Urban Sustainable Stormwater Management Described from a Governance Perspective – Challenges and Interdependencies

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Abstract

Conventional stormwater management systems have been criticised as being unsustainable due to increased flood risks downstream and water quality degradation in the receiving water bodies. Use of green infrastructure to manage stormwater has long been suggested, but implementation is still mainly limited to pilot projects. Based on a systematic literature review and two qualitative case studies, governance challenges and their interdependencies influencing implementation of sustainable stormwater management (SSM) were examined.

In the literature review, nineteen governance challenges hindering SSM implementation from a global perspective were identified. Case study 1 examined governance factors influencing SSM implementation from a local perspective under two distinct governance structures, namely, hierarchical in China and non-hierarchical in Sweden. Governance factors found to influence SSM implementation were mapped into causal loop diagrams (CLD) to describe the governance factor interdependencies. Case study 2, investigating the Sponge Cities initiative in China, identified governance challenges influencing a national SSM policy being implemented locally. It was found that conventional grey infrastructure still plays a significant role in the Sponge Cities initiative due to lack of space, a general lack of knowledge of SSM and prioritization of quantifiable objectives within a short time-frame.

The thesis provides an overview of governance challenges and their interdependencies influencing SSM implementation, as well as a visual tool (SSM-CLDs) to help local authorities and non-governmental stakeholders understand the complexities of SSM from a governance perspective.

Keywords: sustainable stormwater management, governance, green infrastructure, policy arrangement model, system dynamics, causal loop diagrams, literature review, case study, Sponge City.

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Hållbar dagvattenhantering beskriven ur ett styrningsperspektiv – Utmaningar och förutsättningar

Sammandrag

Konventionella dagvattensystem har kritiserats för att leda till ökad risk för översvämning nedströms och försämrad vattenkvalitet i recipienterna. Hållbar hantering av dagvatten genom blågröna lösningar har funnits på agendan länge, men implementeringen är fortfarande huvudsakligen begränsad till pilotprojekt. Avhandlingen undersöker hur utmaningar och deras beroendeförhållanden inom styrning och ledning påverkar implementeringen av hållbar dagvattenhantering (SSM – *sustainable stormwater management*). För detta genomfördes en systematisk litteraturstudie och två kvalitativa fallstudier.

I litteraturstudien identifierades nitton utmaningar inom styrning och ledning som hindrar implementering av SSM ur ett globalt perspektiv. Fallstudie 1 undersökte hur styrningsfaktorer påverkar implementering av SSM ur ett lokalt perspektiv under två distinkta styrningsstrukturer, nämligen hierarkiska i Kina och icke-hierarkiska i Sverige. Styrningsfaktorer som visade sig påverka implementering av SSM kartlades i kausala sambandsdiagram (CLDs – Causal Loop Diagrams) för att beskriva beroendeförhållandena mellan styrningsfaktorerna. Fallstudie 2, som undersökte Sponge Cities-initiativet i Kina, identifierande utmaningar för styrning och ledning som påverkar en lokalt implementerad, men nationell, SSM-policy. Det konstaterades att konventionell grå infrastruktur fortfarande spelar en viktig roll i Sponge Cities-initiativet på grund av brist på utrymme, en allmän brist på kunskap om SSM samt på grund av att kvantifierbara mål prioriteras inom den snäva tidsramen för genomförande.

Avhandlingen ger en översikt över utmaningar för styrning och beroendeförhållanden mellan dessa som påverkar implementeringen av SSM. Dessutom presenteras ett visuellt verktyg (SSM-CLD) för att hjälpa lokala myndigheter och icke-statliga intressenter att förstå komplexiteten i SSM ur ett styrningsperspektiv.

Nyckelord: hållbar dagvattenhantering, styrning, blågröna lösningar, policy arrangement model, systemdynamik, kausala sambandsdiagram, litteraturgenomgång, fallstudie, Sponge City.

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Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

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II Qiao, X.-J., Liu, L., Kristoffersson, A., Randrup, T.B. (2019). Governance factors of sustainable stormwater management: A study of case cities in China and Sweden. *Journal of Environmental Management*, 248. https://doi.org/https://doi.org/10.1016/j.jenvman.2019.07.020.

III Qiao, X.-J., Liao, K-H, Randrup, T.B. (2020). Sustainable stormwater management: A qualitative case study of the Sponge Cities initiative in China. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2019.101963

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The contribution of Xiu-Juan Qiao to the papers included in this thesis was as follows:

I Planned the work (80%). Collected, analysed and summarised the data (80%). Wrote the paper (80%). Responsible for correspondence with the journal (100%).

II Planned the work (80%). Collected, analysed and summarised the data (70%). Wrote the paper (80%). Responsible for correspondence with the journal (100%).

III Planned the work (80%). Collected, analysed and summarised the data (90%). Wrote the paper (80%). Responsible for correspondence with the journal (100%).

1 Introduction

The intensity and frequency of extreme climate events are increasing due to climate change globally (Shastri et al., 2019; Tarmizi et al., 2019; Xiong et al., 2019). For example, Ren et al. (2019) report that the probability of floods and droughts during summer will increase in East Asia. Extreme rainfall events are predicted to increase worldwide, with combined changes in the volume and patterns of precipitation (Brudler et al., 2016). As intensity and duration of rainfall events is unsure, it leads to the increase in risks of flooding events (Wang et al., 2018; Zölch et al., 2017).

The global urbanisation rate is predicted to increase from the current 55% to 68% by 2050, with another 2.5 billion people living in urban areas (especially in Asia and Africa) (United Nations, 2018). With increasing urbanisation, the urban surface is becoming covered by more urban infrastructure, which leads to an increase in compacted soils and impervious surfaces (Berndtsson *et al.*, 2019). The hydrological cycle of cities will be disrupted, i.e. reducing infiltration capacity, decreasing groundwater recharge, increasing evaporation (Rodríguez-Sinobas et al., 2018; Wang et al., 2018; Herslund *et al.*, 2018; Zölch et al., 2017; Newcomer et al., 2014). According to Zhang et al. (2016), urban flooding mainly results from modifications of the hydrological cycle by land use transformation. The increase in impervious surfaces leads to a great increase in stormwater runoff volume and shortens the time taken to reach peak flow, which can increase the risk of urban flooding and water-logging in urban areas (Mahaut & Andrieu, 2019; Brudler et al., 2016; Martin et al., 2015; Burns et al., 2012). It has been reported that if there is more than 10% impervious surface in a watershed, stormwater runoff volume will increase rapidly and stream systems can no longer maintain their natural quality (Sohn et al., 2017). Moreover, stormwater runoff (being drained directly to the nearest water bodies) is a major contributor to water quality deterioration (Lizarraga-Mendiola et al., 2017; Martin et al., 2015; Palanisamy & Chui, 2015) and decreasing biodiversity in water bodies (Mahaut & Andrieu, 2019; Rodríguez-Sinobas et al., 2018;

Newcomer et al., 2014; Burns et al., 2012), since it catches bacteria, heavy metals, etc. by washing roofs, roads and parking lots.

In addition, many developed countries are confronted with ageing and old piped drainage systems in urban areas (Mahaut & Andrieu, 2019; Sörensen, 2018). For example, in Sweden, around half of all sewers were constructed over 50 years ago, during the 1960s-1970s (Sörensen, 2018). Meanwhile, developing countries are confronted with inadequately design standard drainage pipes, e.g. drainage pipes in China are designed to deal with only a 1-1.5-year return period of rainfall (Jiang et al., 2017; Xia et al., 2017).

The combination of ongoing climate change, increasing urbanisation and ageing or low standards of drainage pipes brings great challenges to conventional stormwater management systems as a result of water-logging, pluvial flooding and water pollution frequently occurring in urban areas. These cause severe damage to property and threats to human life (Cousins, 2017b; Cousins, 2017a; Dhakal & Chevalier, 2017; Dhakal & Chevalier, 2016). Consequently, conventional stormwater management solutions have been criticised as being unsustainable (Zhang & Chui, 2018; Gao et al., 2016). Thus to contribute to the achievement of United Nations sustainable development goal (SDG) 13 "take urgent action to combat climate change and its impacts", SDG 6 "ensure availability and sustainable management of water and sanitation for all" (including water pollution, stormwater collection) and SDG 11 "making cities and human settlements inclusive, safe, resilient and sustainable" (providing more green space for citizens) (United Nations, 2015), studies on sustainable stormwater management are relevant and urgently needed.

1.1 Conventional and sustainable stormwater management (SSM)

Conventional stormwater management includes combined and separate drainage systems designed to drain away stormwater runoff as rapidly as possible by using curbs, gutters and pipes (Goulden et al., 2018; Prudencio & Null, 2018; Zhang et al., 2017). Sewage management has a long history worldwide and has an important implications for human health and well-being (Lofrano & Brown, 2010). Initially, stormwater was dealt with by sewage drainage systems, which are now called combined drainage systems (Eckart et al., 2017b; Burns et al., 2012). A problem with combined drainage systems is the risk of water pollution, especially when sewer overflows happens, which decreases both the quality and biodiversity of water bodies, e.g. rivers, ponds and lakes (Eckart et al., 2017b; Carlet, 2015; Jayasooriya & Ng, 2014; Burns et al., 2012). Separating the drainage of stormwater from wastewater can decrease the amount of wastewater that needs to be treated in wastewater treatment plants. However, the stormwater runoff drained by separate drainage systems carries oils, heavy metals, bacteria and dust from roads, driveways and roofs, which can still lead to water pollution if the stormwater runoff is drained directly to water bodies. It can be even worse if private stakeholders connect wastewater drainage pipes to stormwater drainage pipes by mistake (Flynn, 2017; Cettner, 2012). In addition, as mentioned above, conventional stormwater management systems have also been challenged due to climate change and urbanisation.

Efforts have been made to develop alternative solutions to manage stormwater in a sustainable way, resulting in concepts and technologies, such as low impact development (LID) in the USA (US EPA, 2018; Ahiablame et al., 2013), water sensitive urban design (WSUD) in Australia (Fletcher et al., 2015; van der Sterren et al., 2009) and sustainable urban drainage systems (SUDS) in the UK (Haghighatafshar *et al.*, 2018a; Ossa-Moreno et al., 2017; Fletcher et al., 2015; Casal-Campos et al., 2012). The core concept of these new approaches is use of green infrastructure (GI), e.g. rain gardens or bio-swales, green roofs, retention and detention ponds, constructed wetlands, etc. to manage stormwater at source and to drain stormwater slowly (Liu & Jensen, 2018; Prudencio & Null, 2018; Liao et al., 2017; Mguni et al., 2016; McMahon, 2002). Such approaches can mitigate environmental problems such as water-logging, pluvial flooding and stormwater pollution (Haghighatafshar *et al.*, 2019; Jiang et al., 2015; Nickel et al., 2014; Keeley et al., 2013). In addition, GI can supply many other socio-economic and environmental benefits, such as providing more green space, improving biodiversity, improving air and water quality, decreasing urban heat island effects and generally creating a coherent networked landscape (Prudencio & Null, 2018; Eckart et al., 2017a; Francis &Jensen, 2017; Shafique & Kim, 2017; Jiang et al., 2015; Ahiablame et al., 2012). In this thesis, these new concepts are referred to as sustainable stormwater management (SSM), which is defined as using GI to control stormwater runoff, purify stormwater and provide many other ecosystem services of benefit for social, economic and environmental purposes.

The fundamental difference between conventional stormwater management and SSM is that SSM tackles stormwater runoff locally through natural processes, while conventional stormwater management relies on grey infrastructure or engineering measures to drain stormwater runoff away as quickly as possible. Thus, SSM addresses the problem on-site, while conventional stormwater management shifts the problem elsewhere. In addition, SSM can provide multiple benefits besides flood hazard mitigation and water quality treatment.

