated otter *Lutrogale perspicillata*, a species that is listed internationally as "vulnerable" in the IUCN Red List of Threatened species [30,31].

Figure 3. Bishan-Ang Mo Kio Park during and after storm event [32] (photo credit to the Ramboll Studio Dreiseitl, reproduced with permission from Ramboll Studio Dreiseitl).

Figure 4. Bishan-Ang Mo Kio Park before and after ABC Waters Programme upgrade [32]. (Photo credit to the Ramboll Studio Dreiseitl, reproduced with authorization from Ramboll Studio Dreiseitl).

3.1.3. NbS for Coastal Protection

Singapore first announced its plan in 2019 to adopt nature-based solutions to combat sea level rise, in addition to the possibility of implementing engineering solutions such as empoldering [33]. Mangroves, for example, are increasingly recognized as an effective nature-based solution for coastal flood risk reduction and erosion prevention [4]. Currently, Singapore has an estimated area of 8.1 square km of mangrove forest coverage, equivalent to 1.1% of the country's total land area [15] (Figure 5). This combination of hard and soft engineering solutions could be effective to mitigate coastal erosion and to protect the coast from sea level rise [34]. With the recognition of the importance of these coastal ecosystems, mangrove restoration in Singapore is being actively undertaken through multi-stakeholder and collaborative projects such as the Coastal Protection and Restoration of Mangrove Biodiversity at Pulau Tekong and Restore Ubin Mangroves Initiatives (R.U.M) on Pulau Ubin [35,36]. Further ongoing restoration efforts are also being conducted through the Forest Restoration Action Plan under the NParks One Million Trees Movement, which aims to plant more than a million trees across Singapore over the next 10 years [37].

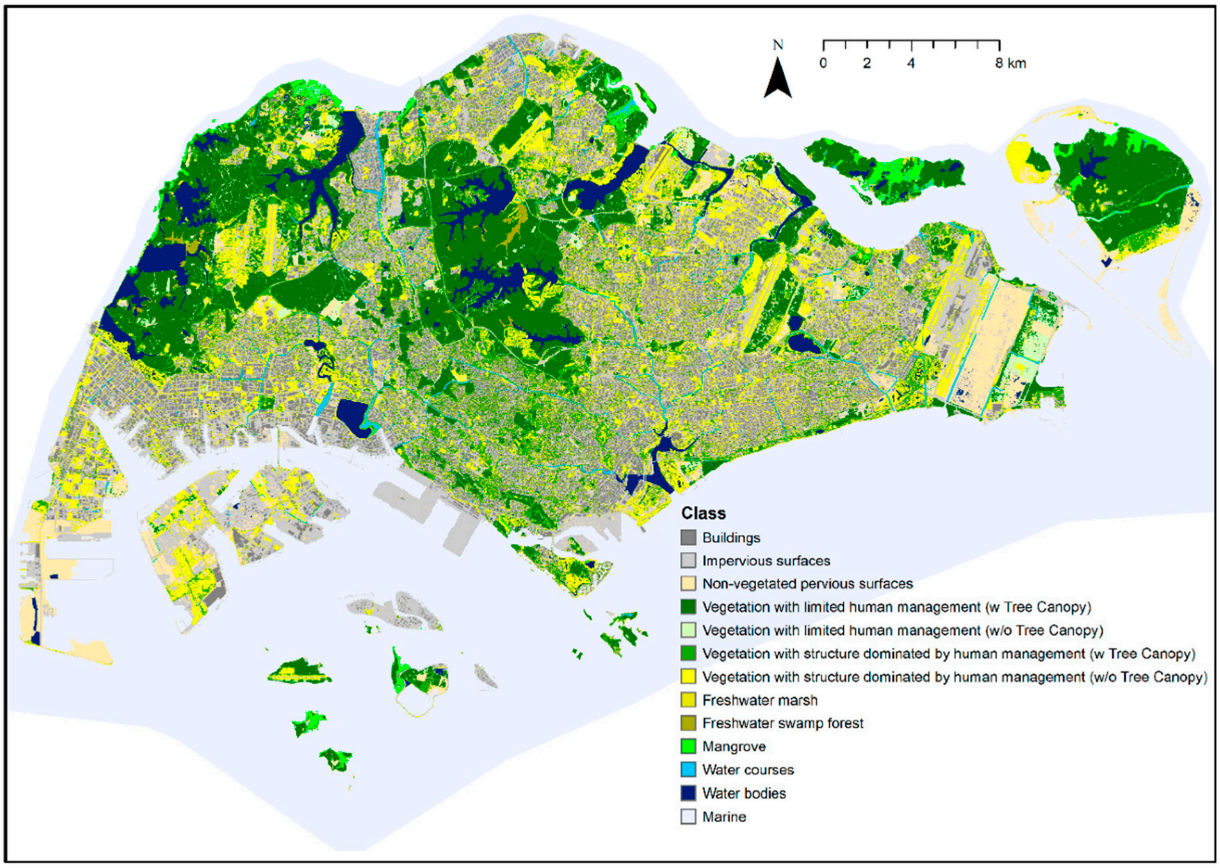

Figure 5. The classified map of Singapore made from satellite images taken from 2003 to 2018 [15]. Reproduced with permission from Gaw, Yee, and Richards (2019), licensed under CC-BY 4.0.

