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Innovative Adaptation to Climate Change: Chinese Sponge Cities Program (SCP)

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Abstract

According to the IPCC (2021), the vulnerability of the cities to flooding and water scarcity will increase. At the same time, the population of the cities is constantly increasing. That's why it is very important to strengthen the city resilience through nature based solutions. At present, the Sponge City Concept (SCC) is gaining ground, Sponge Cities technologies are becoming more and more accepted by Chinese city governments, and the first best practices are shared. However, there are still many challenges ahead, which hamper effective implementation and upscaling. This paper presents some opportunities and constraints based on the assessment of the Sponge Cities Program (SCP) of China (2013-2030). The Chinese Sponge City Program, initiated in 2013 and adopted by 30 pilot cities, is developing solutions to manage urban flood risk, purify storm water, and provide water storage opportunities for future usage. The methodology is based on an extensive literature review, combining aspects of the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines", and the Recursive Content Abstraction (RCA) analytical approach. Analyzing the Chinese experience will be very illustrative for developing countries that have similar vulnerabilities and could be interested in applying the SPI. Key challenges will be to align the sponge city program projects with infrastructure and urban renovation portfolios to affront the substantial investment need and a lack of reliable financing schemes. On this basis, the paper puts forward practical suggestions for the financing of the Sponge Cities.

Keywords

Sponge City, Nature-Based Solutions, Climate Change Adaptation, Resilience, Urban Flooding, Storm Water Management, China

1. Introduction

Climate change is now bringing more extreme weather worldwide and rendering the assumption of hydro climatic stationarity untenable. This increases uncertainties in near- and, especially, long-term forecasts for the frequency and intensity of both urban floods and droughts. Meanwhile, rapid urbanization is not only changing urban and peri-urban surfaces but also significantly altering urban microclimates.

According to the IPCC (2021), the vulnerability of the cities to flooding and water scarcity will increase. At the same time, the population of the cities is constantly increasing. More frequent and extreme weather events—including storms, floods and droughts—could displace more than 200 million people by 2050. Water scarcity is a key driver of migration because of its impact on health and livelihoods as well as the conflicts it risks triggering. Increased natural disasters will be a consequence of climate change that threatens all countries around the world (Rachman, 2021; UNHCR, 2021). That's why it is very important to strengthen the city resilience through nature based solutions. At present, the Sponge City Concept (SCC) is gaining ground. include Nature-Based Solutions (NBS) is an umbrella concept that emerged from Europe, which encourages the holistic idea of considering wider options that combine "Blue-Green" practices with traditional engineering to deliver "integrated systems of Blue-Green-Grey infrastructure". NBS includes interventions making use of natural processes and ecosystem services for functional purposes, and this could help to improve current pilot SCP practices. The Chinese "Sponge City Program" (SCP), initiated in 2013 and adopted by 30 pilot cities, is developing solutions to manage urban flood risk, purify storm water, and provide water storage opportunities for future usage. Emerging challenges to the continued implementation of Sponge Cities. Key challenges will be to align the sponge city initiative (SCI) projects with infrastructure and urban renovation portfolios, so as the substantial investment need and a lack of reliable financing schemes.

The methodology to analyze the progress and challenges of SCP is based on an extensive literature review, combining aspects of the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines", and the Recursive Content Abstraction (RCA) analytical approach. Secondary data were collected through review of relevant materials including peer-reviewed papers, conference presentations and official organization documents available on the internet. The documents were identified through a combination of searches, using keywords and terms associated with climate change adaptation, nature-based solutions, sponge cities and green financing.

The paper is structured into three sections after this introduction. After presenting the IPCC scenarios for precipitation, sea level rise, and flooding, we analyze the innovative adaptation through nature-based solutions and green infrastructure, in the first section. The second section explores nature-based solutions to improve cities resilience to sea level rise, storms, flooding and water supply. After presenting the vulnerability of Chinese cities to climate change impacts, in the third section we analyze innovative urban water management policy in China: the sponge cities initiative, launched in 2014, exploring its current achievements and future challenges. Based on the topics discussed, at the end, the paper presents some final remarks.

2. IPCC Scenarios for Precipitation, Sea Level Rise and Flooding

The facts and scenarios presented in this section are based on the results of the contributions of the Working Group I to the IPCC Sixth Assessment Report (AR6) (IPCC, 2021).

2.1. Scenarios for Precipitation and Storms

Globally averaged precipitation over land has likely increased since 1950, with a faster rate of increase since the 1980s. It is likely that human influence contributed to the pattern of observed precipitation changes since the mid-20th century, and extremely likely, that human influence contributed to the pattern of observed changes in near-surface ocean salinity. Mid-latitude storm tracks have likely shifted poleward in both hemispheres since the 1980s, with marked seasonality in trends. For the Southern Hemisphere, human influence very likely contributed to the poleward shift of the closely related extratropical jet in austral summer.

The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area for which observational data are sufficient for trend analysis, and human-induced climate change is likely the main driver. Human-induced climate change has contributed to increases in agricultural and ecological droughts in some regions due to increased land evapotranspiration. It is very likely that heavy precipitation events will intensify and become more frequent in most regions with additional global warming. At the global scale, extreme daily precipitation events are projected to intensify by about 7% for each 1˚C of global warming. The proportion of intense tropical cyclones (categories 4 - 5) and peak wind speeds of the most intense tropical cyclones are projected to increase at the global scale with increasing global warming.

It is likely that the global proportion of major (Category 3 - 5) tropical cyclone occurrence has increased over the last four decades, and the latitude where tropical cyclones in the western North Pacific reach their peak intensity has shifted northward; these changes cannot be explained by internal variability alone. Event attribution studies and physical understanding indicate that human-induced climate change increases heavy precipitation associated with tropical cyclones. With every additional increment of global warming, changes in extremes continue to become larger. For example, every additional 0.5˚C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves, and heavy precipitation, as well as agricultural and ecological droughts in some regions. Discernible changes in intensity and frequency of meteorological droughts, with more regions showing increases than decreases, are seen in some regions for every additional 0.5˚C of global warming. Increases in frequency and intensity of hydrological droughts become larger with increasing global warming in some regions. There will be an increasing occurrence of some extreme events unprecedented in the observational record with additional global warming, even at 1.5˚C of global warming.

2.2. Scenarios for Sea Level Rise

Global mean sea level increased by 0.20 m between 1901 and 2018. The average rate of sea level rise was 1.3 mm·yr^{-1} between 1901 and 1971, increasing to 1.9 mm·yr^{-1} between 1971 and 2006, and further increasing to 3.7 mm·yr^{-1} between 2006 and 2018. Human influence was very likely the main driver of these increases since at least 1971. Global mean sea level has risen faster since 1900 than over any preceding century in at least the last 3000 years.

It is virtually certain that global mean sea level will continue to rise over the 21st century. Relative to 1995-2014, the likely global mean sea level rise by 2100 is 0.28 - 0.55 m under the very low GHG emissions scenario (SSP1 - 1.9), 0.32 - 0.62 m under the low GHG emissions scenario (SSP1 - 2.6), 0.44 - 0.76 m under the intermediate GHG emissions scenario (SSP2 - 4.5), and 0.63 - 1.01 m under the very high GHG emissions scenario (SSP5 - 8.5), and by 2150 is 0.37 - 0.86 m under the very low scenario (SSP1 - 1.9), 0.46 - 0.99 m under the low scenario (SSP1 - 2.6), 0.66 - 1.33 m under the intermediate scenario (SSP2 - 4.5), and 0.98 - 1.88 m under the very high scenario (SSP5 - 8.5). Global mean sea level rise above the likely range—approaching 2 m by 2100 and 5 m by 2150 under a very high GHG emissions scenario (SSP5 - 8.5)—cannot be ruled out due to deep uncertainty in ice sheet processes.