1.2 Why a governance perspective?

To date, conventional stormwater management still dominates in cities worldwide (Cousins, 2017b; Dhakal & Chevalier, 2016; Cettner et al., 2014a; O'Sullivan et al., 2012), while SSM practices are most often limited to demonstration areas or pilot projects (Jiang et al., 2018; Cettner, 2012). Much research has been conducted on the technical aspects of SSM in terms of: infiltration function, e.g. rain gardens (Chaffin et al., 2016; Church, 2015), green roofs (Locatelli et al., 2014; Mees et al., 2013) and wetlands (Schulte-Hostedde et al., 2007); reducing pollutants, e.g. phosphorus and heavy metals (Kaplowitz & Lupi, 2012); and hydraulic models for hydraulic routing on-site (Dietz, 2007; Roldin et al., 2012; Randall et al., 2019). Less research has focused on governance aspects in terms of policies, strategies, resources and perspectives and attitudes of relevant actors (government officials, landscape architects, urban planners, private stakeholders, etc.). The lack of governance-related research can be illustrated by an example. In 2018, the journal *Water* published a Special Issue called *Sponge Cities – Emerging Approaches, Challenges and Opportunities*, which was based on reprinting articles on stormwater management published in the journal from 2017 to 2018 (Zevenbergen et al., 2018). In the preface to this Special Issue, the editors state that approaches and technologies, such as WSUD, SUDS, LID, etc. in many different parts of the world are covered and that case studies from Singapore, India, UK, USA, Vietnam, Uruguay, Norway and the Netherlands are presented. A review of the 29 articles included in the Special Issue revealed that only two were concerned with governance issues, while all the others focused on technical issues.

It is often argued that the slow pace of SSM implementation at city level is mostly influenced by governance factors, rather than technical aspects (Dhakal & Chevalier, 2017; Cettner et al., 2014a; Jeong, 2010). Similarly, it is claimed that governance issues, as opposed to purely technical issues, are a significant factor for a successful social-technical transition, e.g. SSM implementation (Bos & Brown, 2012). For example, governance challenges such as multiple administrative boundaries, numerous stakeholders and the involvement of different levels of government can influence the scaling up of SSM implementation at city level (Bos & Brown, 2012). Some of the research conducted to date using a governance perspective were reviewed in the following.

Some studies have focused on finding challenges to SSM implementation. Roy et al. (2008) listed seven impediments to SSM implementation, based on cases in the USA and Australia. Barbosa et al. (2012) discussed relevant factors affecting SSM including geophysical, law and social, technical and economic factors. Ferguson et al. (2013) explored factors influencing the water system changes in Melbourne, and revealed that cultural-cognitive, normative and regulative dimensions influencing greatly, e.g. cultural beliefs for the water profession, new knowledge through evidence and learning, political leadership, better coordinated governance arrangements and strong market mechanisms. Cettner et al. (2014a) examined contexts influencing Swedish municipality actors' receptivity to SSM, and claimed that respondents were professionally prepared for change but not practically prepared due to inadequate supportive contexts. Flynn & Davidson (2016) identified influencing factors of GI adoption in urban stormwater governance decisions. Dhakal & Chevalier (2017, p. 171) explored 29 barriers to implementing GI in 10 U.S. cities by assessing relevant city, state and federal policies, which showed that most of the barriers arose from "cognitive limitations and socio-institutional arrangements". Herslund *et al.* (2018, p. 327) argued that a transition towards more sustainable GI practices in two Africa cities potentially hindered by "little capacity for adapting planning regimes towards GI thinking", lack of knowledge within the city administrations, lack of coordination between administrative bodies and lack of public participation.

Some research had focused on private stakeholder involvement or public participation. Bos & Brown (2015) studied the role that communities play in managing stormwater runoff from their properties and found that increasing motivation and building community trust were significant for community participation. Newburn & Alberini (2016) studied the willingness to pay for a rain garden based on household survey data from the Baltimore-Washington corridor, while Chui & Ngai (2016) also studied willingness to pay of city dwellers for sustainable drainage systems in Hong-Kong. Habtemariam *et al.*, (2019) identified that a hierarchical and centralized governance system may hinder the engagement of potential executive champions into GI projects.

Some research have been conducted from a general governance perspective. The current stormwater governance was pointed out not suitable for the decentralised stormwater management approach which tends to involve multiple stakeholders (Dhakal & Chevalier, 2016). A participatory governance is recommended by including private stakeholders in GI implementation (ibid.). The stakeholders' perspectives of stormwater management in the city of Chicago were examined and two dominant perspectives existed: science and data-driven approaches and integrated management approaches (Cousins, 2017a). A study examined stormwater governance in Los Angeles in terms of the reasons behind different understandings of stormwater and how relevant actors interact in different institutions (Cousins, 2017b). A study taking Melbourne and Copenhagen as cases, compared the different physical, organisational and cultural contexts in the two cities and concluded that Melbourne currently has a strong integrated understanding of stormwater control measures, while that does not exist in Copenhagen (Madsen et al., 2017).

Research on governance issues can provide many opportunities for improving understanding, increasing political and private stakeholder support and formulating policies and strategies for more sustainable landscape development (Albert et al., 2019). However, there was no overview on the current status of SSM seen from a governance perspective, on how different governance factors influence each other and on how their interdependencies may influence SSM implementation. Governance structures and governance arrangements are expected significantly influence SSM implementation, but currently no research focuses on these aspects. Moreover, several studies on SSM has been conducted on a community or local government level, as described above, but few studies have examined how a national level SSM policy is implemented locally. Therefore, it is also relevant to study the actual implementation of a national policy at local level see from a governance perspective.

In this thesis, several governance related terms were used, i.e. governance challenges, governance factors, governance structures, governance arrangements. Table 1 explains the slight difference among these terms.

Table 1. *Explanation of terms used in this thesis*

Terms used in this thesis	Explanation
Governance challenges	To describe the challenges hindering SSM implementation. It is written like ‘lack of funding’, ‘lack of space’, etc.
Governance factors	To describe the factors influencing SSM implementation. The factor can be a barrier or a driver e.g. ‘funding’ and ‘space’, etc.
Governance structures	To describe the organizational structures of governments in a country e.g. China: hierarchical; Sweden: non-hierarchical.
Governance arrangements	To describe the interaction between actors and other dimensions including resources, rules of the game and discourses in a governance issue.

1.3 Aim and objectives

The overall aim of this thesis was to determine how different governance factors influence SSM implementation. Specific objectives were to:

1. Create an overview of governance factors (or challenges) to SSM implementation.

2. Determine how different governance factors influence each other in relation to SSM implementation.

3. Critical review on how governance challenges influence a national SSM policy being implemented locally.

1.4 Background to case studies-stormwater management in China and Sweden

During the past 10 years many Chinese cities have been confronted with severe water problems, especially pluvial flooding. For example, 62% of 351 cities suffered pluvial flooding during 2008-2010 and a heavy rainstorm in Beijing, the capital city of China, caused the death of 79 people in July 2012 (People.cn, 2012b). It is one of the consequences of the significant increase in impervious surfaces (Jiang et al., 2018; Li et al., 2017; Xia et al., 2017). The rate of urbanisation in China has increased from 18% in 1978 to 60% in 2018 (National Bureau of Statistics of China, 2018). At the 18th National Congress of the Communist Party of China in 2012, 'ecological civilisation' was set as an important national goal. Environmental protection and sustainable development were stressed to address urgent environmental problems, e.g. water pollution, pluvial flooding, air pollution, etc. (People.cn, 2012a). In 2013, the Chinese president Xi, Jinping stated the necessity of building "Sponge Cities that are capable of natural accumulation, infiltration and purification" of stormwater (People.cn, 2013). This is viewed as a part of 'ecological civilisation' of China (Ministry of Housing and Urban-Rural Development (MHURD), 2014). 'Sponge City Technical Guidelines – Low Impact Development' was published in 2014 (MHURD, 2014), which can be considered as the official launch of the Sponge Cities initiative, as a national policy to guide the building of Sponge Cities throughout mainland China. During 2015-2016, a total of 30 cities were selected as pilot Sponge Cities and granted financial support of amounting to a total of 39.9 billion RMB (approx. 5.4 billion Euro) by the central government to complete relevant projects within three years i.e. by 2018 and 2019.

A Sponge City, the Chinese form of SSM, is defined as a 'sponge-like city' that can infiltrate, retain, store, purify, use and drain stormwater when needed (MHURD, 2014; Randall et al., 2019). Differences between the Sponge City concept and conventional stormwater management are shown in Figure 1. To accelerate the construction of Sponge Cities, a series of documents has been published by the Chinese central government. The document 'Instructions on Promoting Sponge City Construction by the General Office of the State Council NO.75' establishes the goals for Sponge City construction, which are that 70-85% of annual precipitation should be managed onsite, that 20% of urban built areas should achieve this goal by the year 2020 and that 80% of urban built areas should achieve this goal by 2030 (The General Office of the State Council, 2015). The documents ‘Performance Evaluation and Assessment Indicators for Sponge City Construction’ (MHURD, 2015) and ‘Assessment Standards for Sponge City Construction’ (MHURD, 2018) are intend to assist in implementing and assessing the performance of Sponge Cities. As the Sponge City concept is quite new, it is still driven by pilot projects located within demonstration zones (the demonstration zone in each pilot city exceeds 15 km^2) and has not yet been implemented at city or regional scale (Dai et al., 2017).

In Sweden, annual precipitation and extreme rainfall events are predicted to increase during summer in the future (SMHI, 2016). In 2014, an extreme rainfall event led to pluvial flooding in Malmö, Sweden, that caused great economic losses estimated at 60 million Euro (Malmö Municipality, 2017). In 1980s, Peter Stahre, working at VA Syd (a water and sewage organization cooperating with five municipalities Burlöv, Eslöv, Lomma, Lund and Malmö in Skåne, Sweden), began strongly promoting the implementation of ‘sustainable urban drainage systems’ (Swedish term for SSM). Many successful pilot projects were implemented in Malmö as described in the book *Blue-green Fingerprints in the City of Malmö* (Stahre, 2008). One of the best known projects is ‘Eco-city Augustenborg’, which was implemented in 1997 in the Augustenborg district of Malmö (Haghighatafshar et al., 2018b; Stahre, 2008). In this case, most stormwater is managed near the source, while excess water is managed in open drainage systems. In the extreme rainfall event in 2014 that caused damaging pluvial flooding in many areas of Malmö, Eco-city Augustenborg suffered no pluvial flooding (Sörensen, 2017). The leaders in the project are the MKB housing company in Sweden, Malmö Service Administration and Malmö Water. Before implementation, the design ideas were discussed with local residents and then refined and developed further based on these discussions (Stahre, 2008).

In Stahre’s book, SSM solutions are categorised into four types (Figure 2): (i) ‘source control’ on private land; (ii) ‘on-site control’ on public land. Both are using small-scale solutions such as green roofs, rain gardens and permeable pavements, to manage as much stormwater locally as possible; (iii) ‘process control’, using swales, ditches/creeks, canals, etc. to transport stormwater slowly; and (iv) ‘downstream control’, using large-scale facilities, e.g. dry basins, large ponds, wetlands, etc. for temporary detention. However, SSM has not yet been mainstreamed at city level in Sweden, despite growing knowledge of the increasing risks of pluvial flooding and water pollution (Cettner et al., 2014b; Cettner et al., 2014a). Social-organisational barriers are reported to be the main factor inhibiting implementation of SSM solutions in Sweden (Sörensen, 2017; Cettner et al., 2014b; Cettner et al., 2014a; Cettner et al., 2013; Cettner et al., 2012).

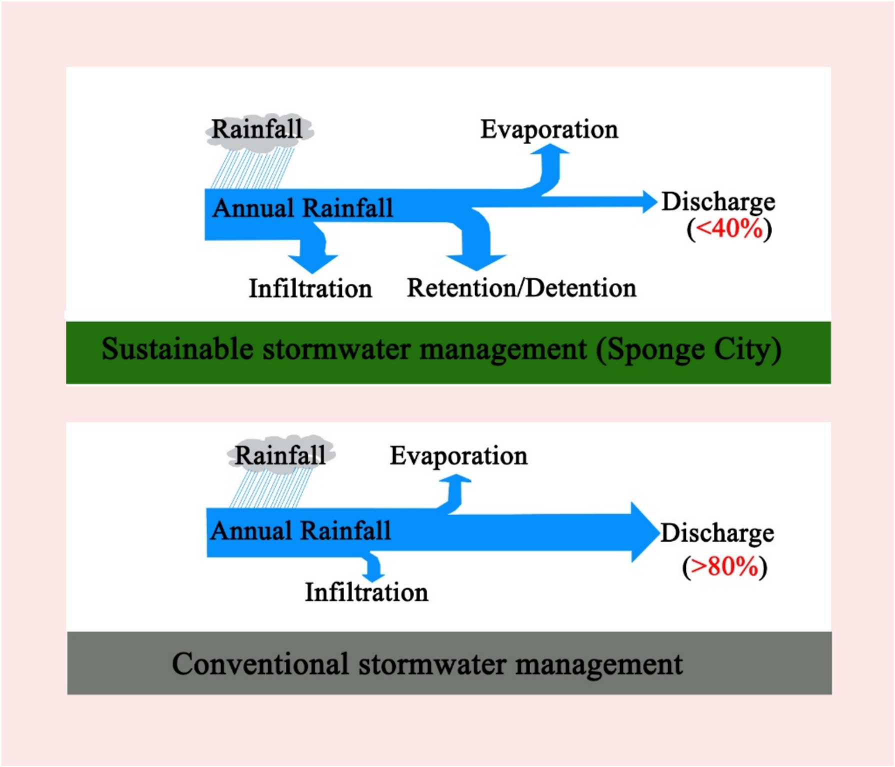

Figure 1. Sponge City concept in China (adapted from Sponge City Technical Guidelines – Low Impact Development. MHURD, 2014).

