



Sponge City Concept: Integrating Green Infrastructure for Water Resilience

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Abstract: Urbanization and climate change have intensified water-related challenges, including frequent flooding, water pollution, and declining groundwater levels. The Sponge City Concept presents an innovative, sustainable approach to urban water management by integrating green infrastructure to enhance water resilience. This research explores the principles, strategies, and benefits of sponge cities, emphasizing the role of permeable surfaces, green roofs, urban wetlands, and rainwater harvesting systems in mitigating flood risks and improving water retention. Through a review of case studies and policy frameworks, the study evaluates the effectiveness of sponge cities in fostering sustainable urban environments. Furthermore, it highlights the socio-economic and environmental benefits of nature-based solutions in urban planning. The findings underscore the need for comprehensive policy support, interdisciplinary collaboration, and adaptive design strategies to successfully implement sponge city initiatives. This research contributes to the growing discourse on climate-resilient urban infrastructure, advocating for a shift toward water-sensitive cities that harmonize with natural hydrological cycles.

Keywords - Sponge City Concept, Green Infrastructure, Water Resilience, Urban Water Management, Rainwater Harvesting, Nature-Based Solutions, Urban Planning.

I. INTRODUCTION

Urbanization and extreme weather have intensified water issues, including floods, groundwater depletion, shortages, and pollution (Jia et al., 2015; Marlow et al., 2013). The dominance of impermeable surfaces like concrete and asphalt prevents water absorption, worsening urban flooding. Rapid city expansion has removed natural rainwater-retaining features such as green spaces and wetlands, reducing groundwater recharge. Poor stormwater management and ineffective drainage systems further degrade water quality and ecosystems, threatening public health (Brown et al., 2009; Pahl-Wostl, 2007). Since the 1970s, research has emphasized green infrastructure and smart urban planning to enhance water resilience (Fletcher et al., 2014; Liu & Jensen, 2018).

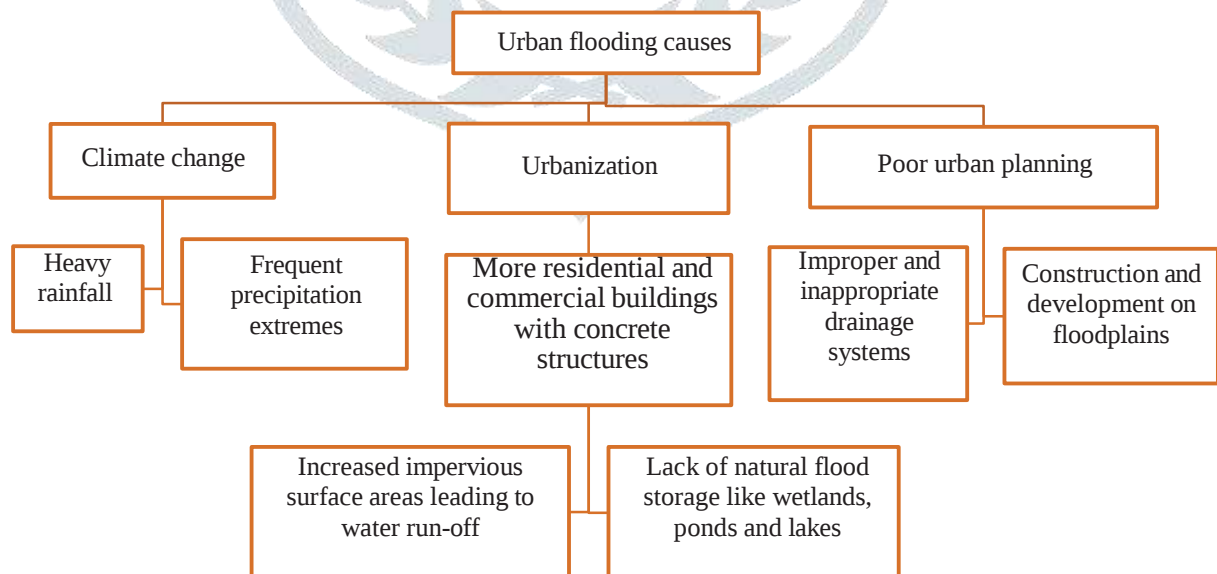


Figure 1. The main causes of urban flooding

It promotes natural and semi-natural measures in managing urban stormwater and wastewater as well as other water cycles. The primary goals for China's sponge city construction include retaining 70–90% of average annual rainwater onsite by applying the green infrastructure concept and using LID (Low Impact Development) measures, eliminating waterlogging and preventing urban flooding, improving urban water quality, mitigating impacts on natural ecosystems, and alleviating urban heat island effects. The sponge city program will also create investment opportunities in infrastructure upgrading, engineering products, and new green