In the longer term, sea level is committed to rise for centuries to millennia due to continuing deep ocean warming and ice sheet melt, and will remain elevated for thousands of years. Over the next 2000 years, global mean sea level will rise by about 2 to 3 m if warming is limited to 1.5˚C, 2 to 6 m if limited to 2˚C and 19 to 22 m with 5˚C of warming, and it will continue to rise over subsequent millennia. Projections of multi-millennial global mean sea level rise are consistent with reconstructed levels during past warm climate periods: likely 5 - 10 m higher than today around 125,000 years ago, when global temperatures were very likely 0.5˚C - 1.5˚C higher than 1850-1900; and very likely 5 - 25 m higher roughly 3 million years ago, when global temperatures were 2.5˚C - 4˚C higher.

2.3. Scenarios for Global Water Cycle

There is strengthened evidence since the Fifth Assessment Report of the IPCC (AR5) that the global water cycle will continue to intensify as global temperatures rise, with precipitation and surface water flows projected to become more variable over most land regions within seasons and from year to year. The average annual global land precipitation is projected to increase by 0% - 5% under the very low GHG emissions scenario (SSP1 - 1.9), 1.5% - 8% for the intermediate GHG emissions scenario (SSP2 - 4.5) and 1% - 13% under the very high GHG emissions scenario (SSP5 - 8.5) by 2081-2100 relative to 1995-2014 (likely ranges). Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and limited areas in the tropics in SSP2 - 4.5, SSP3 - 7.0 and SSP5 - 8.5. There is high confidence in an earlier onset of spring snowmelt, with higher peak flows at the expense of summer flows in snow-dominated regions globally.

If global net negative CO_2 emissions were to be achieved and be sustained, the global CO_2-induced surface temperature increase would be gradually reversed but other climate changes would continue in their current direction for decades to millennia. For instance, it would take several centuries to millennia for global mean sea level to reverse course even under large net negative CO_2 emissions. Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events.

3. Nature-Based Solutions to Improve Cities Resilience to Sea Level Rise, Storms, Flooding and Water Supply

3.1. Growing Risks for Coastal Cities

World Economic Forum (2022) identifies as the first two of the more severe risks: the climate change action failure (including adaptation and mitigation) and the extreme weather (directly related with storms, flooding, droughts, etc.) (See **Figure 1**). Other important issue is that out of ten principal risks, five are environmental. World economy is set to lose up to 18% GDP from climate change if no action taken (Swiss Re, 2021). This is why one of the priorities to avoid these global risks should be to strengthen the resilience of the coastal cities through innovative adaptation.

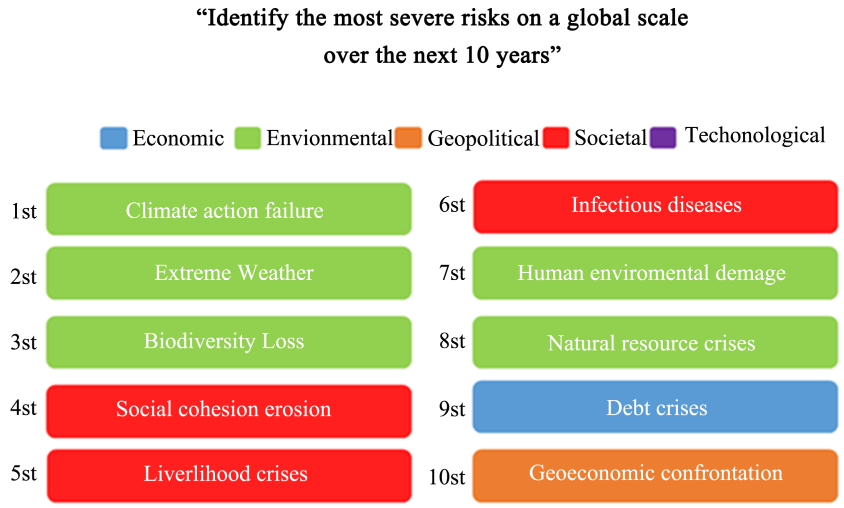

Figure 1. Most severe risks on global scale over the next 10 years. Source: World Economic Forum, 2022.

Cities intensify human-induced warming locally, and further urbanization together with more frequent hot extremes will increase the severity of heatwaves. Urbanization also increases mean and heavy precipitation over and/or downwind of cities and resulting runoff intensity. In coastal cities, the combination of more frequent extreme sea level events (due to sea level rise and storm surge) and extreme rainfall/river flow events will make flooding more probable (Cheng & Chen, 2017).

According to estimates, the world population will grow from approximately 7 billion in 2012 to more than 9 billion by 2050, and virtually all of the population increase will be absorbed by urban areas in developing countries. With 70 percent of the population living in urban areas by 2050, it is also no surprise that, while cities will be centers of wealth and relative prosperity, the number of urban poor may well be higher than that of the poor rural population (Gandolfo, 2021).

The demand for water and sanitation services will continue generating high costs, whose management will be problematic, especially in relation to the poor neighborhoods. Factors that will drive increased public expenditures in urban areas include: 1) population growth; 2) per capita income growth; 3) corporate demands; 4) improvement of infrastructure and public services; 5) the need to address the negative externalities that come with urbanization, such as pollution (e.g., solid waste management); And 6) the special needs of a large concentration of families in expanding poor neighborhoods that require large public investments from governments (Ivanova, 2017).

Between 2000 and 2020, natural disasters, such as climate, health and seismic events, caused GDP $1.1 trillion worldwide in damages, taking into account both the direct impacts on infrastructure, resources, communities, and the environmental and indirect impacts, such as decrease in business profitability and economic growth in the affected regions (Siemens, 2021).

3.2. Strategies of the Cities to Affront the Challenges

A growing number of cities are stepping up to the challenge of sea-level rise. Most of them literally have no choice. Alongside mitigating their carbon footprints through reducing emissions, there are three ways that states and cities are taking action. First, they are fielding hard engineering projects like sea walls, surge barriers, water pumps and overflow chambers to keep water out. Second, they are adopting environmental approaches involving land recovery and the restoration of mangroves and wetlands to help cities cope with floodwater inundation. The third strategy involves people-oriented measures including urban design, building resilience and retreating after all other options have been exhausted.

While all coastal cities will be affected by sea-level rises, some will be hit much harder than others. Asian cities will be particularly badly affected. About four out of every five people impacted by sea-level rise by 2050 will live in East or

South East Asia. US cities, especially those on the East and Gulf coasts, are similarly vulnerable. More than 90 US coastal cities are already experiencing chronic flooding—a number that is expected to double by 2030. Meanwhile, about three-quarters of all European cities will be affected by rising sea levels, especially in the Netherlands, Spain and Italy. Africa is also highly threatened, due to rapid urbanization in coastal cities and the crowding of poor populations in informal settlements along the coast. The coming decades will be marked by the rise of ex-cities and climate migrants (Muggah, 2019; Bevere and Weigel, 2021).

However, most of the coastal cities have deep stores of knowledge and expertise. For centuries, cities bordering oceans and waterways have had to contend with local sea-level fluctuations and periodic storms. Many coastal cities have experimented with a combination of all three types of measures for hundreds of years. However, past successes do not necessarily guarantee future safety. Today's cities are different from their predecessors. Many of them are of an unprecedented size and complexity. Complicating matters, sea levels are rising more rapidly than in the past, in some cases overwhelming local capacities to respond.