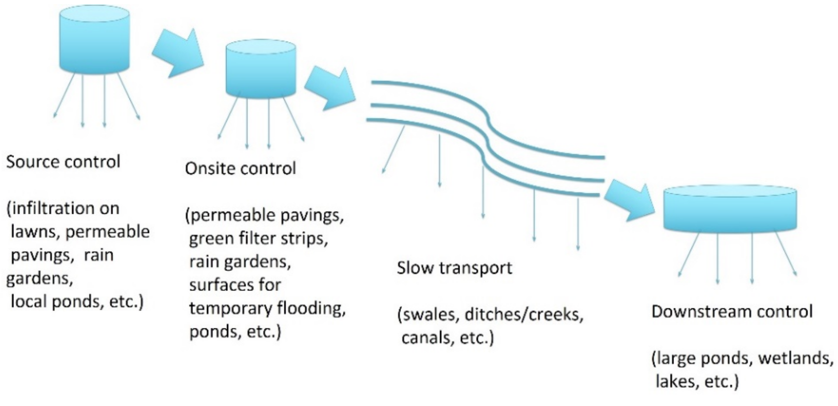

Figure 2. Sustainable stormwater drainage systems in Sweden (adapted from Stahre, 2008).

1.5 Thesis structure

This thesis consists of six chapters.

The present chapter (Chapter 1) provides an overall introduction to the thesis by describing the conventional stormwater management and SSM, the aim and objectives and background to case studies.

Chapter 2 introduces the core theoretical concepts and frameworks used in the thesis: green infrastructure, governance, policy arrangement model, governance arrangements and system dynamics and causal loop diagrams (CLD).

Chapter 3 describes the research design and the methods used in the thesis, i.e. literature review, interviews, site visits and document analysis.

Chapter 4 presents results of this thesis by summarising and synthesising Papers I, II and III.

Chapter 5 provides suggestions on ways to address the identified governance challenges and then discusses the unique challenges faced by SSM implementation, the validity of built SSM-CLDs, suitable governance arrangements and the importance of long-term management.

Chapter 6 presents some overall conclusions and proposes potential topics for future research.

2 Theoretical concepts and frameworks

This chapter describes the core concepts and theoretical frameworks used in the thesis.

2.1 Green infrastructure

In general, green infrastructure (GI) is known as “the ecological framework for environmental, social and economic health” (Benedict, 2006, p. 1). GI as a concept originated in the USA in the 1990s as a new design approach or green framework to deal with urban sprawl. It stresses sustainable use of land and protection and restoration of interconnected green spaces to provide benefits for environmental, social and economic development (Benedict & McMahon, 2002). Benedict (2006) defined GI as “an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions to sustain clean air and water and provides a wide array of benefits to people and wildlife” (p. 1).

Later in its development in the USA, GI came to be viewed as an important tool for managing stormwater in a sustainable way and is now often used interchangeably with the term low impact development (LID). LID aims to tackle stormwater at source with natural, small-scale approaches and it helps to delay the time to reach stormwater runoff peak flow, reduce the runoff volume and stormwater pollution (US EPA, 2018; Ahiablame et al., 2012). Commonly used LID practices are generally of two types, namely, (i) infiltration-based techniques: swales, infiltration trenches, basins, unlined bio-retention systems (rain gardens), sand filters, porous pavements, etc. and (ii) retention-based techniques: wetlands, ponds, green roofs, rainwater harvesting (tanks, storage basins) (Liao et al., 2017; Fletcher et al., 2014). In the LID approach, GI refers to natural or semi-natural measures for stormwater management, e.g. bio-swales, rain gardens, green roofs, wetlands, etc. Detailed explanations of these GI-based measures can be found on the website of the United States Environmental Protection Agency (US EPA, 2018). In the LID context, GI is green stormwater infrastructure for mitigating pluvial flooding and reducing stormwater pollution (Finewood et al., 2019; Harrington & Hsu, 2018; Ahiablame et al., 2013). It is emphasised that high technological and professional knowledge of GI is needed for stakeholders who would like to engage in stormwater management (Finewood et al., 2019).

In Europe, the understanding of GI is broader and focuses more on socio-ecological principles, e.g. human well-being, rather than technological strategies (Gulsrud et al., 2018; Pauleit et al. 2017). The European Commission describes GI as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Commission, 2019). Thus, the function of GI is not only to manage stormwater, but also to provide general ecosystem services in terms of provisioning services (e.g. providing food and raw materials), regulating services (e.g. improving stormwater quality, reducing stormwater quantity, decreasing urban heat island and increasing air quality), cultural services (e.g. providing recreation and education opportunities and increasing human health and well-being) and supporting services (e.g. providing habitat for biodiversity) (Gulsrud et al., 2018; Faivre et al., 2017; Maes & Jacobs, 2017; Kabisch et al., 2016; Eggermont et al., 2015; Lerer et al., 2015). In this broader understanding of GI, stakeholders are more likely to engage in the process of GI management than stakeholders in the USA who has to have a more strict technological understanding of the term. Involvement of various stakeholders in GI-related processes has led to use of the term 'governance'.

2.2 Governance

Governance, as a concept, is widely used in social and political science. van den Bosch (2015) defined it as "efforts – typically at the more strategic level – to direct human action towards common goals and more formally as the setting, application and enforcement of generally agreed to rules" (p. 3). In a strict definition, governance, as opposed to conventional government, is characterised as non-hierarchical, less formal, involving multiple decision centres and focusing on the involvement of citizens and other stakeholders in the process of decision making (Jansson et al., 2018; van den Bosch, 2015; Goetz, 2008). It aims to shift from 'governance by government' to 'governance with government' or even 'governance without government' and to increase involvement by citizens and other stakeholders in decision making (van den Bosch, 2015). However, the shift from 'governance by government' to 'governance with/without government' has been criticised as ambiguous (Goetz, 2008), since “governance cannot supplant government, but is, in fact, critically reliant on the latter” (ibid., p. 264). Studies also show that very large units (e.g. the national government) or very small units (e.g. community-based organizations) alone do not perform better than a mixture of large-, medium- and smaller-scale organization (Nagendra and Ostrom, 2012; Ostrom, 2010). In a broad definition, governance is viewed as a policy process of the organisational ways or the interaction between different social and political actors (Kooiman, 2003), which aims to promote the policies for public purposes in many ways at multiple scales and can comprise governing by, with or without the state (Jansson et al., 2018; Arts et al., 2006). In this thesis, governance is viewed from a broad perspective and the policy arrangement model (Arts et al., 2006) is applied as an outset for broader understanding of various governance arrangements.

2.3 Policy arrangement model

The policy arrangement model (PAM) was first developed in environmental policy studies. It is defined as the temporary stability of substance and organisation of a policy domain (Arts et al., 2006) “at a certain policy level or over several policy levels – in case of multi-level governance” (Leroy & Arts, 2006, p. 13). A policy domain means policy practice regarding an issue, e.g. climate change, pluvial flooding, air pollution, etc. An arrangement shows the link between patterns of interactions among actors and its social-political structure (Arts et al., 2000). The definition of PAM is based on two key concepts: institutionalisation and political modernisation.

Institutionalisation means the steady stabilisation of e.g. defining problems and approaches, practising strategies and solutions in a specific policy domain and gradually fixed “patterns of divisions of tasks, interactions between involved actors and rules of the game, etc.” (Leroy & Arts, 2006, p. 10). Based on this concept, a policy arrangement means that daily policy practices and the interactions of the actors involved evolve into almost stable patterns. These institutionalised patterns include both substantial and organisational matters and their interactions (Arts & van Tatenhove, 2006) and the institutional dynamics reflect recent changes and stabilisation of patterns in environmental policies.

Political modernisation means that “structural transformations in political domains in contemporary societies” (Arts & van Tatenhove, 2006, p. 21) and influence daily policy practices and vice versa. This is an ongoing, but not a simple, linear and historical process, e.g. from ‘tradition’ to ‘early modernity’ and to ‘late modernity’. The changing process is complex, non-linear and normally unplanned, containing traditional and modern structures and a mixture many-sided loops and feedbacks (ibid.). Structural transformations provide the social-political structural context for the actors involved to take relevant actions (ibid.). In other words, a policy arrangement reflects a “long term contextual societal and political trend and process” (Leroy & Arts, 2006, p. 13).

In summary, PAM represents a temporary state or balance between institutionalisation (stability) and political modernisation (change) and aims at explaining institutional patterns of ‘change and stability’ in substantial and organisational matters and the mechanisms behind these dynamics. A PAM structure can be depicted as a tetrahedron (Figure 3), which helps to understand the approach. The structure includes four dimensions: actors (including their oppositions and coalitions), resources (resources division between these actors), rules of the game (e.g. procedures, routines, legislations, etc.) and discourses (e.g. concepts, ideas, views, values, definitions and solutions of problems, etc.) (van den Bosch, 2015; Liefferink, 2006). The former three represent organisational matters, while the ‘discourses’ represents substantial matters (Leroy & Arts, 2006; Liefferink, 2006; Arts et al., 2000). The four dimensions are profoundly interconnected and each dimension affects the others and changes the shape of the entity (ibid.). For example, actors’ interactions are governed by rules; resources e.g. money and personnel, are controlled by certain actors and the division of resources can be changed by the powerful actors; discourses can help to gain resources, e.g. political legitimacy; discourses can also influence the involvement of different actors, such as the emerging concept of public private partnership; and actors can change the content of the narratives and even introduce new narratives, which means a discourse is produced and transformed by relevant actors (Liefferink, 2006; Arts et al., 2000).

In the specific context of stormwater management, actors are individuals or organisations involved in governance processes, e.g. landscape architects, urban planners, water professionals, organisers of municipalities, stakeholders, etc. Resources include many types, e.g. financial resources, knowledge, skills and land. Rules of the game are the current guidelines for actors when determining actions on implementation of stormwater infrastructures. Discourses refer to perspectives on the practices of stormwater management and, through this, new ideas and concepts of stormwater management being produced.

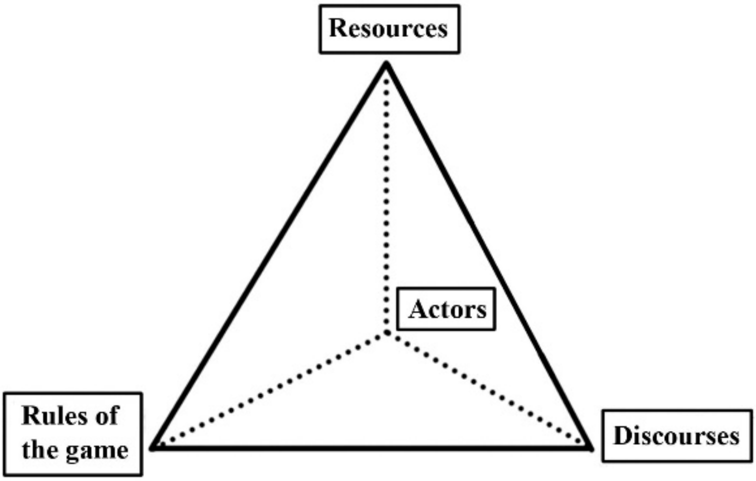

Figure 3. Policy arrangement model (adapted from Arts et al., 2006).