3.1.4. NbS in Urban Design

Singapore's "City in a Garden" vision was unveiled in 1998 to replace the previous Garden City vision (Figure 1). This shift in vision has brought a series of new policies that laid the foundation of Singapore's adoption of NbS, including the aforementioned ABC Waters Programme. Another important piece of regulation that has led to the adoption of green roofs and green walls is the LUSH Programme [38] (Landscaping for Urban Spaces and High-Rises). The programme was launched in 2009 by the Urban Redevelopment Authority (URA) to incentivize greenery creation in private developments. The LUSH guidelines have been updated a number of times to further align with design guidelines from ABC Waters and integrate NbS such as roof gardens, bioswale, and green walls. The LUSH Programme is supported by the National Parks Board (NParks), which has compatible capabilities to help with the implementation of green roofs and green walls. Under NParks' Skyrise Greenery Incentive Scheme, private developments can receive both funding and implementation support from NParks when they adopt green roofs and green walls.

The Biophilic Town Framework further these efforts through identifying water as one of the five key elements of the environmental landscape for ecosystem services provision and liveability in residential estates [39]. The framework, which was developed by the Housing and Development Board (HDB) in collaboration with the National University of Singapore (NUS), the URA, and NParks in 2013, provides guidelines for integrated design strategies such as installing green roofs on buildings and planting of urban greenery to enhance performance in water cycling and reduce stormwater runoff [40].

These government programmes work collectively to scale up the building of urban greenery in Singapore, which has become an integral part of the parks, the green corridors, rain gardens, and bioretention ponds, setting buildings, people, and activities in a nature-centric environment.

One review on the costs and benefits of green roofs and green walls concluded that green roofs and green walls bring multiple benefits when implemented at scale, including a reduced urban heat island effect (UHI), improved water management, and social benefits related to health and well-being [41].

3.2. The Experience of NbS in Lisbon

Lisbon's water engineering probably started in Roman times. The ancient aqueduct and the fountain system served the city for hundreds of years before modern water infrastructures were built. Water management solutions were typically seen as concrete civil engineering infrastructures. Only recently, since 2015, have NbS been integrated in urban planning, mostly as stormwater management facilities [42].

Lisbon currently has a strong commitment to sustainable land use, with particular focus on establishing green infrastructure, or connected networks of green space, to counteract the effects of climate change, such as drought, extreme heat, and storm flooding.

The city is proof that sustainability, rather than being an extra cost or a more expensive method of doing things, can deliver long-term savings and economic growth, while fostering social inclusion, improving biodiversity, and raising the health and wellbeing of residents.

3.2.1. Integrated Planning for Wastewater Reuse

To address water scarcity across Europe, the European Union (EU) calls for a more efficient management and preservation of water resources [43]. This includes aiming at decreasing the demand for water and finding alternative water supply source options. For southern European cities, harvesting rainwater is not the most effective solution, since the number of rainy days is low and rainfall events are very intense. However, the reuse of treated wastewater poses a reliable alternative for various purposes [44] that does not depend on climate uncertainty, contributing to the transition to a circular economy.

Lisbon consumes annually 50–60 million m^3 of potable water, of which half is consumed by the domestic sector [45]. In the non-domestic sector, CML is the biggest consumer, with a share of 15%. Half of CML's share accounts for park irrigation, which consumes 4–5 million m^3 of potable water annually; the second biggest water consumption is street cleaning, totalling 1–2 million m^3 yearly [19]. The latter is especially frequent in popular districts with intense night life activities.

Within the city's water efficiency program, the freshwater demand has been reduced dramatically by controlling water loss in the distribution network from 23.5% in 2005 to 7.9% in 2013 [45]. Another noteworthy water consumption reduction strategy, the creation of a green infrastructure that is resilient to drought based on rainfed meadows and

Mediterranean climate-adapted species, has been implemented. In addition, sustainable irrigation for green public spaces, particularly in summer months when city temperatures are higher, has been promoted.

In this context, Lisbon city has promoted the "Lisbon Strategic Plan for Water Reuse" (PLERAL 2020) [46], the first city-wide encompassing recycled water (RW) network in Europe, to irrigate and clean the most popular parks and streets with RW. The RW originates from the effluent of three wastewater treatment plants (WWTPs of Alcântara, Chelas and Beirolas) within the city, where 250,000 m^3 of wastewater is treated daily. With the source of RW close to the potential points of demand, the benefits of reusing water within the city are promising.

The Strategic Reuse Plan network (Figure 6) aims at finalization by 2025 and will promote the reuse of 1.6 million m^3 of water per year. Overall, the construction of about 55 km of main pipelines, 13 water tanks, and 19 pumping stations is foreseen. This network will serve, among others, the following areas:

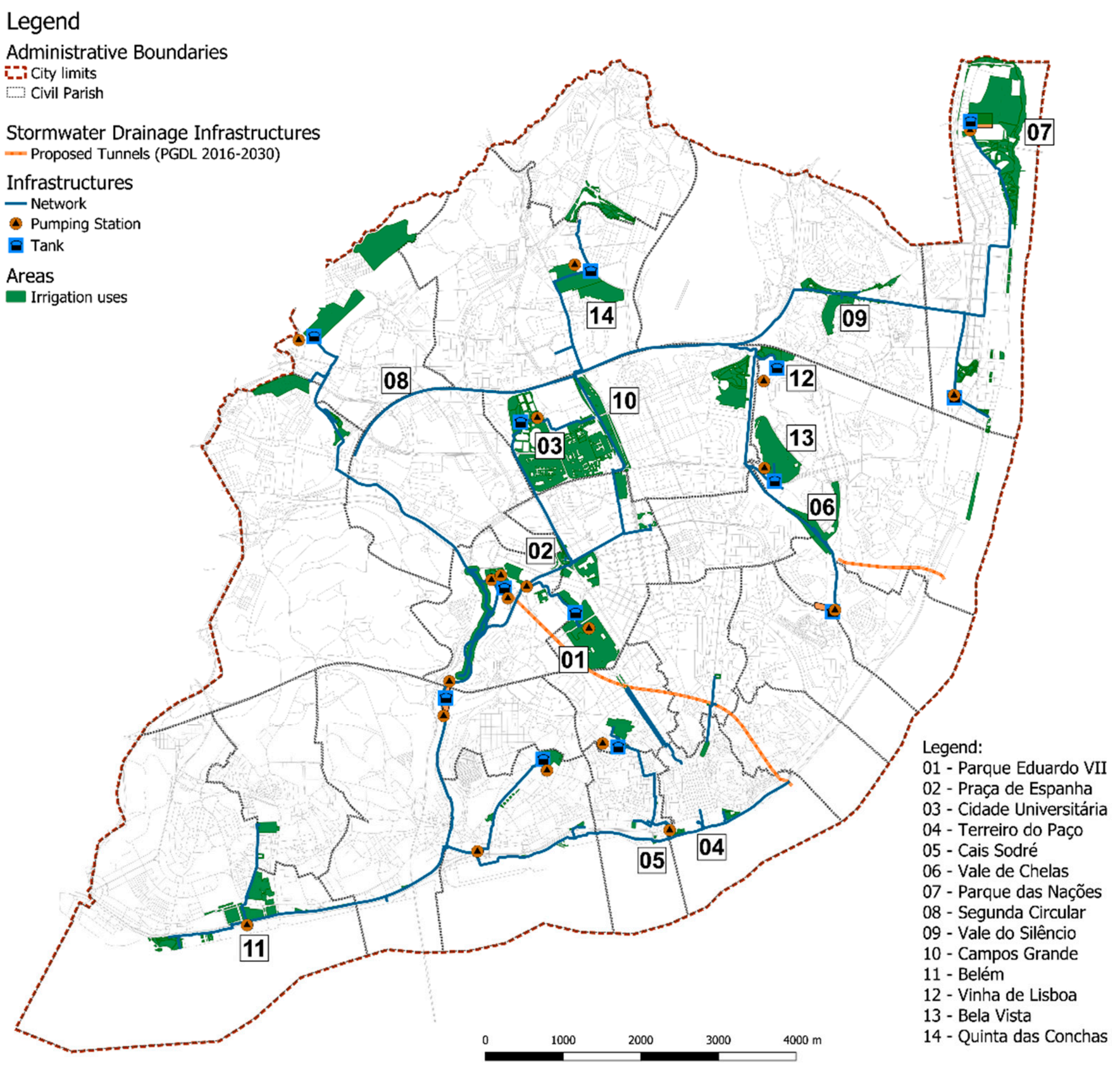

Figure 6. Interventions planned in the "Lisbon Strategic Plan for Water Reuse" (2020–2025).

- The Lisbon waterfront (from number 11 to number 7 in Figure 6) and typical areas of nocturnal activity (namely Cais do Sodré–number 5 in Figure 6);
- The axis Parque Eduardo VII–Cidade Universitária (numbers 1 to 3 in Figure 6);
- The Chelas Valley (number 6 in Figure 6).

The implementation of PLERAL 2020 constitutes an important process of environmental valorization and protection of natural resources, with the conservation of water and minimization of effluent discharge into the Tagus estuary, along with an increase in the reliability and resilience of Lisbon's water distribution systems, with the use of three new water sources for urban irrigation and other non-potable urban uses (e.g., urban cleaning). It is expected that the urban recycled water system will reach 25% of the green structure in 4 years.

3.2.2. NbS for Flood Control

The Lisbon Drainage Master Plan 2016–2030 [42] was approved by the city Council in 2015 and proposes several interventions to control flooding problems and to adapt the city's drainage system to new challenges. These challenges arise, mainly, from land use and climate change; namely, the already confirmed sea water level rise and the increased risk of extreme rainfall events. In fact, these situations aggravate the risk of flooding in particular in low-lying areas located downstream of large river basins, close to the Tagus estuary and with significant impermeabilization, as is the case of Alcântara and Chelas (examples in Figure 7).

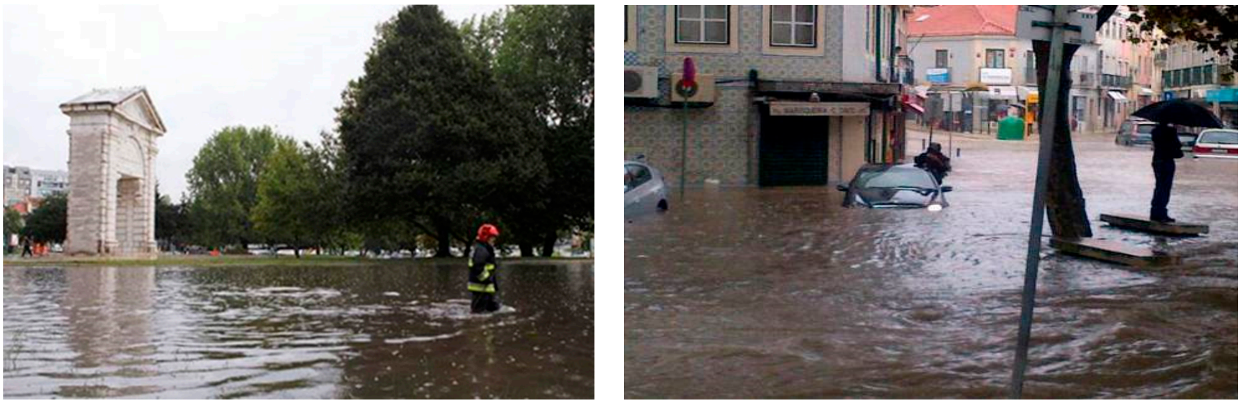

Figure 7. Flooding in Praça de Espanha on 22 September 2014 (**left**) and in Alcântara on 13 October 2014 (**right**).