3.3. Nature-Based Solutions and Combination of Approaches

A growing number of wealthy states and cities are making massive investments in technical solutions to keep seas at bay. It is true that large infrastructure schemes including barriers and break-walls can at least temporarily reduce the risks of losses. Nevertheless, an overreliance on concrete walls and pump systems to beat back rising tides, storm surges and downstream floods can only go so far. The lesson from the most successful cities is that a combination of approaches is essential. What is more, environmental-based solutions to reinforce the existing ecology's protective capacities are not only effective, but lower cost (Mendes et al., 2020).

During the last two decades, concepts such as "Sustainable Development", "Biodiversity", and "Ecosystem Services" focused primarily on what nature can provide to humans, which is an anthropocentric notion (Ferreira et al., 2020). Global societies are seeking to address challenges relating to health, food security, and water and energy sustainability, while aiming to reconnect the urban environment with nature (Rui et al., 2018).

There are many examples that demonstrate a shift with respect to nature in urban planning and water management policies, such as "Making Space for Water" in the United Kingdom (established in 2004) (Fish et al., 2016) and "Room for the River" in the Netherlands (established in the late 1990s) (Busscher et al., 2018)—and also, more recently, creating more "Blue-Green" spaces to generate multiple co-benefits, improve biodiversity, and increase climate change resilience in cities (O'Donnell et al., 2019). On the same spectrum, NBS appeared as a concept at the beginning of the 21st century and supported the proactive management of nature with the goal of enhancing urban ecosystem services and benefits from them (Cohen-Shacham et al., 2016). Evidently, NBS seeks to combine and build on earlier approaches as they have been defined in the literature (Mendes et al., 2020). For example, the International Union for Nature Conservation (IUCN) has recently defined NBS as "actions to protect, sustainably manage and restore natural or modified ecosystems in ways that address societal challenges efficiently and adaptively to provide both human well-being and biodiversity benefits" (IUCN, 2016). This definition focuses on nature, rather than the practical utility of nature, while stressing how becoming closer to nature can help communities deal with social challenges and adaptation to a changing environment. Conversely, although the European Commission (EC) has defined the concept similarly, they focus more on the social and political aspects of NBS, emphasizing how it can contemporaneously provide social, economic, and environmental benefits through local-adaptive interventions, such as restoring urban ecosystems, and improving urban resilience and sustainability (Ferreira et al., 2020). The goals of NBS stated by the EC include essentially sustainable urbanization, the restoration of degraded ecosystems, climate change adaptation and mitigation, resilience, and risk management (Qi et al., 2020). Therefore, this definition appears more related to a society's market orientation and economy.

The importance of nature and its functions in cities have been studied for many years, using different approaches, such as urban forests (UF), ecosystem services (ES), urban green spaces (UGS), biophilic urbanism (BU), green infrastructure (GI) and, more recently, nature-based solutions (NBS) (Qi et al., 2020). While ES are often valued in terms of immediate benefits to human well-being and economy, and UF, UGS, BU, and GI focus on the provision of these ES through biodiversity protection. NBS simultaneously addresses diverse societal challenges in the long-term, allowing benefits to people and the environment (Eggermont et al., 2015). Nature-based solutions have largely evolved from previous ecosystem-based concepts and/or principles (e.g., ecosystem services, green infrastructures, ecosystem-based management, and natural capital), but it also pays attention to the social and economic benefits of resource-efficient and universal solutions that combine technical, business, finance, governance, regulatory, and social innovation (Raymond et al., 2017).

Parker and de Baro (2019) reviewed the literature dealing with green infrastructure and identified that the concept is diffuse and imprecise, with a focus on environmental, ecological, and social planning and policy, neglecting its economic, health, and wellbeing effects, as well as its performance. Mendes et al. (2020) presented a discourse analysis of emergent literature on institutionalization of Nature-Based Solutions. These authors show the challenges in the coordination between the stakeholders in the planning and implementation of green infrastructure and NBS.

Building resilience requires long-term coordination and cooperation between decision-makers, communities, companies and other stakeholders to reduce disaster risk, both through policies and investments to reduce specific risks , and by improving infrastructure and service provision (Carraro et al., 2013; CCFLA, 2022).

Resilient infrastructure systems may require large-scale changes in planning, design, and management and maintenance modes. While technology is part of the solution, the ability to anticipate risks and plan long-term urban development is critical. Resilience should not only be included as a decision-making criterion for new infrastructure projects, but should also be systematically taken into account in evaluating projects to maintain and improve existing infrastructure (Siemens, 2021).

Resistance to climate change not only influences the ability to respond to extreme weather events, but also has implications for the safety of the inhabitants of the cities (Angster, 2015). Insurance against catastrophic events and other forms of risk transfer are essential for the maintenance of urban assets and for financing recovery from extreme events. While governments have historically absorbed the gap between private insurance losses and total economic losses, their ability to continue to do so is limited by declining public finances.

On the other hand, the unpredictability of such events and the magnitude of the losses are undermining the insurability of urban infrastructure and assets (CCFLA, 2022). Decision-making cities and insurers have much to gain, working together to improve and strengthen city security through better resilience (ClimateWise, 2021).

The Chinese Sponge Cities Program refers to a type of urban management that allows cities to resolve urban waterlogging, improve water storage and discharge capacity, enhance water quality, and alleviate heat island effects through a mix of nature-based solutions and grey solutions. The overview of the SCP in the next section provides an opportunity to analyze and learn from the experiences, drawing on the strengths of the approaches to enhance the benefits of nature-based solutions for managing floods and other societal challenges.

4. Urban Water Management Policies in Chinese Cities: The Sponge Cities Initiative

4.1. Vulnerability of Chinese Cities

Since the Chinese National Government established its reform and opening-up policy in 1979, many cities have developed rapidly, especially along the coast (Nguyen et al., 2019). In the 1980s, urban populations only accounted for 19% of the population, but by 2015, this had increased to 60%. Rapid urbanization has led to multiple urban water issues, including water shortages and pollution, increased urban flooding, and the deterioration of urban water quality. Since the millennium, over 60% of Chinese cities have suffered water shortages, including 30 out of the 32 Chinese megacities (NBSC, 2019). In the 2018 National State of the Environment Report, more than 74% of cities were identified as having a poor groundwater quality status (Ferreira et al., 2020). Currently, urban drainage standards are mostly 1-in-1 to 1-in-5 year return period storms, which is insufficient to cope with rising urban flood risk. In July 2020 alone, more than 20 million people were affected by floods, across many cities in 24 Provinces (Li et al., 2019).

The Chinese scientific community acknowledges the immense impact that climate change, rising sea levels and severe flooding can have on the Middle Kingdom. The country's "Third National Climate Change Assessment Report", published in 2015, said China's coastal seas rose 2.9 millimeters more than the global average each year from 1980 to 2014. The study also notes that for every 1 centimeter the sea level rises, it could push the coastline back at least 10 meters—roughly the length of a London double-decker bus.

According to a survey of 351 Chinese cities conducted by the Ministry of Housing and Urban-Rural Development (MHURD), more than 62% suffered urban flooding between 2008 and 2010, and in 2012 and 2013, urban floods were documented in 184 and 234 cities, respectively, including severe events such as the Beijing flood on 21 July 2012, which caused widespread disruption and 79 deaths (Qi et al., 2020). The frequency, geographical spread, and severity of these urban shortage and flood events convinced central government that historical and current urban flood prevention strategies were insufficient, prompting the move towards novel and innovative solutions to urban flood and water management (Nguyen et al., 2020). In 1998, floods killed roughly 4000 people when the Yangtze River basin overflowed. A growing number of big cities such as Beijing—which more than doubled its total land coverage in the last decade—are also suffering a rise in floods. Today, roughly 641 of China's 654 largest cities are affected by regular flooding, especially those on the coast.