2.4 Governance arrangements

The discourses dimension in the PAM at a macro level refers to "general ideas about the organisation of society, particularly the relationship between state, market and civil society, e.g. the preferred mode of governance" (Liefferink, 2006, p. 58). Kooiman (2003) suggests three governance modes (hierarchical governance, co-governance and self-governance) to illustrate modern governance structures. However, it is difficult to distinguish and define interactions between government and non-government actors in the co-governance mode. Arnouts et al. (2012) expanded these three modes into four, namely hierarchical governance, closed co-governance, open co-governance and self-governance (Figure 4). Governance modes shift in terms of the active actors in a specific period, because of the changes of other dimensions in PAM. To permit analysis of governance shifts, the four governance modes can be connected with the four aspects of PAM to address the changeability and stability of governance (see Table 1 in Paper I). Four government arrangements emerge: hierarchical governance, closed co-governance, open co-governance and self-governance (Arnouts et al., 2012). In a hierarchical governance arrangement, the primary actors are mainly from a government and hold the power to decide on use of resources and to force actions. In a closed co-governance arrangement, strictly selected actors, including government and non-government actors, cooperate based on specific goals and pooled power. In an open co-governance arrangement, many different types of actors conduct actions by devising power and cooperate flexibly based on their resources. In a self-governance arrangement, non-government actors play a leading role in distributing resources and decision making, which is consistent with the strict definition of governance as described in section 2.2. In addition, a polycentric governance arrangement was suggested for the analysis of collective-action problems involved in the provision of diverse public goods and services (Ostrom, 2010). "Polycentric connotes many centres of decision making that are formally independent of each other" (ibid. p. 552). A polycentric governance system is a governance system, which recognizes the complexity of natural resource governance and relies on multiple levels of governments and also seeks to cope with individuals (Nagendra & Ostrom, 2012; Ostrom, 2010). The polycentric governance arrangement as described by Ostrom (2010) is similar to the open co-governance arrangement defined in this thesis as they both include multiple actors, e.g. individuals from outside the formal governments.

In many cases, co-governance or even self-governance arrangements are emerging, especially with the appearance of grass-root innovations (Smith et al., 2014). However, a self-governance arrangement or grass-root innovations are difficult in practice. For example, based on the study of community-based forest management, Ostrom (2010) showed that not all local communities held the needed skills and knowledge for practising forest management. Based on the strict definition of governance, actors are dependent on each other by achieving landscape management-related knowledge (Jansson et al., 2018). However, in both conventional stormwater management and SSM, private stakeholders rely on municipalities to provide relevant knowledge. Water management is usually considered the responsibility of local governments, which are tasked with building water supply and drainage systems. Actually, in many countries stormwater management is seldom the designated responsibility of any specific municipal department. The more frequent occurrence of pluvial flooding in recent years has brought this to the attention of citizens and governments. The municipal water department is normally viewed as being responsible for stormwater management. Even in a non-hierarchical government society such as that in the USA, researchers have found that local governments play a leading role and that a hierarchical governance arrangement is still the mainstream approach in stormwater management (Finewood et al., 2019; Harrington & Hsu, 2018; Finewood, 2016). This confirms the validity of defining governance in a broad way in this thesis.

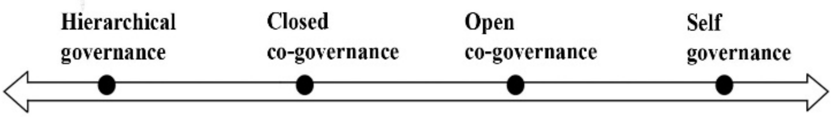

Figure 4. Governance arrangement model (adapted from Arnouts et al., 2012).

2.5 System dynamics and causal loop diagrams (CLD)

System dynamics, which was originally developed by Jay W. Forrester in 1950s, is an approach that helps to understand a complex, non-linear system (Forrester, 2007; Stave, 2003). A system dynamics model can describe core feedback structures in a system (Stave, 2003). In a complex system, one component change may lead to a series of consequences and unexpected changes in other components (Stave, 2003; Guo et al., 2001). People can observe the structure of a system, but it is not easy to predict the behaviour of a complex and interdependent system (Stave, 2003). Based on the approach, government officers or decision makers can testify optional policies, make sound decisions, formulate long-term strategies and communicate information about the structure of a system with multiple stakeholders by displaying them visually.

As described in section 2.3, PAM is not a static model, but stresses ‘change and stability’. PAM aims at explaining the institutional patterns of ‘change and stability’ in matters of organisational (actors, resources and rules of the game) and substantial (discourses) and the mechanisms behind these dynamics. The changing process is complex, non-linear and largely unplanned and includes many-sided loops and feedbacks (Arts et al, 2006). Thus, system dynamics can act as a good tool for in-depth analysis of the dynamics behind the ‘changing and stabilising’ institutional patterns within a PAM.

System dynamics modelling comprises the following six steps (Gohari et al., 2017; Stave, 2003):

- Define the problem: identify one or more key variables whose behaviour over time defines the problem (step 1).
- Describe the system: set a system boundary; based on causal loop diagrams (CLD) describing the system structure which can show the problematic trend (step 2).
- Develop the model: develop a stock and flow diagram to build a simulation model (step 3).

- Build confidence of the model: with computer simulation technology evaluate model performance before using the model to identify and test policy options. The model developed must be validated against the anticipated problematic trend (step 4).
- Use the model for policy analysis (step 5).
- Use for public outreach (step 6).

In step 2, the CLD is introduced as a key tool in system dynamics for visually describing the holistic understanding of the structure of a system (Winz et al., 2011). In a feedback loop in a CLD, a change in one component can lead to changes in other components along the loop, resulting in further change to the initiating component (Stave, 2003). The causal relationships between components can be positive or negative. If a change in the originating component causes a change in other components that strengthens the feedback loop, it is a reinforcing (positive) feedback loop (marked R). If changes in other components counteract the original change, the feedback loop is a balancing (negative) feedback loop (marked B). The depiction of relationships between the components is based on arrows with a positive (+) or negative (-) sign placed beside the arrow head to indicate link polarity (Sterman, 2001).

In this thesis, the overall problem defined was that conventional stormwater management still dominates in cities worldwide, while the SSM implementation is still limited (step 1). In many studies, system dynamics as an approach has been applied to analyse a physical system, like energy, water resources, or waste management (Gohari et al., 2017; Wei et al., 2016; Caponio et al., 2015; Vafa-Arani et al., 2014; Zarghami & Akbariyeh, 2012; Rehan et al., 2011), but in this thesis, the system defined focuses on the internal relationships of a governance system for SSM implementation set by the four aspects of the PAM (step 2). In this system, the discourses are viewed from a concrete policy level, which means particular actors (landscape architects, urban planners, water professionals, organisers of municipalities, stakeholders, etc.) act based on division of resources and rules of the game regarding SSM implementation. The discourses in terms of general ideas regarding the organisation of a society (Liefferink, 2006), e.g. governance modes as explained in section 2.4, lie outside the boundary of the system. Factors, e.g. climate change, urbanisation and ageing piped systems, influencing the general ideas regarding the organisation of a society are also viewed as outside the boundary of the defined system. Figure 5 shows the governance system defined in this thesis and its external influencing factors. Within the governance system, the actors, resources, rules of the game and discourses in the PAM describe the hypothetical structure. CLD can help to map the structure and analyse the interdependencies of these four aspects. As the system defined in this thesis is not a physical system, the quantitative stock-flow model was not built (step 3). The related step 4 (computer simulations) was also not applied, but testifying the validity of the CLDs built was covered in the discussion section 5.3. Step 5 (use for policy analysis) and step 6 (use for communication) were also discussed in section 5.3.

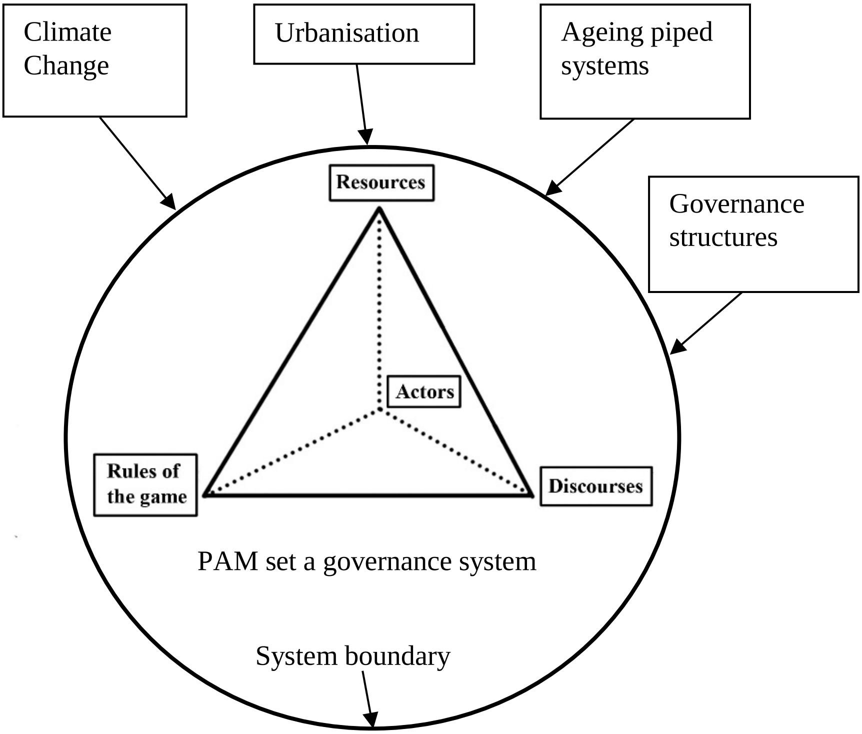

Figure 5. A governance system for SSM and its external influencing factors.

3 Research design and methods

This chapter describes the research design and methods used in this thesis. Overall, a mixed method research approach was applied. An initial comprehensive literature review was conducted in order to gain an overview of the current research setting (Paper I). Then, two qualitative case studies (Yin, 2015) were conducted (Papers II and III). The research design is depicted in Figure 6 by showing the interrelations of the three individual papers.

3.1 Literature review

Before conducting qualitative research, a literature review can provide an overview of the research topic (Yin, 2015). Therefore, a systematic literature review was conducted to review governance challenges to SSM implementation from a global level. The detailed search process used to locate relevant literature is shown in Figure 3 in Paper I. In total, 44 papers were reviewed. The governance challenges identified were categorised in terms of four aspects (actors, resources, rules of the game, discourses), based on the theoretical PAM framework described in section 2.

3.2 Case studies

A case study is an empirical investigation of a contemporary phenomenon in depth and within its real-world context, especially when the boundaries between phenomenon and context may not be clearly evident (Yin, 2013). The focus in the two case studies conducted in this thesis was on understanding the behaviours, roles, attitudes and perspectives of local government officials as the primary participants in stormwater management in a real-world contextual condition of urban areas. A case study can address the explanatory ‘how’ and ‘why’ questions by studying the phenomenon in depth (Yin, 2013). Thus, it is

