# Assessing Climate adaptation transition in urban area

## Comparative study between China and the Netherlands

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by

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TU Delft

# Preface

It has been an amazing two-year journey in Delft. I feel both grateful and a little sentimental as I bring this Master program in Environmental Engineering to an end with this final thesis. The inspiration for my thesis came from the course *Operation, Control, Management and Adoption of Urban Water Infrastructure* in Q4, where I was first introduced to the concept of adaptation. I am deeply grateful for the chance to gain hands-on experience in this field.

First of all, my heartfelt thanks go to my supervisor, Jeroen, for giving me the opportunity to explore my interests and for helping me shape this thesis topic. I am also grateful for your dedication to the Urban Water Infrastructure track, which I truly enjoyed and feel very welcomed by this lovely community. A big thank you as well to my thesis committee member, Erik. Thank you for your thoughtful feedback during our meetings, and for the course you have given, which has been instrumental in my growth.

I would also like to thank all my friends and classmates in the Netherlands. It has been such a joy to share these precious memories with you. To my friends and family in China, thank you for always supporting me wholeheartedly, even from afar.

This master thesis is rooted in the idea of living with rain. I grew up in Guangzhou, a city in southern China with a humid climate. Working on this thesis brought back some beautiful childhood memories of rain. As a child, I loved splashing my feet in the little rainwater streams running along the roads, what I now know as urban runoff. I would dash to the market with umbrella for my grandma when she was caught in a sudden downpour. I even remember feeling secretly delighted when a typhoon came, meaning that school would be canceled. I would stand by the window to watch the street gradually flooded (not a good sign though).

Looking back, I realize these moments planted the seeds of my fascination with urban storm water management. To me, a rainproof future does not mean making cities literally waterproof, but rather making them resilient to heavy downpours, while leaving room for children to create their own unique memories with rain, just as I once did.

*Ziqi Wang*
*Delft, August 2025*

# Summary


Climate change has increased extreme precipitation, heightening urban flood risks. In cities, impermeable surfaces created by urbanization require effective drainage solutions. Sustainable Urban Drainage Systems (SuDS) are emerging nature-based measures to manage storm water, which are widely adopt in climate adaptation strategies.

The aim of this thesis is to investigate the local interpretation and implementation of China's Sponge City Policy, and to explore lessons learned from comparison with Dutch climate adaptation practices. The scope of this research focuses on extreme precipitation adaptation through local adaptation strategies related to SuDS. Literature Review is provided to improve understanding of the national climate adaptation strategies, storm water governance structure in China and the Netherlands. Interviews were constructed with 7 experts in the field of urban planning, urban development and drainage engineering to facilitate understandings in the Chinese part of study. Policy Analysis framework is applied to investigate local interpretation of Sponge City. To further see the outcomes of the policy and compare with international practices, site visits are paid to both cities followed by a comparative study.

The results suggest that Guangzhou's Sponge City policy was well aligned with water-related themes established by the central government. However, this alignment reflects a *one-model-fits-all* phenomenon, limiting the capacity of policy adjustment to address local issues. Three local implementation problems were identified: 1) institutional challenges; 2)highly criteria-oriented indicator systems; 3) the overall lack of climate adaption capacity. The results reveal that institutional issues could lead to technical failure and lack of land scarcity in SuDS integration. High SuDS coverage required in Sponge City implementation tends to overlook the on-ground performance. Climate adaption capacity is limited considered in both the central policy and local interpretation. The combined impacts of the above mentioned issues could add stress to improve local climate adaption capacity.

Compare with experience of Amsterdam, a similarity was found as both cities tend to prioritize urban development over climate adaptation. By studying the divergence in applied approaches and principles, opportunities are suggested for the cities to learn from each other. The lessons learned from Amsterdam indicate that an open platform plays an important role in local spatial adaptation, which could potentially contributes to address challenges faced in Guangzhou. The Guangzhou experience has indicated the necessity of regulation integrations to ensure a steady implementation, however, the lack of soft tools could result in wasted potential of private contributions and unsatisfied adaption performance. Therefore, a balance of strong and soft tools is suggested for better local climate adaption.

# Contents

# 1

# Introduction

## 1.1. Problem Statement

In recent decades, it has been evident that climate change is profoundly altering rainfall and runoff patterns (Rodina, 2019). As a result of the accelerated growth of urban areas, the urban landscape has deviated notably from the natural environment, lowering the capacity of natural rain water infiltration. The compounded impacts have resulted in a greater increase in extreme inland flooding events in urban areas comparing to non-urbanized regions (A. Jiang et al., 2023).

Traditionally, urban drainage systems are mainly applied as urban flooding control measures. Researchers have revealed that the current pipe systems are limited in coping with the combined impact of climate change and urban development( population growth, changes of land use and land cover, etc.) (Kourtis & Tsihrintzis, 2021). Technically, pipe drainage systems are designed for long-term service but lack flexibility to adjust their capacity. The existing pipe systems can be relatively old and were designed based on the past predicted climate conditions, showing constraints in dealing with future events (Kang et al., 2016; Kourtis & Tsihrintzis, 2021; J. Wang et al., 2021). For example, Kumar et al. (2022) modeled the impacts of climate change on the current storm water drainage systems in Delhi, India. The result indicates that an event with 2-year return period under future climate can potentially cause the same damage as an event with 20-year return period predicted based on current rainfall data. Excessive runoff generated by extreme rainfall and inadequate capacity of pipe drainage systems can lead to more frequently observed surface flooding (Eckart et al., 2017). In addition, traditional pipe solutions have shown limitations in pollution controls and found potential damage to the receiving water bodies (Sörensen et al., 2016). These necessitate a paradigm shift towards a more integrated and adaptive urban storm water management regime.

To increase the resilience to extreme precipitation, climate adaptation of urban water infrastructures has been widely discussed (Dai et al., 2018; Sörensen et al., 2016; Zevenbergen et al., 2008). Strategies are significant as proactive measures to facilitate adaptation , especially at local scales. Kourtis and Tsihrintzis (2021) has reviewed on urban drainage adaptation, indicating a focus on conventional solutions (constructions related to pipe systems) and the emerging sustainable solutions. Compared with conventional approaches, Sustainable Urban Drainage Systems (SuDS) are built on nature-based principles. This type of system applies a range of technologies to drain runoffs in a more sustainable manner (Fletcher et al., 2015). Subsequently, SuDS can be more flexible and can delivered at a lower cost, comparing to the pipe drainage improvement, gaining increased attentions for urban flooding control (Xu et al., 2021).

The effectiveness of SuDS depends primarily on governance frameworks that enable its integration in urban planning and implementation (Van de Meene et al., 2011). The scheme of integrating adaptation options can be various. As climate adaptation becomes a new focus, it challenges the policy integration(Hurlimann et al., 2021; Broto, 2017a). The Netherlands and China have both given considerations to climate adaptation and its integration in policy domains. However, given the differences in natural environments, socio-economic contexts, and governance structures, their implementation strategies differ significantly. Comparing these strategies could reveal context-specific barriers and transferable lessons for local climate adaptation. China has adopted a initiative known as the *Sponge City* initiative. According to the SC initiative, by the year 2030, 80% of the built-up urban area will be equipped with sustainable drainage techniques to manage rainfall on site (GOSC, 2015). The initiative calls on a focus on managing storm water with SuDS, aiming at a rainproof future without urban flooding. Sponge City policy is implemented through a top-down approach, requiring municipalities to align with the grand vision established by the central government (D. Yin et al., 2021). The Dutch scheme of climate adaptation is characterized by a decentralized distribution of power, enabling local municipalities to implement adaptation practices at their own pace (Dai et al., 2018).

## 1.2. Research Gap

In the light of climate adaptation, scholars have suggested frameworks to identify the degree of policy integration, implementation progress, and implementation barriers (Moser & Ekstrom, 2010; Reckien et al., 2019; Ulibarri et al., 2022). Despite extensive policy analysis and technology application discussions of urban climate adaptation, little is known about how local implementation strategies translate goals into tangible on-ground outcomes.

Local governments are key actors in the formulation and implementation of climate adaptation policies, as the impacts are manifesting at regional and local scales (Baker et al., 2012; Vogel & Henstra, 2015). The complexity at local level, such as political goals, organizational routes and resources, results in various ways of local climate adaptation (Uittenbroek, 2016). Critically, how local governance practices shape the effectiveness of adaptive responses remains understudied (Fischer, 2021).

This gap impedes scalable solutions, as policy success hinges on understanding the behavioral pathways from governance to deliverables. Adaptive capacity relies on complex policy-society interactions. For instance, national-level decisions and policies shape the local implementation arenas, while the characteristics of (multi-level) governance regimes influence the ability of actors to adapt to climate change (Dąbrowski et al., 2021). In China, the goal of Sponge City policy is ambitious to achieve within 15 years of implementation period. Considering the variety of geological and sociol-economical conditions across the country, the policy implementation must be tailored into local conditions, requiring engagement of sub-provincial or municipal-level government entities (Griffiths et al., 2020).

While studies evaluate SuDS performance in pilot cities (D. Yin et al., 2021) or city-level resilience (Yuan et al., 2024) in the light of Sponge City policy , few trace how governance shape the implementation behaviors. While the SC initiative is theoretically well-founded and appropriate by its design principles, it is shown to be subject to diverse challenges when implemented locally (Y. Jiang et al., 2018; Xia et al., 2017). A recommended strategy involves an adaptive, opportunistic approach to implementation, facilitating learning and adjustment, rather than rushing through construction of visible, hard infrastructure (Y. Jiang et al., 2018). The interest of this research is to link the deliverables with the local strategies, to explore the behavioral impact on the outcomes.

Comparative studies have been performed to compare the climate adaptation of China and other countries. Lashford et al. (2019) compare the SuDS management between China and the UK, suggesting future improvement and lesson-learned. Zhao et al. (2022) revealed the different features of the transition toward Sustainable storm water Management in the U.S. and China, highlighting the importance of study the transition history and thinking between different country. L. Li et al. (2020) identified the mutual barriers and opportunities of integrating green infrastructure in China and UK, presenting as an example of comparative learning to facilitate adaptation transition. As climate change has become an important policy issue in the Netherlands, due to its low-lying geographical characteristic, the country is actively engaged in climate adaptation transition (Stead, 2014). Different from the top-down initiative of China, in the Netherlands, municipalities have chosen to focus on taking adaptation measures themselves and soft policy instruments such as awareness campaigns, participation, facilitating private actor engagement and subsidies (Dai et al., 2018). The divergence lies in the two countries could provide opportunities to gather experience in both themes, facilitating the local adaptation transitions.

## 1.3. Research Relevance

This research is designed with a focus on investigating local climate strategies and their resulting technical outcomes. It addresses a critical gap in policy assessment framework

As climate adaptation policies being established among cities around the world, researchers have recognized the need to evaluate the effectiveness of the policies in the face of risks. Assessment frameworks are established by researchers to examine the quality and climate adaptation, which suggest the consideration of adaptation knowledge usage, goals and measures, implementation, and participation (Olazabal et al., 2019; Reckien et al., 2023; Woodruff & Stults, 2016). Previous researches indicate that the production of usable climate adaptation knowledge and its integration in policy is an iterative process, which is shaped by the participated actors and organizations, conditions, and mechanisms of adaptation (Dilling & Lemos, 2011; Dunn et al., 2017). Therefore, the complex nature of climate adaptation generates large difficulties of assessment and governance (Moser & Ekstrom, 2010).

This research contributes to knowledge improvement of the resulting technical solutions after implementing local adaptation strategies, which can provide information for policy assessment. Comparative study between China and the Netherlands is designed to compare the influence of the complex impacting factors on the deliverables of adaptation. The results can further contribute to evidence-based policy-making in local conditions, which is seen as an emerging opportunity in dealing with water problems under climate change (Gu et al., 2017).

## 1.4. Research Objectives

As aforementioned, the Sponge City (SC) is promoted through top-down national policy, resulting in divergent interpretations in local implementations. This research aims to analyze local interpretations of China's Sponge City policy and draw comparative insights from Dutch climate adaptation practices. The main research question is formulated as:

> **How do cities interpret and implement China's Sponge City policy, and what lessons emerge from comparative experience with Dutch climate adaptation practices?**

This main research question necessitates a deeper understanding of governance and strategy implementation in climate adaptation transitions. To address this, five sub-research questions are formulated:

1. How are national Sponge City regulations translated into implementation frameworks at the city level?
2. What strategies do implementers employ to integrate Sustainable Drainage Systems (SuDS) within climate adaptation initiatives in China and the Netherlands?
3. How do implementers perceive the roles of SuDS versus conventional drainage systems in climate adaptation?
4. What governance, technical, and socio-economic factors enable or constrain climate adaptation implementation?
5. What transferable lessons can be drawn for future urban climate adaptation strategies?

Notably, sub-question 1 specifically examines China's Sponge City policy translation, while sub-questions 2—5 facilitate comparative analysis at the local implementation level in both contexts.

## 1.5. Research Scope

The scope of this research is described in the following aspects: thematic boundaries, geographic focus.

### 1.5.1. Thematic Boundaries

Climate adaptation is an inclusive topic. Adapt to future precipitation condition is the main theme in this research. The research aims at discovering the policy outcomes through qualitative analysis approach. SuDS are the fundamental climate adaptation practices investigated in this research. Drivers and trends related to the formation of the policy at central level are limited addressed. Instead, this research is designed with a focus on the local scale strategies translations and the corresponding SuDS implementations. The research does not aim to study why such interpretations happened, but more on how the implementers understand the interpretations.

### 1.5.2. Geographic Focus

This study is carried out in China and the Netherlands. Two different cities are selected: Guangzhou and Amsterdam. The size of the two cities are significantly different, while they are governed at the same municipal level with regard to climate adaptation. Two study sites within the cities are selected for case study, where demonstration projects were constructed . Therefore the results can limited present the adaptation progress of the whole city, but suggest the typical understanding on climate adaptation facilitated by the local strategies.

## 1.6. Reading Guide

In this chapter, problem statement and the objective of this research is introduced. Chapter.2 consists of a literature review, introducing the sustainable water management of China and the Netherlands under the context of climate adaptation. This chapter aims at providing background understanding of the values and institutional structure in national scales for local level discussion. Classification of implementation strategies is described for comparison between local strategy implementation. Chapter. 3 explains the methodologies used in Sponge City policy interpretation and the comparison framework of local climate adaptation strategies implementation. The results and discussions are included in Chapter.4 and 5. Chapter.6 is the conclusion of this thesis.

# 2
# Literature Review

In this chapter, literature review is presented. The review aims to provide understanding for further research, consisting the following aspects:

- The terminology of Sustainable Storm Water Management
- Sustainable Storm Water Management in the context of climate adaptation
- Classification of implementation strategies

## 2.1. Terminology of Sustainable Storm Water Management

Historically, storm water in urban area has been directly discharge into drainage approach (Karvonen, 2011). This conventional type of management primarily relies on the conveyance capacity of drainage pipes, which is now challenged by emerging issues, such as the extreme weather conditions and non-source pollutions.

As the focus of storm water management has shifted from the conventional methods to multi-objectives approaches, the principles of a sustainable management now emphasize: 1) Restoring natural hydrological processes ; 2) Improving water quality and mitigating water pollution (Fletcher et al., 2015). A diverse range of terminologies has been applied to describe similar approaches of storm water management. Fletcher et al. (2015) identified different terms shaped by regional and contextual factors. Rooted in preventing pollution to the water environment, urban storm water *Best Management Practices* (BMPs) were introduced in the United States, which includes both structural and non-structural practices. In the UK, *Sustainable Drainage Systems* (SuDS) were developed to replicate the pre-development drainage regime through a range of technologies and techniques. The most authoritative guide to SuDS is currently *The SuDS Manual* (Woods-Ballard et al., 2007) , which provides technical guidance to the construction of different measures. In North America and New Zealand, the term *Low Impact Development* (LID) has been commonly used. LID was introduced as an approach to minimize the cost of storm water management, by taking a design-with-nature approach. *Low Impact Development Design Manual* was published to aid the implementation in the States. The shift from BMPs to LID in the United States indicates a expended scope from pollution control to a near-nature site design. Considering a boarder scope of water systems, the term *Water Sensitive Urban Design* (WSUD) was introduced in Australia. WSUD was developed as an philosophy, which included several objectives related to water resource protection, pollution control, storm water management and cost-effectiveness (Lloyd et al., 2002). *Blue-Green Infrastructure* (BGI) and *Green Infrastructure* (GI) are emerging terms, which connect the scope of landscape architecture and ecosystem services (Ashley et al., 2018). The term GI is increasingly synonymous with LID, indicating a network of decentralized storm water practices (Fletcher et al., 2015). In China, the term Sponge Cities (SC) refers to the strategy, which adapts LID and SuDS, WSUD principles to stress water flooding issues (Nguyen et al., 2019)

While these terms share similar principles, their scope and emphasis differ. As this research examines climate adaptation policy implementation in China and the Netherlands, a unified term referring to technical solutions is required to enable cross-country comparison. Among the options, SuDS encompasses a wide array of structural measures, aligns with European usage, and directly addresses the need for sustainable alternatives to conventional storm water systems. LID is used in the manual of Sponge city construction in China, while the term itself has been integrated into the Chinese content (see Chapter 4), and the LID can refers to boarder principles than SuDS (Fletcher et al., 2015). Therefore, the term SuDS is used in this study referring to technical measures, while Sponge City is retained for Chinese policy study.

SuDS measures include green roofs, permeable surfaces, infiltration trenches, swales, shallow drainage channels, detention basins, ponds, wetlands, and flooding parks (Woods-Ballard et al., 2007). They can be classified into source-control systems (e.g, green roofs, permeable pavements) and downstream systems (systems that enable re-use of water by incorporating treatment).

## 2.2. Sustainable Storm Water Management in the Netherlands

The Netherlands is located in the delta of the Rhine, Meuse, Scheldt, and Ems rivers, which run along the North Sea coast. The country lies approximately 26% below the normal sea level, and approximately 60% is vulnerable to flooding (Diakomopoulos et al., 2024). Due to this unique geographical condition, the Netherlands has been recognized as the pioneer in water management and pluvial flooding mitigation. This section starts with a brief investigation on principle and strategy evolution in the Dutch way of managing in-land flooding and climate adaptation (section 2.2.1). In section 2.2.2, the institutional organization and responsibilities of the stakeholders related to sustainable storm water management is explained.

### 2.2.1. Principle and Strategy Evolution

In the long history of living with water, the Dutch water management has shifted from defensive approach to adaptive approach. In the past century, focus was given to constructing dike systems in prevention of the increasing risk of flooding. Flooding damages accelerated the construction of *Afsluitdijk* in the North Holland and *the Delta Works* constructed in the south-west of the Netherlands (Brouwer, 2015). These projects, which marked the success of Dutch water engineering, reflected the dominance of defensive water control paradigm (Wolsink, 2006). This paradigm applied the principle of *Pumping-Drainage-Dike* raising, and later shown a lack of ability in preserving sustainable water system (Van der Brugge et al., 2005). Driven by these engineering activities, large-scale land reclamation had caused damage to natural water systems, which resulted in frequently observed river flooding (Brouwer, 2015). Only in the 1990s did policymakers begin to address the ecological impacts of engineering solutions and the vulnerabilities posed by climate change.

A turning point came in 1995 with the introduction of the *Room for the River* policy, which sought to restore floodplains and provide rivers with more space. This represented a significant shift toward adaptive water management, integrating ecological restoration with flood risk reduction (Ritzema & Van Loon-Steensma, 2018; Wolsink, 2006). Built on this policy, a general water management strategy was advocated by the Advisory Committee on Water Management in the 21st Century (CW21) when entering 2000s. The core principle of this strategy can be concluded as *Space-Water-Adjustment Management* Wolsink (2006). This principle recognizes the significance of connecting water management with spatial planning, and facilitating water retention near cities and rivers in a sustainable manner (Woltjer & Al, 2007). In 2001, guidelines were produced by CW21 and enacted in the new approach to ensure water safety and to mitigate other water related problems in the face of climate change. The guideline emphasized on the role of spatial adaptation, proposing zoning schemes on water systems in the context of urban development (Van Stokkom et al., 2005). Subsequently, a three-step-strategy was published facilitating spatial adaptation, which shares a similar understanding as sustainable storm water management. The steps suggested are : 1) retaining excess water on site by encouraging water infiltration and storage in the soil; 2) storing more water in the drainage by increasing its capacity; 3) discharge in a controlled manner (Ritzema & Van Loon-Steensma, 2018). The transition towards spatial adaptation has a profound influence on Dutch sustainable water management.

At national level, policy integration of spatial adaptation was led by the Delta Program. In 2007 the Dutch government commissioned an independent committee, Delta Committee, to advise on the long-term (2100–2200) flood protection and freshwater supply of the Netherlands (Bloemen et al., 2019).

This later led to the establishment of the national Delta Program, in which authorities from central to local levels jointly prepare key decisions, develop strategies and implement measures, in close cooperation with the public, private parties, stakeholders and knowledge institutions (Bloemen et al., 2019). The Delta Program 2018 (DP2018) is the first to comprise a proposal for the new Delta Plan on Spatial Adaptation (DPRA), which is focused on climate-proof and water-resilient spatial planning in the Netherlands, providing recommendations for climate adaptation and a general ambition for a climate-proof delta in 2050 (the National Delta Programme, 2017). To achieve this aim, a *Analysis, Ambition, Action* approach has developed. The AAA approach compromises: i) mapping out the vulnerabilities (Analysis); ii) subsequently formulating goals (Ambition, see Fig 2.1); iii) setting to work to render our living environment climate-proof and water-resilient (Action). The most urgent challenges against climate adaptation defined in the DPRA are waterlogging, heat stress and drought (the National Delta Programme, 2017). Additionally, the DPRA has provided input for the National Climate Adaptation Implementation Program (NUPKA), which was integrated in the National Climate Adaptation Strategy (NAS) in 2023. To date, the Delta Program 2025 (DP2025) has continued the work on DPRA, with a principle of Water and Soil ss Leading Factors. DP2025 has a focus on promoting stronger role in spatial adaptation by a design-oriented approach to learn from a range of possibilities for planning the Netherlands on spatial-resilient lines (the National Delta Programme, 2024).


**Figure 2.1:** Seven ambitions of water-resilient and climate-proof spatial planning in the Netherlands, adopted from the National Delta Programme (2017)

### 2.2.2. Management Structure

The Netherlands is a decentralized unitary state where different governmental levels share responsibilities for spatial planning and flood risk management (Dai et al., 2018). The institutional structure of water management in the Netherlands is considered to be multi-layered, with various parties engaging (see Figure 2.2)

At national level, Ministry of Infrastructure and Water Management (MIWM) are responsible for water-related policy making, and Rijkswaterstaat (RWS) is responsible for the maintenance and operation of main water systems (seam rivers and large lakes) at national level (Pot et al., 2024). The provinces can be seen as a intermediate authority whose are responsible for groundwater regulation, and supervise waterboards (Brouwer, 2015).