On July 21, 2012, China's capital city experienced its heaviest rains on record, with at least 77 dead following catastrophic flooding. Urban flooding has become a serious issue in most Chinese cities due to rapid urbanization and extreme weather, as evidenced by severe events in Beijing (2012), Ningbo (2013), Guangzhou (2015), Wuhan (2016), Shenzhen (2019), and Chongqing (2020). The severe storms may have served as a wake-up call for authorities to address severe flooding, with a slew of measures released to help address the issue. The issue became very urgent, and in 2014, the Central Government and Ministry of Housing and Urban-Rural Development formed a sponge city national committee and 30 Chinese cities were named trial cities.

Shanghai a low-lying metropolis 3 - 5 meters above sea level and flanked on three sides by Hangzhou Bay, the Yangtze River estuary and the East China Sea, has built 520 kilometers of protective seawall to reduce rising sea exposure, according to the World Economic Forum. However, half of the city is still at risk of being flooded by 2100 due to the impact of land subsidence. This puts the Chinese mainland's biggest economy in dangerous territory if high levels of carbon emissions continue and infrastructure remains the same (Cheng & Chen, 2017).

Down in the economic powerhouse of Guangdong, the picture is equally grim. Li et al. (2019) note that about one fifth of Guangzhou's urban area is considered at high or extreme risk, according to the Sea Level Rise Index. In the Greater Bay Area, over 3000 kilometers of sea defenses have been constructed, however the protection will be rendered less effective if global sea level rise reaches 30 centimeters.

The first turning point in China was in 2002, when central government set a societal water-saving construction policy (Shang et al., 2017). There was further progress between 2003 and 2007, as megacities including Beijing began to better manage storm water by improving their urban drainage systems and water pollution treatment works (Li et al., 2019). Between 2008 and 2010, water resource-optimization strategies were invoked to optimize the spatial redistribution of water resources. Traditionally, Chinese water resource management policy was to rely solely on engineering measures (i.e., dams, canals, and water transfers) to manage water resources. For example, since the 1950s, over 97,000 reservoirs have been constructed for the purposes of enhancing the potable water supply, irrigation, hydroelectric power generation, and flood control. These dams are primarily located upstream of urban conurbations (Ferreira et al., 2020).

These traditional approaches have been effective in reducing inundation frequencies in cities located along streams and rivers (flash and fluvial floods) lower in the catchment, although urban growth means that the damage generated when a flash or fluvial flood does occur have increased. Furthermore, pluvial and surface water flooding remains an issue in Chinese cities due to substantial reductions in urban greenspaces (Qi et al., 2020). Analyzing the priority criteria to adapt to climate change impacts in Chinese cities Ma et al. (2019) point out the development of urban infrastructure, and as its main component, and as more important option in this context the Sponge City Planning and Operative Technology.

4.2. Sponge Cities Program (SCP)

Primarily as a response to increasing flood impacts, the Chinese Central Government called for widespread uptake of the Sponge Cities Approach across China in 2013 and provided financial support to foster the implementation of this approach in a selection of pilot cities. At present, the Sponge Cities Approach is gaining ground and becoming more and more accepted by city governments. The best practices of Chinese cities are being shared, and international exchange activities between research institutions and cities are providing guidance to the design and implementation of new concepts and technologies. However, there are still many challenges ahead that hamper uptake by the selected pilot cities and up scaling to the remainder of the 600-plus cities in China. City governments at all institutional levels in China have to support the implementation of the Sponge Cities Approach in new built-up areas of city districts, industrial parks, and development zones (Li et al., 2018).

An important requirement for implementing the Sponge City program is to learn from similar experiences from around the world. The term "Sponge City" actually originated in Hyderabad when the city authorities started collecting storm-water to offset water demand during planting season. Likewise, Vinh in Vietnam also adopted a "city as sponge" strategy to lessen the impacts of seasonal floods on vulnerable urban areas, but was first implemented on greater scale in China. "Sponge City" aims to mimic natural hydrological and ecological processes; the last three decades have seen numerous developments in using nature-based solutions to address urban water problems particularly in the U.S., E.U., and Australia. Practical experiences with concepts such as low-impact development, sustainable (urban) drainage systems, water sensitive cities, and green infrastructure, while not identical, are more and more generating useful lessons and inspiration for the design and implementation of the Sponge Cities approach and technologies.

A Sponge City is a city that has the capacity to mainstream urban water management into urban planning policies and designs (See **Figure 2**). It should have the appropriate planning and legal frameworks and tools in place to implement, maintain, and adapt the infrastructure systems to collect, store, and treat (excess) rainwater. In addition, a Sponge City will not only be able to deal with "too much water" but will also be able to reuse rainwater to help to mitigate the impacts of "too little" and "too dirty" water.

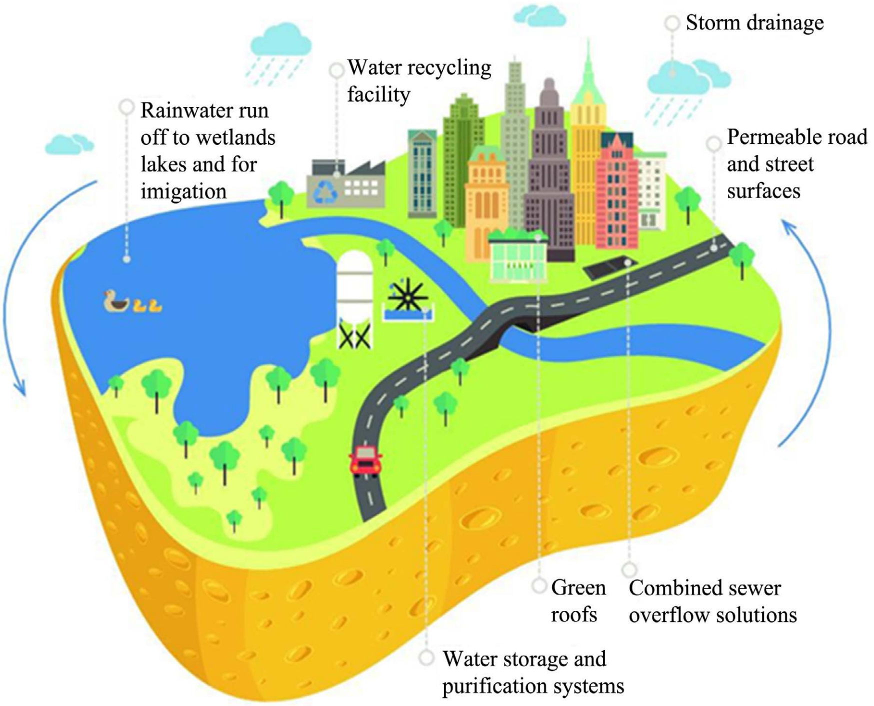

Figure 2. Sponge city. Source: China-Britain Business Focus, https://focus.cbbc.org/sponge-citiies/#.YhWnXzjMLIU.

While the Sponge Cities Concept is new, the approaches and technologies involved in it have been tried out in many different parts of the globe under the guise of terminologies like, Water Sensitive Cities, Sustainable Drainage Systems, Low-Impact Development, ABC waters, etc. (Zevenbergen, Fu, & Pathirana, 2018).

Li and Zhang (2021) review the progress of the Sponge City Program in recent years and shows the main challenges faced by the Sponge City Program in terms of connotation, investment, and technology. As of 2021, this program has led to SCP projects in 30 pilot districts all over China, the Sponge City Program construction impacts both urban development and residents' lives. However, there are risks and challenges associated with these projects.

Chinese cities are also taking action to mitigate and adapt to sea-level rise. As in the case of the Netherlands, the Chinese were motivated in part by disaster. The Chinese government has responded with a combination of hard engineering, environmental and people-based strategies, together with the relocation of millions of citizens.