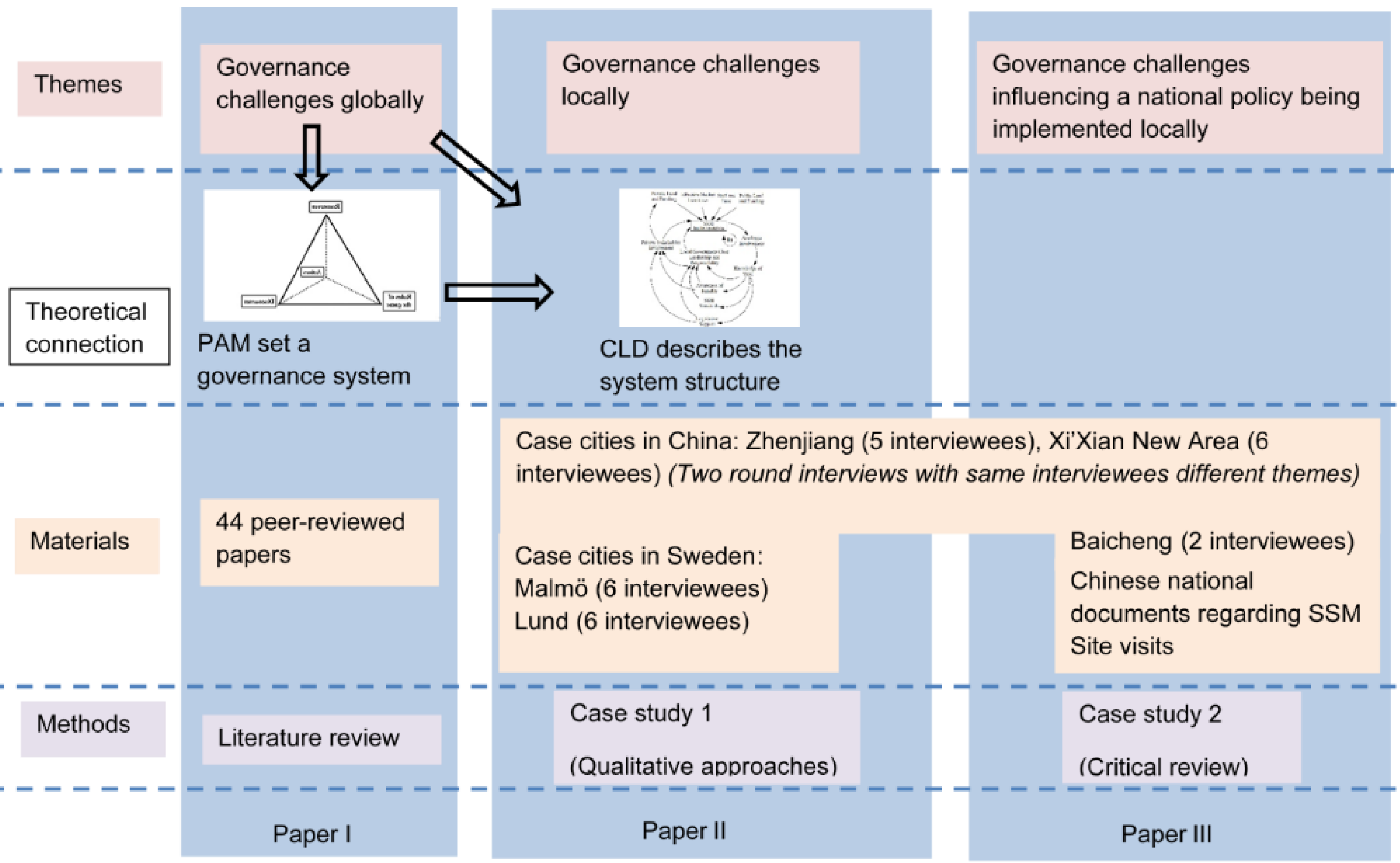

Figure 6. Research design of the thesis and the interrelations of three individual papers.

an appropriate research approach for this thesis. There is no control over behaviours when performing case studies. However, to strengthen the credibility of the results, a multiple-case study design based on the principle of triangulation can be applied. The selected cases in a multiple-case design should either "predict similar results (a literal replication) or predict contrasting results but for anticipatable reasons (a theoretical replication)" (Yin, 2013, p. 57). According to Yin (2015, p. 87) "triangulation" means "seeking at least three ways of verifying or corroborating a procedure, piece of data, or finding". Thus, a mixture of data collection methods was applied in this thesis. These were: (i) interviews, (ii) site visits and (iii) document analysis.

3.2.1 Case selection

Two case studies were performed. Case study 1 had two main objectives: (i) in the context of different governance structures, to describe governance challenges from a local perspective and (ii) to determine how different governance factors influence each other in relation to SSM implementation. China and Sweden were chosen to represent two distinct governance structures. China is a one-party unitary country with a top-down political system comprising three levels of government: central, provincial and local (Dai et al., 2017). Local governments are expected to accept the unified leadership of the central government and changes in local government priorities are normally required or incentivised by the central government based on formal legislation, political speeches, policy documents, etc. In Sweden, decision making and responsibility for approaches relating to stormwater management lie entirely with local government and Sweden can thus be denoted as having a bottom-up political system. To achieve a multiple case study, two cities in China (Zhenjiang and Xi'Xian New Area, hereafter referred to as Xi’Xian) and two cities in Sweden (Malmö and Lund) were selected as cases because of their representativeness of each of the two overall governance approaches (top-down and bottom-up) and because of their similarities. Lund and Malmö share similarities in terms of population density, climate, local governance structures, same water supply and drainage company (VA Syd: water department in Swedish case cities) and local government financial support for SSM implementation. The two Chinese cities also share similarities, e.g. they receive a same amount of financial support from the central government and follow the same national standards for Sponge City implementation. Although city size and population are 10-20 times larger in the Chinese case cities than in the Swedish case cities, the urban area population density of all four cities is approximately similar. Background information on the four case cities can be found in Table 2 in Paper II.

Case study 2 is a critical review on how governance factors influence a national SSM policy being implemented locally. In 2015, the Chinese MHURD, selected 16 cities to act as pilot Sponge Cities and to implement SSM solutions and the pilot period ended at 2018. In case study 2, to gain a clear understanding how the Chinese national policy-Sponge Cities initiative was interpreted and implemented on the ground and to achieve a multiple case study, three case cities were selected based on the following two criteria: (i) Different climate conditions. The climate in China varies from region to region, with the rainiest part of the country being the south-east and the least rainy being the north-west. North-west China is hot and wet in summer, while north-east China has hot and rainy summers from June to August, which is the only season when there are significant rains. In central China, near the Yangtze River, the summers are hotter and longer and rainfall increases throughout the year. Annual rainfall in central China ranges between 1000 and 1600 mm per year, because the summer monsoon lasts longer than in the north. One pilot Sponge City was selected from each of these climate regions, namely: Baicheng in the cold north-east China, Xi'Xian in north-west China and Zhenjiang in south-central China, near the Yangtze River. (ii) Different demonstration zones. In old urban areas, pluvial flooding and water pollution are regarded as common problems. The challenges and strategies related to stormwater management in newly developed urban areas are not as clear. Therefore, cases should include both new and old urban areas. The cases selected were: Zhenjiang Sponge City demonstration zone, which is located in an old urban area, Xi’Xian Sponge City demonstration zone, which is located in a new urban area and Baicheng Sponge City demonstration zone, which includes both old and new urban areas. Detailed information on these three case cities can be found in Appendix B in Paper III.

3.2.2 Interviews

Conducting interviews is a commonly used data collection method in qualitative research. There are two possible forms: structured interviews and qualitative interviews (Yin, 2015). Structured interviews require the interviewer to exhibit strict and consistent behaviour and follow a set of formal listed questions or closed-ended questions (Yin, 2015), which are likely to be performed as a survey. Qualitative interviews do not require a strictly scripted relationship between interviewer and interviewees and the questions are often open-ended. A disadvantage of this approach is that the interviewees may include irrelevant matters. Consequently, in this thesis, semi-structured interviews using a research protocol (listed related topics with open-ended questions) were conducted with local government officials in all the case cities. Most of the interviews took about one hour and all interviews were audio-recorded and transcribed verbatim.

In case study 1, the interviews in Malmö and Lund, Sweden, were conducted during the first half of 2017. Since the governance structures are similar in the two cities, the interview protocols were the same. The interview protocol questions (see Appendix C-supplementary data in Paper II) were organised based on the four aspects (actors, resources, rules of the game, discourses) of the theoretical PAM framework (see section 2.3). Six interviewees in Malmö (March 2017) and six in Lund (April 2017) were selected as the informants. They all represented the local government departments perceived as most relevant, namely: Spatial Planning, Environmental Health, Parks and Streets, Real Estate Development and VA Syd. Due to the different governance structures in China and Sweden, the topics in the interview protocol for the Chinese case cities were altered slightly. For example, in China there is no private land, so the topic of private stakeholder involvement in stormwater management was changed to deal with public participation. An important influencing factor identified in the literature review – staff and time for stormwater management is not a question for Chinese cities, because currently labour is not a limiting factor in China. Five local government officials from the Sponge City Leader Office in Xi'Xian (September 2017) and four local government officials from the Sponge City Leader Office in Zhenjiang (October 2017), all of whom are responsible for Sponge City construction, were selected as the interviewees. The Sponge City Leader Office, an institution within the local government, sets tasks and coordinates the work of relevant departments, e.g. Planning, Water, Streets, etc. to implement Sponge City construction. In each city, one additional interviewee was selected from the local contractor responsible for Sponge City construction. Information on all the interviewees can be found in Appendix A and Appendix B in Paper II.

In case study 2, another round of qualitative interviews was conducted with the same individual interviewees in case cities Xi'Xian and Zhenjiang during July-August, 2018. Qualitative interviews were also conducted with two leaders in the Sponge City Leader office in Baicheng. The interview protocol in the three case cities was the same and mainly focused on three issues: (i) understanding of the Sponge City concept, (ii) technical measures implemented in Sponge City projects and (iii) reasons for implementing green and grey infrastructure in the pilot Sponge Cities. In addition, a semi-structured interview was conducted in August, 2018 with one of the co-authors of 'Sponge City Technical Guidelines – Low Impact Development'. In this, the interview protocol topics mainly focused on the development of the guidelines and the overall purpose of the Sponge Cities initiative.

In addition, a one-hour focus group interview (McLafferty, 2004) was conducted in Zhenjiang on 10th October, 2017. It included five interviewees related to Sponge City implementation in Zhenjiang (a planner of the Zhenjiang Sponge City master plan, a stormwater management modelling expert, a board member of the Zhenjiang Sponge City construction company, the top leader of the Sponge City Leader Office and a secretary to the top leader). The value of focus-group interviews lies in the "group dynamics" (Rabiee, 2004, p. 656), which are considered to generate deeper and richer data or information because of the interactions between the group members. However, if group members do not feel comfortable with each other and engage in the discussion, the data generated may not be very rich (Rabiee, 2004). During the focus group interview in Zhenjiang, it was mainly only the top leader of the Sponge City Leader Office who talked. Therefore, this focus group interview was not regarded as successful, since not all interviewees had the chance to express their ideas. It seems that the internal hierarchy in the local government in Zhenjiang can influence the data generated in focus group interviews, since some of the interviewees may feel uncomfortable talking in front of their leader. This indicates that more time should be spent on selection of focus group members on ensuring that each member can engage in the topic, in order to get deep and rich data in focus-group interviews.

3.2.3 Interview data analysis method

All the interview data were qualitatively analysed with a thematic analysis method (Braun & Clarke, 2006). Thematic analysis is a theory-independent method "for identifying, analysing and reporting patterns (themes) within data" (ibid., p. 6), which "can be used within different theoretical frameworks" (ibid., p. 9). The theoretical framework: SSM-CLD (see section 2 in Paper II) showed the basic assumptions on the relationship between governance factors based on the results of the systematic literature review (see section 3 in Paper I). Thematic analysis of the interview data was performed to help make the theoretical framework more transparent and specifically to identify the relationships between governance factors in the case cities.

In the case study 1, to identify the governance factors influencing SSM implementation in local government, a deductive thematic analysis method was applied by analysing the interview data. To identify the relationships among the governance factors, an inductive thematic analysis was applied. This involves finding the underlying meaning of the interviewees, rather than only the explicit or superficial meaning of the data. The identified interdependencies of governance factors were mapped into SSM-CLDs based on computer software – Vensim PLE X32. The analysis process can be found in section 3 in Paper II.

In case study 2, an inductive thematic analysis was applied to investigate the national policy – Sponge Cities initiative implemented locally. The analytical processes was as follows: familiarisation with the data by repeated reading, identifying and searching for the themes of each case city in terms of: (i) understanding the Sponge City concept; (ii) projects implemented locally and (iii) perspectives on the implementation of both green and grey infrastructure within the Sponge City concept.

3.2.4 Site visits

To investigate the actual actions of SSM implementation on the ground, site visits were conducted in the case cities during September 2017 and July 2018 in Xi'Xian, during October 2017 and August 2018 in Zhenjiang and in August 2018 in Baicheng. A site visit is visiting a real existing place over a short period of time (1-3 days) with an evaluative purpose, to gain an opinion about the quality of the object being visited (Yin, 2015; Lawrenz, 2003). A site visit has been described as an approach which includes methods such as interviews, document analysis, etc. (Lawrenz, 2003). However, in this thesis, site visits were used as a data collection method within the approach of case study. In this study, the sites are the selected pilot Sponge City projects. Before the site visits, existing information describing the sites was collected, e.g. address, investment, technical measures, etc.

3.2.5 Documentary analysis

Documentary analysis was conducted in case study 2. Since Sponge Cities initiative is a top-down policy, national policy documents published by the Chinese central government were critically reviewed. These documents describe how the Sponge City concept is formulated at central level and how it should be implemented. The policy documents reviewed can be seen in Table 1 Paper III. The analytical process comprised two steps: (i) Determining the definition, purpose, technical measures and assessment standards of Sponge Cities initiative provided in the documents; and (ii) comparing similarities and differences of these aforementioned aspects.