When it comes to urban storm water management, municipalities and water boards are the two most related sectors. Municipalities are responsible for local spatial planning (e.g., water storage, blue-

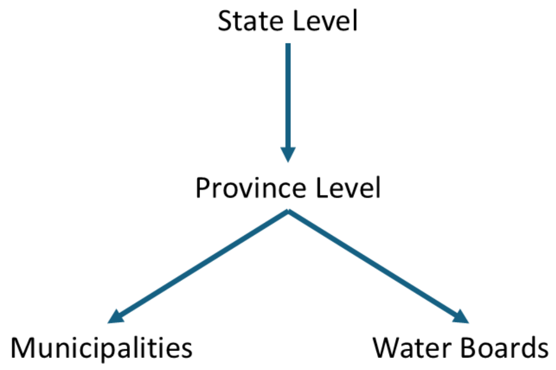


**Figure 2.2:** Multi-layered water management structure in the Netherlands, adopted from Brouwer (2015)

green infrastructure), urban drainage and storm water collection, as well as sewerage collection and wastewater transport. Water boards are unique Dutch water management organizations, who are in charge of the quantity and quality of surface water, the management of polder water levels and flood defenses, and wastewater treatment. The water boards are among the oldest local government bodies in the Netherlands and operate independently from the national government. In total, there are 21 waterboards throughout the Netherlands (Brouwer, 2015). Municipalities and regional water boards are in close relation. When municipalities initiate spatial planning projects, they are required to consult the water boards in the preparatory phase (Dai et al., 2018). Furthermore, municipalities have a large margin of choosing policy instruments, such as local regulations and permit systems, or more informal ones such as subsidies and facilitating participatory projects (Dai et al., 2018).

The role of the DPRA is independent from the above mentioned institutions. The DPRA provides recommendations for climate adaptation and a general ambition for a climate-proof Delta in 2050. However, the DPRA does not undertake climate adaptive projects itself. Municipalities are expected to integrate climate adaptation within their local policies and projects. The DPRA and Delta Commissioner mainly focus on efforts to facilitate cooperation and raising awareness (Pot et al., 2024).

## 2.3. Sustainable Storm Water Management in China：Sponge City

From 2008 to 2013, multiple organizations and specialized plans with regards to climate adaptation were issued by the Chinese central government, while little local responds were given and stalled at provincial level (Dąbrowski et al., 2021). Sponge City policy, which was initiated to address urgent need of mitigating urban waterlogging, is recognized as an innovation of China to shift to adaptive spatial planning (Meng et al., 2019).

In this section, the sponge city policy is briefly introduced, of which the implementation is investigated in later chapter. Section.2.3.1 describes the background of the policy, following by the core values and principles of sustainable storm water management rooted in this policy (section.2.3.2). Institutional organizations and structures related to sponge city is introduced in section.2.3.3.

### 2.3.1. Background of Sponge City

The rising urban floods across China can be attributed to three main factors, including climate change, urbanization and urban development patterns plus drainage systems development, which each plays a different role.

More frequent precipitation extremes induced by climate change are predicted to occur in the Pearl River Delta (PRD) area located in the southern China(M. Wang et al., 2023; X. Chen et al., 2021). While in the northern China, where the drier climate is witnessed since 1960 and a water shortage is predicted to be worsen due to climate change (Y. Jiang, 2015).

China has experienced rapid urbanization over the past few decades. Research shows that the mean urban built-up area in China has an increment rate of 380% over 26 years (1990 - 2016), especially the major urban agglomerations with high population densities and economy growth, such as the Yangtze River Delta, and Pearl River Delta (Z. Ren et al., 2022). This rapid expansion speed is much faster than the western country which would takes over near a century in France and Germany (Duan et al., 2016). China' s urban development, however, has historically been shaped within a political culture dominated by development and economic growth in the past, with less attention paid to ecosystem and environmental protection at system level integrated with development (Y. Jiang et al., 2018).

Most critically, China's urban development pattern was characterized by inadequate planning and unsustainable land conversion (Chan et al., 2021). This had resulted in rapidly increased imperious urban surfaces, accompanied by the loss of aquatic ecosystems (such as lakes and wetlands), and the fragmentation of natural water pathways across cities (Mao et al., 2018).

Since the last decades, the strategic role played by water in China's urbanization and the associated socio-economic development is more realized (Y. Jiang et al., 2018). The turning point came in 2011 when the protection of important ecological regions was put on the political agenda, proposing the concept of ecological redline (Mao et al., 2018). Subsequently, China formulated a series of reform plans, which can be seen as a shift towards sustainable development and eventually introduced the specific policy of urban storm water management: Sponge City Policy (Deng et al., 2023). Additionally, in the recently established Wetland Conservation Law, the natural function of urban wetland has been emphasized as means of sustainable storm water management.

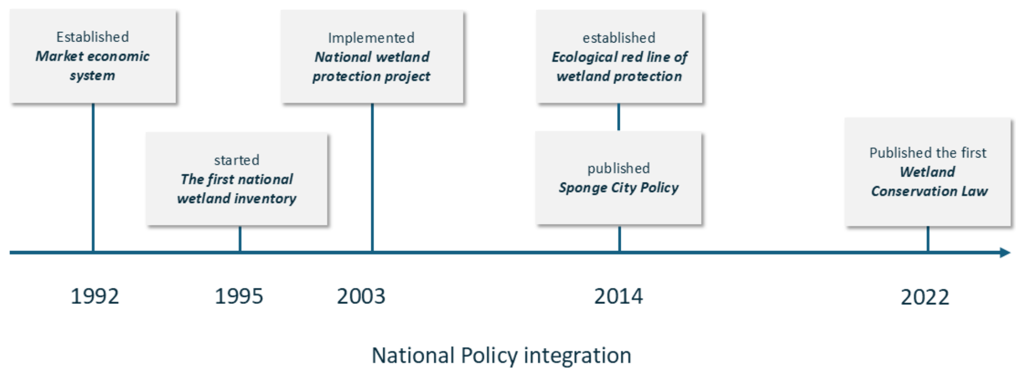


**Figure 2.3:** Evolution of the concept of sustainable development in China, modified based on Mao et al. (2018):

## 2.3.2. Principles of Sponge City

In 2014, the Ministry of Housing and Urban-Rural Development (MoHURD) together with the Ministry of Finance (MoF) and the Ministry of Water Re-sources (MWR) started the national Sponge City (SC) program. *Technical Guide for Sponge City Construction—Construction of Low Impact Development Rainwater System* was issued in the same year. The guide suggested the protection and conservation of the existing water bodies within the urban area, while integrating the SuDS methods. Three core concepts were suggested: natural storage, natural infiltration, natural purification in order to manage the precipitation on site. This storage-infiltration-purification principle primarily algins with the Dutch three-step strategy. By applying this principle in Sponge City, on-site storm water should be controlled in a sustainable manner (as illustrated in Figure.2.4).

The Sponge City must respect the Basic Laws, which are issued by the National People's Congress, providing the basis for action. These include the Construction Law , the Urban-Rural Planning Law and the Environmental Assessment Law. The initiative was introduced to promote a paradigm shift in urban

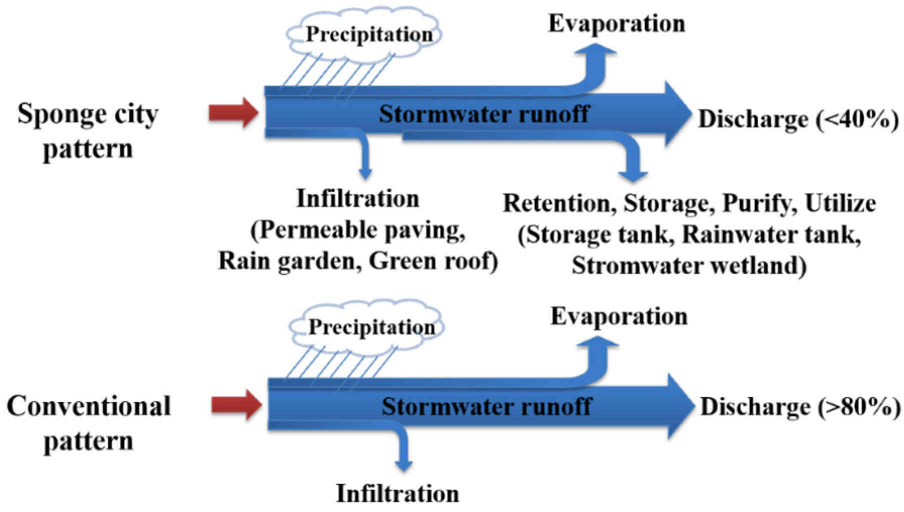


**Figure 2.4:** Concept of Sponge City, adopted from Lashford et al. (2019): In Sponge City regime, direct on-site storm water discharge is permitted durig no greater than 40% of the total annual rainfall events.

drainage and storm water management towards rainwater retention and sustainable use integrated in urban planning and development. It is recognized as a holistic approach that accommodates urbanization, promotes development sustainability, and simultaneously addresses the water and environmental challenges (Y. Jiang et al., 2018).

Similar to the western practices, the sponge city policy promoted the use of LID measures, which is refer to SuDS in this study, as major solutions comparing to the traditional pipe drainage to improve the sustainability in urban areas.

To date the Sponge City has been implemented at the national level in two batches. Sixteen cities were selected as pilot cities in the first batch in 2015, and 14 more were added in the second batch in 2016. The central government provides different amounts of start-up funding for these pilot cities, which are discussed in the following sections.

### 2.3.3. Management Structure

When is comes to Sponge City implementation, the governance mechanism is integrated into the political structure (see Figure. 2.5). Political system in China is organized according to a hierarchical structure, where local governments are supposed to implement decisions made by the central government. Any changes in local governments' priorities are usually a result of requirements instituted or incentives offered by the central government, whether by formal legislation, political speeches, or policy documents (Dai et al., 2020). Therefore, it is recognized as a multi-level governance, where the central government is considered as the policy-maker and supervisor, and local governments shoulder the responsibility of policy implementer and addressing its own water issues in Sponge City construction. The internal position of a government can be seen as a organizer, implementer, supervisor and service provider (Yawen et al., 2020). For instance, at central level, the MoHURD is primarily responsible for the organizing and supervising the construction, and progress evaluation, while the MoF is responsible for financial support (GOSC, 2015).

Comparing with the management structure in the Netherlands, the emphasis on water's impact on spatial development is less reflected in the Sponge City governance. This could result in challenges in planning design, cross-sectoral collaboration and concept understanding, as the governance requires engagement from all departments and from central to local level (H. Li et al., 2017; Yawen et al., 2020).

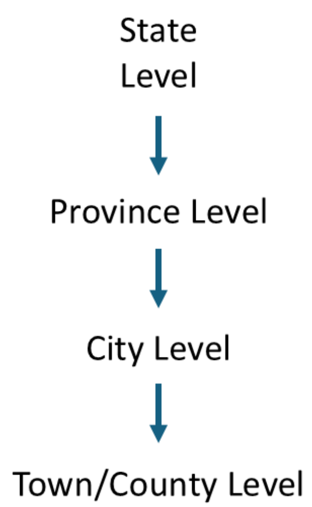


**Figure 2.5:** The political structure of Chinese governments

## 2.4. Implementation Strategies at Local Level

As aforementioned, both the Netherlands and China have integrated climate adaptation strategies in storm water management. The way of integration itself can be classify into different categories. In this section, two main type of integration is introduced.

It has been realized that implementing an adaptation strategy does not only includes the technical measures, but also the ways of implementation. When considering the climate change adaptation in the coastal area, Klein et al. (1999) reflected that technical options can only be implemented effectively in an appropriate economic, legal and institutional context. This rises a question of governance of climate change adaptation, which related to the means to align efforts to address climate change as a process (Broto, 2017b). The approaches of climate adaptation governance can be classified into two: dedicated approach and mainstreaming approach (see Table 2.1) (Uittenbroek et al., 2013).

**Table 2.1:** Different features of dedicated approach and mainstreaming approach, based on Uittenbroek et al. (2013)

| | **Dedicated Approach** | **Mainstreaming Approach** |
|---|---|---|
| **Focus** | Stand-alone adaptation policies/-plans | Integration into existing sectoral policies |
| **Policy Commitment** | Direct, explicit | Indirect, embedded within other policies |
| **Implication** | Fast/effective | Erratic/deliberate |
| **Resource Allocation** | Specific to adaptation | Shared with other sectoral objectives |

The key difference between the two approach is the relationship between the policy commitment and the municipal responses. As explained by Uittenbroek et al. (2013), a direct political commitment to climate adaptation implies a creation of a new policy domain, and the corresponding resource allocation. When apply a dedicate approach, climate adaptation is placed high in the agenda, and new organizational structure is created to facilitate the achievement of the commitment. The responses of the municipal are expected to be fast and effective (Uittenbroek, 2016). However, when it comes to the local scale, it is hard to ensure that all all cities or institutions have the political will and sufficient resources to develop and implement stand-alone adaptation strategies, especially when political agendas are already overloaded (Uittenbroek, 2016).

While a mainstreaming method, with indirect political commitment, focuses on a more pragmatic approach when integrating climate adaptation. This approach aims to integrate climate adaptation into existing policy domains such as spatial planning, water management, and public health. In this case, the institutional entrepreneurs are the main ice-breakers to break through the existing political structures to find synergies and to gather resources (Uittenbroek, 2016). As mainstreaming requires coordination across multiple sectors, it is difficult to make concrete actions from the indirect political commitments, which often leads to slow or inconsistent implementation and requires a more clear responsibility clarification (Uittenbroek, 2016).

Dedicated and mainstreaming approach are widely adopted in the policy integration within European countries (Reckien et al., 2019). As climate adaptation is a board topic related to storm water management, heat stress and energy efficiency, etc., the scope of climate adaptation plans can be further classified into horizontal (holistic sustainability or resilience) plans and vertical (specific sectoral) plans (Reckien et al., 2019). In the Netherlands, due to the national Delta Program, the climate adaptation is managed at the national level, where the municipalities do not play a major role in policy making, therefore mainstreaming is used as the main approach at city scale (Reckien et al., 2019).

## 2.5. Conclusion from the literature study

SuDS is the term referring to physical climate adaptation measures in this thesis report.

Sustainable storm water management in the two countries share similarities in principle transitions. The

Dutch approach to water management has undergone transformation, from human-controlled systems to adaptive, nature-inclusive systems. In the 21st century, climate change has been recognized as one of the drivers of developing a more integrated water management scheme. Drawing on past experiences, in which natural water systems were compromised to accommodate urban development, China has realized the need of sustainable storm water management in recent decades.

The Dutch three-step strategy (retention-storage-discharge) suggests a same core value of the Chinese natural infiltration-storage-purification principle embedded in Sponge City strategy. In 2018, adaptation of climate was first integrated into Dutch political agenda by the Delta Program, demonstrating a forward-thinking approach that emphasis on spatial adaptation. The climate adaptation scheme consists of waterlogging, heat stress and drought. Adaptation is advised by the Delta program, while it is more important for local governments to take their actions. In addition, water management governance in the Netherlands is multi-layered. The same structure applies to storm water management, in which local municipalities and water boards work in close relation. In spatial adaption, local municipalities are responsible for making plans and regulations. Therefore, climate adaptation is primarily subjected to local factors.

In 2014, Sponge City policy was established as a multi-objective policy to address with urban water issues. Climate Change has been recognized as one of the cause of waterlogging. A quantifiable goal was published by the central government, requiring local adaptation implementations. Water governance system in China is integrated into its political structure, which suggests less fragmented power distributions comparing to the Netherlands.

Climate adaptation is executed and presented at local level, which requires integration in local strategies. Dedicated and mainstreaming approach are the two widely applied strategy. The key difference between the two is whether a new policy domain is created. Dedicate approach generates stand-alone focus, following by specific resource allocations, which could add pressure to local actors. While mainstreaming approach aims to integrate climate adaptation into existing domain, encouraging cooperation and mutual understanding, while could constrained in adaptation speed and effectiveness.

# 3
# Methodology

In this chapter, the research design and methodology are elaborated, which consist of the chosen methods and how they are executed.

## 3.1. Research Design

The main focus of this study is to understand the policy interpretation and implementation, namely, how a policy is turned in ground practice measures from the top design. Therefore, a qualitative study approach is applied in this research. A qualitative research approach prioritize understanding phenomena of interest through linguistic data rather than numerical analysis, covering a wide range of interpretive techniques (Elliott & Timulak, 2005; Tisdell et al., 2025). The research is designed to be exploratory and explanatory, investigating the local considerations and ground practices of climate resilient projects with SuDS, which implies finding a description, understanding, and interpretation of the findings related to the research objective. The design of the research is illustrated in Fig.3.1.

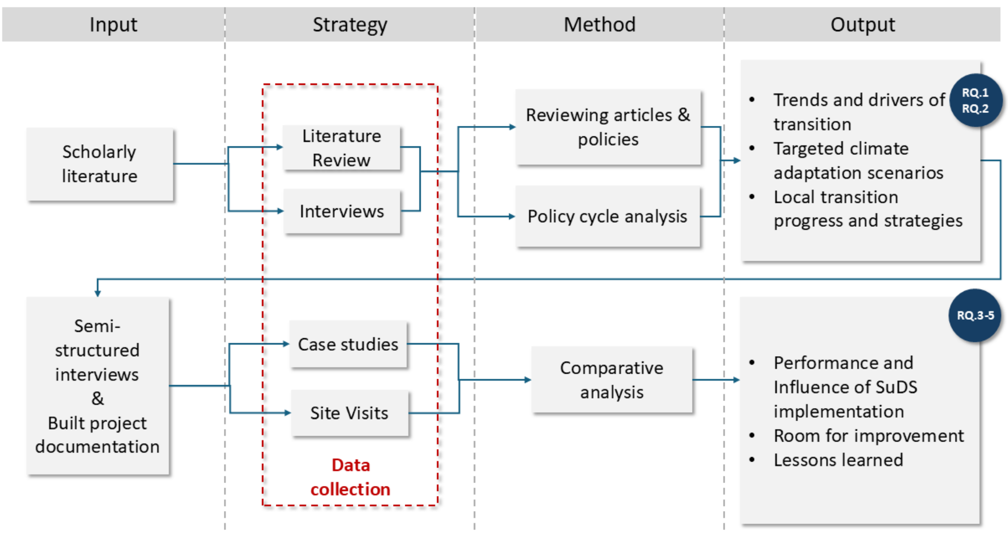


**Figure 3.1:** Research design

The research can be divided into two phases. The first phase consists of study in China, with the objective of answering research question 1 and 2. A combination of literature review and semi-structured interviews is utilized as a data collection strategy to examine the local adaptation strategies implementation in China and the Netherlands. To facilitate understanding on local Sponge City interpretation, a method of analyzing the policy cycle in China is applied. In the second phase of the study, site visits were performed to investigate the implemented SuDS driven by local adaptation strategies. The study employs a comparative analysis with the objective of answering research question 3 to 5.

### 3.1.1. Case Study Site Selection

To serve the purpose of this research, the study sites are selected to investigate:

- The local implementation strategies of Sponge City (SC) policy in China.
- The local implementations of SuDS in a specific project led by SC policy.
- The climate adaptation and water resilient strategies issued in a Dutch city.
- The local implementations of SuDS in a specific project in a Dutch city.

Considering the municipal level of China (see Chapter 2), local implementation is investigated at city and lower level. The local case study sites are selected to assess the SuDS performance and to compare with the case in the Netherlands. Therefore, study site selection includes two level, city level and neighborhood level.

For further comparison of the two case study, the selection of the study sites should fulfill the following requirements:

- At city level, the two study sites have issued climate adaptation strategies.
- At neighborhood level, the two case study sites should have SuDS projects implemented.
- Professionals in urban water and the related fields will be willing to participate in the research.

In this study, the city of Guangzhou and the city of Amsterdam are selected as the grand level study site of China and the Netherlands respectively. The local characteristics of the two cities are listed in Table.3.1 (KNMI, 2024;Guangzhou Meteorological Observatory, 2024;Guangzhou Municipal People's Government, 2024;IWA, 2016).

**Table 3.1:** Study site characteristics of Guangzhou and Amsterdam

| | **Guangzhou** | **Amsterdam** |
|---|---|---|
| **Location** | Southern China, Pearl River Delta | North Holland, Dutch Delta (IJ Bay) |
| **Area ($km^2$)** | 7343 | 220 |
| **Population (million)** | 18.9 | 0.9 |
| **Elevation** | $\sim$11 m (above sea level) | $\sim$−2 m (below sea level) |
| **2024 Annual Rainfall (mm)** | 2536.7 | 1043.1 |
| **Urban Water Systems** | Pearl River, urban water channels | Extensive canal network, polder systems |

## 3.2. Data Collection

### 3.2.1. Interview

Interview is used as a common method to gather qualitative data. Semi-structured interviews approach is applied in this study. This approach is seen as the preferred data collection method to better understand the participant's unique perspective of the phenomenon (Adeoye-Olatunde & Olenik, 2021). The interview should be continued in an open conversation, which allows the researcher to explore ideas that may come up in the course of the interview (Adeoye-Olatunde & Olenik, 2021).

The goals of the interview are to:

- To have a better understanding of the local policy translation;

- To identify the vagueness lies in the policy and the potential problems leads to the ground practices;
- To find out experts' opinions on the implementation of SuDS require by the policy;
- To collect general experience from experts of working with SUDS and the potential of future improvement;

The execution of the semi-structured interview was executed following the guide by Kallio et al. (2016). The interview questions were formulated based on the literature review, covering the research questions. Before each interview, research questions were sent to the interviewee and discussed in the interview. The first three interview in China were served as the pilot testing to examine the relativeness content-wises and to refine the detail questions. Interview invitation was sent to a Dutch expert on local climate adaptation and the corresponding working team, while no confirmation on participation was given.

The selection of the participated interviewee used a snow-ball method to get reach to the experts in specific fields related to the topic. In this research, experts in Amsterdam were invited for the interviews, while no confirmation was given. Therefore, interview data was gathered only for the Chinese part of study. The list of interviewee is shown in Table.3.2. As shown in the table, the backgrounds of the interviewee cover the full chain of the project implementation, including the top designers (Urban planning), project owners (Urban Development), and project designers (Environmental Engineering /Urban Drainage Engineering). The interviews were semi-structured, face-to-face interviews, allowing the interviewee to provided information in a guided manner. Interviewee 5 to 7 were interviewed as a group.