The approved solution (an investment of over 170 million EUR) includes the construction of two tunnels that are about 5 km long (Monsanto–Santa Marta–Santa Apolónia tunnel) and about 1 km long (Chelas–Beato tunnel). Simultaneously, the construction of different source control solutions for upstream rainwater management is planned (including NbS that promote retention and infiltration, as presented in Figure 8). In this context, the open-air retention basins of Alto da Ajuda and Vale da Ameixoeira (numbers 1 and 3 in Figure 8, respectively) have already been built, and the infiltration trenches and modular retention infrastructures of Parque Eduardo VII (number 9 in Figure 8) are presently under construction.

The retention basins of Alto da Ajuda (number 1 in Figure 8) will promote the infiltration and attenuation of the stormwater peak flows of Ajuda catchment. The basins are inserted in a green area of 32 ha, contributing to landscape requalification and territory valorization, with a connection interface to the "Rio Seco green corridor". The two retention basins, with a total volume of 2150 m^3, were designed for a return period of 10 years and a peak flow of 1.84 m^3/s, with a maximum effluent flow of 370 l/s. In order to monitor the hydraulic performance of the system, a rain gauge and ultrasonic sensors to measure the water levels in the retention basins and in the discharge chambers were installed.

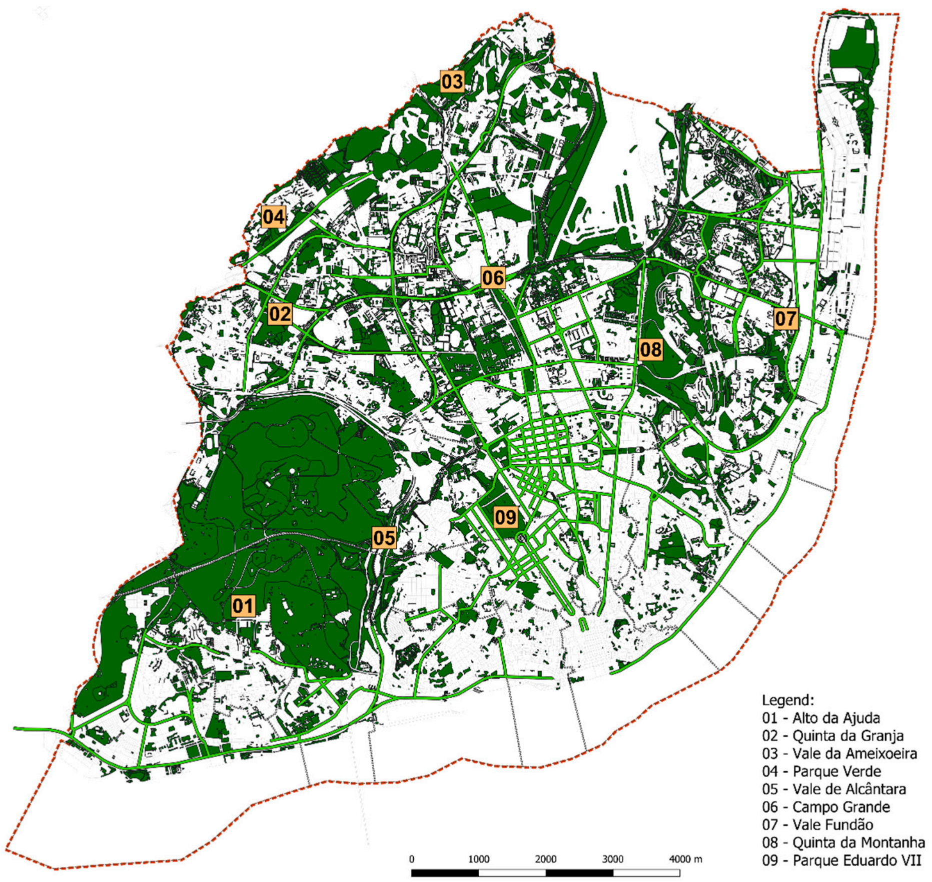

Figure 8. Lisbon retention basins, infiltration trenches, and modular retention infrastructures.

The "Parque Eduardo VII" presents multiple valences and unique characteristics of high patrimonial, socio-cultural, landscape, and environmental interest. The park has an aging, combined wastewater drainage system that has undergone few interventions since its conception. Due to its location, the area presents high potential to generate rainwater flows, in the case of intense precipitation, that hydraulically overload the downstream system and aggravate flooding risks in the "Baixa" area of Lisbon.

The rehabilitation of the park's pavement is currently in progress. In terms of drainage, NbS will be constructed (number 9 in Figure 8). The excess stormwater will be drained to a new separate sewer system. The four retention basins, with a total volume of 660 m^3, were designed for a two-year return period event, corresponding to a peak flow of 140 L/s each, with a maximum effluent flow of about 20 L/s. The two drainage trenches have a size of 80 m^2 each, while the three infiltration trenches have a size of 18 m^2 with a depth of 1 m.

As in Ajuda, rain gauges and ultrasonic sensors will be installed in Parque Eduardo VII to monitor the hydraulic performance of the system.

3.2.3. Other NbS for Green and Recreational Areas

Since 2008, Lisbon has seen a 13% increase in new and renewed green spaces, and the city intends to achieve a 20% increase by 2025 (Figure 9). Urban planning and the re-zoning of ecologically sensitive areas to curtail construction laid the groundwork for its Green Corridor Strategy, designed to preserve and increase permeable areas and rehabilitate underground waterways. Currently, 80% of people live within 300 m of green urban spaces (this percentage was 76% in 2016), and ongoing projects might increase this to 93%. Over 55,000 trees have been planted since 2017, directly on streets.