In 2014, China launched the so-called sponge city initiative In the case of China, the sponge strategy requires that 80% of all urban land is able to absorb or reuse 70% of storm-water. More than 30 cities are currently part of the initiative including Shanghai—one of the most flood-prone cities in the world. The Chinese expect that at least another 600 cities will join in the coming decade (Li et al., 2018).

In Shanghai, a city that is particularly vulnerable to rising sea levels, a sponge city project was constructed in Houtan Park. Located along the Huangpu river, the area was reconstructed from a landfill for industrial parts to a green space in 2010 around the time of the Shanghai Expo. Today, Houtan Park offers ecological services such as food production, flood control and water treatment. Field-testing of the wetland indicated 2400 cubic meters of water were treated each day for non-potable uses—saving a substantial amount of money compared with conventional water treatment.

Shanghai's authorities are putting enormous stock in adaptation strategies. And not without good reason—by 2050, the city is expected to experience flooding and rainfall that is 20% higher than the global average. The city is already rocked by two to three typhoons every year. Shanghai is also sinking, albeit less slowly than Jakarta. To reduce its exposure to rising seas, Shanghai has constructed 520 km of protective seawalls that stretch across the Hangzhou Bay and encircle the islands of Chongming, Hengsha and Changxing. As in the case of Rotterdam, Shanghai has also installed massive mechanical gates to regulate overflowing rivers (Gandolfo, 2021).

Lingang, a planned city in Shanghai's Pudong district, is working to become the largest sponge city to date. This effort is supported by $119 million in funding from the city government (Li and Zhang, 2021). So far, the city has begun planting on rooftops, building wetlands (which will store rainwater), and laying down permeable roads that are capable of storing runoff water.

The modern city is very dependent on industrial technology, or gray infrastructure, with steel pipes and pumps, among other industrial products. We know that current cities cannot solve the [water] problem, so we need an alternative (Shang et al., 2017).

One of the early sponge city projects by Dr. Yu Kongjian and his team was on the southern island of Hainan—known for its monsoon climate. In Sanya, Turenscape carried out a massive mangrove restoration project to increase flood resilience. The mangroves were restored along the river and bay area so that sea level rise would be mitigated. The idea that sponge city is more resilient than gray infrastructure (Jover Biboum, García Rubio and Ávila Calzada, 2020).

A similar project was carried out along Haikou's 23-kilometer-long Meishe River, which transformed a concrete-built drainage system to an ecological infrastructure project that united the river once again with all its tributaries, wetlands and green spaces to divert storm water from sewage flow.

Sponge city projects span from coastal areas to inland cities like Wuhan, with each project addressing local water-related issues. While sea level rise is a major concern, the immediate task seems to be mitigating severe flooding in certain Chinese regions, such as Guangdong, Guangxi, Guizhou and the Yangtze River Delta.

In 2020 at least 150 people have died and around 1.8 million people have been evacuated, according to the Ministry of Emergency Management. Direct losses attributed to flooding are estimated at over RMB49 billion (Gandolfo, 2021). The Sponge City Initiative invests in projects that focus on absorbing floodwater. Currently, spongy designs are being explored in 30 cities, including Shanghai, Wuhan, and Xiamen. The current aim of the initiative is that, by 2025, 80 percent of urban areas in China will re-use at least 70 percent of their rainwater.

The 30 cities included in the initiative have received more than $12 billion in funding for sponge projects. However, the federal government only provides between 15 and 20 percent of this funding, with the rest coming from local governments and private investors (**Figure 3**).

China's ambitious program is both a creative and effective approach to this life-threatening problem. However, there is lack of suitable simulation tool for SCP evaluation, which is a bottleneck of SCP construction (Nguyen et al., 2020). Developed countries have long been involved in the development of urban storm water management systems. For instance, the Storm Water Management Model (SWMM) developed by the US Environmental Protection Agency (EPA) in 1971, after decades of development, is popular commercial storm water models worldwide (Li and Zhang, 2021). These models are widely used in the study of various aspects of urban storm water management, including feasibility evaluation, monitoring, and infrastructure planning (Ding et al., 2016). However, although such models play an important role in urban water management, they still face many challenges of application due to the complexity and diversity of

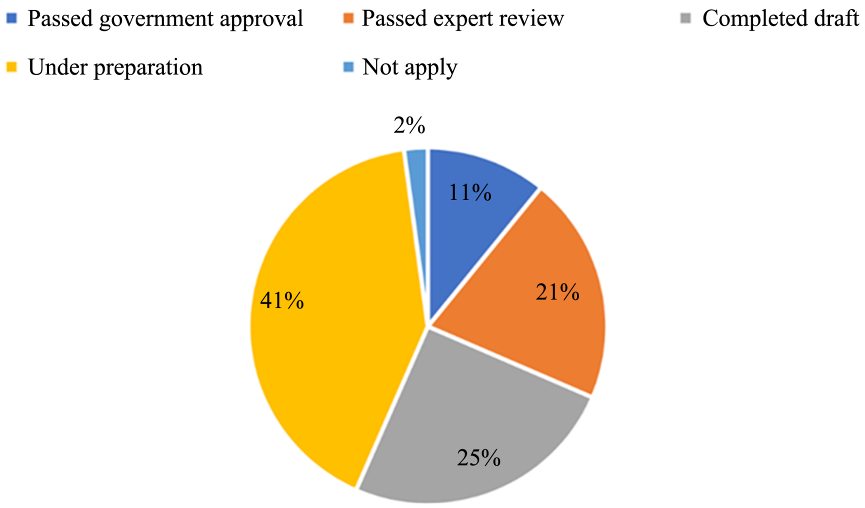

Figure 3. The preparation of Sponge City Special Plan for local governments by 2017. Source: Li and Zhang (2021).

urban water systems (Huang et al., 2020). Compared with other storm water management systems, the later start time of the SCP is a disadvantage, and this point may cause it to lack compatibility with existing urban storm water management systems models. China's unique natural conditions and development model, coupled with the ambitions of the Chinese government, complicate the application of urban water models (Huang et al., 2020). Besides urban storm water management, the connotation of the SCP covers flood disasters, water pollution, and water reuse. The Chinese government aims to build a comprehensive approach to combat all water-related problems. An ideal SCP model should be an integration of multiple sub-modules; however, this goal seems difficult now (Nguyen et al., 2020). The gap between reality and goal necessitates a national strategy for SCP construction involving "learning-by-doing", summarizing experience, and iterating technology during construction (Huang et al., 2020).

The concept of a Sponge City is abstract. The fundamental goal of the SCP is to minimize the impact of urbanization on the natural environment and establish a sophisticated urban water cycle system. The construction path of the SCP is complex and diverse, and comprehensive thinking about the urban water system is necessary and important for SCP construction (Huang et al., 2020). There is a need for comprehensive thinking that can integrate multiple aspects, including landscape, infrastructure, regulations, planning, water resources, finance, agriculture, monitoring, and property management (Li and Zhang, 2021). It considers not only the roles of low impact development (LID) and storage functions of the city lake and river system, but also the issues of water quantity, quality, and eco-system, as well as human alterations to the whole urban water system (O'Donnell et al., 2019). Systematic comprehensive thinking can change the urban designer's view on watershed scale, enhance the connectivity between source-community-region watershed scales, avoid the subdivision and isolation of the watershed during planning, and pay more attention to other control items such as peak runoff, runoff pollution, and rainwater recycling (Li et al., 2018).