**Table 3.2:** Interviewee list of the study in China

| Interviewee | Type of interview | Fields | Role |
|---|---|---|---|
| Interviewee 1 | Individual | Urban Planning | University Professor |
| Interviewee 2 | Individual | Urban Planning | University Professor assistant |
| Interviewee 3 | Individual | Environmental Engineering | Senior Engineer |
| Interviewee 4 | Individual | Urban Drainage Engineering | Senior Engineer |
| Interviewee 5 | Group | Urban Development | Senior Engineer |
| Interviewee 6 | | | Senior Engineer |
| Interviewee 7 | | | Senior Engineer |

### 3.2.2. Site Visit

The goal of the site visits is to investigate the performance of the SuDS projects. As the projects may be constructed due to top-down or bottom-up requirements, it is important to examine the situation of these measures. The site visits data is later used in the comparative study.

Site visits are planned, aiming to provide observational data about the study areas, focusing on:

- The link between local policy and the resulting SuDS projects
- The maintenance and operational conditions of existing SuDS.

Quantitative data will be collected from the documentation of built projects, including:

- Initial design documents for SuDS, with a focus on volume-based control capacity.
- Reflective reports, literature or online news evaluating the flood control performance of built projects.

### 3.2.3. Data Validation

All the site visits were supervised with an experts for on-site questions. In Chinese study, project documentations were used as a source to help improve the understanding of the projects.

## 3.3. Data Analysis

### 3.3.1. Policy Cycle Analysis

To understand how the policy is translated into implemented projects and the corresponding selections of the measures, the question is in close relation to the science of the policy. The policy-science approach is first given voice in the literature by Lasswell and Lerner (1951). The orientation was a call for a linear orientation in in policy formulation, staring with the identifying the problems and clarifying the goals. Moreover, Lasswell and Lerner (1951) explained the importance in of the modeling of policy, and first introduced a linear policy process model in 1956. The model itself has been highly successful as a fundamental framework for policy studies, while it is limited in the descriptive and analytical analysis of the process (Jann & Wegrich, 2017). The framework of policy cycle is developed to close the loop of policy-making, taking into account the feedback between different elements of policy process (Jann & Wegrich, 2017). The stages of policy cycle includes:

- Agenda-setting: problem recognition and issue selection;
- Policy formulation and decision-making;
- Implementation;
- Evaluation and termination.

While the proposed frameworks in the studies are slight different in names and order of stages, the fundamental elements are retained: staged-feedback cycle architecture and problem-solving focus (Howlett et al., 1995). The policy cycle framework has been adopted by many researchers (Bridgman and Davis, 2003; Howard, 2005 ).

Studies on Sponge City policy have been widely discussed, while a clear framework is limited suggested for policy analysis (Griffiths et al., 2020). A double-wheel framework of policy cycle was introduce in the work of X. Liang et al. (2020). Considering the Chinese policy context, the policy cycle has been tailored into two individual cycles: central government and local government (see Fig.3.2).

As aforementioned (see Chapter 2), a top-down mechanisms is applied to the Sponge City policy implementation. The central government usually decentralize parts of decision-making power to the local government to make policies better adapted to the local situation. Therefore, the problem definition process occurs at the local government level in fact, and policy adjustment is allowed and encouraged by the central government. Consequently, the policy cycle of the central government consists of three parts (problem identification, policy formulation and evaluation), while the policy cycle of the local government focuses on problem identification and policy adjustment, policy implementation and policy evaluation.

The communication between the two cycles occurs through the process of *policy order sending* and *feedback returning*. After the central government completes policy formulation, it will send a policy order to the local government. Then the local government starts the policy adjustment in terms of its own situation. After project implementation and evaluation, the local government returns its feedback to the central government. Subsequently, the central government makes an evaluation according to the feedback and the outcomes of the policy.

In this study, the local government refer to provincial level, city level and district level. A list of the study objectives is presented in Table.3.3. While in Sponge City Policy implementation, the province government plays a supervisory role rather than a policy adjustment role (see Chapter 4). It is the city level government that plays an important role in policy adjustment and decentralize the work to district level governments. Consequently, the local policy cycle analysis is conducted in manner that combines the workflow within local level governments.

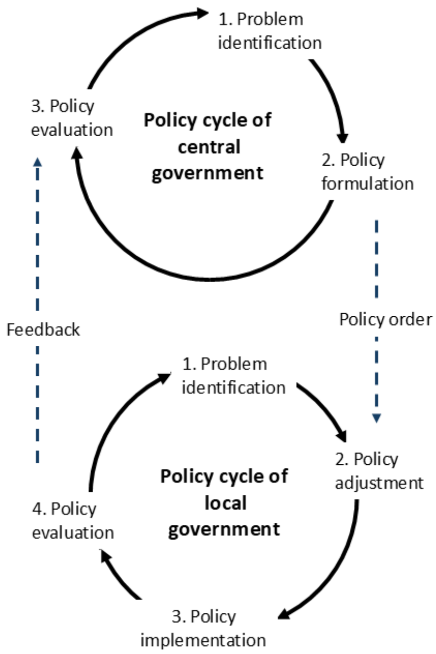


**Figure 3.2:** A double wheel model of the policy cycle, adopted from X. Liang et al. (2020).

**Table 3.3:** Objective Lists of Policy Cycle Analysis

| **Central Level** | **Local Level** | | |
|---|---|---|---|
| | Province | City | District |
| China | Guangdong | Guangzhou | Districts of Guangzhou |

### 3.3.2. Comparative Analysis Framework

As policy cycle analysis is planned to facilitate understanding in the Chinese content, a comparative framework is required for international study. In order to answer research question 3 and 5, a comparative analysis is planned to gain more insight into the local practices of the two study areas under different transition process.

A model suggested by Torgersen et al. (2014) for comparison is presented in Figure 3.3, which illustrates four factors influencing the implementation of Sustainable Drainage Systems (SuDS).

Goals analyzed in this study are drawn from policy documents, which suggest the targeted futures of the two study areas. Specific indicators, such as climate scenarios or the runoff reduction rates outlined in policy documents, can be incorporated to assess adaptation progress toward these objectives. This comparison provides essential background knowledge and helps extract lessons learned that could potentially benefit both contexts.

Conditions refer to the state of existing technical infrastructures, including both SuDS and conventional pipe drainage systems, within the study area, as well as the implications of their coexistence. Key indicators to evaluate the effectiveness of these conditions include the runoff reduction capacity (rate) and the frequency of flooding occurrences.

Instruments represent the factors that can be leveraged to modify existing conditions. These may include financial support allocated by the local government, the availability of technical expertise, and the willingness to prioritize SuDS implementation over conventional drainage systems.

Methods refer to the solutions for mitigating urban flooding and achieving the desired goals. These solutions are shaped by the choices and strategies adopted to improve the system's condition. For example, the percentage of different types of SuDS implemented can serve as a measurable indicator of progress.

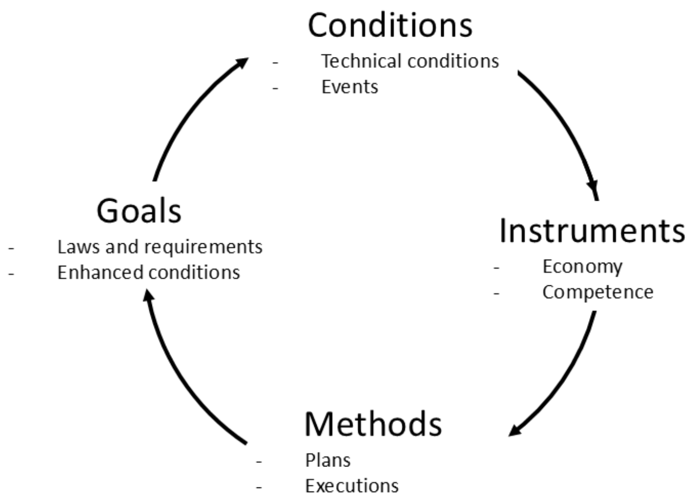


**Figure 3.3:** A model used for comparing the storm water management, focusing on factors affecting flood and SuDS implementation, adopted from Torgersen et al. (2014)

# 4

# Policy Cycle Analysis of Sponge City

## 4.1. Policy cycle at central level

In 2014, the Ministry of Housing and Urban-Rural Development (MoHURD) together with the Ministry of Finance (MoF) and the Ministry of Water Re- sources (WMR) started the National Sponge City Program (SCP), hereby refer to as Sponge City policy. The time line of the policy cycle is summarized and illustrated in Figure 4.1.

The scope of Sponge City policy can be concluded as *urban flooding control, water environment improvement, water resources conservation, and water ecology rehabilitation* (D. Yin et al., 2021). As aforementioned in section.2.3.2, *natural storage, natural infiltration and natural purification* is recognized as the principle of addressing multiple water-related problems within the scope of the policy.

The first implementation phase was from 2015 to 2020, with detail guidelines, performance indicators and evaluation standards issued. In year 2015, three staged-goals of SC policy were established (Ministry of Housing and Urban-Rural Development (MOHURD), 2014) :

- Short-term (2015—2018): Introduction of Sponge City construction and development concepts, and promotion of small-scale urban pilot projects.
- Medium-term (2018—2020): Establishment of Sponge City standards, management systems, and monitoring and early warning systems by 2020; with greater than 20% of built-up areas able to manage 70% of the annual precipitation on-site.
- Long-term (2020—2030): Complete integration of the Sponge City concept in urban development, planning and construction management by 2030; with greater than 80% built-up areas able to manage 70% of the annual precipitation on-site.

The central policy cycle of Sponge City policy is illustrated in Figure.4.1 The first evaluation window is in year 2020. Year 2021 to 2030 can be classified as the second implementation phase, following by the finally assessment in 2030. The ultimate goal is used as the only assessment standard, with detail criteria specified in the construction standard, issued in year 2018, being applied to the built-up area. After the first evaluation, the concept of Sponge City construction was further clarified in the policy documents in 2021 and 2022.

In the following part, problem identification and implementation plans of the first cycle of Sponge City is explained in section 4.1.1, policy evaluation is explained in section 4.1.2, clarification and new actions of Sponge City in the second cycle is explained in section 4.1.3.

### 4.1.1. Top design of the central policy

*Technical guide for Sponge City Construction - Construction of Low Impact Development Rainwater System* (hereafter "the Technical Guide" ) was issued in 2014 as the fundamental guideline of Sponge City implementation (Ministry of Housing and Urban-Rural Development, 2014). In the following section,

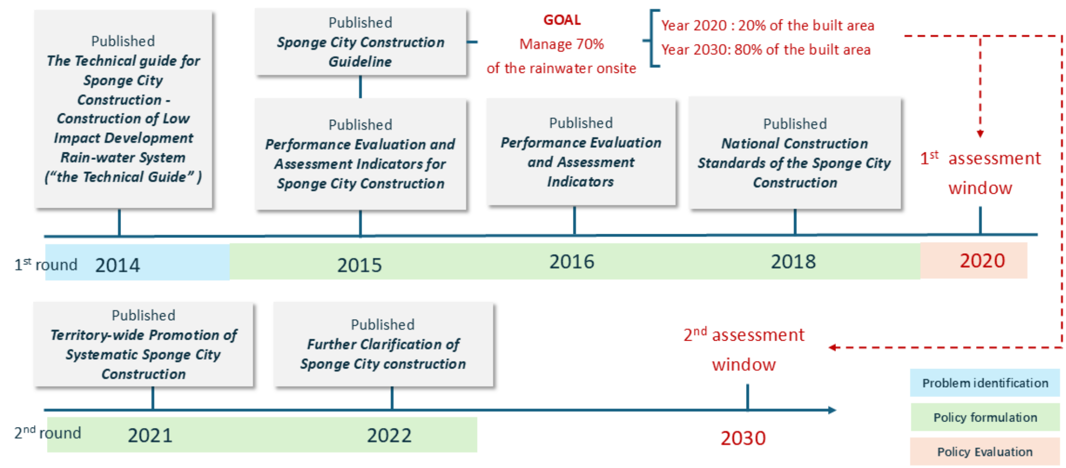


**Figure 4.1:** The timeline of Sponge City Policy cycle

the Technical Guide is reviewed to provided a better understanding of Sponge City design at central level.

While sharing the same concept with Low Impact Development (LID), the Technical Guide had specified the concept of Sponge City, which emphasize the application of coupled the LID measures and the grey infrastructures. As aforementioned in Chapter 2, LID measures (refers to SuDS in the following study) are small-scale decentralized control measures to maintain the hydrologic regime as pre-development regime. As the urban areas in China is heavily developed, SuDS are limited to achieve the goal of replicating the pre-development hydrologic regime. In the Chinese content, the concept of Low Impact Development has been extended to include control measures at different scales at the source, mid-way and end. As shown in Figure. 4.2. The Design of Sponge City aims to addressed water-related problems in urban areas through the core principle of natural infiltration, natural purification and natural storage. The corresponding 7 methods were suggested: *Infiltration, Retention, Purification, Storage, Drainage and Utilization*. Assets and systems equipped with these methods are categorized into 3 systems, which response to the aforementioned source, midway and end control. Source control systems and urban storm water pipe and channel systems are the two broadly discussed combination of solutions (Qiao et al., 2020). Excess storm water Runoff drainage systems can refer to connected receiving water bodies or environment with storage capacity , with the aim to address runoffs exceeding the pipe drainage capacity.

To facilitate the building of Sponge City , general planning control objectives were introduced in the Technical Guide. These objectives include volume control of annual runoff ratio (VCRa), peak runoff control, runoff pollution control and storm water resource utilization (as shown in Figure 4.3). Local authorities are encouraged to select one or more of these goals as the planning control objectives, considering the local status of water environment and hydro-geological conditions. The central policy recognized that total runoff control plays a crucial role, as most of the other objectives can be achieved through the total runoff control. Therefore it is selected as the primary planning and control objective.

Total runoff control aims to manage the runoffs on-site through natural storage and infiltration. It is considered that under the Sponge City regime, the total annual runoff leaving the site should be lower than 40%, meaning a runoff control rate of 60%. Considering the different climate and hydro geological conditions across China, five zones of runoff control were determined (see Figure.4.5).

The determination of the design rainfall value corresponding to the total annual urban runoff control rate

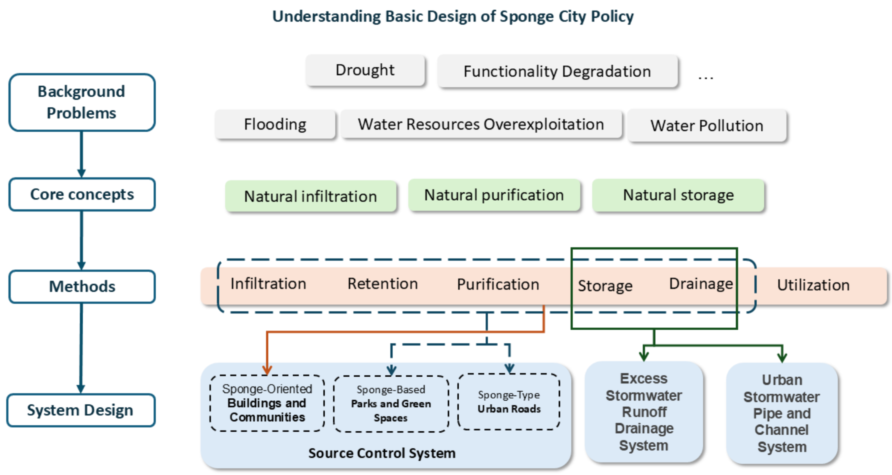


**Figure 4.2:** Basic Design of Sponge City :base on (Ministry of Housing and Urban-Rural Development, 2014)

was obtained by statistical methods. Daily rainfall data for at least 30 years was selected with the aim to reflect long-term climate pattern. The data was validated by deducting a rainfall amount of rainfall events less than or equal to 2 mm. The calculated volume control ratio is illustrate as Figure 4.4. By sorting the events, the design rainfall of not generating surface runoffs is algin with the percentage of daily rainfall lower than this event, which can be referred as the VCRa.

The statistical analysis of daily rainfall from 1983 to 2012 in nearly 200 cities in China has obtained the relationship between the total annual runoff control rate and its corresponding design rainfall value for each city. Based on the above data analysis, this guideline roughly divided China's mainland into five zones, and provided the minimum and maximum limit values of the total annual runoff control rate $\alpha$in each zone, namely Zone I (85% $\leq \alpha \leq$ 90%), Zone II (80% $\leq \alpha \leq$ 85%), Zone III (75% $\leq \alpha \leq$ 85%), Zone IV (70% $\leq \alpha \leq$ 85%), Zone V (60% $\leq \alpha \leq$ 85%).

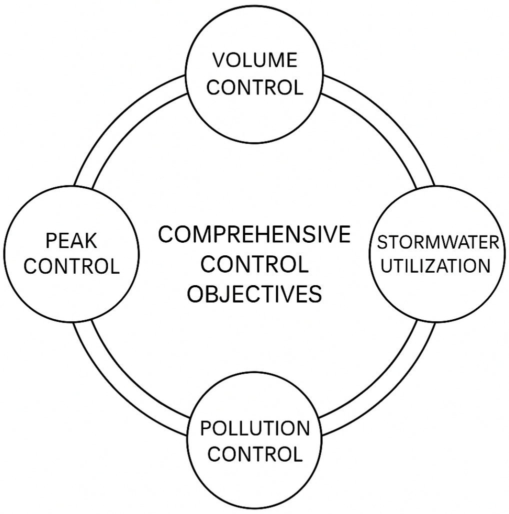


**Figure 4.3:** The planning objectives of Sponge City construction, adopted from Ministry of Housing and Urban-Rural Development (2014)

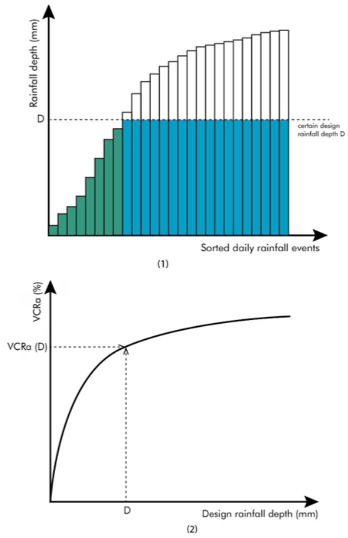


**Figure 4.4:** Illustration of Volume control ratio of annual rainfall, adopted from S. Chen (2020a)


**Figure 4.5:** Zoning map of total annual runoff control rates for the continental region of China, adopted from Ministry of Housing and Urban-Rural Development (2014). Light blue:Zone I, light yellow: Zone II, purple: Zone III, green: Zone IV, orange: Zone V.

### 4.1.2. Evaluation at central level

The evaluation system is the central government's main mechanism to ensure the implementation of the Sponge City policy at the local level. The five dimensions of performance indicators (see Table A.1) are the fundamental aspects that the evaluation mechanism has built on, which includes: 1) Water Ecology; 2) Water Environment; 3) Water Resource; 4) Water Safety; 5) System Construction and implementation. The dimensions are closely aligned with the five themes of Sponge City planning (D. Yin et al., 2021). The indicators are either compulsory or recommended depending on the local situations (X. Liang et al., 2020). While in the evaluation process, the evaluation standards published in 2018 are referred as the only evaluation standard (see Table 4.1) . These new standards allowed MOHURD to address issues omitted from the earlier 2014 guidance, which only emphasize on runoff control (Griffiths et al., 2020). While comparing to the performance indicators, the evaluation standards yield a deeper focus on sustainable storm water management and ecology conservation.

**Table 4.1:** Performance Evaluation and Assessment Method(2018)

| No. | Assessment Standards |
|---|---|
| 1 | Runoff Control Ratio |
| 2 | Effectiveness of implementation of source reduction project |
| 3 | Urban Flooding Control |
| 4 | Water Quality of Urban water Bodies |
| 5 | Protection of ecological shorelines |
| 6 | Groundwater Depth |
| 7 | Mitigation of Urban Heat Island Effect |

In 2015 and 2016, 30 pilot cities were selected, considering their different natural and social conditions (with the average construction area of 31.3 $km^2$ for each city), for the Sponge City construction exploration, and all of them have completed performance assessment in the end of 2019 (D. Yin et al., 2022). Before the evaluation at central government, a pilot city should first apply a self-assessment based on the compulsory requirements. These assessment results need to be submitted to the provincial government. Second, the provincial government or its trusted third party reviews the results and draws up assessment reports, submitting them together with the city's self-assessment reports to the Ministry of Housing and Urban-Rural Development (MHURD). Third, the MHURD evaluates the submissions selectively. A city that fails the evaluation will receive a Notice of Criticism (depending on the performance) from the MHURD, and the provincial government leadership will also be held accountable. Although the evaluation policy does not prescribe specific consequences, a Notice of Criticism is usually considered a negative result (Dai et al., 2020).

### 4.1.3. Sponge City in the Long term: Demonstration

Although 30 national pilot cities have completed sponge city construction and corresponding assessment, it does not mean that the construction is coming to an end (D. Yin et al., 2021). In 2021, China began to systematically promote the sponge city demonstration on a national scale (Ministry of Finance, 2021). Up to 2023, 60 demonstration cities have been selected and supported by the Ministry of Finance in 3 batches (Ministry of Finance of the People's Republic of China, 2023).

The nature of Sponge city has confined its capacity in dealing with light to moderate rainfall events(Ministry of Housing and Urban-Rural Development, 2014). In the global demonstration of the sponge city construction, the concept of Sponge City is again refined to emphasize on the systematic understanding of storm water management. According to the renewal concept of *source reduction, process control, and systematic remediation* (Ministry of Finance, 2021), Sponge City construction is planned systematically, and the 7 methods of *infiltration, detention, retention, purification, reuse and discharge* are continued to be used to achieve the goal of comprehensive (D. Yin et al., 2021) The demonstration yields the need of the city to develop technical road map for sponge city construction. The systematic demonstration is illustrated in the work of D. Yin et al. (2021) and D. Yin et al. (2022). Comparing the widely constructed

SuDS projects in the pilot cities, The demonstration phase emphasize the importance to see urban storm water management as a whole with the integration of the Sponge City concept.

## 4.2. Policy cycle at local level

Guided by the central government's policy, construction of Sponge City had been cascaded down to local level, with tailored interpretation and implementation procedure. In Sponge City implementation, the central policy is cascaded down to the provincial governments, who then supervise the municipal governments to ensure the implementation of corresponding actions (Interviewee 3). Similar phenomenon can be observed throughout China, wherein the municipal governments play a pivotal role in the local implementation and policy adjustment processes (S. Chen, 2020b).