3.3 Reflections on the research methods

As regards conducting interviews in China, it is very difficult for a research student to just go to the local government to ask for interviews with the local officials. The local government officials need permits from their leaders before they can agree to be interviewed. In the case studies described in this thesis, a professor from Peking University helped to contact one of the leaders of Xi'Xian Sponge City Leader Office, while a professor from Beijing University of Civil Engineering and Architecture helped to contact one of the leaders in Baicheng. A professor from Tongji University helped to organised the formal field work in Zhenjiang and Jiaxing (the latter was not selected as a case, since it is near to Zhenjiang and has similar climate characteristics) and provided the opportunity to hold the group interviews. Thus, in conducting similar interviews in China, making contact with local government leaders was necessary, but was experienced as very difficult.

Regarding the reliability of the information collected through site visits in this thesis, for example, in Baicheng, I conducted the site visits alone rather than as part of a larger site-visit group. This helped maintain the consistency of the information collected. My impression was that the quality of the pilot Sponge City projects implemented (GI: rain gardens, bio-swales) in the demonstration zone in Baicheng was poor. To ensure that this impression was representative of the situation in Baicheng, I visited most of the Sponge City projects implemented in its demonstration zone. This confirmed that the GI implemented in Baicheng is of low quality (see Figure 2 in Paper III).

4 Results

This chapter presents results of this thesis by summarising and synthesising Papers I, II and III. First, it describes eight frequently mentioned governance challenges to provide an overview of governance challenges hindering SSM implementation. Next, it describes the SSM-CLDs built to explain the interdependencies between the governance factors and how governance structures influence the governance factors. Then, it describes different governance arrangements in SSM implementation. Last, I made some reflections on the reality of the results.

4.1 Governance challenges influencing SSM implementation

The eight frequently mentioned governance challenges (see Table 2) described below are based on the summarised results of Papers I, II and III. In Paper I, nineteen global generic governance challenges to SSM implementation were identified and categorized into four aspects based on the theoretical PAM framework (see Table 2 in Paper I). In Paper II, local level governance challenges influencing SSM implementation were identified based on the four case cities of China and Sweden (see Table 3 in Paper II). The challenges identified on the local level were related to the global generic challenges. In Paper III, based on a case study of three pilot Sponge Cities in China, four main governance challenges (lack of space, time, knowledge and evidence on SSM efficiency) were identified as hindering a national SSM policy from being implemented locally.

- Unclear leadership and responsibility

There are different opinions regarding who should play the leading role in SSM implementation within local governments. The local government as a public entity is suggested to play a leading role and take the main responsibility for ensuring SSM implementation. However, relevant actors within local authorities, e.g. landscape architects, urban planners and water professionals are often confronted with unclear leadership and responsibilities regarding SSM implementation. For example, in the Swedish case cities, the parks department is responsible for the green space above the ground including stormwater, while VA Syd (water department in Swedish case cities) is responsible for wastewater drainage, but not responsible for managing stormwater before it is drained to sewage pipes. A similar situation was identified in the Chinese case cities with different departments being responsible for wastewater drainage, pluvial flooding, fluvial flooding, etc. before the Sponge City Leader Office was established to be responsible for SSM.

- Lack of private stakeholder involvement

At present, private stakeholder involvement in SSM is often limited to demonstration projects. On one hand, local governments are not sure if private stakeholders have the ability to manage stormwater on their private land. On the other hand, private stakeholders show unwillingness to participate in managing stormwater, since they view the management of stormwater as a local government responsibility. In the Swedish case cities of Lund and Malmö, 70% of land is privately owned. A widespread involvement of private stakeholders in providing private funding and land is crucial for solving the challenges, e.g. lack of funding and space and lack of funding for long-term maintenance. However, there is currently a lack of awareness of SSM in the Swedish case cities. Increasing public awareness and making people aware of the culture of stormwater management was suggested by the interviewees, which is argued to help to increase the local politician priority on SSM. In the Chinese case cities, there is no private land, but increasing public awareness of Sponge Cities was considered important for the construction and maintenance of Sponge City infrastructures, especially in the old residential areas with very limited room for SSM implementation. Public awareness and public opinion can also influence decision making on retrofitting existing green spaces.

- Lack of funding

Lack of funding was always viewed as a barrier to SSM implementation. It arises because of a general national, regional or local government deficit, or because of local governments cannot get financial support from state or central governments. On the other hand, it is because local governments cannot invest money into SSM solutions due to existing legislation and regulations do not allowed them to do so. In addition, due to lack of detailed cost data and lack of evidence on the efficiency of SSM solutions, getting financial support from local or central governments to implement SSM becomes even more difficult. An increase in maintenance funding can help to improve the performance of SSM projects and keep stormwater solutions functioning, which is important for increasing the trust in SSM among local politicians who make the decisions on implementing SSM. However, there seems to always be a lack of funding for long-term maintenance. This was observed not only in the Swedish case cities, where the interviewees claimed that "maintenance never gets enough money", but also in the different Sponge Cities studied. The Sponge Cities received three years of financial support from the Chinese central government for construction, but they did not receive any maintenance funding.

- Lack of space

Due to increasing urban densification and the generally large proportion of privately owned land in cities, SSM implementation is often challenged by lack of space. There is a direct conflict between increasing urban densification and the requirement of space for implementing SSM solutions. The interviewees in the Swedish case cities pointed out that many other, often more significant issues such as residential housing and recreation places, need to be prioritised and considered, rather than SSM implementation. In the Chinese Sponge Cities, lack of space was perceived to be one of the major limitations to implementing green measures. Interviewees in the pilot Sponge Cities stated that "we can only implement as much green measures as we can" in the old neighbourhoods.

- Lack of knowledge

Lack of knowledge regarding SSM solutions was reported frequently by researchers. It leads to low institutional capacity for SSM, e.g. failure to implement suitable local SSM solutions. It also leads to lack of confidence in SSM and a general reluctance to implement SSM solutions. Lack of knowledge of SSM appears to be a general problem in the Chinese Sponge Cities studied, since the local government officials interviewed did not recognise the fundamental difference between SSM and conventional stormwater management. Similar situations exist in the Swedish case cities. Creating a deeper understanding of the essential difference between sustainable and conventional stormwater management is a first step for increasing SSM implementation.

- Lack of evidence on SSM efficiency

Despite much scientific research, there is still a general lack of evidence on SSM efficiency at city level, which leads local governments and private stakeholders to show unwillingness to pay for SSM solutions. Thus, it leads to a lack of trust in SSM and a general reluctance to implement SSM. Moreover, based on pilot projects implemented in the demonstration zones in the pilot Sponge Cities, the Chinese interviewees argued that, GI alone cannot solve pluvial flooding problems. This has led to the ongoing upgrading of existing drainage systems and installation of larger pump stations in Sponge Cities construction. Meanwhile, due to the lack of trust in SSM, all the interviewees in the case city Lund stated to find 'the best solutions', 'the most cost-efficient solutions' and 'safe solutions'. In the case cities in China and in Sweden, SSM solutions are currently always implemented together with conventional stormwater management solutions.

- Lack of legislative support

Current legislation supports the construction of conventional drainage systems, which usually impedes SSM implementation as local governments have to follow the existing legislation and tend to build grey infrastructure to manage stormwater. For example, in China, there are some national documents encouraging implementation of SSM solutions, but also other national documents requiring implementation of conventional stormwater management systems. This leads to uncertainty for local governments seeking to prioritise and divide funding between conventional and SSM solutions. In addition, there is no national legislations regarding SSM in China or in Sweden.

- Lack of SSM standards

The lack of SSM standards is due to the lack of evidence on SSM efficiency leading to disagreement on strategies to achieve stormwater management goals. Neither China nor Sweden have SSM standards.

Table 2. *The eight frequently mentioned governance challenges*

Challenges	Number of papers (N=44) mentioned each challenge in Paper I (see Table 2, Paper I) and the percentage	Number of interviewees (N=23) mentioned each challenge in Paper II (see Table 3, Paper II) and the percentage	Challenges hindering Sponge Cities implemented locally (see section 3.4, Paper III)
Lack of funding	12 (27%)	19 (82%)	
Lack of space	6 (13%)	19 (82%)	x
lack of legislative support	13 (29%)	14 (60%)	
Lack of knowledge	10 (22%)	15 (65%)	x
Lack of private stakeholder involvement	8 (18%)	12 (52%)	
Unclear leadership and responsibility	14 (31%)	7 (30%)	
Lack of evidence on SSM efficiency	14 (31%)	7 (30%)	x
Lack of SSM standards	8 (18%)	9 (39%)	

4.2 SSM-CLDs and governance structures

As described above, the identified governance challenges influence each other. The interdependencies of governance factors identified in the case cities were mapped into SSM-CLDs (see Figures 2 and 3 in Paper II). These SSM-CLDs help to explain and visualise the interdependencies between the governance factors and to achieve the objective 2: Determine how different governance factors influence each other in relation to SSM implementation.

By comparing the two SSM-CLDs (see Figures 2 and 3 in Paper II) with the analytical framework SSM-CLD (see Figure 1 in Paper II), it indicates that different governance structures were able to affect the governance factors so as to influencing SSM implementation.

In the Chinese case cities, ‘local leader priority’ (to SSM) was mentioned frequently as being of high importance for Sponge City implementation. The governance structure in China is hierarchical. Policies, finances, legislative support and standards are decided at national level, while local governments in the case cities follow and act upon the national policies and central government strategies. Therefore, the national Sponge Cities initiative policy is a high priority for the local leaders in the selected pilot cities. It is illustrated by the establishment of a specific SSM implementation division, the Sponge City Leader Office, in each of the pilot Sponge Cities and by having the mayor (or vice-mayor) as leader and setting tasks for relevant bureaus. This has been a driver for the rapid implementation of pilot Sponge City projects in the case cities and it is also important for the future mainstreaming of Sponge City practice.

In the Swedish case cities, 'local politicians' priorities' (to the most important matters for city development) was highlighted by interviewees as an important governance factor for SSM implementation. A cooperation group comprising representatives from different departments in the city council is responsible for SSM implementation and it sends its working plans to local politicians and wait for a decision to be made. The Swedish case cities have non-hierarchical governance structures, in which financial support, standards and the priority given to SSM are mainly decided at the local level. Thus, local government politicians have more freedom to develop their city than their counterparts in the two Chinese case cities. Since local government politicians in Swedish case cities have to choose and prioritise between different services (e.g. residential areas, schools, social welfare, etc.), they can be reluctant to implement SSM and instead rely on the existing conventional stormwater systems.

4.3 Governance arrangements of SSM implementation

Understanding governance arrangements of SSM implementation is also help to achieve objective 2. Based on the governance arrangement model (see section 2.4), in Paper I governance influential factors were divided into three governance arrangement types. Hierarchical and closed co-governance arrangements appear to dominate in contemporary stormwater management. In these two governance arrangement types, the costs of building stormwater management systems are covered by the government and the systems are built on public land. The governance arrangement for Sponge City implementation in China is an example of a hierarchical governance arrangement (Paper III). In Paper I, I suggested that an open co-governance arrangement was to be useful for SSM implementation, by sharing land, costs, knowledge and responsibilities and negotiating decision making between local authorities and private stakeholders. Thus, whether private stakeholders are involved or not is decisive for the type of governance arrangement possible.

4.4 Reflections on the results

As mentioned in section 3.2, a multiple case study approach can be expected to strengthen the credibility of the research, as either predict similar results or predict contrasting results but for anticipatable reasons. In case study 1, the governance challenges identified in the Chinese and Swedish case cities (see Table 3 in Paper II), overlapped with the generic governance challenges identified in the literature review (Paper I). Moreover, four common governance factors were identified in the Chinese and Swedish case cities (see Table 3 in Paper II). In addition, there were some specific governance factors influencing SSM implementation in only the Chinese or Swedish case cities. These site-specific factors appeared to be influenced by the different governance structures. In case study 2 (Paper III), the governance challenges identified in the three case cities are mainly resource challenges, as described in section 4.1. The interviewees expressed many similar and recurring opinions regarding construction of Sponge Cities in China. Therefore, it is reasonable to assume that the credibility of the results is high.

5 Discussion

This chapter first discusses potential ways to approach the eight challenges described in section 4.1 in order to increase SSM implementation. It then discusses the unique challenges faced by SSM implementation, the validity of built SSM-CLDs and suitable governance arrangements. Last, the importance of long-term management is highlighted.