4.3. Current Challenges to SCP: Finance and Investment

An integrative opportunistic strategy must create enabling conditions for linking the SCP investment agenda with those from other sectors. These transformations cannot be made overnight: completing the transformation process will typically take a lifetime of one generation. The progress in sustainable urban water management is also impacted by innovations in technologies as well as in management strategies. These technological innovations create fertile ground for businesses to adapt state-of-the-art developments from around the world and contextualize them into fit-for-purpose products. China is well placed to play a leading role in this process in the coming decade. This paper presents a brief overview of the recent developments and challenges in the area of urban water management from a global perspective relevant for Sponge Cities Approach

Several significant SCP projects have been constructed in Chinese megacities, including the Olympic Park in Beijing and the Guangming New District in Shenzhen. These projects are exemplary SCP projects that are showcased to stakeholders and the public. Historically, only wealthy cities could afford iconic blue–green infrastructure such as wetland parks, due to the high cost of land needed for this type of SCP development (Li and Zhang, 2021). For example, the first round of investment (0.3 to 0.5 billion RMB per pilot city) in the SCP was sponsored by the National Government (Liao & Wishart, 2021), but Municipal Governments are required to finance the latter stages of these projects. Despite the MHURD strongly promoting Public-Private Partnerships (PPPs) within the construction industry over the last 5 years, there are few PPPs that are financially safe due to difficulties in balancing costs and benefits between the public and private investors (Li et al., 2018).

Most community-scale SCP projects are built by developers in accordance with local, mandatory SCP regulations. To share responsibilities for maintaining larger-scale public SCP projects is a challenge that requires detailed planning. To mobilize investments, governments and public governmental institutions need to promote innovative tools and solutions. Thus, it is very important to ensure that regulatory frameworks do not constitute barriers to innovation (Ivanova, 2017).

Moreover, even in case of supranational institutions (EU budgets, MDBs, development finance institutions), the nationality of decision-makers appear to shift allocations towards "home" countries (Gehring and Schneider, 2018) and strategic choices. Such extensive home bias means that even if national actions are announced and intended to be implemented unilaterally and voluntarily, the ability to implement them requires access to climate finance that are constrained by the relative ability of domestic financial and capital markets, and access to global capital markets that requires supporting institutional policies in source countries. Enabling public policies and actions locally (cities, states, countries and regions), to reduce investment risks and boost domestic climate capital markets financing, and to enlarge the pool of external climate financing sources with policy support from source capital countries thus matter at a general level.

The particular context, however, is that the biggest problem in climate finance is likely to be in developing countries, even in the presence of such enabling policies and quite apart from any other considerations such as equity and climate justice (Klinsky et al., 2017) or questions about the equitable allocations of future "climate budgets" (Ivanova, 2020). The differentiation between developed and developing countries matter most on financing. Most developed countries have already achieved very high levels of incomes, have the largest pool of capital stock and financial capital (which can be more easily redeployed within these countries given the "home bias" of financial markets), the most well-developed financial markets and the highest sovereign credit-ratings, in addition to starting with very high levels of per capita carbon consumption—factors that should allow the fastest adjustment to low carbon investments and transition in these countries from domestic policies alone. Whether this is happening at a fast-enough rate there is a different question, relatively unconstrained by access to well-developed financial markets and public resources.

The financial and economic circumstances are the opposite for virtually all developing countries, even within a heterogeneity of circumstances across countries. The dilemma, however, is that the fastest rates of the expected increase in future carbon emissions are in developing countries. The biggest problem of climate finance globally is thus likely to be the constraints to climate financing because of the opportunity costs and relative under-development of capital markets and financing constraints (and costs) at home in developing countries, and the relative availability or absence of adequate financing policy support internationally from developed countries. The Paris Agreement and commitment by developed countries to support the climate financing needs of developing countries thus continue to matter a great deal (Ivanova, 2020).

Other topics of concern are the subnational governments (OECD, 2020). That's why it is important to introduce activate or reorient existing multi-level coordination bodies that bring together national and subnational government representatives to minimize the risk of a fragmented adaptation response. Support cooperation across municipalities and regions to help minimize disjointed responses and competition for resources. Promote inter-regional or inter-municipal collaboration in procurement especially in emergencies. Promote the use of e-government tools and digital innovation to simplify, harmonize and accelerate procurement practices at subnational level.

The goal of the Sub-national Climate Fund Global (SnCF Global) is to catalyze long-term climate investment at the sub-national level for mitigation and adaptation solutions through a transformative financing model. The SnCF Global's business model is designed to attract primarily private institutional investment and to deliver certified climate and Sustainable Development impacts and Nature-based Solutions at global scale (SDGs, NbS). The subnational level is key: 70% of known climate solutions are located within the boundaries of subnational authorities. Significant additional investment is needed in this sector to achieve the climate goals of the Paris Agreement (OECD, 2020).

In order to ensure fiscal space for climate action in the coming decade of post pandemic recovery, a mix between debt relief, deferrals of liabilities, extended debt levels and sustainable lending practices including new solidarity structures need to be considered in addition to higher levels of bi/multilateral lending to reduce dependency on capital markets and to bridge the availability of sustainably structured loans for highly vulnerable and indebted countries. More standardized debt-for-climate swap, a higher share of GDP linked bonds or structures ensuring (partial) debt cancellation in case countries are hit by physical climate change impacts/shocks appear possible. The collective action clause might be a good example of a loan/debt term which became market standard. Definition of triggers is likely the most complex challenge in this context (Ivanova, 2022).

5. Main Findings

- The goals of Nature-Based Solutions (NBS) stated by the EC include essentially sustainable urbanization, the restoration of degraded ecosystems, climate change adaptation and mitigation, resilience, and risk management.
- Resilient infrastructure systems may require large-scale changes in planning, design, and management and maintenance modes. While technology is part of the solution, the ability to anticipate risks and plan long-term urban development is critical.
- The lesson from the most successful cities is that a combination of traditional and NBS approaches is essential. What is more, environmental-based solutions to reinforce the existing ecology's protective capacities are not only effective, but lower cost.
- The Chinese Sponge Cities Program refers to a type of urban management that allows cities to resolve urban waterlogging, improve water storage and discharge capacity, enhance water quality, and alleviate heat island effects through a mix of nature-based solutions and grey solutions.
- The main benefits of SCP are the following: 1) Recovering or simulating natural hydrological conditions via the protection or restoration of urban ecosystems; 2) Improving water quality; 3) Mitigating urban flood risk; and 4) Improving quality of life for residents. Furthermore, systematic comprehensive thinking in the SCP is beneficial for other non-water-related infrastructure projects. This can promote the transformation of the management ideology of all Chinese traditional infrastructure construction from a focus on technology and engineering to a new model involving management and go-

vernance thinking; however, this transformation requires the government to pay more attention to capacity building and collaborative research.

- Developers in accordance with local, mandatory SCP regulations build most community-scale SCP projects. To share responsibilities for maintaining larger-scale public SCP projects is a challenge that requires detailed planning. To mobilize investments, governments and public governmental institutions need to promote innovative tools and solutions. Thus, it is very important to ensure that regulatory frameworks do not constitute barriers to innovation.
- The main challenge for Chinese SCP is the financing and investment. Municipal Governments are required to finance the latter stages of the SCP. Despite the strongly promotion of Public-Private Partnerships (PPPs) within the construction industry over the last 5 years, there are few PPPs in China, that are financially safe due to difficulties in balancing costs and benefits between the public and private investors.
- The Sub-national Climate Fund Global (SnCF Global) is to catalyze long-term climate investment at the sub-national level for mitigation and adaptation solutions through a transformative financing model. The SnCF Global's business model is designed to attract primarily private institutional investment and to deliver certified climate and Sustainable Development impacts and Nature-based Solutions at global scale. That would be a very important solution for the financing of SCP in China and in other developing countries.
- Finally, key challenge will be to align the sponge city program projects with infrastructure and urban renovation portfolios to affront the substantial investment need and a lack of reliable financing schemes.