Local understanding of Sponge City can be found in the Guangzhou Municipal Sponge City Plan (2016-2030). In the follow sections, analysis of the plan is provided to give insights into local implementation framework, applying the policy cycle analysis aforementioned in Chap.3.

### 4.2.1. Problem identification at local level

Guangzhou is a city with abundant water networks, which refer to 河涌 (He Chong) water systems. 河 (He) indicates large river in Chinese, while 涌 (Chong) indicates smaller (natural or artificial) urban water channels, which makes up the main water systems within the city. There are 580 urban river and water channels locates in urban central area, with length over 1500 km (Y. Liang & Xiao, 2024). Most of the water systems in central areas are semi-tidal influenced.

In 2016, Guangzhou conducted assessments of local challenges aligned with the five water-related themes outlined in the central Sponge City policy (see section.4.1.2). As shown in Figure.4.6, the left column presented the following themes: Water safety, Water Environment, Water Resource, Water Ecology and Water Culture. In total, 7 problems were determined. Causes of the problems are classified into 4 categories, with numbered detailed causes. The detailed causes are linked to the problems.

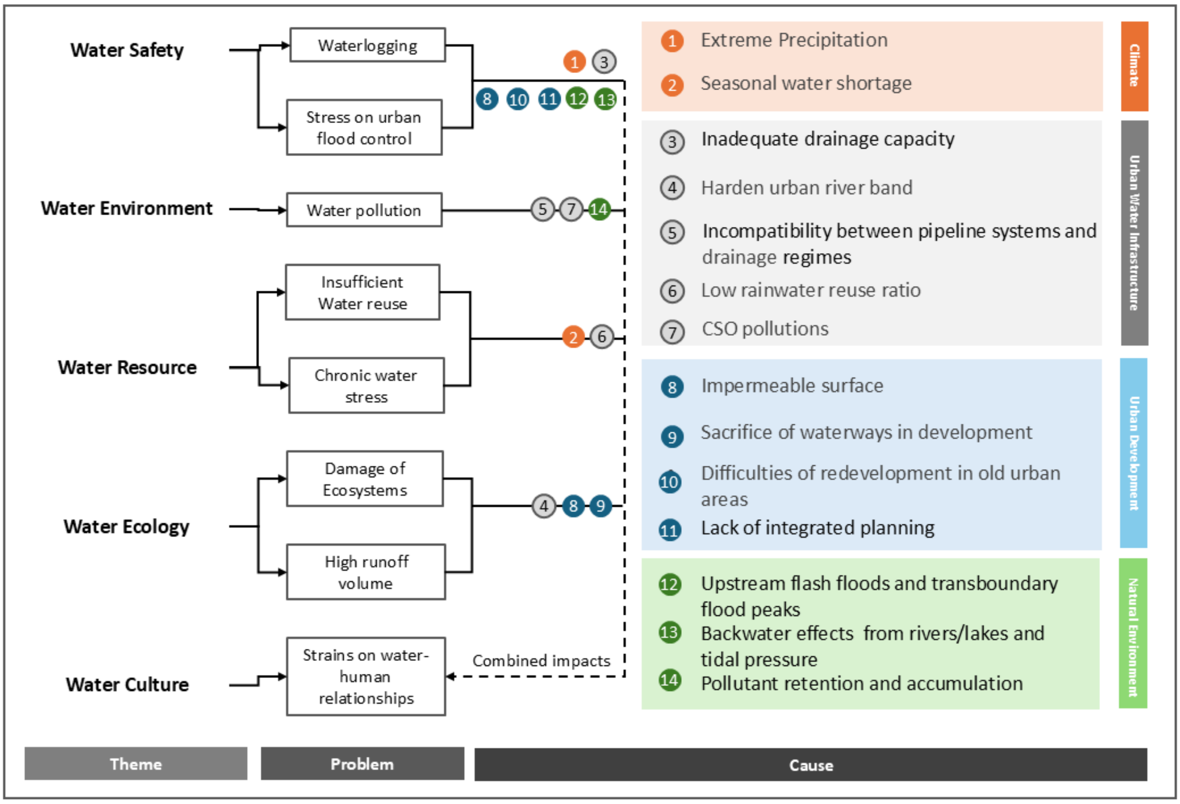


**Figure 4.6:** Problem identification at local level: Guangzhou(2016-2030)

#### Water Safety

Water Safety is the major theme of Sponge City policy and discussed the most into detailed in the local plan. Waterlogging and the stress on urban flood control were identified as the major problems. Guangzhou has established a list of waterlogging black-points, listing the pluvial flood-prone locations and the analyzed causes.

Guangzhou features a subtropical maritime monsoon climate, with abundant rainfall for most of the year and a distinct wet season. However, precipitation in Guangzhou is highly variable in both temporal and spatial distribution, with over 80% of annual rainfall concentrated during the flood season. Climate change has resulted in a reduction of medium level of rain event, while extreme precipitation (50 250 mm/day) are frequently observed. Additionally, heavy downpours with short duration (≥ 20-30 mm/h) are observed to be more frequently happened (H. Yang et al., 2021). Though not stated clearly in the plan, climate change can put more stress on regional water hydrology, resulting in greater stress on up and downstream flooding impacts.

Guangzhou locates at the Pearl River Delta, where largely impacted by the flash floods upstream and backwater impacts and tidal pressure downstream. It is climate change have been putting pressure on these effects.

The inadequate capacity of drainage systems was the major issue in central district areas, with less than 50% of the pipe systems capable to address rain event with a return period of 3 years , only 80% of the systems can deal with event with annual recurrence (Guangzhou Municipal People's Government, 2017a). The most recently targeted improvements on rain water drainage was reflected in the specialized plan of *Comprehensive Drainage (Storm water) and Flood Control Plan for Guangzhou (2022 — 2035)* (Guangzhou Water Affairs Bureau, 2024a).

#### Water Environment

Urban water systems pollution has been a serious problem since 1990s (S. Li & Yuan, 2016). This was caused by the pollutants retardation due to tidal influences, and drainage inadequate. Water pollution problems reflected a need in improving drainage scheme coverage and the capacity. The need of water pollution treatment was recognized in the political announcement of *Implementation Plan for the Campaign to Remediate Black and Odorous Water Bodies in Guangzhou* (Guangzhou Water Affairs Bureau, 2018), which had driven the release of specialized planning: *Three-Year Action Program for Improving Urban Sewage Treatment in Guangzhou (2019—2021)* (Guangzhou Municipal People's Government, 2019b).

#### Water Resource

Guangzhou faces chronic water stress due to time and spatially uneven distribution of rainfall, which was accelerated by the water pollution and growing water gap due to urbanization. Major water supply in Guangzhou is from surface water and ground water, with the northern mountainous area being the crucial conservation area. Water reuse systems are not well-established in Guangzhou, which indicates a potential in construction rainwater reuse systems.

#### Water Ecology

Water ecosystems fall victim of the urban development. The conceal ground has resulted in an increase of impervious surface in urban area, which leads to greater runoff volume and contamination into the urban water systems. Additionally, large proportion of natural urban water networks (Chong), which can be recognized as historical water-adaptive landscapes, were buried, covered or channelized to give ways to urban development. This had caused a passive decrease of the climate resilience ability.

#### Water Culture

The strains on water-human relationships can be seen as a combined impacts of the above-mentioned aspects, which calls on the need of transition towards a human-water harmony future.

### 4.2.2. Policy adjustment at municipal level

Policy adjustment at municipal includes establishment of standards and guidelines, and the indicator systems of Sponge City construction.

### Standards and guidelines

In order to achieve the objectives and requirements required by the national guidelines, the municipality of Guangzhou has issued the local guidelines and plannings in relation to sponge city construction. The policies were driven by the problems determined locally, and adopted for the newly-developed areas and the re-construction projects. As such, this represented a major step towards city-scale planning and integration of Sponge City objectives. Subsequent municipal guidance documentations were planned to facilitate future developments within the city. Table 4.2 summarized the interpretation of the national standards at local level.

Among which, the *Guangzhou Sponge City Special Planning (2016–2030)* can be seen as the fundamental guidelines of the local implementation of sponge city (see section 4.2.3).

| **Municipal Standards and Guidelines** | **Specification** | **Citation** |
|---|---|---|
| Storm water Runoff Control Measures for Guangzhou Construction Projects (September 2014) | • Integrate the principles of source control and low-impact development<br>• Reduce impermeable area<br>• Improve rainwater storage and retention capacity<br>• Hardened Area Rule: Hardened Area = Total Construction Area – Green Space (includes green roofs) – Permeable Pavement<br>• For projects ≥ 10,000 $m^2$ Hardened Area: provide ≥ 500 $m^3$ of rainwater storage per 10,000 $m^2$ | (Guangzhou Municipal People's Government, 2014) |
| Implementation Opinions on Innovating Investment and Financing Mechanisms in Key Areas to Encourage Social Investment (February 2017) | • Attract investment for Sponge City construction<br>• Encourage enterprise investment and government subsidies for operation | (Guangzhou Municipal People's Government, 2017b) |
| Guangzhou Sponge City Special Planning (2016–2030), June 2017 | Retain 70% of rainfall locally<br>• By 2020: 20% of built-up areas compliant<br>• By 2030: 80% of built-up areas compliant<br>Four Aspects:<br>• Water Safety: 1-in-50-year storm protection<br>• Water Environment: Reduce pollution, improve sewage<br>• Water Ecology: Restore natural systems<br>• Water Resources: Reuse rainwater and wastewater | (Guangzhou Municipal People's Government, 2017a) |

*Continued on next page*

| **Municipal Standards and Guidelines** | **Specification** | **Citation** |
|---|---|---|
| Three-Year Action Program for Improving Urban Sewage Treatment in Guangzhou (2019–2021), September 2019 | • Enhance wastewater treatment capacity<br>• Centralized collection rate ≥ 80%<br>• Enhance drainage management | (Guangzhou Municipal People's Government, 2019b) |
| Classification Guidelines for Sponge City Construction Control Indicators for Guangzhou Construction Projects (October, 2020) | Control Framework for 18 Project Categories:<br>• Primary control indicator: Annual runoff control rate<br>• Secondary control indicators: Permeable pavement ratio; Storage volume per unit of impervious area; Wadi ratio | (Guangzhou Water Affair Breaue, 2020) |
| Guangzhou Sponge City Construction Management Measures (December 2020) | • Enforce requirements from planning to inspection<br>• Apply territorial jurisdiction, manage public/private projects separately<br>• Incorporate sponge development into River/Lake Chief assessment system | (Guangzhou Municipal People's Government, 2020) |
| Guangzhou Sponge City Special Planning (2021 – 2035), March 2025 | • By 2025: ≥ 45% built-up areas compliant<br>• By 2030: ≥ 80% built-up areas compliant<br>• To build healthy storm water management system | (Guangzhou Municipal People's Government, 2025) |
| Comprehensive Drainage (Stormwater) and Flood Control Plan for Guangzhou (2022 – 2035), March 2024 | • BY 2035: establish a high-standard, multi-dimensional drainage and flood control system, encompassing green-grey-blue, and smart management infrastructure.<br>• Urban water logging standards: Design recurrence interval ≥ 100 years<br>• Urban drainage design standards (Existing area): ≥ 2-3 years recurrence interval<br>• Urban drainage design standards (New area): ≥ 5 years recurrence interval | (Guangzhou Water Affairs Bureau, 2024a) |

**Table 4.2:** Guangzhou Municipal Sponge City-Related Standards and Guidelines

#### Indicator system

To better facilitate the construction of Sponge City, the specialized plan developed an indicator system with the aim to address problem diagnosed locally. As shown in Table.4.3, the system consists of indicators within 4 themes, which aligned with the national indicators (Ministry of Housing and Urban-Rural Development, 2015) and local problems.

The indicator system suggests a highly criteria-oriented implementation manner in local implementation. In 2020, *Classification Guidelines for Sponge City Construction Control Indicators for Guangzhou Construction Projects* (Guangzhou Water Affair Breaue, 2020) was published. It is an instructive guideline based, which provided refined requirement of detail indicators, without changing the content, with regards to different construction project types.The guidelines follows a content-sensitive principle of ”Implement wherever feasible and maximize coverage” (Guangzhou Water Affair Breaue, 2020), suggesting to mainstreaming Sponge City Construction into all urban construction projects.

In the indicator system, Volume Control Ratio of annual rainfall (VCRa) is recognized as the primiary control indicator. Combing with the above mentioned related standards and guidelines, it becomes clear that some of the indicators are contributed by other projects apart from Sponge City construction. For example, the *ThreeYear Action Program for Improving Urban Sewage Treatment in Guangzhou (2019–2021)* issued projects within its own domain, which can largely address the Water Environment indicators (No.6-9). Therefore, the unique indicator which is encouraged by Sponge City policy is the SuDS implementation ratios (sub indicators of No.1).

| Theme | No. | General Indicator | Detail indicators | Type | |
|---|---|---|---|---|---|
| | | | | Constrained | Encouraged |
| Water Ecology | 1 | Volume Capture Ratio of annula rainfall (VCRa) | on-site VCRa | ✓ | |
| | | | Sunke green space ratio | | ✓ |
| | | | Greenroof ratio | | ✓ |
| | | | Permeable Pavement ratio | | ✓ |
| | | | Unit area storage ratio | | ✓ |
| | 2 | Restoration Ratio of ecological shorelines (RRe) | RRe within planned area | ✓ | |
| | 3 | Coverage Ratio of water body (CRw) | CRw within planned area | ✓ | |
| | 4 | Coverage Ratio of forest (CRf) | CRf within planned area | ✓ | |
| | 5 | Urban Heat Island Effect | \ | | ✓ |
| Water Environment | 6 | Water environment quality | On-site water environment quality | ✓ | |
| | 7 | Municipal Wastewater treatment rate | | ✓ | |
| | 8 | Urban non-point pollution control | | ✓ | |
| | 9 | Combine sewer overflow ratio | Combine sewer overflow ratio | | ✓ |
| Water Resource | 10 | Wastewater recycling rate | On-site waste water recycling rate | ✓ | |
| | 11 | Rain water resource utilization rate | On-site rain water resource utilization rate | ✓ | |
| | 12 | Pipe leakage control | Improvement ratio of degraded pipelines | | ✓ |
| Water Safety | 13 | Urban flooding control | Urban drainage standards | ✓ | |
| | | | Urban waterlogging prevention standards | ✓ | |
| | 14 | Flooding control | | ✓ | |
| | 15 | Rainwater Pipe Network Design | | ✓ | |

**Table 4.3:** Guangzhou Sponge City Construction Indicator Systems

### 4.2.3. Policy implementation and evaluation

In the early stage of policy implementation, priority was given to existing projects that already started with sustainable water management concept integrated. An example suggested by Interviewee 1 was the Daguan Wetland Park. The construction of the park started in 2012, and finished in 2015. The park integrated artificial retention ponds and sunken green space, which largely increase the storm water retention rate. Though it was design before the issue of Sponge City, it is later promoted as an successful prototype of Sponge City construction (Turenscape, 2015).

> Initially, the Sponge City policy did not inspired new construction projects. Instead, projects with ”sponge-like” potential that were already in progress locally were included under the

name of Sponge City construction. Projects could be launched before Guangzhou even began formulating its Sponge City Plan. (Interviewee 1)

With the specialized plan formulated, the sponge city implementation in Guangzhou was regulated in a more systematic manner. City scale construction is decentralized into smaller construction segments. As shown in Figure 4.7, firstly, the city was divided into 8 catchment areas based on the nature watersheds within the city. Secondly, sponge city construction zones were specified within each watersheds. The construction zones were designed with reference to the ongoing storm water drainage zones in 2016, to better utilize the drainage capacity. The design consisted 35 construction zones, each with distinct runoff control ratios, taking into account the local geographical conditions and the existing urban water infrastructures. Lastly, construction zones were subdivided into construction units for administrative purposes, ranging from hundreds to thousands of hectares.

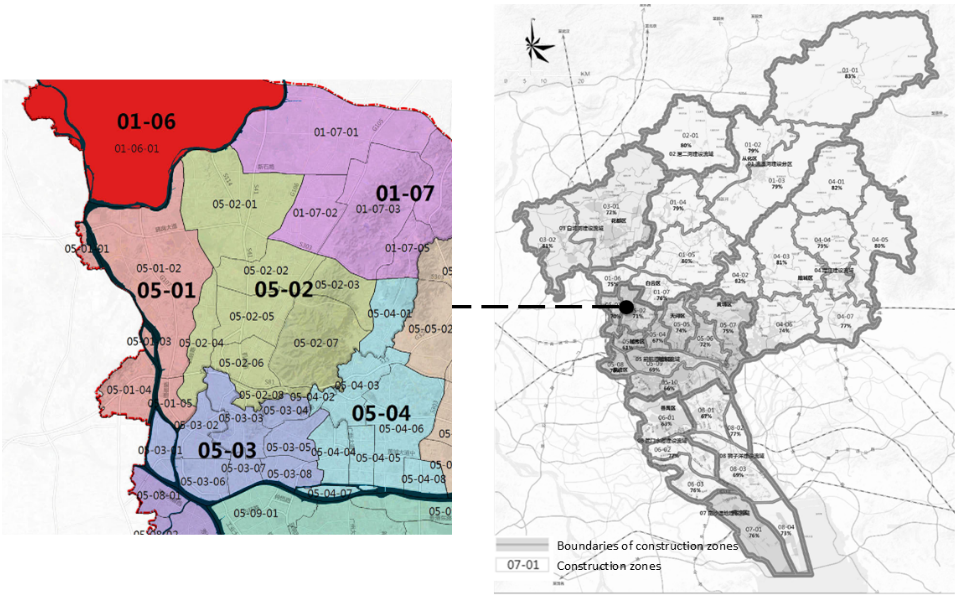


**Figure 4.7:** Sponge city construction units map, adopted from Guangzhou Municipal People's Government (2017a): (left) An example of construction Zones and construction units within each zones; (right) The overall map of construction zones of Guangzhou city

These construction units are specified with detail runoff control ratios, with corresponding construction requirements.The requirements have specified the storm water storage volume capacity ($m^3$/ha) and the SuDS measures coverages, including the percentage of sunken green space, permeable paving and green roof. An example of how the SuDS should be integrated into each construction units is shown table 4.4. The design criteria are in close alignment with the indicator systems, while limitedly reflect other water-related theme.

In the detail plannings and project implementation of each districts, the implementers should first consider which construction zones are assigned to the districts and what are their detail runoff control ratios. At this stage, the designed construction units, which blurring the district boundaries, were assigned back to administrative systems. Specialize Sponge City plans of each district were issued with more specific construction goals and construction project plannings. In the district plans, the runoff control ratios were dissolved and replaced by a series of floating runoff requirements. The advantage is that the floating codes create flexibility for local practices in the face of an uncertain future (Meng et al., 2022).

The evaluation of sponge city starts at the district level. The national standards of the sponge city construction are used as the only evaluation standards. Every year, the progress of evaluation will be first evaluation by each district, then report to the city level. The construction progress will be then reported to the province, and report to national government for evaluation at the two examination windows (2020 and 2030). The workload of construction is designed at the beginning of the year, and the construction speed is controlled at city level. It is important to notice that the evaluation standards only applies to the built-up area within the construction units. The final progress of evaluation is sum of the built-up area of each districts (see Figure 4.8).

**Table 4.4:** Detail criteria of SuDS implementation rate in different construction units (example of construction zone 05-03), from Guangzhou Municipal People's Government, 2017a

| Control items | | 05-03-01 | 05-03-02 | 05-03-03 |
|---|---|---|---|---|
| **Runoff control ratio** | | 73% | 63% | 62% |
| **Sunken green space (%)** | **Built environment** | 45 | 50 | 45 |
| | **Road** | 40 | 40 | 40 |
| | **Square** | 45 | 50 | 50 |
| | **Greenspace** | 40 | 45 | 40 |
| **Permeable paving (%)** | **Built environment** | 50 | 50 | 40 |
| | **Road** | 50 | 50 | 60 |
| | **Square** | 50 | 60 | 50 |
| **Green Roof (%)** | | 50 | 60 | 45 |

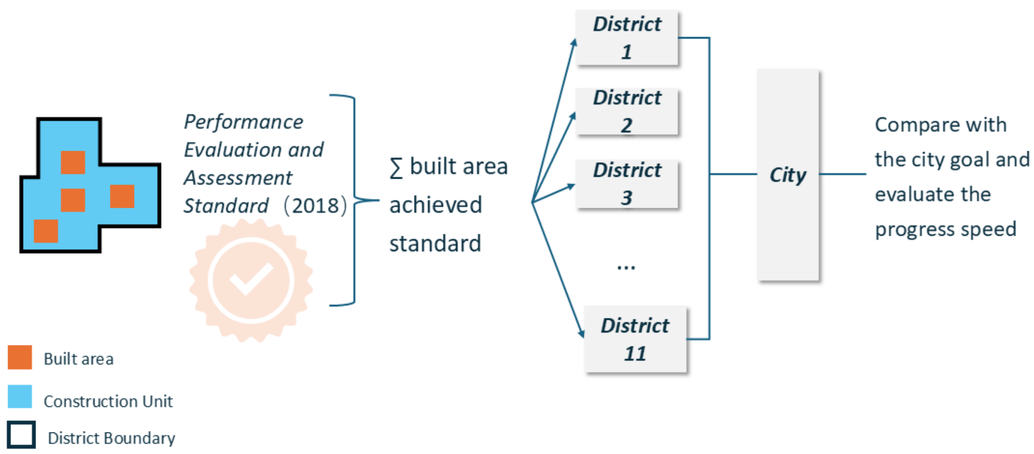


**Figure 4.8:** Illustration of the evaluation process at local level(Guangzhou)

### Implementation governance

It is notable that three major governmental institutions are related to flood affairs in Guangzhou: (1) the Pearl River Commission (regional flood control sector), (2) the Water Affairs Bureau (municipal water engineering sector), and (3) the Planning Bureau (municipal planning sector). The Pearl River Commission (PRC) leads coastal flood defense regionally (within and also beyond Guangzhou's territory) under the supervision of the national sector Ministry of Water Resources (MoWR), and focuses on designing, building, and consolidating dyke systems, which work as a safety baseline in the Pearl River Delta. Each governmental institutions have related working terrains (see Figure 4.9).

When it comes to municipalities, the Sponge City policy leaves flexibility for local authorities to choose institutional leaders in a multi-disciplinary and multi-stakeholder context, combining national requirements with local needs for concrete implementation (Meng et al., 2023). For instance, in Guangzhou, the Land Resources and Planning Commission (a governmental institution focusing on urban planning with limited experience and knowledge in flooding issues) was designated as the leader of the Sponge City Plan locally. The Guangzhou Water Affairs Bureau, even though naturally seen as the first candidate for leadership, was appointed as a supporter to assist the planning sector (Meng et al., 2023). The SuDS measures are located in the administrative terrains of the planning bureau.