technologies. However, these concepts and strategies are still very much in the development stage (Chan et al., 2018), and they have only been applied in small-scale contexts like experimental pilots and localized areas. Moreover, the integration of sponge city principles into wider urban planning remains limited due to challenges such as institutional fragmentation, insufficient funding, and gaps in technical capacity (Wang et al., 2019). Public engagement and inter-sectoral collaboration are often overlooked but are vital for ensuring the long-term sustainability of such initiatives (Li et al., 2020). To achieve broader adoption, continuous policy support and adaptive governance mechanisms are essential (Yu et al., 2019).

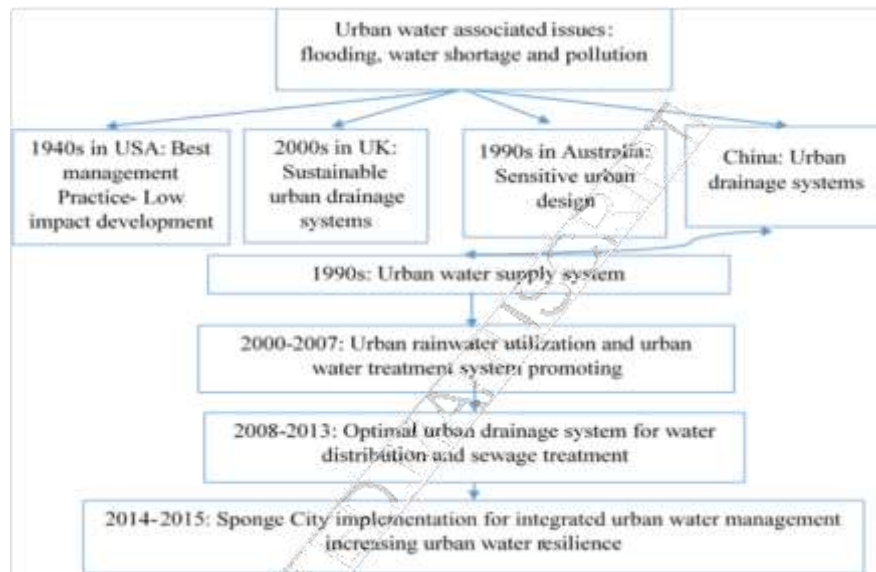


Figure 2. Different urban water strategies of the 20th century

1.2. Historical Evolution of Urban Water Management

For developing countries like China, most urban areas have witnessed high density population growth, intensive expansion of impermeable roads and rooftops and pressures of water flood disasters in terms of climate change. Their urbanized areas with existing urban water management systems are struggling to cope with these issues. As such, a new approach to urban water management is essential for developing countries. The Sponge City program was launched in 2013-14 to address and overcome the above-mentioned issues (Li et al., 2017) by delivering multiple advantages for urban communities to improve water runoff reduction, water quality enhancement, better water storage and mitigating greenhouse gas emissions (GHGs) (Wang et al., 2018). The ambition in China is to create a new kind of urban water management system known as the Sponge City. Many pilot Sponge City programs commenced in 2015 and 2016 with the Chinese government stating that approximately 70% of stormwater would be recycled from implementing measures to improve permeation, detention, storage, purification and drainage systems (Li et al., 2017). Additionally, the Chinese government has aimed to target 20% of its urban areas with the Sponge City concept by 2020; this will rise to 80% of city regions by 2030.