Figure 9. Fast increase in green infrastructure implementation after 2008 (orange areas).

According to the HUGSI index (Husqvarna Urban Green Space Index), the Portuguese capital has 44% of green area (against the world average of 39% and European average of 45%), with a total of 111.85 m^2 per capita [47].

Lisbon has adopted NbS solutions such as woodlands, biodiversity meadows (16 hectares), and vineyards (3 hectares), selecting species that demand less water and ensuring a sustainable management suitable for a Southern European Mediterranean climate. Lisbon's green corridors and tree-planting have increased green spaces and biodiversity, while also mitigating pollution and climate change effects (such as drought, extreme heat, and storm flooding) and achieving considerable economic impacts due to energy efficiency for neighbourhoods and land for urban farming. There are now 850 Urban Allotment Garden (UAGs) that contribute to social inclusion, with 150 more planned by 2025.

Lisbon intends to continue its rapid progress in developing new green areas, targeting 20% more land than in 2025 (more 350 ha) throughout the nine green corridors. One example is the Vale de Alcântara green corridor, which links the city's natural amenities, such as Monsanto Park with the Tagus River, giving its citizens greater access to green spaces. This 6.4 million EUR project includes the restoration of 13 ha along 3 km, resurfacing a river (creating a natural surface course and a wetland park), new green areas enabling wastewater irrigation, the planting of over 700 trees, building cycle–pedestrian corridor, and involving the population in NbS.

Another example is Ribeira das Naus, once a disused landscape regenerated into a modern largely pedestrianized public space that includes an old dock, a wide river walk where wetlands (Figure 10) are used to treat the water and ensure its quality, and a large green space and a pedestrian path along the riverfront, linking other public spaces.

In Lisbon, recent green projects were used to rehabilitate industrial/degraded areas, mostly located on the riverfront, re-establishing citizens' access to these areas. Some before and after comparison pictures are provided as Supplementary Materials.

Overall, Lisbon is proof that sustainability, rather than being an extra cost or more expensive method of doing things, can deliver long-term savings and economic growth, while increasing social inclusion, biodiversity, and the health and wellbeing of residents.

Figure 10. Riverside Ribeira das Naus wetland.

4. Discussion

Singapore and Lisbon are two relatively different cities in terms of location, climate, and water availability. Table 1 describes the key differences between the cities. However, both cities have had success with NbS implementation in recent years. It is not surprising that a wide range of NbS can be applied in these two very different contexts and generate social, environmental, and economic benefits due to their flexibility and adaptability to local environments and situations. It is interesting, however, to understand how the two cities arrived at adopting NbS when facing a common set of urban development challenges.

Table 1. Key differences between Singapore and Lisbon cities (2019) [48].

Indicator	Singapore	Lisbon
Location	Southeast Asia	Southern Europe
Climate	Tropical	Mediterranean
Population	5,685,000 inhabitants	510,000 inhabitants
Population Density	7810 inhabitants/km^2	5959 inhabitants/km^2
Area	725 km^2	100 km^2
Per capita GDP	89,547 SGD (56,246 EUR)/inhabitant	26,900 EUR/inhabitant
Water resources	No fresh water except rainwater	Tagus River
Community structure	Planned townships with intentional communities built over the past 50 years	City civil parishes (organized communities are uncommon)

4.1. From Civil Engineering to Nature Building

Singapore and Lisbon have vastly different engineering-based water infrastructure. Singapore's aggressive water engineering started after the country became independent and has since become a world-class water technology hub. The city has over 8000 km of canals, drains and rivers, and advanced water treatment plants that supply 1.6 million m^3 of water per day. Lisbon's water treatment plant is located in Castelo do Bode, Tagus River, more than 100 km upstream of the city. Its drainage system has over 1430 km of sewers of different materials and ages, some more than two centuries old.

However, despite the two cities' different conditions (e.g., location, climate, per capita GDP) and water infrastructure systems, both have gone through an engineering-centric to nature-based journey in their approaches to water management in recent years. With increasing uncertainties brought by climate change, both cities have faced challenges with regard to water management. Singapore's case of the Kallang storm water canal rehabilitation is an example that demonstrates a sophisticated combination of using advanced engineering skills to harness nature's capacity. Additionally, the ABC Waters Programme, LUSH Programme, the Sky-Rise Greenery Scheme and the Biophilic Town Framework have transformed Singapore's water infrastructures, facilities, and other supporting functions into a natural part of the city that integrates with the landscape and fulfils multiple urban demands.

Recently, as defined in the Lisbon Drainage Master Plan 2016–2030, the city has adopted NbS to control flooding, change the landscape, and promote the retention and infiltration of stormwater. In addition, Lisbon's Urban Allotment Garden, green corridors, and tree-planting programmes have increased green spaces and biodiversity, while also mitigating pollution and the effects of climate change, with several social and touristic benefits.

In the two cities, which are historically, climatically, economically, and culturally different, the common shift in approach sends a clear message that instead of taming nature with concrete and advanced technologies, cities of the future need to exist in harmony with nature. This shift has occurred as part of the major trend of building more sustainable and liveable cities and a set of common drivers.

4.2. The Common Drivers

Both Singapore and Lisbon face water challenges. Singapore currently uses 584 million m^3 of water annually, and this is expected to grow to almost double by the year 2060. Lisbon uses nearly 55 million m^3 water annually, and the number is projected to decrease given the expected small population decline and the general effort to save water.