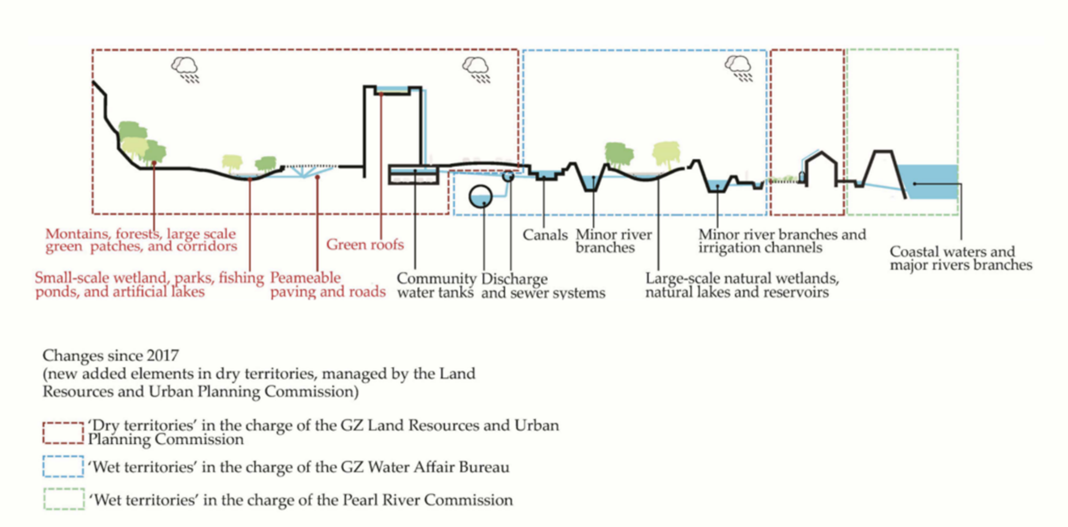


**Figure 4.9:** Illustration of the administrative domain of different municipal parties (Guangzhou, adopted from Meng et al. (2023)

Apart from the traditional institutions, a Sponge City Office was developed deliberately under the Water Affair Bureau of Guangzhou to facilitate the construction. The Office is established as a temporary institution and will dismiss after the end of the Sponge City policy cycle. The members of the office include representatives from related bureaus, districts heads and entrepreneurs. The role of the office is more of administrative and supervision purpose to ensure a smooth construction (D. Yin et al., 2022).

### Evolution: local systematic integration

It is recognized by the practitioners that the SuDS implementation projects can only be able to handle small rain fall events (interviewee 1,2,3,4), therefore in the content of the runoff control ratios, a systematic integration of the Sponge City is developed. In systematic integration phase, the motto of Guangzhou can be described as *No waterlogging in light rain, no urban flooding in heavy rain, no black and odorous water bodies, and mitigated heat island effect* (Guangzhou Municipal People's Government, 2025).

Aiming at the city-wise implementation, the city has been classified for a more targeted integration of the different zones according to the hydraulic characteristics (Guangzhou Municipal People's Government, 2025) (see Figure.4.10). The northern part of Guangzhou is a mountainous region, with more greenery and are the source of one important river which flows across the whole city. The reservoirs also locate in this region and serve as significant drinking water supply sources of the city. Therefore, the systematic implementation goal of the northern area is to restore ecological values and slow release of the water to ease the pressure for down-streams.

Mid-stream part is relatively flat, with large area of around 5 to 11 m above sea level. It is the central metropolitan area of Guangzhou and very densely built with low permeability. The goal of management in this area is to operate the sponge city systems to actively cope with downpours.

Down-steam part is coastal area which connects Southern China sea. The goal of this area is to mitigate the risk of costal flooding the the compound risk with pluvial flooding.

Inspired by the central Technical Guide, which explains the concept of Sponge City systems with source-mid-end control, systematic implementation of Guangzhou integrate the idea of coordinating between different projects (see Figure.4.10). The SuDS, which in this content is recognized as the source control project. It has been recognized that the SuDS is not able to deal with urban flooding, according to the interviewees. The SuDS, remains as the iconic measures promoted by the Technical Guide, is aiming to mitigate the peak flow and deal with small rain event, in order to achieve the political commitment of *No waterlogging during light rain*.

In the systematic demonstration period, the construction and upgrade of the drainage zone is integrated into the account of Sponge City construction. At drainage zone level, projects are aim to make better

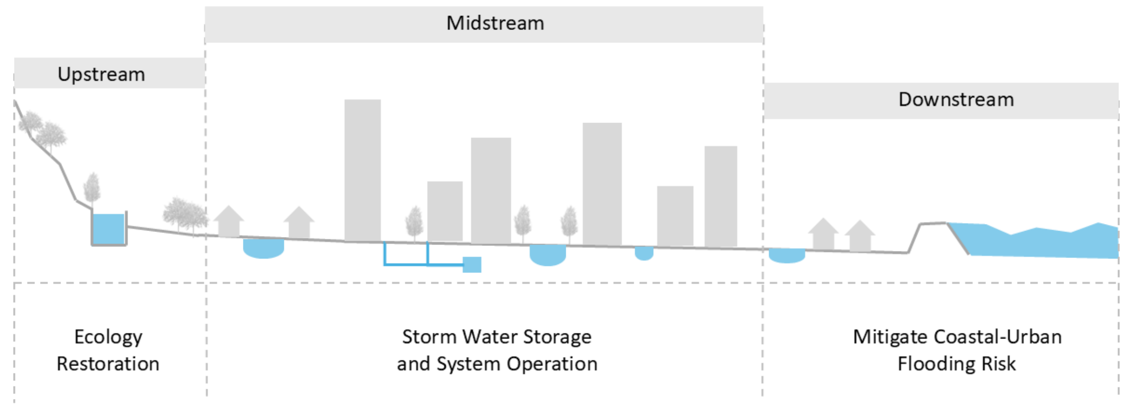


**Figure 4.10:** Systematic implementation of Sponge City at city scale, Guangzhou: Coordinating between spatial scales to manage urban flooding

use of the synergies the drainage pipe construction (from combine sewer system to separate sewer system), considering the potential of the grey infrastructures and the combine effectiveness of the SuDS. The returning of the urban canals and large water bodies including lakes in the parks have high potential in storm water management (interviewee 3, 4). Due to the extreme difference of precipitation between summer and winter, the streams in the urban areas are mostly rain-sourced, therefore with high capacity in holding waters during downpour (interviewee 4). At drainage zone level, projects should make good use of the capacity in monitoring and operating the grey system.

At catchment scale, projects place an emphasis on the hydraulic connectivity thinking of the urban rivers.

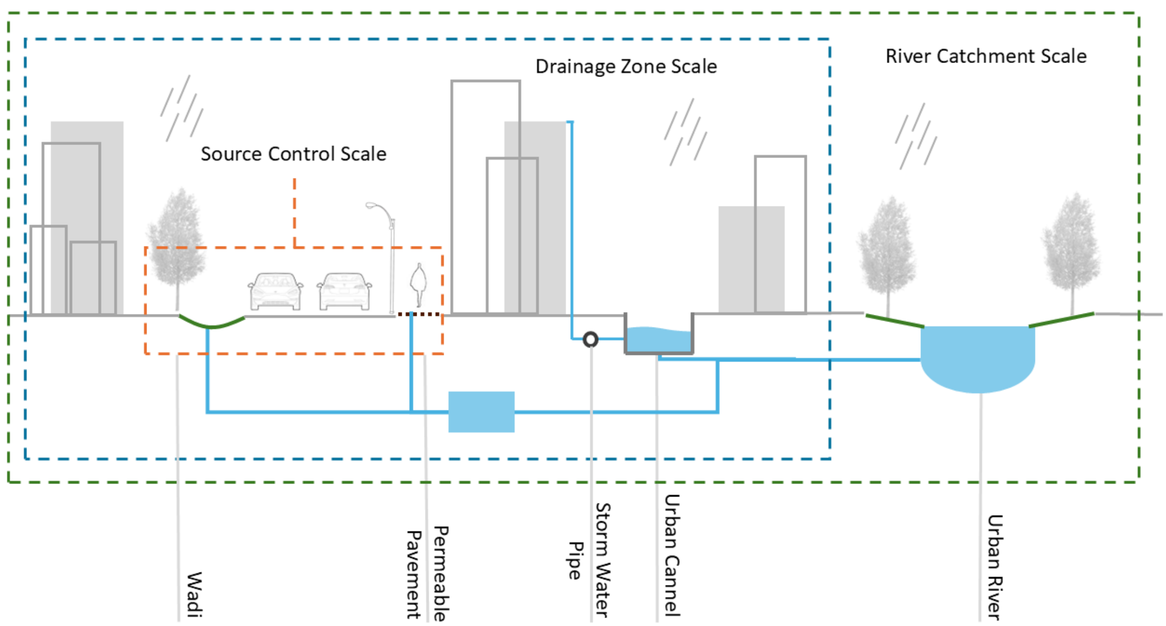


**Figure 4.11:** Systematic implementation of Sponge City at city scale, Guangzhou: Coordinating between project scales to manage urban flooding

To better facilitate the implementation of Sponge City, Guangzhou has established a set of strong measures to regulate the implementation starting from 2020.One of the approach is to integrate Sponge City construction into evaluation of a special localized governance system to ensure its construction. It is not a direct system established for Sponge City construction, while can serve as a mean of dedicated governance. Starting from 2016, China has established the *River Director System*, a new governance mechanism for improving quality of water environment (Shen and Jin, 2018;M. Ren, 2015). Major officials of all levels of governments are assigned as the River Directors within, who are responsible for the water environment of the rivers within their jurisdictions (He, 2020). The aim for the system is to maximize the administrative power of the directors to gradually manage water pollution, while adopting a rigorous evaluation mechanism (He, 2020). In 2020, Sponge city construction was included as one of evaluation criteria of River Directors' political performance (Guangzhou Municipal People's Government, 2020). In addition, small-scale SuDS projects should be integrated into all construction projects within the urban areas (Guangzhou Municipal People's Government, 2020). To ensure this, controls on different phrase of the projects are executed.

> In the phase of project set-up, SuDS integration should be clearly stated before obtaining the key documents for construction, which include approval of construction site, construction land use planning permit, and the building permit. In design and bidding phase, the design blueprints of SuDS are checked as well. The acceptance of measures will be assess at the final completion phase. (Interviewee 3)

## 4.3. Discussion of local Sponge City Interpretation and Implementation

In this section, discussion is presented, consisting discussion on policy analysis and problems encountered during policy implementation.

### 4.3.1. Policy Analysis Discussion

#### Central Policy Cycle

The central policy indicates a *one-model-fits-all* type of political commitment, which is limited in addressing the physical diversity across the whole country. This requires local governments to reflect on its own conditions and to make adjustments to adapt. The goal of Sponge City policy has a clear focus on volume control by setting a quantified indicator to facilitate rainfall interception (Ministry of Housing and Urban-Rural Development, 2014). The VCRa can be considered as a safe goal in policy-making, especially when catchment hydrology modelling has not been performed, as volume regulations always result in less surface runoff under current event (Petrucci et al., 2013). The Sponge City's aim, in general, is to preserve pre-development water balance through the control of annual runoff volume captured in urban built-up area (Ministry of Housing and Urban-Rural Development, 2014). It is evident that in regions with abundant annual precipitation, greater quantities of rainfall should be captured. This principle also indicates that cities with more built-up area should store more water correspondingly. G. Dong et al. (2018) conducted a local water balance analysis, assuming the Sponge City goal is fulfilled. The result indicates that highly developed cities in Beijing-Tianjin-Hebei region with less precipitation could end up in greater runoff intercepted than natural surface runoff in the watershed. For cities locate in the Pearl River Delta, with substantial precipitation and extensive urban development, they are facing pronounced challenges in storm water interception now, and even in the future.

#### Local Policy Cycle

It can be observed from the policy analysis that Guangzhou has interpreted Sponge City policy with close alignment with the central policy. Due to the political nature in China, the Guangzhou interpretation can be recognized as sufficiently and effectively follow the central order. While this kind of highly aligned policy translation can inherited the limitations rooted in central policy (H. Li et al., 2017).

Guangzhou had clearly analyzed its own problem in relation to the central issued water themes, while the problems were explained in a parallel manner, without addressing the synergies among them. Local Sponge City policy adjustment and implementation still follows the central policy-making logic, by applying the same solution framework. Solutions outlined in the Guangzhou Sponge City Plan includes a high ratio of SuDS constructions, while limited considered the local conditions which itself has identified. While all interviewees have agreed that the top priority of Guangzhou is to drain, solutions promoted are not much different with northern cities facing drought and water-shortage. Therefore, the Guangzhou Sponge City plan has not been successful in establishing an integrated storm water management framework embedded within the concept of Sponge City (Nguyen et al., 2019).

Multiple urban water policies were considered in Sponge City construction, with clear statement to integrate Sponge City concept, while the management of these policies are still in separation to each other. Grey infrastructure construction projects driven by drainage improvement plan can have positive contributions to Sponge City implementation, while the Sponge City policy its self is largely restricted to SuDS integrations. In addition, the progress of urban flooding control is assessed by the elimination of waterlogging black points, which is limitedly reflected in the Sponge City indicator assessment. Therefore, it is challenging to assess the contributions of Sponge City policy in urban flooding control, as the evaluation does not reflect the performance of Sponge City projects. The effectiveness of SuDS in urban flooding control is considered relatively low by the experts interviewed in this study:

> The mitigation of waterlogging blackpoints are primarily addressed through the improvement of drainage systems, including building new pumping stations and drainage enlargements. (Interviewee 6).

### 4.3.2. Local Problem Discussion

#### Institutional Challenges

In Guangzhou, the Land Resources and Urban Planning Bureau is assigned to lead the implementation of Sponge City. Consequently, the planning bureau has a primary right in the design of the project construction locations (Interviewee 1). The Sponge City Office in this case, is responsible for mainly facilitate the the criteria establishment and fulfillment. Therefore, in urban dry territories (see Figure.4.9), there is no conflict between the planning bureau and other organization in Sponge City implementation, from an administrative perspective. However, the centralization of the governance responsibility has the potential to cause negative impacts on climate adaptation. The Planning Bureau may prioritize land use for economic development, thereby putting Sponge City at the lower position in land use planning. The Land scarcity was mentioned as one of the barriers in Sponge City construction (H. Li et al., 2017; Qiao et al., 2020), as urban areas are often densely built and with complex existing infrastructure. This research reveals that institutional problems can contribute to land scarcity. Urban flooding control is recognized with low priority by the actors involved in urban planning and design (Dąbrowski et al., 2021). As the implementation of Sponge City should be maximized to the full extent (Guangzhou Water Affair Breaue, 2020), the implementation of Sponge City construction is then regarded as a remediation to fulfill the regulatory requirement (Interviewee 4, 5, 6), which could leave inappropriate land to implement SuDS (see section.4.3.2).

As the Chinese political environment is highly segregated, cross-sectoral coordination and dialogue are limited to take place, constraining idea exchange between different bureaus (Dąbrowski et al., 2021; Nguyen et al., 2019). Sponge City construction could be difficult without mutual understanding and cooperation (Nguyen et al., 2019). The result of this study indicates that lack of cross-sectoral dialogue could constrained the use of knowledge(H. Li et al., 2017; Qiao et al., 2020; D. Yin et al., 2021). In addition, the cost-effectiveness of SuDS are shown to be a concern to the local practitioners (H. Li et al., 2017), while this lack of communication can generate misunderstanding between different sectors. As interviewee 1 mentioned, the benefits brought by the current Sponge City construction are limited, which results in unwillingness of implementation. Through the interview with interviewee 6, who is an urban developer, a different idea was expressed:

> We fully recognize the benefit of SuDS, but is has to be *real* SuDS. Many *fake* SuDS are constructed, which are not functioning but were built to meet the standards. Therefore, no one can see the benefits brought by these SuDS. (Interviewee 6)

#### Criteria-oriented Mainstreaming Strategy Causing Problems

The Sponge City construction and evaluation is well planned at administrative level, with clear instructions and guidelines as aforementioned. While this type of highly criteria-oriented construction can leads to gold-plating when cascading down to district level. Ratios of SuDS implementation and goals of urban flooding control are lifted in some of the district plans. When designing a construction project within construction units, the requirements are lifted again, which puts a lot of pressure on the engineers

(Interviewee 5).

Additionally, Book-keeping is frequently observed in project management. Accordingly, the construction should be in strict accordance with the Sponge City criteria. One example is the Nansha Sports Center provided by Interviewee 7. The Sport Center locates at the southern part of the city, with close access to the sea. According to the guideline of *Storm water Runoff Control Measures for Guangzhou Construction Projects*, which the Sponge City construction should follow, project area lager than 10,000 $m^2$ should provide rain storage facility with a volume greater than 500 $m^3$ per 10,000 $m^2$. Correspondingly, the Nansha Sports Center project should construct a rain water storage tank, even the location allows the surface runoffs to drain natural into the surface water. The water retention potential of urban water bodies within or close to project area can be neglected, with awareness, when designing the project.

> The implementation ratios of the SuDS are applicable to the construction area, which only account for the land. It existing water surface area will not be included. (Interviewee 6)

The interviewee mentioned the Huafu Middle School project, where a lake has existed in the construction site. Rain water storage tank and a high ratio of permeable pavement were still implemented according to the Sponge City requirement, while the potential of the natural lake was ignored.

The combined problems of the limited land left for construction and the criteria-oriented implementation manners can result in complicated and inappropriate urban design. A typical example is the sunken-green belt constructed alongside the road, where tree pits, lamp post, and underground pipelines are compacted (as presented in Figure 4.12).

The construction of the pipelines often go in the first place, while the construction of the tree pots could cause damage of the pipe, therefore the tree should be planted to avoid damage of the pipelines, and cannot be planted too deep. Meanwhile, the sunken green belt construction should considered slope and storage layers, therefore the tree pot should be planted deeper to prevent sinking in the stored water for too long. In addition, the lamp posts are required to find a place when constructing the sunken green belt, which could cause conflicts with the trees and decrease the performance of SuDS. As the climate in Guangzhou is sub-tropical, humid summer always raise attention to the Dengue fever, which is a mosquito-borne disease. The stored water in the green belt during summer require extra usage of insecticides to control the breeding of mosquito.

Following a mainstreaming approach, criteria-oriented nature can resulting in lack of consideration of the hydrological connectivity (Griffiths et al., 2020). At in-land projects, project area within the up-stream district can affect the up-stream district while the hydrological impacts are limited studies. Consequently, areas belong to different administration jurisdictions share one catchment basin. This mismatch can cause trouble for lowlands. Infrastructure in a lower area in one district administratively requires greater investment for protection from the flooding stress created by another district at a higher elevation (Meng et al., 2022). While the national guidelines recommend that flood modelling should be integrated with catchment-scale flood and water resource models, support from central government is focused on urban development, such that integration with the larger catchment planning processes is under-represented (Griffiths et al., 2020).

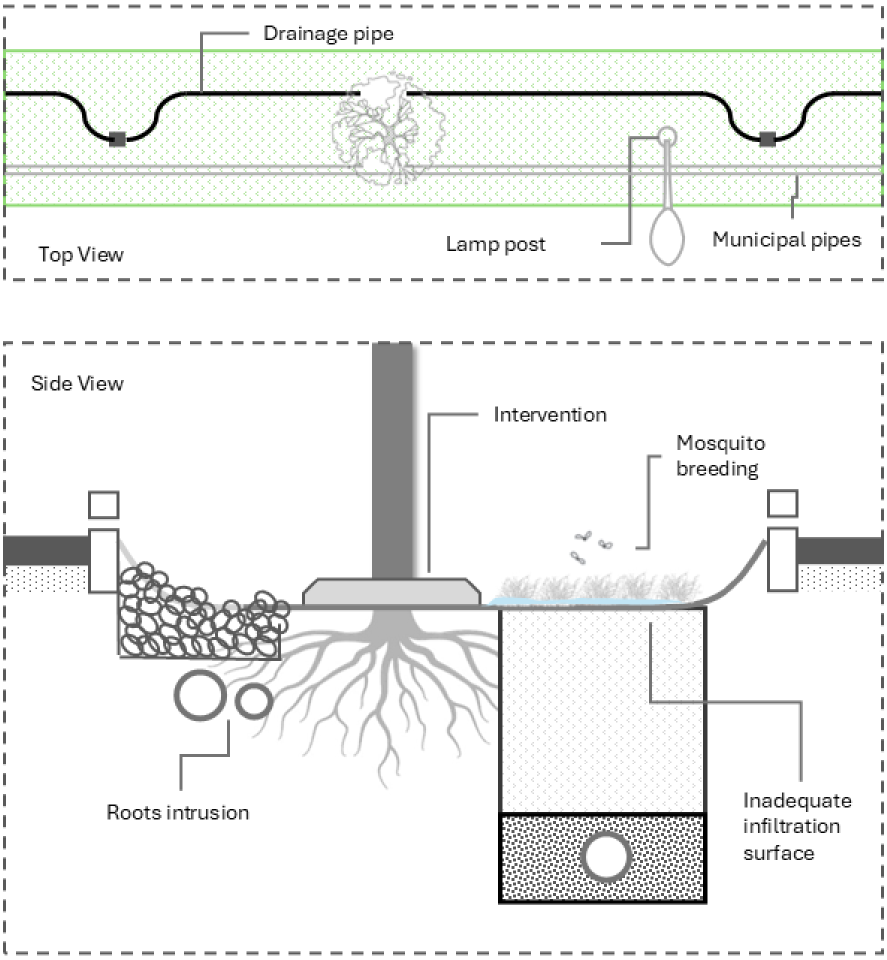


**Figure 4.12:** Compacted design of SuDS under criteria-oriented approach

### Limited Climate Adaptive Capacity

Climate adaptive capacity of Guangzhou's Sponge City implementation is relatively limited, with large remaining potential (Dąbrowski et al., 2021).

The aforementioned institutional factors present hindrance in improving the city's climate adaptive capacity. In addition, the lack of long-term decision-making constrains the consistency of adaptive planning (Dąbrowski et al., 2021). Due to political structure in China, the city mayor is only in governance of a short or medium timescale, whose blue-prints of the city development may not be adopted by the next mayor. This could result in uncertainties in spatial planning and construction preference, specially for new district development, where an appropriate plan can leave very good foundation for urban flooding management.