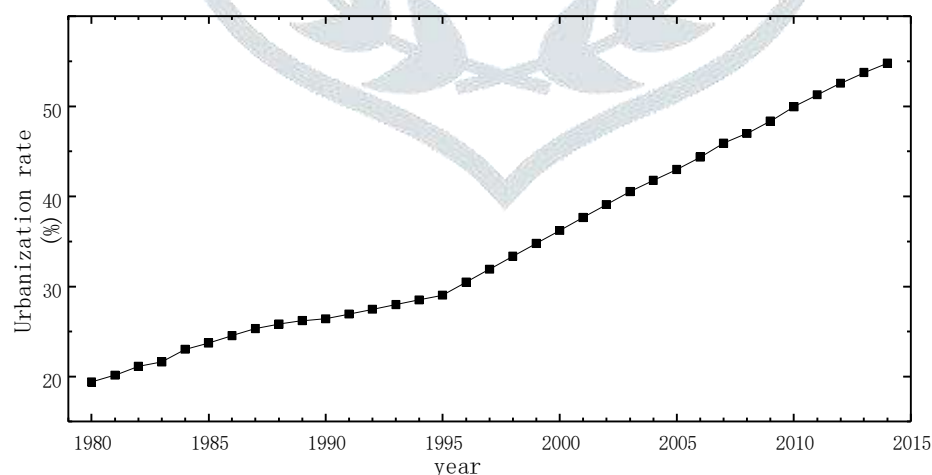


Figure 3. China's urbanization rate from 1980 to 2014.

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1.3. The Need for a Sponge City Approach

Urban development has disrupted natural ecosystems, causing flooding, water pollution, and reduced groundwater recharge. The Sponge City Concept addresses these issues by integrating green infrastructure like green roofs, wetlands, bio-retention systems, and permeable pavements to enhance stormwater absorption and purification (Li et al., 2018; Wang et al., 2018). Recognizing its benefits, China launched Sponge City projects in 30 pilot cities (Chan et al., 2018). Despite challenges, these nature-based solutions promote sustainable water management, flood risk reduction, and urban resilience amid climate change and rapid urbanization (Jia et al., 2017). However, scaling these solutions requires cross-sector collaboration, supportive policy frameworks, and robust

monitoring systems to ensure performance and adaptability. There is also a growing need for public education and stakeholder engagement to maintain long-term effectiveness and social acceptance (Dong et al., 2020). Moreover, integrating sponge city elements into conventional urban planning remains a key step toward achieving sustainable urban transformation (Zhang et al., 2019).

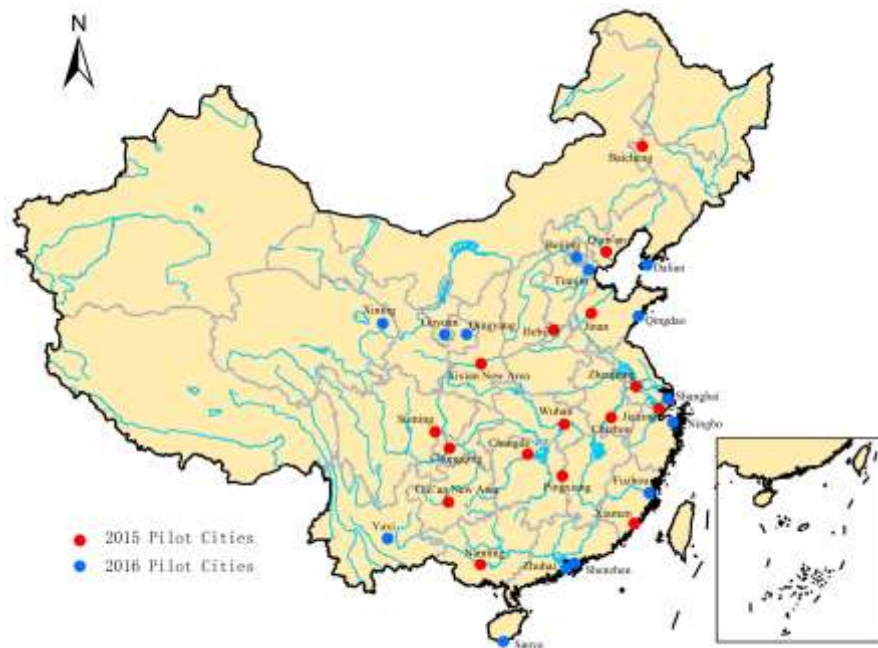


Figure 4. Location of pilot sponge cities.

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1.4. Research Objective

1. Aim

This research aims to evaluate the effectiveness of the Sponge City Concept in enhancing urban water resilience through green infrastructure. It seeks to analyze its role in mitigating urban flooding, improving water retention, and promoting sustainable urban development.