5.1 Ways to increase SSM implementation

5.1.1 Leadership and responsibility and private stakeholder involvement

'Unclear leadership and responsibilities' of relevant actors in different departments of a municipality hinders SSM implementation (Dhakal & Chevalier, 2017; Hoang & Fenner, 2016; Burns et al., 2015; Perales-Momparler et al., 2015; Porse, 2013; Dolowitz et al., 2012). An institution such as the Sponge City Leader Office in Chinese pilot Sponge Cities, which is a newly built government division led by the mayor (or vice mayor), can be helpful for securing SSM implementation by coordinating and setting tasks for relevant actors (Papers II and III). A similar institution holding jurisdiction across different relevant departments (parks and streets, environment, water, etc.) can be built to secure SSM implementation in Swedish cities. However, it is worth noting that the Sponge City Leader Office has been created within a hierarchical governance structure. Whether such a structure functions within non-hierarchical governance structure has to be tested. In addition, the Sponge City Leader Office is responsible for a political boundary, which may be confronted with the challenge of incongruence between political and hydrological boundaries (Paper I). For example, the water pollution problem exists in the Xin

River which runs through Xi'Xian and great efforts have been made to deal with the problem according to the Xi'Xian local officials. However, the continuing pollution happened in the upstream of the Xin River, which is, however, out of the political boundary of Xi'Xian-Sponge City Leader Office. Thus, Dhakal & Chevalier (2016, p. 1119) suggested to establish a local hydrological district, which means "landowners and other stakeholders within its jurisdiction determined by hydrological boundary" and by encompassing all local land features, e.g. parks, open spaces, ponds and road side rain gardens for stormwater management.

Increasing market incentives is one way to increase private stakeholder involvement, which is described in combination with the 'lack of funding' challenge in the next section. However, Brown et al. (2016) argued that money is not the only decisive factor and multiple factors influence private stakeholder involvement. They pointed that the process complexity (of implementing SSM) and distrust (e.g. the project and the implementing agency) were primary barriers hindering the Little Stringybark Creek project (ibid.). Thus, public education and more information regarding SSM is needed. Building a shared space for discussing SSM implementation can help to build trust among relevant actors. The sharing platform 'Learning Action Alliances' was built in Newcastle, UK, in which different stakeholder groups influence decisions regarding SSM implementation (Hoang & Fenner, 2016). These actors include representatives from local government departments, local interest groups, water companies, academics and major landowners (ibid.).

5.1.2 Funding and space

Increasing market incentives is a potential way to solve the lack of funding challenge. Below two approaches are described focusing on (i) allowance and (ii) fees.

(i) Stormwater allowances for private stakeholders could be provided by local governments, so as to encourage more private capital investment in SSM. For example, in the Chinese case cities, public private partnerships (PPP) were promoted by the central government as a way to provide funding for Sponge City projects (Paper III). Still, more research is needed on the effectiveness of PPP in SSM implementation (Paper II). A previous study suggested to establish a stormwater market "by distributing allowances of runoff controlling to each landowner within a hydrological boundary and permitting those allowances to transfer through a free trade" (Dhakal & Chevalier, 2016, p. 1121). In this system, stakeholders who could manage more stormwater runoff than the required amount could sell the additional capacity to those who cannot manage on their own land. In addition, the stormwater market could be connected with other ecosystem service markets by setting a price on e.g. green space for reducing urban heat island or air pollution, etc.

(ii) Market incentives could also be promoted as stormwater fees collected from private stakeholders. In Germany, stormwater fees are collected based on a calculation of the actual contribution of a parcel to the total stormwater burden (Vogel et al., 2015; Nickel et al., 2014). The collected stormwater fees can be used for maintenance funding and installations (Hoang & Fenner, 2016).

Introducing stormwater market incentives could also help to solve the issue of lack of space, since increasing the involvement of stakeholders might make their land available for SSM. Using vacant land or retrofitting existing green space to implement SSM solutions are potential partial solutions to the land shortage problem (Liao, 2019; Qiao et al., 2018). Deploying more above-ground solutions, e.g. green roofs and green walls, could also help. It has been shown that green roofs are effective in retaining rainfall during most storm events (Qin et al., 2013). Furthermore, due to the inevitable increase in urban densification, finding the best combination of conventional and sustainable stormwater solutions should be considered as a reasonable way to deal with the lack of space. It was found in Paper III that, lack of space was the one of the main reasons for not implementing SSM solutions in Chinese Sponge Cities and in practice, conventional and SSM were implemented together in those cities. Similarly, Wild et al. (2017, p. 179) reported that in practice, it is "indeed integrating both 'green and grey'". Others have also pointed out that a combination of conventional and SSM is the most practical solution (Dong et al., 2017; Zhang et al., 2017).

5.1.3 Knowledge of SSM and evidence on SSM efficiency

There are several ways to increase knowledge of SSM. For private stakeholders, public education is a good way to increase public awareness and knowledge of SSM (Dhakal & Chevalier, 2017; O'Sullivan et al., 2012). Interviewees in the Chinese case cities claimed that "it is necessary to provide effective public education, so that the public can understand what we do and plan to solve" (Paper II). Providing more approaches, e.g. local government SSM guidelines, community training courses and mass media campaigns, etc. directed at private stakeholders to communicate relevant information on SSM can be helpful (O'Sullivan et al., 2012). Establishing good pilot projects can also help to increase SSM knowledge. For example, the first step in SSM implementation in China was to build pilot projects within demonstration zones in the pilot Sponge Cities (Papers II and III). The Chinese interviewees pointed out that good performance of pilot projects can help to increase public awareness of SSM (Paper II). For local government staff, staff training can be organised (Nguyen et al., 2019; Dhakal & Chevalier, 2016; Ahiablame et al., 2012). Via information sharing platforms, experience and knowledge can be established to help local government actors to achieve SSM knowledge. Such platforms should not simply provide information about an individual city, but should seek to improve city to city communication. A recent publication provides examples of knowledge and information management platforms, e.g. Local Governments for Sustainability (http://www.iclei.org/) or 100 Resilient Cities (http://www.100resilientcities.org/) (Jiang et al., 2018). For researchers, providing more documented knowledge of SSM and distributing the knowledge to policy makers and practitioners is important. Researchers can act as information brokers between private stakeholders and local governments by holding workshops and building pilot projects to provide knowledge of SSM. In the long run, universities offering research opportunities and courses on SSM to relevant graduate and undergraduate students can be helpful (Dhakal & Chevalier, 2017).

More research should be conducted to determine the effectiveness of SSM solutions.

5.1.4 Legislative support and standards

Providing legislative support is crucial for increasing SSM implementation. As shown in section 4.1, current legislation on stormwater is impeding SSM implementation in China and Sweden. Neither China nor Sweden has national-level SSM legislation. Similarly, existing regulations and legislation in the USA do not include SSM solutions, so local authorities have to follow the existing stormwater management approach (Dhakal & Chevalier, 2017; Keeley et al., 2013; Ahiablame et al., 2012). Changes to the legislation on stormwater management were recommended by interviewees in Paper II and have also been suggested in previous studies (Dhakal & Chevalier, 2017; O’Donnell et al., 2017). Dhakal & Chevalier (2017) provided suggestions such as removing the requirement on draining stormwater into pipe systems; adding requirements on using GI to infiltrate or retain stormwater at source; allowing implementation of GI in open spaces where technically feasible, etc. In Germany, newly developed urban areas are required by law to retain/infiltrate rainwater on-site (Zhang et al., 2017). This can provide an inspiration for amending stormwater-related legislation.

Establishment of standards and guidelines for design, construction and maintenance is crucial for acceptance and future implementation of SSM (Cettner et al., 2014b). However, the local context should not be neglected when selecting specific SSM solutions. In the Chinese Sponge Cities initiative, Sponge City Technical Guidelines were provided by the central government. However, these guidelines were not based on local context. Thus, local implementations of Sponge City projects have been confronted with many problems arising from the generic structure of the national guidelines (Papers II and III).

5.2 Unique challenges for SSM

The governance challenges hindering SSM implementation at a global level identified in Paper I and the governance challenges hindering SSM implementation at a local level identified in Paper II provide an overview of the current status of SSM. The GI approach has similarities with other approaches e.g. nature based solutions (NBS) and urban forestry and scholars often discuss these terms together (Vasiljevic et al., 2018; Pauleit et al., 2017; Wild et al., 2017). Thus, comparison of governance challenges confronted in these approaches can shed light on the unique challenges confronting GI-based SSM.

In September 2019, a search was conducted on Web of Science for Papers with a title including ‘nature based solutions’ and ‘from all years (1945-2019)’. Fifty-nine papers were found, namely, one in 2009, one in 2015, three in 2016, 22 in 2017, 10 in 2018 and 21 by September 2019. Most of these papers focused on describing the benefits of NBS based on case studies. NBS was described as an approach to tackle societal challenges, e.g. climate change, human well-being, water management, flooding risk management, etc. (Albert et al., 2019; Dorst et al., 2019; van den Bosch & Sang, 2017; Vujcic et al., 2017). It is interesting to note that there were few studies focusing on governance challenges to implementing NBS in practice. Lafortezza et al. (2017) briefly mention the potential challenges to implementing NBS in the future, but only in general terms. One reason can be that NBS is a new term (the publication of relevant papers started around 2016). This provides a new direction in research on NBS: studying challenges to implementing NBS on the ground rather than only describing its benefits. GI-based SSM has many benefits as described in the introduction to this thesis, but still does not dominate in practice. It is reasonable to assume that NBS faces similar problems. Thus, the governance challenges identified for SSM in this thesis can act as reference in studies of governance challenges to NBS.

A similar search process was conducted on Web of Science for papers whose title included the key words ‘urban forestry’ or ‘urban forest’. The results showed that studies on urban forestry started in the 1960s, much earlier than studies on GI and NBS. Studies focusing on governance challenges to urban forestry implementation on the ground are frequent in the literature. Ordonez et al. (2019, p. 170) published a paper entitled: '*Urban forest governance and decision-making: A systematic review and synthesis of the perspectives of municipal managers*' in the journal *Landscape and Urban Planning*. In this review paper, they summarised governance challenges mentioned by municipal urban forest managers and reported that they used similar review methods and the same theoretical framework as "used by Qiao et al. (2018)" (Paper I in this thesis). Thus, it was interesting to compare the governance challenges identified for urban forestry (Ordonez et al., 2019) and for GI-based SSM (Paper I). Based on the comparison, many of the challenges are similar, especially in the aspects of 'actors' (including e.g. unclear leadership and responsibility and lack of public participation) and 'resources' (including e.g. lack of funding, lack of knowledge and lack of staff and time). Meanwhile, differences exist. Ordonez et al. (2019) did not mention 'lack of space', 'lack of evidence on SSM (urban forestry) efficiency' and 'lack of effective market incentives' in the aspect of 'resources', but listed a challenge 'lack of management plan/policy/strategies'. In the aspect of 'rules of the game', the challenges identified were very different, with the two challenges listed in Paper I ('lack of legislative support' and 'lack of SSM (urban forestry) standards') not mentioned by Ordonez et al. (2019). In the aspect of 'discourses', the challenges identified were again different, but due to the different topics covered (urban forestry and SSM). Experts Jim et al. (2018) in urban forestry reviewed institutional and social challenges confronted by urban forestry in compact and densifying cities, which indicates that 'lack of space' is also a challenge for urban forestry implementation on the ground. In addition, they listed a governance challenge 'lack of relevant tree and related laws' (ibid.). Thus, on comparing the eight frequently mentioned governance challenges for SSM with challenges identified for urban forestry in these two papers, 'lack of evidence on SSM efficiency' and 'lack of SSM standards' are the unique governance challenges faced by GI-based SSM. This indicates the necessity of more research on the effectiveness of SSM solutions as stated in section 5.1.3.

5.3 Validity of built SSM-CLDs

Explaining the interdependencies of various governance factors and challenges related to SSM implementation is complex. The SSM-CLDs created in Paper II (Figures 1, 2 and 3) can act as a visual tool in efforts to understand the system structure. Policy makers can use the CLDs to evaluate the effectiveness of strategies for SSM implementation. The SSM-CLDs can also help local officials to prioritise and communicate with multiple stakeholders. Getting support from non-government stakeholders is important for implementation of relevant policies, since it often requires stakeholders to support funding initiatives or legislative changes, or even to change their behaviour (Stave, 2003). The SSM-CLDs built in this thesis can be used as a visual tool to communicate with private stakeholders in workshops, forums and seminars. For example, Stave (2003) built a system dynamics model for water managers to discuss water resources management with pubic stakeholders and found that stakeholders without experience or knowledge of system dynamics were easily able to join in workshop discussions in that study.