> The development of the district is primarily determined by the mayor...The previous mayor favored urban lakes, leading to the construction of an artificial lake halfway up the hill. The location was selected to maintain earthwork balance. Accordingly, ponds and low lands with naturally high infiltration capacity were covered...The decision has already caused an inappropriate foundation from urban water management perspective. (Interviewee 5)

To examine from a urban water management perspective, the policy commitment itself can limited adaptive to future extreme precipitation. Firstly, in both central and local Sponge City policies, future climate adaptive data and modeling were not applied. Due to climate change, an event with a longer return period can become a frequently occurring event (Kumar et al., 2022). Historical climate data were used to calculate the runoff control ratio, while it has been observed that the annual rainfall has increased increased in recent year (Guangzhou Meteorological Observatory, 2024). Secondly, the commitment did not take into account of the local characteristics. Extreme precipitations in Guangzhou are frequently generated by localized convective storms with life spans of more than 10 h (J. Yin et al., 2020). Climate adaptive solutions should consider these conditions, while limited address through Sponge City implementation.

Despite the limited consideration for the impacts of climate change, constructions in Guangzhou with multiple goals can be frequently observed, which are in close accordance with climate adaptation concept, while not framed as part of adaptive policy (Dąbrowski et al., 2021). Potentials in increase of climate adaptation capacity can be seen in the demonstration period of Sponge City implementation, where nature water bodies are involved and projects are designed considering different scales of drainage. While these is still limited studied from climate adaptation perspective.

# 5

# Comparative Analysis

## 5.1. Amsterdam

Amsterdam, the capital of the Netherlands, is home to over 800,000 people (Van Leeuwen & Sjerps, 2015). The city is intimately connected to water: its name refers to the adjacent Amstel River, which empties into the well-known historical canals that run through the city center. The city aims to develop as a competitive and sustainable European metropolis (Van Leeuwen & Sjerps, 2015). Amsterdam holds a leading position internationally in integrated water resources management (IWRM) (Van Leeuwen & Sjerps, 2015). In 2006, various urban water services were consolidated into the country's first water cycle company, Waternet (IWA, 2016). Waternet is responsible for surface water (rivers, canals, ditches, and lakes), groundwater, storm water, the supply of drinking water, and the treatment of wastewater. In the face of climate change, urban densification, and the resulting increased risk of flooding, Amsterdam has developed a multi-layered safety approach (van der Hoek et al., 2014). This approach includes three layers: 1) Flood protection and the implementation of standards by taking technical and spatial measures; 2) Spatial climate adaptation planning; 3) Disaster management. (van der Hoek et al., 2014)

### 5.1.1. Urban Drainage and Climate Change

As aforementioned in section 2.2.2, urban drainage and spatial adaptation are parts of the legal responsibilities of the municipality of Amsterdam. The municipality and the regional water board (Waterschap Amstel, Gooi en Vecht) have assigned all their water management affairs to Waternet (IWA, 2016).

In 2022, the established of *Omgevingsprogramma Riolering 2022-2027 (OPR)* (Sewerage Environmental Program 2022-2027) had replaced the old *Gemeentelijk Rioleringsplan Amsterdam 2016-2021 (GRPA)* (Municipal Sewerage Plan Amsterdam 2016 −2021). This shift in plan has marked a shift of view in the application of SuDS, which was not recommended in the old plan (Guidobono, 2021).

Rain drainage systems were the main solution used in the city. In 1923, Amsterdam was the first dutch municipality to stop the construction of combined sewer systems. The long history of different management of rain water and waste water has lead to 76% of the sewers in the city being separate sewer systems, with 1,674 km of rain water drainage pipes and 4692 rainwater outlets (Gemeente Amsterdam & Waternet, 2022). This provides great benefits of the transition to a climate adaptive city in relation to climate-proof storm water systems.

Climate adaptation of storm water systems requires resistance on extreme downpours. Amsterdam's concept of storm water management is aligned with the Dutch three-step-strategy and shares similar idea with the sponge city concept. Rain water retention facilities are encouraged to deal with regular showers at the first place. Runoffs generated on-site are discharged into rainwater pipes or into surface water bodies (Gemeente Amsterdam & Waternet, 2022). The drainage capacity of pipe systems is designed to cope with showers that occur with a return period of 2 years without causing urban flooding. The ambition of the city is to cope with rainfall event with a return period of 100 years, which is in accordance with a rain intensity of 70 mm/h (Gemeente Amsterdam & Waternet, 2022). Additionally, the newly construction (and renew) projects are applicable when they are technically feasible and more efficient than the above-ground projects (Gemeente Amsterdam & Waternet, 2022).

It is clear that Amsterdam emphasize a lot on the above-ground rainwater retention projects, which leave a pivotal role of SuDS to play. Though the historic city center of Amsterdam was elevated during its construction, which still are an important asset in reducing the flood risk of the city (Nillesen, 2022), half of the city still lies below sea level (van der Hoek et al., 2014). Due to the geographical conditions, water remains predominant in city topology, with a percentage of never lower than 24% (Kinder, 2015). The extensive canals in Amsterdam are acknowledged for their great aesthetic value, while not designed for rain water discharge(Peters et al., 2021). Base on *No problem shifting* principle of Dutch water management (Brouwer, 2015), the rain water should preferably drain to the surface water in a delayed manner.

### 5.1.2. Amsterdam Rainproof (Weatherproof)

In 2014, Waternet had introduced the Amsterdam Rainproof initiative, which aims to manage the risk posed by urban flooding buy building resilience to cloudbursts (Rainproof, 2023). Cloudbursts are defined as rain events with an intensity of at least 15 mm precipitation within 30 minutes, when in 2011, Copenhagen had experienced a cloudburst of more than 150 mm fell in 2 hours (Ziersen et al., 2017). This has become the waking alarm of Amsterdam to consider active reaction of dealing with this kind of extreme event (Rainproof, 2023). The goal of Amsterdam Rainproof is to be resilient to extreme precipitation of 60 mm/h. The program was set up to be fully focused on building resilience to rain by avoiding multi-objectives integrations (Rainproof, 2023). As one of the founders of the national Climate Adaptation Board, Amsterdam Rainproof started to participate in the decision-making on Climate Adaptation Implementation Agenda, which consists of four climate themes: extreme precipitation, drought, heat, and flooding (Amsterdam Weerproof, 2025). In 2024, the program has evolved into Amsterdam Weatherproof (Weerproof) with a comprehensive focus on the aforementioned theme(Amsterdam Weerproof, 2025). Considering the scope of this study and the progresses made in the past 10 years, the name Amsterdam Rainproof is still used in the following parts.

#### Identification of Bottlenecks

To examine the stress of future precipitation and to gain a better understanding of actions to be taken, analysis were done to identify the risk that the city is facing. A stress test was applied to show the above-ground accumulation of storm water in the city under event of 100 mm/h, addressing the necessity of preparing Amsterdam for the increasing frequent severe downpours. The map had also revealed that the problems and the related damage would occur on both public and private grounds. A second stress test was applied to show the bottle necks within the city under event of 60 mm/h. At the beginning of the program, 97 bottlenecks were identified and mapped out, with a categorization of different levels of urgency of changes (see Figure. 5.1). The role of Amsterdam rainproof was to ensure the schedules of the adaptation projects tie in the the on-going projects within the city, while accelerate the changes when necessary, for example, when the extremely urgent bottlenecks are not yet scheduled to be addressed (Rainproof, 2023). By the end of 2021, The most urgent rainwater bottlenecks including Betondorp, Oosterparkbuurt, Bellamybuurt and Rivierenbuurt have been addressed during the period of GRPA (2016-2021) (Gemeente Amsterdam & Waternet, 2022). These bottle necks are served as indicators for rainproof strategy implementation (Gemeente Amsterdam & Waternet, 2022). From degree to urgent and extremely urgent, the planned problem-resolved time are within 15 years to 5 years.

#### Implementation Approach and Technical Solutions

The role of Amsterdam Rainproof was explained in the GRPA(originally in Dutch), indicating a mainstreaming strategy in adaptation implementation (Gemeente Amsterdam & Waternet, 2015):

> The Amsterdam Rainproof program motivates, informs, and activates residents, entrepreneurs, civil servants, and knowledge workers to incorporate rainwater management into roof, street, garden, park, and square renovations.

The fundamental tool that Amsterdam Rainproof applied was a climate adaptation local network (Willems et al., 2023; Willems and Giezen, 2022). As the first step, stakeholder analysis was conducted by Amsterdam Rainproof, which identified twelve stakeholder categories, including residents, community initiatives, property owners, homeowners' associations, housing corporations, civil servants, directors,

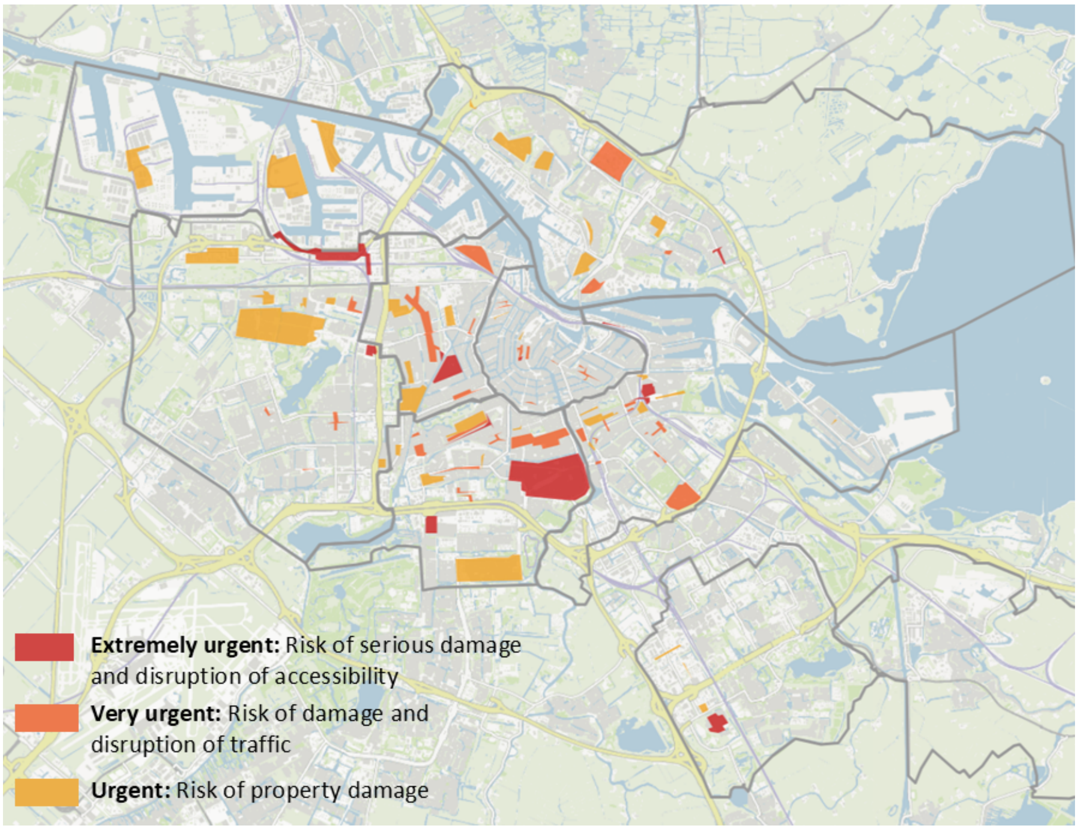


**Figure 5.1:** Map of bottlenecks in Amsterdam, adopted from website of Amsterdam Rainproof. The map shows three level of urgency to be addressed: Red zone(Extremely urgent), Orange Zone(Very Urgent), Yellow Zone (Urgent).

insurers, research and educational institutions, business owners, media companies and NGOs (Rainproof, 2023). As these stakeholders and the corresponding knowledge and resources are fragmented among difference domains, the local network was formed as a platform to connect with all sectors to contribute in climate adaptation (Willems & Giezen, 2022).

The network approach was intended to build resilience to urban flooding through individual awareness, actions and public-private partnerships (PPP) (Sharma, 2023). While rainproof may not be on the top of the list of the stakeholders, the role of Amsterdam Rainproof is to find the shared theme and interested when mainstreaming the rainproof idea (Rainproof, 2023). This is achieved by defining the boundary objects (Willems & Giezen, 2022). The definition of boundary object were introduced by Star and Griesemer (1989), which refers to conceptual or material instruments belongs to both sides of the boundary. For example, the bottleneck map and the Amsterdam Rainproof website are recognized as material boundary objects, which provide visualized and shared information to communicate with stakeholders (Willems & Giezen, 2022). Conceptual boundary object refers to the motto *Rainproofing the city*, which positioned the concept for climate adaptation in a scope of livable urban life to link to which more parties could related with (Willems et al., 2023).

In the vision of mainstreamed adaptation, overarching infrastructural development such as enlarging the capacity of sewer systems to absorb more rainfall is not the answer: there are no *expensive, large-scale mono-functional solutions*, evident by the GRPA (Gemeente Amsterdam & Waternet, 2015) :

> The basic principle is that small-scale, targeted, intricate, and cost-effective measures will make the city more resistant to rainwater while also making it more attractive and livable. Instead of expensive, large-scale, mono-functional solutions, the program uses smart adjustments to increase the sponge effect of the city.

Private sectors are encouraged to take their own actions. Information and tutorial materials can be found on the website of Amsterdam Rainproof under section Do-it-yourself, such as how to take off the tiles, constructing facade gardens, and installing rain barrels. Public projects were carried out in pilot district through SuDS implementation.

## 5.2. Study Sites

Two study sites were selected to investigate the type of SuDS as reflection of the strategy performance.

### 5.2.1. Amsterdam, Zuidas

Amsterdam Zuidas locates at a strategic filed of Amsterdam's southern ring road. The area connects city districts (Buitenveldert and Oud Zuid) and conservation areas (Nieuwe Meer and Amstel), and is close to the international airport. In 1998, Zuidas Master Plan was issued, striving to create new office locations and facilitate economic development, while integrating multiple goals for vibrant urban lives(Majoor, 2006). To date, Zuidas is a densely built area, and is still under development, challenging local storm water management (Gemeente Amsterdam / Zuidas-development, 2016). Rainproofing Zuidas has been put on the political agenda from 2016 to 2030 (Gemeente Amsterdam / Zuidas-development, 2016).

#### Water-retardant Green Strip

In 2016, the first water-retardant green strip was placed on Kop Zuidas, Zuidelijke Wandelweg (see Figure 5.2 (a-b)). The water-retardant green strip refers to the similar concept as Wadi (Dutch), which can temporarily collect water and facilitate natural infiltration. The strip is approximately 35 cm lower than the surrounding area. Runoffs are the street and roofs of the houses can flow into the green strip, through rainwater pipes or open channels on the edge of the strip. The designed retention time is 24 hours, after which the water will infiltrate into the sub-soil. Overflow was constructed as an access to rain sewers during heavy precipitation (City of Amsterdam (Dienst Zuidas) & Waternet, 2016).

The green strip was constructed in front of the the new houses. Each home has their own entrance with a granite bridge over the green strip. It can be seen as a good practice to add values to living quality , while improve water resilience. The project is a project in public space, as the location of the green strip belongs to public road. The responsibility of maintenance is assigned to the public service, while the residents shows high competence in participation in keeping the green strip in good condition. After nearly 10 years, the wadi is still maintained at its good function through eye observation (Figure. 5.2(a)).

#### Permeable Paving

Porous Pavement and Interlocking Pavement are largely available in the market and widely implemented as SuDS measures. Porous Pavement is constructed with porous asphalt or concrete with permeable surfaces, while Interlocking Pavement relies on wide opening channels on side for infiltration capacity (Scholz & Grabowiecki, 2007). Porous systems are prone to clogging usually within three years after installation and can experience a loss of porosity (Scholz & Grabowiecki, 2007). Interlocking Pavement is more suitable to be applied in low traffic load street (Moretti et al., 2025).

As shown in Figure. 5.3 (a), side permeable paving is applied for the streets. During the site visit, the expert has explained that the side permeable bricks are tested to be more efficient than the surface permeable bricks. Amsterdam has taken years to test these measures as they consider the performance should outstand the fast board scaling of SuDS.


**Figure 5.2:** Water-retardant green strip in Kop Zuidas: left (a) Site visit on May 7, 2025 (photo by author); right (b) Completed construction in 2016, adopted from *Groen en droog in Zuidas* (photo by Merlijn Michon).

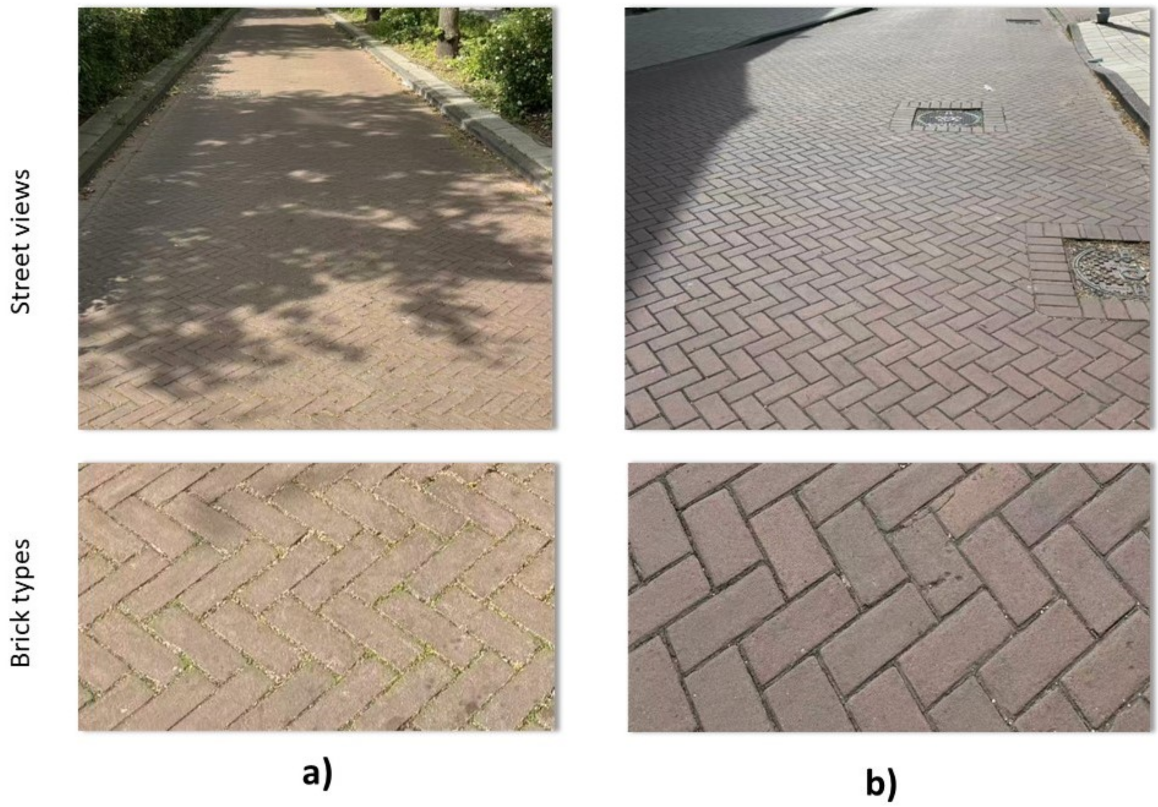


**Figure 5.3:** Street Paving in Zuidas: left (a) Permeable paving with side permeable bricks; right (b) Impermeable paving. All pictures taken during site visit on May 7, 2025.

### 5.2.2. Guangzhou, Sima Chong

As aforementioned in section 4.2.3, sunken green space and permeable paving constructions are required in the city planning. Therefore, these two types of SuDS are most widely seen in city-wide implementation. In the demonstration period, the integration of regional storm water management thinking has largely shaped the Sponge City implementation in Guangzhou.

The study site selected in this research is the Sima Chong water catchment. *Chong* indicates open water channel in Chinese. Sima Chong is a historical waterway in Guangzhou, the catchment area is 10.1 $km^2$, crossing 3 districts from north-east to south-west. Culvert was constructed in upstream and midstream of the catchment, with 5.5 km long, and entered the Sima Chong (open channel) in downstream, with 2.4 km long (C. Yang, 2021). The renovation project of Sima Chong started in year 2021.

#### Sewer Improvement and Urban Lake

During the demonstration phase of Sponge City construction, Guangzhou has recognized the significant potential of urban parks and wetlands in enhancing water storage and drainage capacity. An example of Sponge City implementation in this phase is the Liuhua Lake urban park. Situated in the midstream section of the Sima Chong catchment, the lake previously suffered from severe combined sewer overflow (CSO) pollution during heavy rainfall events due to the inadequate capacity of the upstream combined sewer culvert. The culvert was a bypass, which connect directly with the open channel downstream, while utilizing the lake only as solution to deal with excess water.

Guided by the principle of Sponge City, which addressed cooperation of both SuDS and grey infrastructures (see Figure 4.2), Guangzhou has been upgrading its sewer infrastructures, as mandated by the *Guangzhou Municipal Drainage Management Regulations* (Guangzhou Municipal People's Government, 2019a): *Existing combined sewer systems shall be gradually converted to separate sewer systems.* In this Sponge City project, the main approach is grey solution instead of SuDS. A new separate drainage system was first constructed upstream, while the original culvert was repurposed exclusively for storm water drainage. Storm water from upstream is directly discharged into the lake, thereby fully utilizing the storage capacity of the urban lake. The existing pumping station is used for operation purpose to control the water in the lake, which could pre-empty before the extreme downpours. Figure. 5.4 (a-b) shows the current water environment of Liuhua Lake and the open channel part of Sima Chong. It can be easily seen that the water environment reaches a satisfactory level. Figure.5.5 (a-b) present the Liuhua Lake during dry period, with (a) showing a large remaining capacity in water storage. The Liuhua Lake project is a great demonstration of the integration of Sponge City principle in the new phase, which not only benefit in water safety improvement, but low in cost as well.


a) b)

**Figure 5.4:** Field inspection of Liuhua Lake and Sima Chong (April 9, 2025): left (a) Outlet of upstream culvert in LiuHua Lake; (b) Outlet of Liuhua Lake in open channel (Sima Chong)

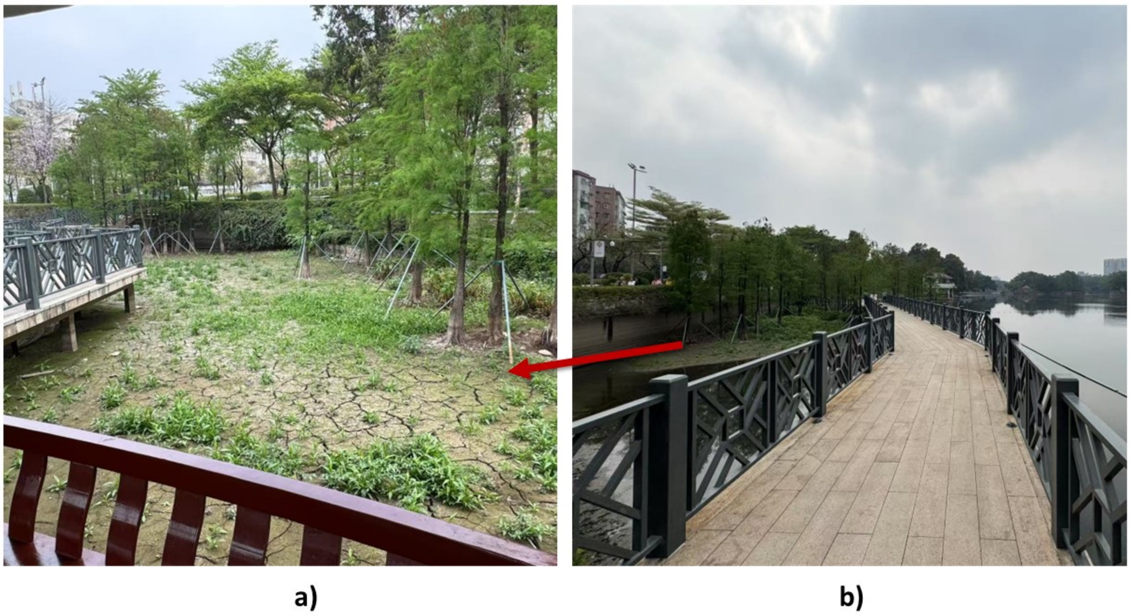


**Figure 5.5:** Liuhua Lake during dry days (April 9, 2025): left (a) flood-prone area of the lake; (b) a bridge on the lake

### Sunken Green Space

As part of the series construction projects, sunken green spaces are constructed as small-scale Sponge City projects within Sima Chong catchment to improve source control capability.