6. Conclusion

Cities around the world are facing a dire need to take action to manage water-related risks that are exacerbated by climate change effects and urban growth. The governments and businesses must enforce, enact or invest in effective climate change adaptation measures, preserve ecosystems, and protect populations.

China is taking the repercussions of climate change seriously. One consequence of our warming world is increasingly frequent and more severe flooding. This is especially problematic in growing, crowded cities, which has made certain regions in China more vulnerable. China's current gray infrastructure as unsuitable to handle increasingly volatile weather. Green infrastructure and sponge cities are resilient, adapt to the fluctuation of water, and are floodable, and cities prone to monsoons benefit greatly from these projects. Strategies include using permeable surfaces and green (meaning that it incorporates plant-life) infrastructure.

China introduced the Sponge City Initiative in 2014 to leverage the benefits of nature-based solutions. This approach integrates green spaces and "blue" systems, like wetlands into conventional "gray" infrastructure, such as concrete embankments, contributing to the 2030 UN Sustainable Development Goal (SDG) 11 to "make cities and human settlements inclusive, safe, resilient and sustainable". By 2030, China aims to turn 80 percent of its urban areas "sponge-like", addressing surface-water flooding, attenuating peak run-off, improving purification of urban runoff, and enhancing water conservation while improving environmental quality, community health and economic prosperity. From advanced drainage systems to roadways capable of absorbing water and creative planting, sponge cities are getting increasingly innovative in how they might be able to better fend off floodwaters.

The SCP is effective for solving urban water-related issues; it is a successful example of innovative adaptation. However, there are many challenges to reaching the final target. Investment and technology are the most important challenges to the program. However, some opportunities are emerging due to the SCP construction, such as systematic comprehensive thinking and the application of new technology.

Some orientations of the green infrastructure and sponge cities financing in the post COVID-19 recovery should be the following: Introduce, activate or reorient existing multi-level coordination bodies that bring together national and subnational government representatives to minimize the risk of a fragmented adaptation response. Additionally it is necessary to align the sponge city program projects with infrastructure and urban renovation portfolios to affront the substantial investment need and a lack of reliable financing schemes.

Support cooperation across municipalities and regions to help minimize disjointed responses and competition for resources. Promote inter-regional or inter-municipal collaboration in procurement especially in emergencies. Promote the use of e-government tools and digital innovation to simplify, harmonize and accelerate procurement practices at subnational level.

The Sub-national Climate Fund Global (SnCF Globa) presents a positive disruptive solution on how subnational climate projects should be structured, de-risked, and funded by both private and public investors, while monitored and benchmarked at the highest level of rigor and quality.

In the coming decade, innovations in research, education, and technology are urgently required to design, engineer, and construct Sponge Cities across the whole of China. The creation of a sponge city is not a singular, defined process. Each project is customized to its region and aims to improve upon previous techniques and overcome difficult challenges. The concept has so much potential that many cities around the world are looking to become more "spongy". China is taking a firm stand against such flooding with this initiative, and the rest of the world might follow suit. The SCP can be implemented in other countries by adopting the lessons of the Chinese experience.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

Angster, R. (2015). *Improving the Mobilization of Climate Finance for Cities: Potential and Role of Local Financial Institutions*. Agence Française de Développement.

Bevere, L., & Weigel, A. (2021, March 30). *Sigma 1/2021—Natural Catastrophes in 2020*. Swiss Re Institute. https://www.swissre.com/institute/research/sigma-research/sigma-2021-01.html

Busscher, T., Brink, M. V. D., & Verweij, S. (2018). Strategies for Integrating Water Management and Spatial Planning: Organising for Spatial Quality in the Dutch "Room for the River" Program. *Journal of Flood Risk Managing, 12,* e12448. https://doi.org/10.1111/jfr3.12448

Carraro, C, Fevero, A., & Masseti, E. (2013). Investments and Public Finance in a Green, Low Carbon, Economy. *International Environmental Agreements: Politics, Law and Economics, 34,* S15-S28. https://doi.org/10.1016/j.eneco.2012.08.036

CCFLA (Cities Climate Finance Leadership Alliance) (2022). *The State of City Climate Finance 2021*. Climate Policy Initiative. https://www.greenfinanceplatform.org/sites/default/files/downloads/resource/The_State_of_Cities_Climate_Finance_Part_1-min.pdf

Cheng, H. Q., & Chen, J. Y. (2017). Adapting Cities to Sea Level Rise: A Perspective from Chinese Deltas. *Advances in Climate Change Research, 8,* 130-136. https://doi.org/10.1016/j.accre.2017.05.006 https://www.omicsonline.org/conference-proceedings/2157-7617-C1-036-011.pdf

ClimateWise (2021). *ClimateWise Report 2019-2021*. ArgoGlobal. https://d1hks021254gle.cloudfront.net/wp-content/uploads/2020/11/2019-20-ArgoGlobal_ClimateWise-reporting-19-20-20-Aug-2020_web_v4.pdf

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). *Nature-Based Solutions to Address Global Societal Challenges*. International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2016.13.en

Ding, P. X., Wang, H. J., Meng, X. W. et al. (2016). *Evolution Trend and Vulnerability Assessment of Typical Coastal Zones in China under the Influence of Climate Change* (p. 413). Science Press.

Eggermont, H., Balian, E., Azevedo, M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P. et al. (2015). Nature-Based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA: Ecological Perspectives for Science and Society, 24,* 243-248. https://doi.org/10.14512/gaia.24.4.9

Ferreira, V., Barreira, A. P., Loures, L., Guerreiro, A. C., & Panagopoulos, T. (2020). Stakeholders' Engagement on Nature-Based Solutions: A Systematic Literature Review. *Sustainability, 12,* Article No. 640. https://doi.org/10.3390/su12020640

Fish, R., Church, A., Willis, C., Winter, M., Tratalos, J. A., Haines-Young, R., Potschin, M. (2016). Making Space for Cultural Ecosystem Services: Insights from a Study of the UK Nature Improvement Initiative. *Ecosystem Services, 21,* 329-343. https://doi.org/10.1016/j.ecoser.2016.09.017

Gandolfo, R. (2021, July 23). *How Rising Sea Levels Could Change Life in China Forever.* https://www.thatsmags.com/china/post/31417/how-rising-sea-levels-could-change-life-in-china-forever

Gehring, K., & Schneider, S. A. (2018). Towards the Greater Good? EU Commissioners' Nationality and Budget Allocation in the European Union. *American Economic Journal: Economic Policy, 10,* 214-239. https://doi.org/10.1257/pol.20160038

Huang, H., Zhang, M., Yu, K., Gao Y., & Liu, J. (2020). Construction of Complex Network of Green Infrastructure in Smart City under Spatial Differentiation of Landscape. *Computer Communications, 154,* 380-389. https://doi.org/10.1016/j.comcom.2020.02.042

IPCC (Intergovernmental Panel on Climate Change) (2021). *AR6 Climate Change 2021: The Physical Science Basis.* Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/

IUCN (International Union for Conservation of Nature) (2016). *IUCN Programme 2017-2020.* https://www.iucn.org/about/programme-work-and-reporting/programme

Ivanova, A. (2017) Ch. 8. Green Financing for Cities: Current Options and Future Challenges. In G. C. Delgado (Ed.), *Climate Change-Sensitive Cities: Building Capacities for Urban Resilience, Sustainability, and Equity* (pp. 283-306.) Program on Climate Change Research, Programa de Investigación en Cambio Climático, Universidad Nacional Autónoma de México.