Despite the differences in scale, meeting the demand for water is fundamental to the cities' healthy and smooth functioning. This common driver is one of the reasons for both cities' interest in a range of different water management solutions, including NbS.

Another common driver is flood control. In recent years, flooding has increased both in frequency and intensity due to the increased storm activities and intensity of precipitation, which is highly likely to be caused by climate change [49]. In Singapore, it is also clear that flash flooding has become the more dominant type of flood in the 21st century, as shown in Figure 11, which presents data taken from archive flooding event data between 1892 and 2015 [17]. Lisbon also has a history of flooding; although smaller in scale, the city of seven hills is facing an uphill battle with rainfall becoming more concentrated (less frequent but more intense), which is particularly problematic in low areas when combined with estuary high tidal levels [42].

Lastly, possibly the most important driver in developing NbS lies with the people. Urban dwellers and visitors are demanding more green spaces and recreational spaces [50,51]. In traditionally crowded and expensive urban centres, NbS has emerged to be a win–win–win solution that fulfils urban infrastructure needs and citizens' demands while delivering environmental benefits [52].

4.3. Pluralism in Spatial Planning

Major cities have a high population density (which is similar in Singapore and Lisbon) and typically face population growth. However, the urban sprawl, traffic, and pollution issues that come with expanding cities, as well as climate change constraints (such as sea level rise, more intense precipitation, and urban heat island effects (UHI), are driving people to rethink urban development models.

Plural urban spatial planning and the intensification of existing urban spaces could be a strategy to avoid such issues. This means that urban spatial planning needs to be creative and innovative, using limited land to provide different and flexible functionalities to its residents. Nature-based solutions such as constructed wetlands, green roofs, and river parks often provide a recreational function on top of their intended water management function, while also helping to reduce UHI. Some NbS also serve as locations for outdoor events, educational facilities, urban farming, and food waste compost sites. Based on the 75 certified ABC Waters projects in Singapore [53], water retention is the number one primary purpose (73 projects), followed by water filtration (43 projects) and recreation (39 projects). All of the 75 projects serve between 2 to 5 primary functions and 1 to 4 secondary functions. The multifunctional spaces help to enrich community-based activities and events, creating more social cohesion, which is seen in both Lisbon and Singapore.

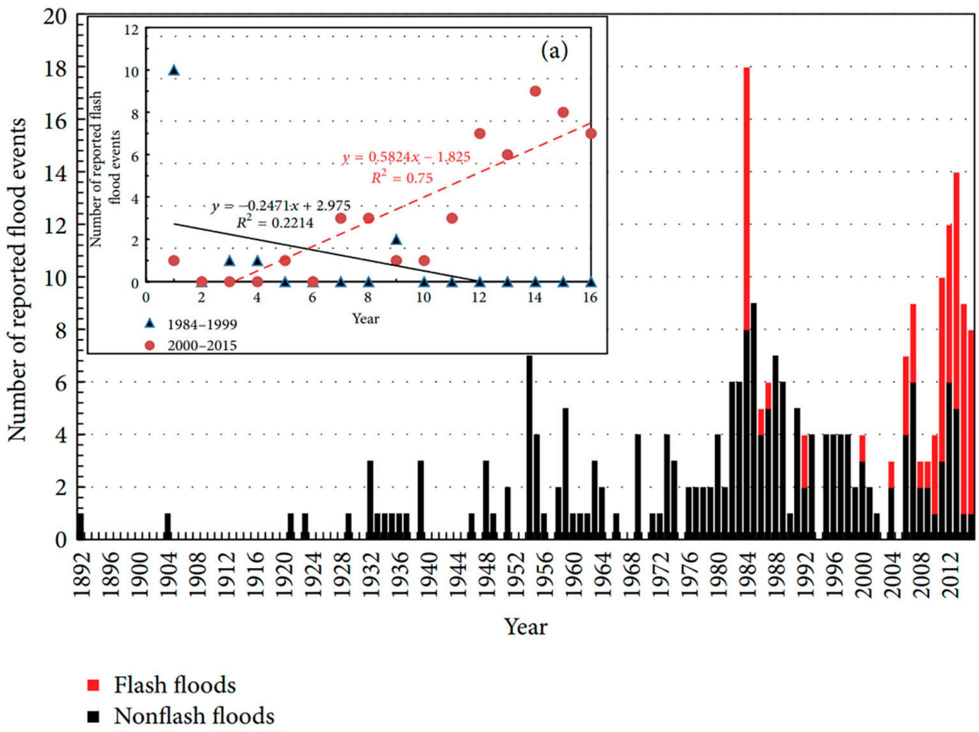

Figure 11. Frequency of the total number of reported floods in Singapore, categorized into flash floods and nonflash floods. Insert (**a**) shows the linear trend, depicted by Ordinary Least Squares (OLS), of reported flash floods from 1984 to 1999 (black) and 2000 to 2015 (red dashed), which is also based on the archived flood dataset [17]. Reproduced with permission from Chow, Cheong, and Ho (2016), licensed under CC-BY 4.0.

4.4. Mindset Shift

The main mindset shift regarding NbS may be the human–nature relationship in an urban setting. This happens both at the government level and the citizen level. Due to the increased uncertainty and intensity of weather conditions, city governments increasingly recognise that traditional urban infrastructure may not be adequate to handle extreme situations. For example, despite the successful water strategy implemented by PUB in Singapore, the changing flood pattern and sea level rise has motivated the Singapore government to find alternative solutions to further complement the current 8000 km of drainage. These alternative solutions, including NbS, represent a new strategy that aims at recognizing the limitation of human engineering and actively seeking for inspiration and help from nature to coexist in the changing climate. In Lisbon, although the city's Master Plan foresees two flow diversion tunnels, different source control solutions (including NbS that promote retention and infiltration) are being constructed. Additionally, since 2008, the city has increased green areas by 16%, allowing 85% of the citizens to live within 300 m of green urban spaces compared to 76% in 2016. Similarly, with the vision to transform Singapore into a City in Nature, 1000 more hectares for green spaces will be set aside by 2035, allowing accessibility to a park within 10 minutes' walk for every household.