In this thesis, a system dynamics model for the governance system of SSM implementation was not built. Instead only SSM-CLDs were created to depict the hypothetical system structure. However, the results in Paper III can partly help to test the validity of the SSM-CLDs created in Paper II. To test the validity of a system dynamics model, the simulated results should be against the defined problem. In this thesis, this defined problem was the dominating use of conventional stormwater management and the limited use of SSM. According to the SSM-CLD built for the Chinese case cities (see Figure 3 in Paper II), the appearing of the national policy – Sponge Cities initiative caused high local leader priority to SSM implementation, with the mayor or vice-mayor of a city acting as the leader in the Sponge City Leader Office. From this, it could be anticipated that SSM solutions would increase greatly. In reality, it was observed that GI-based SSM solutions has indeed been implemented in the pilot Sponge Cities (Paper III). However, a great increase in SSM implementation did not happen, but in fact many conventional stormwater management solutions have been implemented in the pilot Sponge Cities. This means that the simulated results (both conventional and SSM increase) in the SSM-CLD for the Chinese case cities is not totally against the problem defined (conventional stormwater management dominates and SSM is limited). However, this does not invalidate the SSM-CLD built. The simulated results reflect system delays (one component change may not cause the feedback loop change immediately) in the complex governance system. It is the lack of space, lack of knowledge of SSM and the short time-frame of only three years that lead to the conventional stormwater management solutions being implemented widely in the pilot Sponge Cities (Paper III). In other words, a great increase in SSM implementation did not happen in pilot Sponge Cities because several components (e.g. space, knowledge and time) did not change spontaneously with the appearing of the national policy.

In addition, external factors, e.g. climate change, urbanisation, governance structures, etc., should be considered. As argued by interviewees in Paper III, GI alone cannot solve pluvial flooding (with limited space). This means that, due to ongoing climate change, more grey infrastructure to deal with flooding problems is necessary, but to mitigate climate change implementing more GI is also necessary. This conflict of weighting conventional versus sustainable solutions will influence decision makers' choices of future strategies for stormwater management. Moreover, as shown in Paper II, the governance structure of a country has potential to influence the entire system. The high priority given to SSM by the local leaders in the Chinese case cities was strongly influenced by the national policy, which was decided by the Chinese hierarchical governance structure. However, as discussed above, without sufficient resources (land, funding, knowledge and time) in the system, the influence of the governance structure is limited (Paper III). Thus, connecting internal with external factors of the governance system is important for SSM implementation on the ground. The SSM-CLDs built in Paper II are not inflexible and can be modified based on local contexts.

Inspired by the above descriptions, five potential combinations of conventional stormwater management and SSM are anticipated for the future (Figure 7). In phase 1, both conventional stormwater management and SSM increase, but conventional stormwater management dominates; In phase 2, conventional stormwater management decrease and SSM increase, but conventional stormwater management still dominates; In phase 3, conventional stormwater management decrease and SSM increase, but SSM dominates; In phase 4, conventional and SSM find a balance with SSM dominating. Based on internal and external influencing factors discussed above, it is difficult to say that in the future SSM will dominate. Thus, in phase 5, conventional stormwater management and SSM find a balance. SSM increased a lot, but still conventional stormwater management dominates. Considering different local contexts, these five situations may co-exist in different city districts and between different cities.

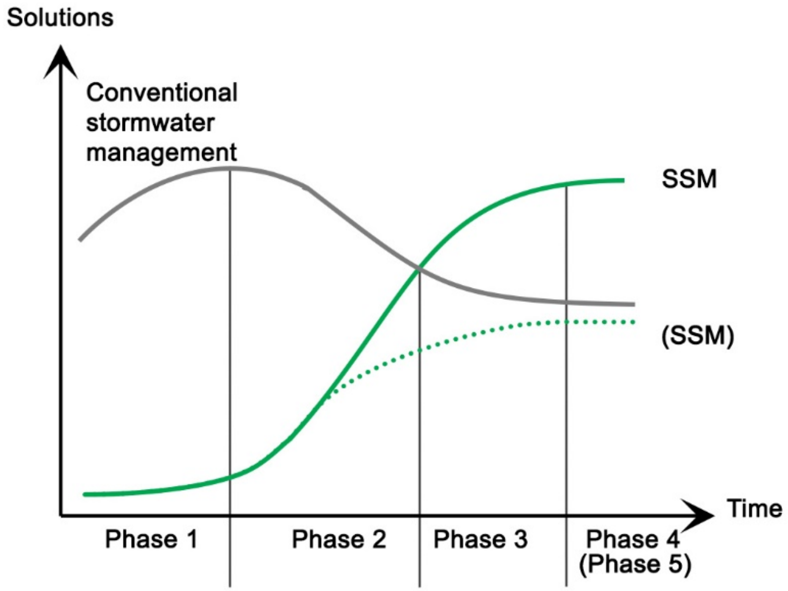

Figure 7. Five potential combinations of conventional stormwater management and SSM in the future.

5.4 Suitable governance arrangements

In the SSM-CLD for the Swedish case cities (see Figure 2 in Paper II), private stakeholder involvement can reinforce the function of the system, since the increase in private stakeholder involvement will greatly influence the resources, including land, funding and knowledge. As suggested in Paper I, an open co-governance arrangement by sharing land, costs, knowledge and responsibilities and negotiating decision making between local authorities and private stakeholders would be a suitable governance arrangement type for those countries where private stakeholders own lands. In the SSM-CLD for the Chinese case cities (see Figure 3 in Paper II), ‘private stakeholder involvement’ is not included, since there is no private land in China. Considering the governance structure is hierarchical in China, a hierarchical governance arrangement may be the best way for the Chinese cities to implement SSM. In addition, as described in section 2.1, the understanding of GI may influence the possibilities of non-government stakeholder involvement. This can further influence the governance arrangement type. The understanding of GI in the

Chinese case cities is as green stormwater infrastructure, which is consistent with its hierarchical governance arrangement. In Sweden (as in Europe in general), GI is understood as a multi-functional approach by providing ecosystem services, which is consistent with the suggested open co-governance arrangement.

However, as described in section 2.4, in both conventional stormwater management and SSM, private stakeholders rely on municipalities to provide knowledge, which indicates that a strict open co-governance arrangement may not work well to some extent in Sweden and countries with similar situations. In addition, in the SSM-CLD for the Chinese case cities (see Figure 3 in Paper II), increasing public awareness and public education regarding the benefits of Sponge Cities can reinforce the function of the system. As discussed in section 5.3 in Paper II, in old urban areas in Chinese case cities, public opinion and awareness influence SSM planning, construction and maintenance to some extent. This indicates that in the Chinese case cities, it is not a complete hierarchical governance arrangement. Nagendra & Ostrom (2012, p.110) pointed out that "strong centralised governments may appear to be dominating force directing reforestation at a national scale", and continued that "in actuality the impact of national governments is often mediated, enhanced or deterred though actions conducted by a diversity of other actors". The study of the national Sponge City policy in Paper III shows a similar result, namely, the national Sponge City policy was distinctly interpreted by a diversity of local actors during its local implementation.

Actually, it is not necessary to select a specific governance arrangement for SSM implementation. As described in section 2.3, PAM is not a static model. Political modernisation is a changing process and 'structural transformations' is not a linear and historical process from tradition to modernity, but rather it is complex and non-linear. A hybrid governance arrangement of hierarchical and open co-governance (Arnouts et al., 2012) or polycentric governance (Ostrom, 2010) for SSM implementation is worth testing. In addition, a mosaic governance, developed on the idea of polycentric governance, was suggested for urban GI to increase active citizenship from a local government perspective (Buijs et al. 2019). It is defined as "the diversity of processes that may facilitate existing active citizenship and stimulate its upscaling through a mix of governance modes and policy interventions tailored to the socio-ecological context of urban landscapes" (ibid., p. 54).

5.5 Long-term management

The above sections mainly focus on the implementing of SSM. This section stresses the importance of long-term management. Dempsey & Burton (2012) use the term ‘place keeping’ to describe long-term management of public space. Landscape architecture is simply defined as ‘place making’ plus ‘place keeping’ (Jansson et al., 2018; Dempsey & Burton, 2012). However, it is argued that long-term maintenance of open space is often overlooked in comparison with the creation of open spaces (Jansson et al., 2018; Dempsey & Burton, 2012). Obtaining maintenance funding for SSM solutions is also difficult as described in section 4.1 of this thesis. This is due partly to a general lack of funding. However, it also indicates that there is a general neglect of ‘place keeping’ on SSM among policy-makers in local governments. GI based SSM solutions require continuous maintenance, which is crucial for keeping good performance and functions of SSM projects (BenDor et al., 2018).

In Paper II, the interviewees argued that getting support from citizens is crucial for the long-term management of SSM. Mathers et al. (2015) also pointed out that ongoing public support is important for the effectiveness of place-keeping. However, while private stakeholders may invest in the construction of SSM infrastructure, the extent to which they would like to invest in long-term maintenance or management is not clear. Mattijssen et al. (2017, p. 78) suggested that strong support from authorities is key to citizen participation in long-term management and recommended that authorities should provide “security via stable policies, formally protecting the involved spaces, allowing long-term management contracts and contributing resources”.

6 Conclusions and future research

This chapter draws conclusions of the thesis and provides suggestions on areas for future research.

6.1 Conclusions

There is a need to implement GI-based SSM solutions since they can help to mitigate stormwater problems and provide various ecosystem services. The thesis provides an example of research on SSM from a governance perspective, which can help to identify challenges to SSM implementation and also provide references for future governance research.

In this thesis, eight frequently mentioned governance challenges hindering SSM implementation have been identified, namely, unclear local government leadership and responsibility, lack of private stakeholder involvement, lack of funding, lack of space, lack of knowledge on SSM, lack of evidence on SSM efficiency, lack of legislative support and lack of standards. ‘Lack of evidence on SSM efficiency’ and ‘lack of SSM standards’ are the unique governance challenges faced by GI-based SSM.

Many interdependent factors influence SSM implementation, as shown in SSM-CLDs (see Figures 2 and 3 in Paper II). These SSM-CLDs act as a visual tool helping local authorities to understand the complexities of SSM from a governance perspective and also help them to communicate with private stakeholders. The SSM-CLDs built in this thesis can serve as basis for the development of local contexts based CLDs.

The overall governance structure of a country proved to have the potential to influence SSM implementation. In China, a central steering body – Sponge City Leader Office acts cross-disciplinary with full support from both the local government and the central government. In Sweden, ‘local politicians’ have no formal obligations to implementing SSM and have to weigh among many priorities. The effectiveness and quality of the two very different systems can be debated, as initially done in this thesis. However, the influence of governance structures on SSM can be limited due to lack of resources, e.g. funding, space, knowledge, time, etc.

Private stakeholder involvement is crucial for the specific governance arrangement of SSM, which also influences acquisition of funding, space and long-term maintenance. No matter in China or in Sweden, a hybrid governance arrangement of hierarchical and open co-governance may be more suitable than hierarchical or open co-governance governance arrangement alone.

In practice, conventional stormwater management and SSM are always implemented together. This was found in the cases cities in China and Sweden. It is difficult to expect that SSM will dominate in cities in the future. Co-occurrence of conventional stormwater management and SSM solutions in different proportions may exist in different city districts and between different cities based on local contexts and the primary challenges identified in this thesis.

6.2 Future research

More research is needed to provide more knowledge to describe the complex stormwater management system.

- More research on the performance of SSM and SSM standards should be conducted.
- This thesis focused mainly on understanding local government officials' perspectives regarding SSM. More work exploring private stakeholders' interests and perspectives is an important part for increasing SSM implementation.
- This thesis studied cases from China and Sweden. Some studies from the USA, Germany and Australia were discussed. To gain a complete view of SSM implementation globally, similar studies should be conducted in different regions.
- It is clear that SSM implementation can provide many ecosystem services, but whether it can bring economic benefits for developers and cities is unclear. Taking the Sponge Cities initiative as an example, if Sponge City construction is connected with retrofitting of shanty towns or squatter settlements in old urban areas, developers can implement SSM solutions when rebuilding these areas. This can decrease the financial burden on local governments. Thus, more research is needed on the challenges and opportunities for connecting SSM implementation with the continuing urbanisation of cities.

- In practice, a combination of conventional stormwater management and SSM is almost always used. However, the optimum combination of these systems is not clear. Areas for future research include developing appropriate design standards for conventional stormwater management in newly developed urban areas and determining the right time for a city to turn to SSM as much as possible in existing urban areas. A suitable governance arrangement for the combination of conventional stormwater management and SSM needs to be identified. Further research is needed on how resources could be divided between conventional stormwater management and SSM.

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