Ivanova, A. (2022). Finance for Climate Action: Postcovid-19 Recovery Challenges. *The Mexican Journal of Economics and Finance (REMEF), 17,* Article No. e717. (Ahead of Print). https://doi.org/10.21919/remef.v17i2.717

Ivanova, A. (2020). *Cuando acabe la pandemia, el cambio climático seguirá aquí, en Perspectivas de Transformación en Tiempos de Emergencia, Cuadernos de Transformación, Friedrich Ebert Stiftung* (pp. 91-95). http://www.fes-transformacion.org

Jover Biboum, M., García Rubio, R., & Ávila Calzada, C. (2020). Kongjian Yu and the Redefinition of China's Cultural Landscape. *ZARCH, No. 15,* 166-187. https://doi.org/10.26754/ojs_zarch/zarch.2020154931

Klinsky, S., Roberts, T., Huq, S., Okereke, C., Newell, P., Dauvergne, P., O'Brien, K., Schroder, H., Tschakert, P., Clapp, J., Keck, M., Biermann, F., Liverman, D., Gupta, J., Rahman, A., Messner, D., Pellow, D., & Bauer, S. (2017). Why Equity Is Fundamental in Climate Change Policy Research. *Global Environmental Change, 44,* 170-173. https://doi.org/10.1016/j.gloenvcha.2016.08.002

Li, B., Dong, S., Huang, Y., & Wang, G. Q. (2019). Development of a Heterogeneity Analysis Framework for Collaborative Sponge City Management. *Water, 11,* Article No. 1995. https://doi.org/10.3390/w11101995

Li, F., & Zhang, J. (2021). A Review of the Progress in Chinese Sponge City Programme: Challenges and Opportunities for Urban Stormwater Management. *Water Supply, 22,* 1638-1651. https://doi.org/10.2166/ws.2021.327 https://iwaponline.com/ws/article/22/2/1638/84332/A-review-of-the-progress-in-Chinese-Sponge-City

Li, Zh., Dong, M., Wong, T., Wang, J., Jagadeesh Kumar, A., & Prasad Singh, R. (2018). Objectives and Indexes for Implementation of Sponge Cities—A Case Study of Changzhou City, China. *Water, 10,* Article No. 623. https://doi.org/10.3390/w10050623

Liao, X., & Wishart, M. J. (2021). *Nature-Based Solutions in China: Financing "Sponge Cities" for Integrated Urban Flood Management.* https://blogs.worldbank.org/eastasiapacific/nature-based-solutions-china-financing-sponge-cities-integrated-urban-flood

Ma, Z., Jiang, Y., Gao, Q., Liu, Q., Feng, P., Song, W., & Liu, J. (2019). Technology Demand Assessment of Adaption of Chinese Cities to Climate Change. *Journal of Geoscience and Environment Protection, 7,* 338-353. https://doi.org/10.4236/gep.2019.78023

Mendes, R., Fidélis, T., Roebeling, P. C., & Teles, F. (2020). The Institutionalization of

Nature-Based Solutions—A Discourse Analysis of Emergent Literature. *Resources, 9,* Article No. 6. https://doi.org/10.3390/resources9010006

Muggah, R. (2019, June 28). *How China's Sponge Cities Are Preparing for Sea-Level Rise.* https://www.weforum.org/agenda/2019/06/how-china-s-sponge-cities-are-preparing-for-sea-level-rise/

NBSC (National Bureau of Statistics of China) (2019). *National Bureau of Statistics of China (NBSC).* China Statistics Press.

Nguyen, T. T., Ngo, H. H., Guo, W. S., & Wang, X. C. (2020). A New Model Framework for Sponge City Implementation: Emerging Challenges and Future Developments. *Journal of Environmental Management, 253,* Article ID: 109689. https://doi.org/10.1016/j.jenvman.2019.109689

Nguyen, T. T., Ngo, H. H., Guo, W. S., Wang, X. C., Ren, N., Li, G., Ding, J., & Liang, H. (2019). Implementation of a Specific Urban Water Management—Sponge City. *Science of the Total Environment, 652,* 147-162. https://doi.org/10.1016/j.scitotenv.2018.10.168

O'Donnell, E., Thorne, C., Ahilan, S., Arthur, S., Birkinshaw, S., Butler, D., Dawson, D., Everett, G., Fenner, R., Glenis, V. et al. (2019). The Blue-Green Path to Urban Flood Resilience. *Blue Green Systems, 2,* 28-45. https://doi.org/10.2166/bgs.2019.199

OECD (Organisation for Economic Co-Operation and Development) (2020). *The Territorial Impact of COVID-19: Managing the Crisis across Levels of Government.* https://www.oecd.org/coronavirus/policy-responses/the-territorial-impact-of-covid-19-managing-the-crisis-across-levels-of-government-d3e314e1/

Parker, J., & de Baro, M. E. Z. (2019). Green Infrastructure in the Urban Environment: A Systematic Quantitative Review. *Sustainability, 11,* Article No. 3182. https://doi.org/10.3390/su11113182

Qi, Y., Chan, F. K. S., Thorne, C., O'Donnell, E., Quagliolo, C., Comino, E., Pezzoli, A., Li, L., Griffiths, J., Sang, Y., & Feng, M. (2020). Addressing Challenges of Urban Water Management in Chinese Sponge Cities via Nature-Based Solutions. *Water, 12,* Article No. 2788. https://doi.org/10.3390/w12102788

Rachman, G. (2021, November 1). The Threat of Conflict over Water Is Growing. *Financial Times.* https://www.ft.com/content/b29578f1-c05f-4374-bbb4-68485ef6dbf7

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., Geneletti, D., & Calfapietra, C. (2017). A Framework for Assessing and Implementing the Co-Benefits of Nature-Based Solutions in Urban Areas. *Environmental Science & Policy, 77,* 15-24. https://doi.org/10.1016/j.envsci.2017.07.008

Rui, Y., Fu, D., Minh, H. D., Radhakrishnan, M., Zevenbergen, Ch., & Pathirana, A. (2018). Urban Surface Water Quality, Flood Water Quality and Human Health Impacts in Chinese Cities. What Do We Know? *Water, 10,* Article No. 240. https://doi.org/10.3390/w10030240

Shang, Y., Lu, S., Li, X., Sun, G., Shang, L., Shi, H., Lei, X., Ye, Y., Sang, X., & Wang, H. (2017). Drivers of Industrial Water Use during 2003-2012 in Tianjin, China: A Structural Decomposition Analysis. *Journal of Cleaner Production, 140,* 1136-1147. https://doi.org/10.1016/j.jclepro.2016.10.051

Siemens (2021). *Annual Report 2021.* https://assets.new.siemens.com/siemens/assets/api/uuid:82e18947-09d4-403e-a30e-26795c949c07/siemens-ar-2021.pdf

Swiss Re (2021, April 22). *World Economy Set to Lose up to 18% GDP from Climate Change If No Action Taken, Reveals Swiss Re Institute's Stress Test Analysis.* https://www.swissre.com/media/press-release/nr-20210422-economics-of-climate-chan ge-risks.html

UNHCR (United Nations High Commissioner for Refugees) (2021). *Global Report 2020*. United Nations High Commissioner for Refugees. https://www.unhcr.org/flagship-reports/globalreport/

World Economic Forum (2022). *The Global Risks Report 2022* (17th ed.). https://www.zurich.com/knowledge/topics/global-risks/the-global-risks-report-2022

Zevenbergen, Ch., Fu, D., & Pathirana, A. (Eds.) (2018). Transitioning to Sponge Cities: Challenges and Opportunities to Address Urban Water Problems in China. *Water, 10,* 1230. https://doi.org/10.3390/w10091230