2. Objectives

- i. To examine the principles and strategies of sponge cities in urban water management.
- ii. To analyze the impact of green infrastructure (e.g., permeable surfaces, green roofs, urban wetlands) on flood mitigation and water conservation.
- iii. To evaluate case studies of sponge cities to understand their effectiveness and challenges. To assess the environmental, social, and economic benefits of sponge city initiatives. To provide recommendations for integrating sponge city strategies into urban planning policies.

3. Scope

- i. Focuses on urban flood management and sustainable water infrastructure.
- ii. Covers green infrastructure solutions such as rainwater harvesting, bio-retention systems, and permeable pavements.
- iii. Includes global case studies of cities implementing sponge city principles (e.g., China, Singapore, the Netherlands).
- iv. Examines the role of policymakers, urban planners, and engineers in sponge city development.
- v. Analysis the long-term sustainability and scalability of sponge city models.

4. Limitations

- i. Geographical focus: Case studies may be limited to regions with established sponge city initiatives.
- ii. Data availability: Access to real-time flood management and water conservation data may be restricted.
- iii. Implementation challenges: Variations in infrastructure, policies, and funding across different cities may impact the feasibility of sponge city solutions.
- iv. Climate variability: The effectiveness of sponge cities may vary based on local climate conditions and rainfall patterns.
- v. Time constraints: Long-term impacts of sponge cities require extended research and monitoring beyond the scope of this study.

2. Design and Implementation of Sponge Cities

Urban areas face increasing challenges from climate change, urbanization, and inadequate water management systems, leading to frequent flooding and declining water quality. The Sponge City Concept offers a sustainable solution by integrating green infrastructure and water-sensitive urban design to enhance water absorption, retention, and reuse. This chapter explores the key principles, strategies, and technologies that define Sponge Cities, with a focus on nature-based solutions, permeable surfaces, rainwater harvesting, and the role of vegetation in flood mitigation.

2.1. Key Principles and Strategies of Sponge Cities

The Sponge City Concept is based on the idea that urban environments should function like a sponge, absorbing, storing, purifying, and slowly releasing stormwater to reduce flood risks and enhance water resilience (Li et al., 2018). The core principles include:

- i.

Absorption – Enhancing urban surfaces’ ability to retain rainwater through permeable materials and green infrastructure.
- ii.

Storage – Creating wetlands, reservoirs, and bio-retention ponds to store excess water.
- iii.

Purification – Using vegetation and biofilters to improve water quality before it reaches waterways.
- iv.

Reuse – Implementing rainwater harvesting and groundwater recharge systems.
- v.

Controlled Discharge – Regulating water release to prevent overloading drainage systems (Wang et al., 2018).
- vi.

To implement these principles effectively, Sponge Cities use a combination of green infrastructure, permeable surfaces, and sustainable drainage systems (Chan et al., 2018).

Sponge City implementation occurs at both micro and macro scales. At the micro-scale, site-level designs like rain gardens, bio-retention systems, and constructed wetlands manage stormwater locally (Zhang & Chui, 2019). Scaling up to the catchment level enhances hydrological and ecological benefits. At the macro-scale, stormwater infrastructure integrates with natural hydrology to protect riparian corridors and green spaces. A model using spatial data (e.g., land use, climate, and hydrology) helps expand Sponge City practices (Golden & Hoghooghi, 2018; Zhang & Chui, 2019). Micro-scale benefits drive macro-scale advantages by improving infiltration and recharge. Maximizing green infrastructure ensures successful large-scale implementation.

Table 3. A comparison of Sponge City advantages in micro scale and macro-scale
(Adapted from Zhang and Chui, 2019)

	Hydrological benefits			Water quality benefit	Bio-ecological benefits		
Micro-scale	Water infiltration and recharge improvement			Water quality control	Soil environment and vegetation improvement		and growth
	Decrease of water surface runoff peak and volume						
	Increase in evapotranspiration						
Macro-scale	Base flow and stream flow recharge improvement			Water quality enhancement	Urban-environment enhancement		
	Enhancement of hydrologic connectivity				Biodiversity conservation		
	Protection against flooding				Erosion reduction		

2.2. Rainwater Harvesting and Urban Wetlands

Rainwater harvesting is a critical feature of Sponge Cities, allowing urban areas to capture and store rainwater for reuse (Wang et al., 2018). Key methods include:

- i.