At the individual level, NbS may change citizens' perception of the city lifestyle and require urban dwellers to adapt to some of the new aspects of nature-based urban infrastructure. There may also be possible issues and inconvenience such as increased insects and wild animal interactions [50]. Although these issues can be partially mitigated, citizens will need to reconsider their relationship with the new urban environment.

4.5. Whole-of-Government Approach

The final discussion point is government planning. The plural nature of NbS means that the planning, building, and operating of solutions require the collaboration of multiple government agencies, as well as working with the private and public sectors and other stakeholders.

In the case of Singapore, the Public Utilities Board (PUB) is the traditional "project owner" of all water-related infrastructure. However, the National Parks Board (NParks) manages all greenery-related projects. This means that an immediate collaboration is necessary between the two boards to plan for NbS [54]. Other agencies that must be involved include the Land Transport Agency (LTA) for any mobility or road related matters; the Building and Construction Agency (BCA) for projects such as green roofs and green walls (in some cases, this may require changing of building code to adapt to new NbS implementation requirements); the Housing and Development Board (HDB), if the project is within the boundary of public housing estates; the Urban Redevelopment Agency (URA), for zoning, planning, and building guidelines-related regulations; and the National Environment Agency (NEA), to comply with environmental regulations including insect and animal control. This means that even in a relatively simple administrative setting in the Singapore context, NbS planning requires seven agencies from three ministries to work together. Indeed, the Singapore Green Plan 2030, which is spearheaded by five ministries (Ministries of Education, National Development, Sustainability and the Environment, Trade and Industry, and Transport), exemplifies the recognition of the importance for multi-governmental agencies to work together towards sustainable development. Furthermore, engagements with a diversity of stakeholders are being conducted emphasizing the importance of more conversations to encourage co-creation and promote inclusiveness and stewardship for the public sector, the people, and the private sector. For example, the currently ongoing review of the Concept Plan ("Long Term Plan Review") involves a year-long public engagement exercise through focus group discussions and online polls in order to capture feedback and ideas from the broader community [55]. This review, led by the URA under the Ministry of National Development, is done on a 10-year basis, and the Concept Plan will guide city planning and development in Singapore over the next 50 years.

In Lisbon, the Municipality is the entity responsible for NbS water-related infrastructure implementation in the city. The "Lisbon Municipality Master Plan" establishes the land use, including over private land, opening the conditions, under the law, to identify *non-aedificandi* areas to become part of the so-called "Ecological Structure", the base of Lisbon NbS strategy. From this point, according to a range of different land planning tools (Master Plan norms, Detail Plans, among others), the Municipality has been able to implement a dedicated program to accomplish the new green targets. The municipality defined some important mechanisms to guarantee the implementation of NbS, such as the allocation of a municipal budget and European funds to support the Green Corridors Programme, the Urban Allotment Garden programme, the Drainage Master Plan, the "One Tree in Each Corner" programme (to increase the number of trees on the streets), and a Water Efficiency Action Plan (including rainfed solutions). The Municipality has a participatory budget, which was launched in 2009 and under which several NbS have been put forward for voting. Since 2015, a mandatory Biodiversity Action Plan was approved to relate new green, climate adaptation targets and ecosystem services. The city is divided into 24 Parishes (or Urban Districts) that have been responsible for local green structure management since 2014 and that may be authorized to promote new interventions in the context of the municipal norms and strategy.

As demonstrated by Singapore and Lisbon, but also in other studies with different cities [56,57], to effectively plan, build, and operate NbS, a whole-of-government approach (WGA) is necessary. In fact, collaborative governance approach is one of the key factors for the successful implementation of NbS, while municipalities and citizens are crucial partners in the design and implementation of NbS [56].

Table 2 uses the RACI framework (Responsible, Accountable, Consulted, and Informed) to illustrate the possible roles of different stakeholders in WGA project management, which are crucial in the planning, building, and operating of NbS.

Table 2. Different stakeholders' roles in WGA project management.

RACI Category \ Stakeholders	Lead Agency or City Department	Support Agency or City Department	General Public	Coordinating Agency (Usually Reports Directly to the Highest Governance Body)
Responsible	√	√		
Accountable	√			
Consulted		√	√	
Informed			√	√

An effective WGA also reduces investments, as illustrated in Figure 12. In a traditional governance approach, city departments work separately to meet their goals, developing different infrastructure solutions to solve problems related to flooding, sea level rise, heat island effects, and decreases in air quality. Conversely, in a WGA, city departments work together on NbS that achieve multiple goals, answering different challenges simultaneously and, overall, reducing city investments and creating a resilient community.