As shown in Figure.5.6 (a-b), the two sunken green space were constructed in two different block residential communities within catchment region. Block residential community, or *Xiaoqu* in Chinese, is type of unique residential gathering in China. According to the *National Code of Urban Residential Areas Planning and Design (GB50180)*, the blocked or gated nature of Xiaoqu indicates an enclosed inhabited land segregated by arterial roads of the city or natural boundaries. Xiaoqu is usually provided with the sufficient public facilities and services for the dwellers (Wallenwein, 2014). Public lands within Xiaoqu are obligated to fulfill this function and plays a significant role in improving dwelling quality, including climate resilience. Additionally, resident-involved activities are normally operated by the resident committee of the Xiaoqu, which is a grass-root administrative organization (Bing, 2012). Resident committee is democratically selected, therefore not required in the process of Xiaoqu formation.

While most of the western countries adopted the land private ownership, Xiaoqu residents only own the land use right in China (J. Zhang, 1996). According to the *Land Administration Law of the People's Republic of China* (Standing Committee of the National People's Congress, 2019):

> In ownership by the whole people, the State Council is empowered to be on behalf of the State to administer the land owned by the State. No unit or individual is allowed to occupy, trade or illegally transfer land by other means. Land use right may be transferred by law. The state may make expropriation or requisition on land according to law for public interests, but shall give compensations accordingly...Land in urban districts shall be owned by the State.

In this case, urban plans considered as strong tool applied by the government in climate adaptation, facilitating spatial transformation (Meng et al., 2019). The construction in public lands within Xiaoqu is subjected to the Sponge City Plans, while requiring acknowledgment and competence of residents within Xiaoqu. The resulting constructions are public projects financed by the Guangzhou government (Interviewee 3).

a) b)

**Figure 5.6:** sunken green space

Figure.5.6 (a) is showing poor performance comparing to (b) after 3 years of installation. The main problem causing the difference is responsibility allocation of SuDS maintenance. There is no resident committee established in Fuli Xiaoqu, where facility (a) is located in, the maintenance of the sunken green space is in charged by no one. While (b) locates in a Xiaoqu which is well organized and the facilities are maintained on a regular basis.

### Pocket Park Integrated with SuDS

Pocket park, with SuDS implemented as source control measures, is an emerging type of mainstreamed small-scale Sponge City projects. The origin of pocket parks can date back to the post World War II era, when they were employed as means of city renovation in war-damaged sites (J. Dong et al., 2023). It can be defined as small-scale green space which contains multi-functional public and ecological services (J. Dong et al., 2023). Sunken green space is suitable to be implemented in pocket parks, preserving the ecological values while adding benefits to storm water management (Liu, 2023).

Figure.5.7 (a-b) presents a pocket park in Sima Chong catchment. Permeable pavements (a) and sunken green space (b) are two main types of SuDS integrated. Both permeable pavements and sunken green space are well maintained, based on eye observation, as the responsibility has been clearly assigned to Urban Utility and Landscape Bureau.

Permeable pavements were implemented on the small square and pedestrians, with the surface sloping towards the sunken green space. In this project, porous infiltration permeable paving are selected, while the foundation of the paving is impermeable (Interviewee 3). According to *Guangzhou Sponge City Planning and Design Guidelines (Section 7.2)*, a permeable construction layer of 20 - 30 mm is required, following a permeable foundation of 100 - 150 mm. Additionally, infiltration pipes are recommended to transport absorbed water when the foundation layer is not equipped with a porosity of 0.3. While in actual condition, the foundation layer remains concrete, meaning that rain water can only goes through 30 mm into the ground.

The research on permeable pavement in China are largely focus on surface materials (Song, 2022). Hu et al. (2018) have studied the flood mitigation performance with hydrological model, considering surface clogging. Guan et al. (2021) studied 5 types of commonly used surface paving materials, indicated that pore characteristics have a significant impact on mechanical and hydrological properties of permeable pavements. Meanwhile, impermeable foundation is a largely raised problem during the interviews with the experts (interviewee 3 - 7). It can be assumed that the high requirement of implementation ratio of permeable pavements could result in relatively high construction cost to change the foundation, accelerated by the quick-effective construction mindset. Additional, the project was designed in 2020, when Guangzhou was no selected as part of the polit cities, therefore no financial support was provided by the central government. While technically, there is not strict design standard of SuDS measures, the deliverables can still be seen as permeable pavements but with low permeability. As researchers have suggested to consider the types of urban surface when designing the corresponding permeability, keeping the concrete foundation is reasonable when constructing projects on main roads with heavy traffic loads (Yu et al., 2017). However, broad scale implementation of low permeability pavements could result in a waste of infiltration capacity on potential sites, as the deliverables are evaluated based on coverage instead of performance.

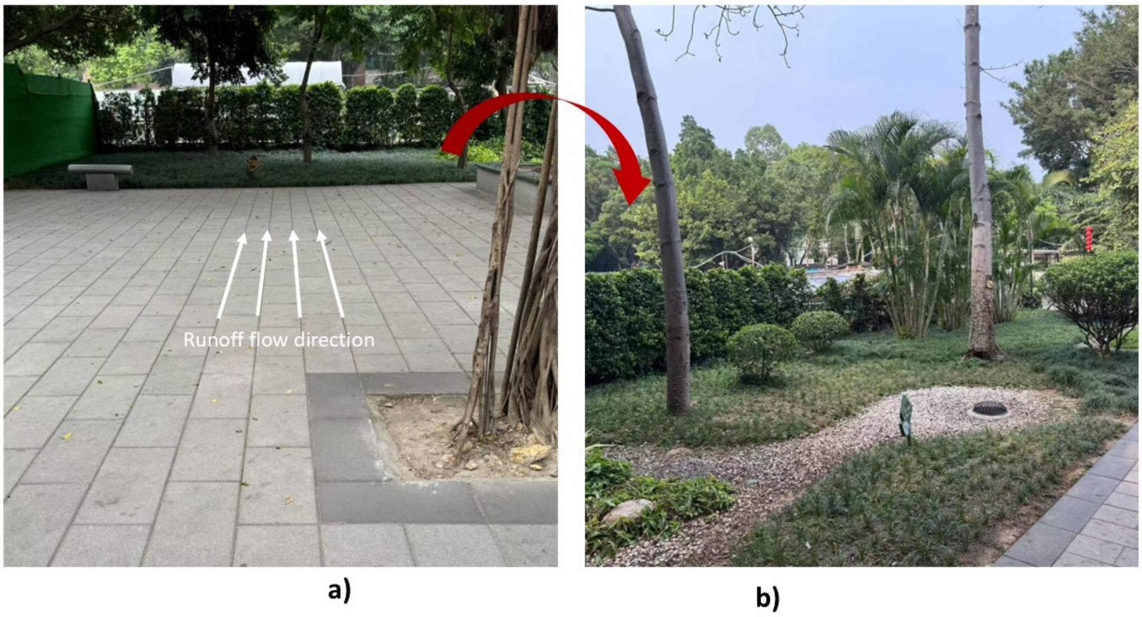


**Figure 5.7:** Pocket Park

## 5.3. Comparative Analysis

The comparative framework is applied to analysis the implementation of climate adaptation strategies in Guangzhou and Amsterdam. The results are presented in Table.5.1, followed by discussions of each items in section.5.3.1 - 5.3.4.

**Table 5.1:** Comparison of Urban Flooding and Climate Adaptation Indicators in Guangzhou and Amsterdam

| Items | Indicators | City | |
|---|---|---|---|
| | | **Guangzhou** | **Amsterdam** |
| **Goal** | Urban Flooding | By 2030, 80% of the urban built-up area should be resilient to 70% of annual rainfall (runoff control ratio); Central districts should be resilient to rain events with a return period of 50 years (100 years). | By 2050, the city should be resilient to rain events with a return period of 100 years (70 mm/h). |
| | Climate Adaptation | No specific target. | By 2050, the city should be climate-proof. |
| **Conditions** | Rate of Separate Sewer | 90% | 75% |
| | Discharge potential (into surface water) | Relatively low | Relatively high |
| | Adaptation responsibility | Mainly Municipality | Municipality, Water Company (Waternet), Individuals |
| | Evaluation Systems | Criteria-oriented Systems | No clear evaluation systems |
| **Instruments** | Implementation Strategies | Dedicated in policy integration, mainstreaming in implementation | Mainstreaming |
| | Public Competence | - | - |
| **Methods** | Financial Support | Central government support; Local Municipality | Support from municipality on public projects. Subsidies for individuals |
| | Ongoing Plans | Guangzhou Sponge City Plan (2015–2030) | Amsterdam Weatherproof (Rainproof) |
| | Tools | SuDS, Grey Infrastructure, Multi-scaled Sponge City Projects | SuDS through public and individual actions |

### 5.3.1. Goal

Both cities have set goals on urban flooding by making the cities resilient to rainfall. In the context of Guangzhou, runoff control ratio is the fundamental indictor to represent the level of rain resistance, with a specific clarification on built-up areas. A comprehensive water safety goal is to be resilient to events with a return period of 50 years by 2030 (see Table 4.2). This goal has been lifted to 1-in-100 years in the most recent plan of the city-scale specialized drainage plan (2022-2035) (Guangzhou Water Affairs Bureau, 2024b). In the According to the storm water intensity formula published in 2023 by the Water Affairs Bureau, the corresponding 1-in-50 years and 1-in-100 years rainfall intensity (with duration of an hour) is 106 mm/h and 120 mm/h respectively.

Amsterdam's rainproof goal by 2020 was to resist rainfall intensity of 60 mm/h without damage to property and infrastructure, as described in the GRPA. It was a sharp change for the city to adapt as the previous rainproof requirement was only established for the piped systems to withstand a 20 mm precipitation within an hour (Guidobono, 2021). The goal has been lifted to 70 mm/h (in accordance with a return period of 100 years) in the OPR, indicating that around 70% of the drainage capacity should be achieved through extra solutions. While the progress of whether the city has achieved the 60 mm/h goal is not provided in the new plan, and the map of bottlenecks (under 60 mm/h) remains the pillar to schedule the project agenda (Gemeente Amsterdam & Waternet, 2022).

It is clear that the climate conditions of the two cities present great difference regarding on annual rainfall volume. In terms of rainfall intensity, Amsterdam is targeting around 2/3 of the capacity that Guangzhou aiming to achieve to deal with (see section.3.1.1) , while time for transition in Guangzhou is 20 years less than Amsterdam, requiring super efficient transformation. Even more rainfall should be handled in Guangzhou, the two cities are targeting at different return period, showing different potential in dealing with future climate changes.

In terms of urban flooding management, the goal of Sponge City policy follows the principle of volume-based control, which requires the municipality to consider own local condition. As aforementioned in Section. 4.3.1, Guangzhou is facing both hydrological and socio-economic challenges to fulfill this goal. While this quantified goal allows the municipality to visualize the progress of administration.

There are no specific climate adaptation plans and goals in Guangzhou. The risks resulting from climate change are not recognized as a major issue by planners and urban designers in Guangzhou (Dąbrowski et al., 2021). While Amsterdam has listed drought, heat stress, flooding and extreme precipitation as the main theme in combating climate change, the mentioned problems are less considered thoroughly in the sponge city plans(interviewee 1, 2). As the goal of sponge city should be adapted to local conditions, water related crises (such as drought, water scarcity are integrated into the category of *Water Safety* which allows the local authorities to plan its own climate adaptive goals (interview 3). Heat stress has been one of the aspect in the consideration of sponge city plan, through the introduce of qualitative goals of mitigation of urban heat island effect (Ministry of Housing and Urban-Rural Development, 2015).

### 5.3.2. Condition

The current drainage systems in both cities show a high ratio of separate sewer systems, which provides great benefits in adaptation. Amsterdam has along history of separate sewer construction, with approximately 75% being separate systems. According to the OPR (Gemeente Amsterdam and Waternet, 2022), The designed and maintained return period for storm water drainage in Amsterdam is 1-in-2 years, with no further plan in enlarging drainage capacity. Drainage construction projects focus on replacing combine sewers with separate sewers. In Guangzhou, the new requirement of designed return period of storm water drainage is 1-in-3 years (Guangzhou Municipal People's Government, 2019a). The existing pipes are capable to address 50 mm/h of rain intensity (Guangzhou Water Affairs Bureau, 2024b), which accounts for half of the capacity of adapting the targeted 1-in-100 years event. The municipality had issued drainage improvement policies, including drainage scheme transition and pumping stations upgrade.

In Amsterdam, due to the regional water draining constrains, the urban canals were not designed with draining capacity. This can be considered as one of the reasons that the municipalities are more in favor of above-ground solutions, such as water retention. Amsterdam Rainproof has included the new Rain Ordinance in the purpose of slow release into surface water. In Guangzhou, urban water channels (Chong) are designed as a historical wisdom to combat with urban flooding. The channels are operated to be a relatively low water level, providing capacities to hold the water during flash downpours and typhoons.

The adaptation responsibility involves the main stakeholders when planing for change. The approach that Amsterdam taken emphasizes on individual responsibility of the residents in climate adaptation, instead of relying on the municipality to provide adaptation service (Dai et al., 2018). In Guangzhou, the role of the municipality is strong in adaptation governance and implementation. It is suggested that climate adaptation plan should consider all stakeholders related, including organizations and city residents, they are currently not included in Sponge City constructions (B. Li, 2013;Nguyen et al., 2019).

A criteria-oriented evaluation system was established in Sponge City construction in Guangzhou. The system is constrained in visualizing the contribution of Sponge City in urban flooding mitigation and climate adaptation. While the evaluation system can serve as an administrative tool to ensure political commitment achievement. The municipality of Amsterdam has acknowledged the necessity of implementing a performance evaluation system, however, there is currently no such system in place (Gemeente Amsterdam & Waternet, 2022).

### 5.3.3. Instruments

Both cities have applied a mainstreaming approach in implementation of the climate adaptation strategies. It is stated in the OPR that the idea of rainproof should be mainstreamed in all urban activities: streets, roofs, parks, buildings, gardens (IWA, 2016). Similarly, Guangzhou's motto of mainstreaming is concluded as *Implemented to the fullest extent* (Guangzhou Water Affair Breaue, 2020).

Due to the unique political nature in China, the mainstreaming of implementation has a dedicated root in policy integration, which indicates a difference in the implementation practices between the two city. As introduced in the section 2, dedicated policy integration generates new political domains and a political commitment which directly calls on local reactions (Uittenbroek et al., 2013). It is clear that Sponge City policy has its own policy domain, consisting a dedicated and constraint requirement for the practitioners to mainstream the implementation. Mainstreaming has lead to board scale project implementation and propaganda, while it was executed in a mandatory way. Sponge City Office was formed in many municipalities in China to supervisor the mainstreaming of Sponge City projects into different urban sectors (D. Yin et al., 2022). A skeptical voice was heard during in the interview with urban developers, questioning the power assigned to this authority.

> The Sponge City Office is a deliberately established institution. There is no other Office established with an equal right as in other domains that the municipality is promoting. (Interviewee 7)

In Amsterdam, the local network approach was applied by Amsterdam Rainproof to mainstreaming the concept of rainproof. The program was established outside the traditional political structure, allowed greater degree of freedom to develop its network and discovering opportunities (Rainproof, 2023). The independent set up of the program was intended to challenge the traditional thinking that government is responsible for addressing all urban water issues, and to spread its motto of engaging all urban sectors (Rainproof, 2023). Internal instruments, such as boundary objects, products for communication, researches are provided by the program.

During the desk-research, not much information on public competence of the two cities were available. Comparing the implementation strategies and land ownership difference, it can be observed that public competence plays a stronger role in Amsterdam.

In Sponge City implementation, local government finance is the main support of project implementation. The Guangzhou is encouraging public-private partnerships (PPP) to attract more funds. From 2015 to 2020, no finical support from central government was allocated, as Guangzhou was not a pilot city. In 2021 , approximately €2.4 billion was provided by the central government to support Guangzhou's demonstration construction.

Amsterdam has designated €1.75 million of a total budget of €70–77 million for the period of 2016–2021 to start the Amsterdam Rainproof policy . This amount does not include the actual implementation of the project but merely costs such as salaries, research and meetings. Sewage levies provide most of the designated budget for Amsterdam Rainproof. Besides these, the municipality also uses other funds to co-finance green projects, such as the budget for transport (Dai et al., 2018). From 2022 to 2027, Amsterdam plans to allocate €3 to 4 million in making the city rainproof. Management cost of the existing SuDS and storage assets was additionally included in budget of operation (Gemeente Amsterdam & Waternet, 2022).

### 5.3.4. Methods

Sponge City construction in Guangzhou has evolved into systematic demonstration phase, which includes the transitional SuDS projects and larger scaled constructions (see Section.4.2.3). Both drainage improvement and Sponge City projects are recognized with contribution to urban flooding (Chan et al., 2021). According to the indicator systems of construction (Guangzhou Municipal People's Government, 2017a), Sunken green space, permeable pavement and green roofs are the three promoted solutions. Sunken green space and permeable pavement are widely construction as they can be easily integrated into different sectors of urban landscape such as urban parks and dwelling areas (Yu et al., 2017;Liu, 2023). Storm water storage tanks are required to compensate for construction with large hard surface coverage (Guangzhou Municipal People's Government, 2017a).

A wide range of solutions are suggested by the Amsterdam Rainproof for residents to make difference to their own living environment. These are small-scale projects which can be implemented by the individuals without complicated designs, such as install rain barrels, taking off tiles and constructing facade gardens. SuDS projects are implemented in pilot districts including green strips and water retention roofs (Rainproof, 2023). The blue-green roof is the backbone of public space projects in Amsterdam (Guidobono, 2021). An individual blue-green roof construction project RESILIO was started 2018 to facilitate the construction of blue-green roofs. In addition, the municipality offers subsidy for the blue-green roof constructions, which drives the (Guidobono, 2021). As suggested by the OPR, drainage-related construction to improve resilience to downpours are avoided.

## 5.4. Discussion and lessons learned

Despite the significant local differences between the two cities of interest, the comparative studies has found a number of similarities regarding the understanding of climate adaptation and implementation approach. The experience analyzed of both cities indicates lessons to learn from each other.

### 5.4.1. Climate Adaptation v.s Economy Growth

Climate adaption has been widely discussed on its ecological values on a more livable future, what kinds of benefit can climate adaptation bring to economy growth are still limited to our knowledge (Adom & Amoani, 2021). One of its benefits can be described through the homogeneous understanding, which is building resilience and address the risk of damage in the face of future uncertainties (Orlove, 2022). While this interpretation in ground practice is found to provide a potential shift to the opposite spectrum of preventing economy damage, aligning with promoting economy growth (Sharma, 2023). In the analysis, the two cities are observed to conserve economy growth over climate adaptation in their strategy implementation.

As analyzed in Section.4.3.2, urban economy development is tended to be prioritized over Sponge city construct, which is treated as a remediation approach to address the risk of urban flooding. Due to the policy nature of China, local governments are the major investors to climate adaptation projects. Financial issues of local government in constructing Sponge City are reported in the previous studied, even within the pilot cities to which specialized funding were provided (H. Li et al., 2017; Nguyen et al., 2019; Griffiths et al., 2020). In addition, money allocated for Sponge City projects does not include the maintenance fee, which could largely impact the cost-effectiveness and performance of the project in the long-term (H. Li et al., 2017; L. Li et al., 2020). Therefore, concerns of whether climate adaptation could pay back are playing as barriers of attracting the interest of both local government and public investors (H. Li et al., 2017; Griffiths et al., 2020). It is not difficult to understand that local government tend to prioritize economy growth over climate adaptation to ensure its own development, as all money comes from one pocket.

While Amsterdam has decentralized the responsibility to all stakeholders, which down-scaled the municipal's role. The government then re-formed into climate adaptation governor instead of major practitioners (Sharma, 2023). This approach is characterized by taking actions through private sectors the challenging the traditional thinking (Rainproof, 2023; Willems et al., 2023). As a result, urban flooding prevention is restructured to be a socio-spatial process whose governance seeks to maximize the voluntary contributions to regulate the threat of climate change and its disruption of economy development (Sharma, 2023). In addition, the resource to improve current sewer conditions are barely attributed , with limited investment allocated to construction a rainproof city in the up coming years as not much facilities were constructed, explained in the OPR (Gemeente Amsterdam & Waternet, 2022). Considering the nature of urban expansion and the city-scale ambition to be the European economy hub, it is arguable that instead of city-scale action on development that enables the climate adaptation, the cost of rainproof is transferred to individuals while the opportunities largely are afforded to corporate and financial interests (Sharma, 2023).

Both cities have discovered the difficulties in bridging the gaps of the significance urban flooding control, and taken a lighter alternatives. Amsterdam has empowered the private parties, while still working towards its initial commitment of being climate adaptive. While the situation in Guangzhou shows more uncertainties. Grey construction may still be favorable in the next coming years (Guangzhou Water Affairs Bureau, 2024b ; Chan et al., 2021). As Sponge City policy is coming to its final assessment in 2030, the next step of the country towards climate adaptation is still unclear.

Through the experience gained from the analysis of the both cases, opportunities in the future planning of adaptation are suggested in the following sections.

### 5.4.2. Opportunities

#### Everyone Counts: Establishing Platform

The role of Amsterdam Rainproof acts like a platform linking all stakeholders, with a well described adaptation motto as *Every drop counts*. The local network approach was examined to be successful in binding stakeholders by providing opportunities for voices being heard and ideas exchange (Willems et al., 2023). When looking at the regional climate adaptation, similar structure exists. The Delta Program acts a long-term advisor to spread the knowledge of adaptation and connecting local governments (Pot et al., 2024).

Similar to the Amsterdam Rainproof motto, the future of climate adaptation should strive to connect everyone in urban community. A platform approach is hereby suggested. Combining the Amsterdam experience and local condition, the characteristics of platforms are summarized as: 1) cross-sectoral communication (within and outside the governance structure); 2) Materials available for public and internal education.

As of the most expressed need to improve climate adaptation capacity of Guangzhou is a open platform to let ideas flow by encouraging communication (Dąbrowski et al., 2021). The current Sponge City Office is only for administrative purpose, by ensuring adaptation through top-down pressure. There is no platform provided by the government or additional institutions to let voices being heard at the table. Standardized methods are provided for private sectors to engage in decision-making and Sponge City implementation, such as that the government's website provides an open window for residents to send their opinions. The overall stakeholder engagement is still constrained in China (B. Li, 2013; Dąbrowski et al., 2021). The strong power executed by the government results in less opportunities for lower-level authorities and individuals to have impacts on implementation. This has raised concerns in multiple aspects regarding climate adaptation. The motivation of private investors on investing Sponge City construction are hindered due to government interventions (L. Zhang et al., 2019). Though residents are not expected to participate in Sponge City construction, the potential lay in the local communities are recognized (such as the public-private-participation model), but not fully utilized in practice. Research suggested that local citizens are willing to participation in construction if contributions of Sponge concept in urban flooding are educated(Y. Wang et al., 2017; Y. Wang et al., 2021). In addition, limited channels and platforms availability has been regarded as one of the main barriers for the public's willingness to participate (Qiao et al., 2020). Apart from public-private communicate platform, internal platform for cross-sectoral knowledge exchange does not exist in the political structure (Dąbrowski et al., 2021). Therefore no tools such as boundary objects can be used to achieve mutual understanding in policy-making. As suggested in Section.4.3.2, it is important to consider drainage scheme in the phase of urban planning, while no platform can facilitate such idea and knowledge exchange. As the implementation of SuDS in climate adaptation strategy may benefit more stakeholders which are not traditionally interested parties, such as health authorities (Ashley et al., 2020), the availability of such a platform could help in policy-making, allowing the maximization of the outcomes. In addition, to facilitate knowledge exchange, the platform should also provide materials made-public to serve as means of public education and engagement (Y. Wang et al., 2021). For instance, a database includes current ground practice and experimental experience of Sponge City and SuDS constructions can significantly benefit the attraction of private investments (H. Li et al., 2017). Additionally, the abundant materials provided by the Amsterdam Rainproof website, such as successful DIY stories and educational reading materials, can be recognized as good examples. During the site visits, educational signboards were established in the sunken green space of Fuli Xiaoqu (see Figure.5.6 (a)), which can be recognized as a form of material availability. It is still confined as one-dimensional communication with residents living in the Xiaoqu.

### Both Soft and Strong Tools

It is analyzed that both of the cities applied a mainstreaming approach in local adaptation implementation, with a target to integrate SuDS projects into all urban activities. Mainstream can be recognized as a soft tool in making impacts on urban development, which provides more flexibility to adapt to future changes (Uittenbroek et al., 2013). While it performs less effective comparing to strong regulations of change, as it relies on actions taken by multiple stakeholders (Uittenbroek et al., 2013).

When considering mainstreaming in terms of content, the dedicated root of Guangzhou Sponge City policy has eased the pressure of finding boundary objects between different stakeholders to gather resources and willingness to participate. Therefore, considering the strongly governed mainstreaming implementation, the Guangzhou experience can be seen as a future vision of how mainstreaming in all urban activities with full cooperation from different parties can look like. A steady speed of change can be hard to grantee without regulations. There is no land ownership conflicts in Guangzhou, therefore the implementation has been put to all scale. While different technical challenges arise due the complexity of existing urban landscape and infrastructures (see Figure. 4.12). The mainstreaming can to an extent to convince local actors to implement SuDS, however, on-field technical solutions are still one of the major challenges. Guangzhou has issued different regulations, management indicators, and design galleries to help different sectors to integrated SuDS into their domains (Guangzhou Municipal People's Government, 2020). It can be difficult to educate all actors without such strong tools (Ashley et al., 2020). Additionally, local regulations were published to ensure SuDS are integrated in all phase of project construction (see Section.4.2.3) to ensure continuity, which was reported as one of problem in Amsterdam Rainproof (Gemeente Amsterdam & Waternet, 2022). While the experience of Guangzhou has shown that experimentation and system performance is given less attention. This can be regarded as a short-cut of a criteria-oriented system. Nevertheless, it can still provide an inspiring perspective that a appropriate mainstreaming could make practical benefits, by encouraging innovations and improvement of knowledge.

The Amsterdam strategy can be summarized as not relying on strong tool (Dai et al., 2018). The rainproof project does not include any regulatory components, while above-ground constructions are criticized by its limitation to fulfill the goal of Amsterdam Rainproof (Sharma, 2023). In addition, private actions could bring a lot of uncertainties, which make it hard to assess the performance of adaptation (Gemeente Amsterdam & Waternet, 2022) and not beneficial to long-term management. The establishment of Rain Ordinance in 2021 can be marked as an new experiment of integrating strong tools by Amsterdam Rainproof, which requires all the new buildings to be equipped to collect 60 mm of rainwater per square foot (Sharma, 2023).

Therefore, it is suggested that both soft tool and strong tool are significant in local adaptation, Which requires a balance. Soft tool is important in establishing mutual understanding and renovations (Willems et al., 2023), while a stronger regulated implementation manner could ensure steadily projects constructions.

# 6 Conclusion

This research was set out to explore the local climate adaption, by studying the Sponge City in China and compare with adaptation strategy in the Netherlands. Addressing urban flooding in the face of climate change was discussed in this studied The research followed a case study approach, where two cities of the countries were selected, Guangzhou and Amsterdam. As China applies a top-down approach in strategy implementation, a policy cycle analysis was first performed to gain better understanding of local interpretation of Sponge City. Amsterdam Rainproof program was studied to explore climate adaptation in Amsterdam. Comparative framework suggested by (Torgersen et al., 2014) was applied to compare implementation of the two cities.

In the following section, conclusions on Guangzhou's Sponge City policy interpretation and implementation are presented in Section.6.1. Section.6.2 concluded the comparison results of climate adaptation in Amsterdam and Guangzhou.

## 6.1. Policy Analysis: Guangzhou

In this study, Sponge City is studied as the on-going climate adaptation strategy in China, as not national climate adaption policy is in power. The principle of Sponge City implicates the principle of address future risks of extreme rainfalls due climate change, requiring cities to seek for adaptive actions (Dąbrowski et al., 2021).

The policy cycle analysis result shows that Guangzhou's Sponge City policy interpretation highly aligns with the national policy in terms of political commitment, planning contents, and the evaluation indicators. Specialized Sponge City plan was composed by Land Resource and Urban Planning Bureau, whose is responsible to localize the policy to at the first place. The plan serves as the primary guidance of Sponge City implementation, dividing the terrain into construction zones with the targeted runoff control ratios. The implementation within the zones applies a mainstreaming approach. Sponge City project is required to be implemented wherever feasible and to maximize coverage. While the local governments are expected to tailored the policy into problem-oriented designed based on their conditions, the Guangzhou version is limited in addressing its own problems.

From strategy making perspective, the interpretation is confined as a one-fits-all model, which is frequently observed in other cities in China (H. Li et al., 2017). The solutions by local government is similar to the SuDS measures promoted by the Technical Design, which is published by central governments as a initial guidance. Sunken green space, Permeable pavements are two widely constructed SuDS in Guangzhou. Additionally, policies on drainage capacity improvements are managed parallel to Sponge City, bringing benefits to urban flooding mitigation. It could result in a greater reliance on the traditional drainage systems, down scaling the benefit of Sponge City.

The analysis has identified three local problems of Sponge City implementation.

Firstly, institutional problems can have negative impacts. As urban planning have multi-objectives, the priority of urban flooding resilience and climate adaptation can be low in the agenda. This research reveals that this institutional problems can contribute to land scarcity and challenges for SuDS implementation. Cross-sectoral communications are constrained in Chinese local government systems. Therefore actors engaged in Sponge City implementation are less heard by each other, resulting in lack of knowledge exchange and misunderstanding.

Secondly, the implementation is highly criteria-oriented. Required coverage ratio of the promoted SuDS are suggested for each construction zones. However, it should be noted that this ratio may not fully capture the actual performance. As a city with abundant seasonal rainfalls, the high requirement of coverage SuDS is limited in dealing with waterlogging. Book-keeping manner in SuDS constructed is observed, which could result in higher cost of construction and ignore the sponge-like potential of natural water bodies. Additionally, high demand on construction and limited space could tend to result in inappropriate designs. While evolutions have been observed in the second policy cycle. In the demonstration phase of Sponge City implementation, traditional SuDS are coupled with drainage zone scale and catchment scale projects to maximized the runoff control capacity.

Thirdly, the capacity of climate adaptation is relatively low. The goal of Sponge City was determined with statistical calculation, which did take climate change into account. Localized weather conditions, such as convective storms with life spans of more than 10 hours, was not considered in the strategy making, while these events are predicted to be severe due to future climate change (J. Yin et al., 2020). Institutional problems could constrain integration of climate adaptation into local political agenda, therefore limiting the capacity.

## 6.2. Comparative Study

The analysis of Guangzhou and Amsterdam reveals different approaches applied by the two cities. Guangzhou translated the top-down policy, while Amsterdam Rainproof determined its own focus on climate adaptation. Their strategies have shown significant difference in governance, stakeholder engagement and implementation approach.

A similarity as analyzed, which indicates a tendency to prioritize economic growth over climate adaption. Local government can tend to prioritize its self-devolvement over climate adaptation (Sharma, 2023). As aforementioned, urban land use could be prioritized for economic development instead of storm water management. Additionally, Sponge City implementation is largely guided by government investment. The stress on finance could lead to shift to capital accumulation instead of Sponge City construction. In Amsterdam, climate adaptation actions are decentralized to all stakeholders, which downscale the municipal's role and limits the investment. This could also lead to a shift to focus on economy growth as less efforts are required from the governments.

This research has suggested opportunities for the two cities in the future based on comparative studies.

First, an inclusive, stakeholder engaging platform is significant in climate adaptation implementation. Amsterdam has provided a good example in engaging all stakeholders, which encourages voluntary contributions and establishes boundary objects to connect everyone. Guangzhou has not yet discovered the potential of its residents. The importance of an platform to facilitate cross-sectoral communicate has also been addressed in the above section. Additionally, the platform should allows material forms information exchange, such as performance data sharing. This could contribute to other barriers in implementation, such as building confident in private sectors to facilitate public-private-partnerships.

Second, a balance between strong tool and soft tool in implementation can bring more benefits. Amsterdam applied the network approach as a soft mainstreaming tool to promote climate adaption, while no strong tools regarding on regulations or policies on drainage improvements were issued. The outcomes shows satisfying quality of projects, while concerns are limited adaptation capacity and the uncertainties of bringing in all stakeholders. Similar mainstreaming approach was applied in Guangzhou, but with means of regulations and standards. The result implicates good steadily implementation speed and coverage, while a relatively unsatisfied performance was observed.

# 7

# Limitation and Recommendation

## 7.1. Limitations

In this study, interview was applied as a data collection method. In the Dutch part of the research, no local experts confirmed the interview invitations within the constrained project duration, which created a significant information gap. Consequently, the findings of Amsterdam are primarily based on desktop study and a supervised site visit. The experience and thoughts of local experts could contribute to a clearer vision of the current progress and obstacles in Amsterdam's spatial adaptation. This would further strengthen the comparison with China and discovering future room of improvements. Therefore, it is reflected in this research that the resource and information availability should be taken into account when designing the research, as it could primarily influences the scope and depth of the research.

In the Chinese part of study, the validity of the data collected could be further enhanced by performing interviews with broader range of interview participants. Interviewee participated in this study involve in policy implementation. However, no experts or officials work in the municipality were included. The absence of municipality officials limited the ability to assess local climate adaptation strategy from a governance perspective, particularly in China, where adaptation goal is closely tied with its political commitment. Interviews with municipal employees could facilitate understanding of institutional capacity, which could further validate the opportunities proposed in this research, such as establishing an open platform encouraging cross-sectoral communication. Additionally, actors responsible for constructed project maintenance were no engaged in this study. As the results indicate that the existing quality of the Sponge City construction and maintenance can be one of the challenges, insights of management and maintenance could contribute to improve the understanding of implementation barriers and technical performance.

Site visits were conducted in both cities to compare the outcome of strategy implementation. Data was gathered through eye observations, which was supplemented by explanations from experts on-site. However, the collected information was limited mainly to the types of technical structures and their apparent quality. Technical details of the SuDS and the local pipe drainage system was not included in this study due to practical reasons, which constrains the ability to evaluate the contributions of SuDS in regional climate adaptation, in response to local strategies. In addition, the site visits did not cover all the SuDS in the study area, which are limited in representing the regional adaptation progress, but rather giving typical examples of the projects implemented.

The comparative framework used in this study considered four indicators, which present a linear process in adaptation: goal setting (Goal), background analysis (Condition), resource allocation (Instruments), and strategy making (Methods). While useful for structuring the analysis, this linear framework may not fully capture the complexity of interactions between actors, and limited reflect the performance of the implementation. The results of this research indicate that adaptation strategy making is not the only one aspect influencing the on-site performance of SuDS, therefore a more comprehensive framework is suggested to assess both policy implementation performance and technical structure performance.

## 7.2. Recommendations for further research

1. This research indicate a perspective of assessing the progress of adaptation, by considering the implemented policy and the resulting implementation behaviors. The result shows that multiple factors could impact strategy implementation, while little information of the quality or quantity of the constructed project is known. To assess adaptation progress, future research direction can contribute to gather field data, such as the coverage, connectivity and hydrological capacity of the SuDS in operation. Qualified or quantified field data is also recommended to be integrated as indicator in policy performance assessment framework, with the objective to reflect on-site performance.
2. The study in Guangzhou shows that the constructed projects may be unsatisfied due to institutional or technical reasons, while such under-performed projects are less studied. Method such as root cause analysis could be of interest to investigate the causes of technical failures.
3. Broader stakeholder engagement is recommended for future research. Including actors across different aspects in climate adaptation, such as municipal officials, designers, and community representatives, would provide a more complete picture of implementation performance. Additionally, such engagement could serve a platform to facilitate cross-sectoral communication.
4. Longitudinal research is encouraged. The example of Fuli Xiaoqu suggests that SuDS performance can degrade rapidly when maintenance is insufficient. Therefore, monitoring SuDS projects over time would reveal how performance evolves under changing climate conditions, and project management, offering insights into long-term effectiveness.

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# A

# Political materials of China

| Item | No. | Citeria | Assessment method |
|---|---|---|---|
| **Water Ecology** | 1 | runoff control ratio | Quantitative |
| | 2 | Ecological shoreline restoration | |
| | 3 | Groundwater level | |
| | 4 | Urban Heat Island Effect | |
| **Water Environment** | 5 | Water environment quality | |
| | 6 | Urban non-point pollution control | |
| **Water Resource** | 7 | Wastewater recycling rate | |
| | 8 | Rainwater resource utilization rate | |
| | 9 | Pipe leakage control | |
| **Water Safety** | 10 | Urban flooding and disaster prevention and control | |
| | 11 | Drinking water safety | |
| **System Construction and implementation** | 12 | Planning and construction control system | Qualitative |
| | 13 | Delineation and protection of blue and green lines | |
| | 14 | Technical specifications and standard construction | |
| | 15 | Investment and financing mechanism construction | |
| | 16 | Performance appraisal and reward mechanism | |
| | 17 | Industrialization | |
| | 18 | Serial demonstration effect | |

**Table A.1:** Performance Evaluation and Assessment Indicators for Sponge City Construction (2015)

| national policy | aims | source (in Chinese) |
|---|---|---|
| The Communist Party of China's State Council policy on urban drainage storm water drainage facility construction notice (April 2013) | — transform water drainage and sewage control systems (by 2023)<br>— promote sustainable drainage construction methods<br>— permeable surfaces area ratio minimum of 40% in new developments<br>— convert impermeable surfaces to permeable surfaces, to store rainwater and reduce hydrograph peak | The State Council of the Peoples' Republic of China (2013) The Communist Party of China's State Council policy on urban drainage stormwater drainage facility construction notice. Notice No. 23 of the State Council (http://www.gov.cn/zhengce/content/2013-04/01/content_5066.htm) |
| The Communist Party of China's State Council policy on promoting the Sponge City-building guidance and aims (October 2015) | — increase implementation of Sponge City approach<br>— rehabilitate urban water ecology<br>— conserve urban water resources<br>— increase storm water drainage capacity<br>— increase public investment in drainage projects<br>— promote human development in harmony with nature<br>— reduce impact of urban development on ecology<br>— infiltrate 70% of rainfall within the development areas<br>— by 2020, 20% of urban areas should achieve the above objectives<br>— by 2030, 80% of urban areas should achieve the above objectives | The State Council of the Peoples' Republic of China (2015) The Communist Party of China's State Council policy on promoting the Sponge City-building guidance and<br>Aims. Notice 75 of the State Council (http://www.gov.cn/zhengce/content/2015-10/16/content_10228.htm) |
| The Communist Party of China's State Council on further strengthening the urban planning and construction management (February 2016) | — draft Sponge City construction guidance<br>— use natural landscape: topography, wetlands, farmlands, woodlands, grasslands, and existing rivers and lakes<br>— develop synergistic eco-spaces to promote water conservation; recycling; flood and water-logging resilience<br>— encourage households to install rainwater collection devices<br>— significantly reduce in urban impermeable surfaces | The State Council of the Peoples' Republic of China (2016) The Communist Party of China's State Council on further strengthening the urban planning and construction management. 6 February 2016 (http://www.gov.cn/zhengce/2016-02/21/content_5044367.htm) |

**Table A.2:** Sponge City related national guidance, adopted from Griffiths et al. (2020)

| national standards | specification | source/citation (in Chinese) |
|---|---|---|
| Outdoor drainage design code (GB50014-2016) | — guidance on rainwater harvesting, transportation, storage, discharge, processing and utilization of natural and artificial facilities, and related management measures<br>— medium-sized cities and small urban water-logging prevention schemes to design for return periods of 10–20 years<br>— no more than 15 cm of runoff depth on road surfaces<br>— engineering and non-engineering measures<br>— used to prepare for and respond to urban water-logging<br>— post-development conditions not to exceed original runoff | Ministry of housing and urban rural development of the People's Republic of China (2016). Code for design of outdoor wastewater engineering (GB 50014-2006), 2016 edition. China Planning Press, Beijing, China. |
| Sponge City construction technology guide—Low-impact development storm water systems construction | — volume runoff objectives:<br>total annual runoff rate to be limited to 15–20%<br>annual runoff control of 80–85% of incident rainfall<br>— peak runoff objectives:<br>city storm sewer and pumping stations to be designed with respect to outdoor drainage design code (GB50014-2016)<br>— stream pollution control targets:<br>classification system for runoff pollutant and to control the frequency and total amount of combined sewer overflow | Ministry of Housing and Urban-Rural Development (2014). The construction guideline of Sponge City in China. Ministry of Housing and Urban-Rural Development, China Planning Press, Beijing, China. |
| The city flood control engineering design code (GBT50805-2012) | — relates to flood control, including storm surge, flood tide and related impacts<br>— flood control and engineering design standards<br>— river flood engineering for 200-year events<br>— urban flood design for 20-year events | Ministry of housing and urban rural development of the People's Republic of China (2012). 'Code for design of urban flood control project (GB/T 50805-2012)', 2012 edition, China Planning Press, Beijing, China. |

**Table A.3:** Waterlogging related national guidance, adopted from Griffiths et al. (2020)

# B

# Challenges of Sponge City implementation

| No. | Implementation Challenges | |
|---|---|---|
| 1 | Technical Challenges | Ambitious goals without sound research basis |
| 2 | | One model to fit every part of the country |
| 3 | | In need of guidance and education/training |
| 4 | | Inappropriate strategies causing further problems |
| 5 | | Unavailable green products and materials |
| 6 | | Insufficient performance data |
| 7 | | Unaddressed operation and maintenance difficulties |
| 8 | Geographical Challenges | Geographical location |
| 9 | | Land scarcity in urban areas |
| 10 | | Climate |
| 11 | | Soil conditions |
| 12 | Financial Challenges | Uncertainty of life cycle costs and benefits |
| 13 | | Challenges in public-private partnership |
| 14 | Legal and regulatory Challenges | |
| 15 | Public acceptance Challenges | |
| 16 | Inter-Agency Cooperation and Data Sharing Challenges | |

**Table B.1:** Local implementation challenges (H. Li et al., 2017)

| No. | Barriers against Sponge City adoption | |
|---|---|---|
| 1 | Technical and physical challenges | Technical gaps and limitations |
| 2 | | Lack of technical guidance and training |
| 3 | | Current and relevant simulation models for Sponge City design |
| 4 | | Unavailable urban performance data |
| 5 | Financial challenges | |
| 6 | Administrative fragmentation | |
| 7 | Public awareness and acceptance challenges | |

**Table B.2:** Local implementation barriers (Nguyen et al., 2019)

| Item | Barriers |
|---|---|
| Institution | • Formal institutional weight and resources of municipal government<br>• Drawing lessons from local experiments is hindered by narrow focus on success stories<br>• Lack of long-termism in decision-making<br>• Extreme segregated policy-making style |
| Idea | • Predominance of short-term thinking about the built environment against planning and urban development stakeholders<br>• Overlook of centuries-old traditions of managing floodwaters in PRD<br>• Perception of flood mitigation as a low priority issue by the actors involved in urban planning and design, let alone real estate developers |
| Interest | • Adaptation goals clash with the political priority given to economic growth and urbanization, forging a close alliance between local authorities and developers<br>• Uncertainties in resources allocated and coordination efforts deployed on the ground<br>• *Planning for growth* paradigm continues to drive rapid urbanization in the PRD |

**Table B.3:** Barriers of improving climate adaption capacity for Pearl River Delta, Dąbrowski et al. (2021)