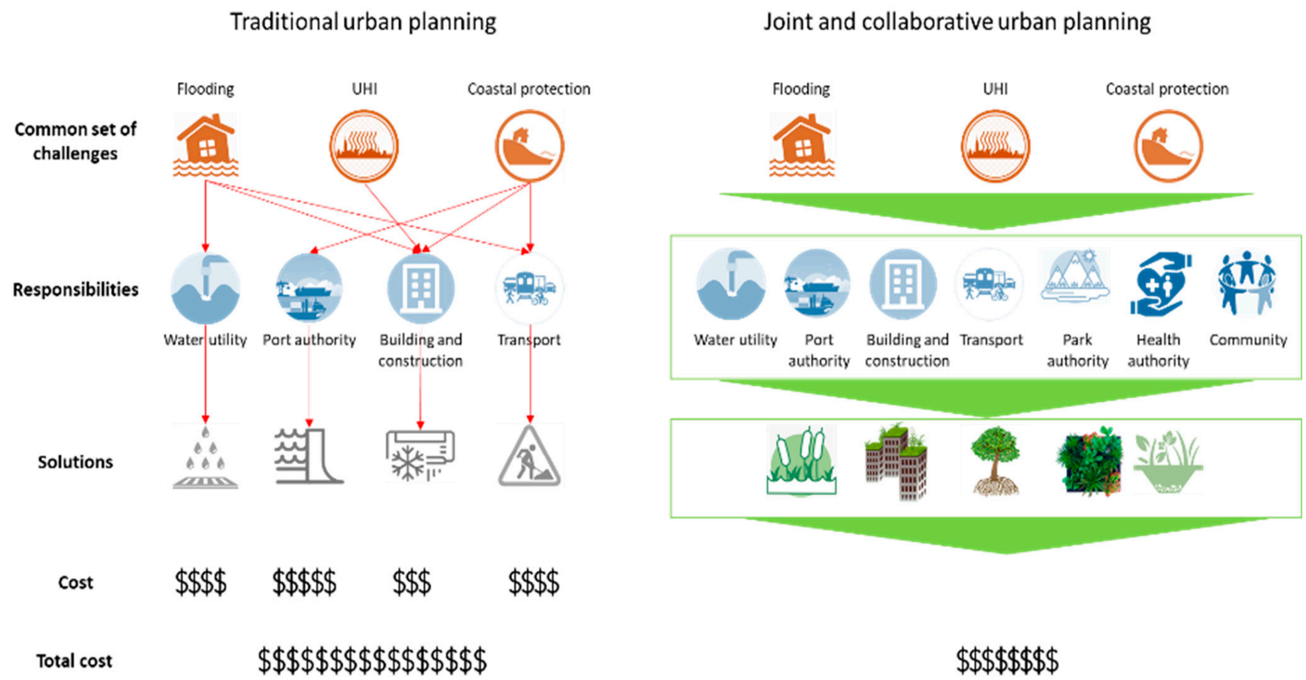

Figure 12. Cost comparison between traditional and integrated planning [58].

4.6. Limitations of Study

This study identified common drivers and outcomes of the transition from engineering-based water management infrastructure to the "blue and green infrastructure". In the process, benefits such as a reduction in the urban heat island effect and increased urban biodiversity were demonstrated. A quantitative understanding of the effectiveness of differing nature-based solutions for water management or other benefits, however, is still lacking, pointing to the need for further research to better understand these knowledge gaps. Other benefits could include mental health benefits, equity improvement from localized food production, access to parks and green spaces, and empowering low-income communities (especially considering grey infrastructure are often located in poorer neighbourhoods). Furthermore, the two cities discussed in this paper are both considered from an urban-upgrade perspective. For future new-build cities, NbS need to be planned from the beginning, which may change the way that urban planning has traditionally been done. Research in these areas is still lacking. In the post-pandemic and rapid climate change era, the fundamental rethinking of urban living is necessary, which can only happen with major shifts in mindset and the understanding of the human–nature relationship. The adoption of NbS in cities also serves this purpose, and perhaps this is the most important benefit of NbS for urban water management.

5. Conclusions

With rapid urban expansion, water use increase, and the impacts of climate change, NbS (including natural ecosystems and "blue and green infrastructures" such as trees, wetlands, parks, or green roofs) are increasingly serving as multi-benefit solutions that meet core community needs and provide diverse co-benefits such as flood regulation, urban heat island (UHI) mitigation, carbon sequestration, shading, wildlife habitat, and mental health improvement [24,59–62].

In this paper, the tales of two cities were told, describing the journeys of Singapore and Lisbon toward creating adaptive and resilient urban water management practices using nature-based solutions. The present discussions highlight how these two cities, which are so different from historical, climatic, economic and cultural perspectives, have been shifting from concrete "grey" water solutions to "blue and green" NbS. Despite the differences, a common set of drivers exists. In the meantime, the pluralism in spatial planning for more liveable and dynamic cities is a key trend that coincides with the need for NbS. The transition journey is the result as well as the driver of major mindset shifts in both locations. The changing views of residents' and demands of the city encourage city governments to test different approaches, which have an impact on residents' perspectives of urban life and inspire deeper reflections on the human–nature relationship. This further drives a different set of government decisions and influences future urban planning. Along this journey, the two cities have both improved their environmental and water management practices, established better urban planning methods and regulations, and increasingly put citizens at the heart of policy-making. These cities have shown how to turn environmental challenges into opportunities and transform urban areas into healthy and enjoyable places to stay, live, and work by adopting NbS.

Furthermore, the coronavirus pandemic has demonstrated that many of our city systems are fragile, highlighting the importance of allocating public resources to mitigate the vulnerabilities of underserved communities. As the world focuses on economic recovery efforts, which will likely include water management infrastructures and better water services, special attention should be given to NbS for the development of resilient, liveable, affordable, and equitable cities.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su131810427/s1. Figure S1. Before (1995) and after (2021) comparison images for Alto da Ajuda NbS, Lisbon; Figure S2. Before (2005) and after (2020) comparison images for Parque das Nações NbS, Lisbon; Figure S3. Before (2001) and after (2021) comparison images for Braço de Prata NbS, Lisbon; Figure S4. Before (2001) and after (2021) comparison images for Alta de Lisboa NbS, Lisbon.

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