Rooftop rainwater harvesting for household and irrigation use.
- ii.

Underground storage tanks to retain and filter stormwater.
- iii.

Retention ponds and artificial wetlands that store and purify excess water.

Urban wetlands play a vital role in flood control and water purification. These ecosystems naturally filter pollutants, regulate water flow, and support biodiversity, making them essential components of sustainable urban water management (Chan et al., 2018). Rapid urbanization and industrialization have strained water resources. Rainwater harvesting (RWH) offers a sustainable solution by capturing and storing rainwater, reducing shortages and urban runoff (Campisano et al., 2017). Methods include rooftop harvesting, underground storage tanks, and retention ponds for purification (Wang et al., 2018). Initially used in Japan and Germany, RWH is now widely adopted globally (Christian Amos et al., 2016). Integrated with LID, Suds, and Sponge Cities, it enhances flood resilience. Urban wetlands further support flood control, water purification, and biodiversity (Chan et al., 2018). Effective RWH requires understanding local hydrology and integrating natural and artificial wetlands for better water management.

2.3. Ecological Water Management

Urbanization and industrialization have worsened water quality, making ecological management crucial. The Sponge City concept enhances urban resilience through self-purification systems and eco-friendly waterfronts (Wu, 2015). Water purification involves physical, chemical, and biological processes, with biological methods being the most eco-friendly and cost-effective (Fletcher et al., 2014; Christian Amos et al., 2016).

There are four major factors influencing water self-purification:

- i. Hydrodynamic Force – Governs pollutant movement, mixing, and oxygen levels in the water, directly impacting water quality and aquatic life (Wu, 2015).
- ii. Soil Filtration – Soil acts as a natural filter, absorbing, sediment, and breaking down pollutants, reducing contamination levels (Pahl-Wostl, 2007).
- iii. Plant-Based Purification – Vegetation plays a crucial role in removing heavy metals, nitrogen, and phosphorus from urban water bodies, improving overall water quality (Liu & Jensen, 2018).
- iv. Microbial Degradation – Microorganisms help in the biological breakdown of contaminants, enhancing natural water treatment processes (Brown et al., 2009).

Ecological waterfront design integrates natural and artificial water systems to create sustainable urban environments, preventing riverbank erosion, enhancing stormwater infiltration, and improving biodiversity (Chan et al., 2018; Jia et al., 2017). Implementing Sponge City principles balances urban development with natural water cycles, promoting climate resilience and water security. By incorporating wetlands, bio-retention systems, and green infrastructure, cities can reduce flood risks, enhance water storage, and ensure long-term sustainability (Campisano et al., 2017; Wang et al., 2018).

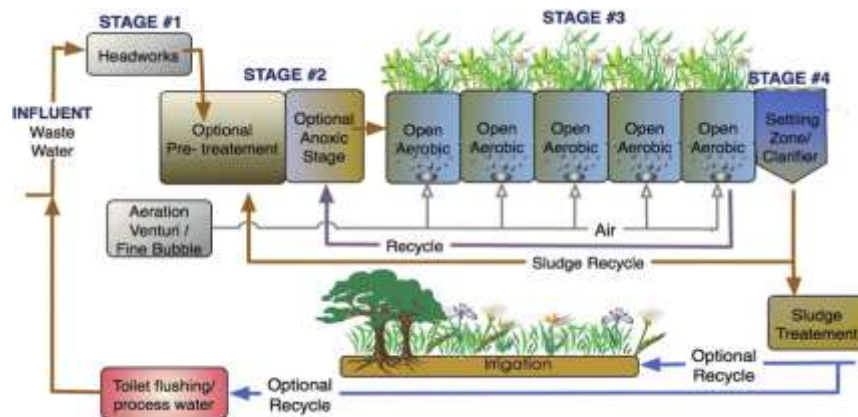


Table 3. Ecological waterfront design integrates natural and artificial water systems

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2.4. Green Infrastructure and Nature-Based Solutions

Green infrastructure is a fundamental component of Sponge City design, mimicking natural ecosystems to manage stormwater sustainably. It integrates vegetation, soil, and water management techniques to improve urban resilience (Jia et al., 2017). Examples include:

- i. Green corridors and parks that absorb rainwater and reduce runoff.
- ii. Urban forests and tree-lined streets that slow down stormwater flow and enhance infiltration.
- iii. Constructed wetlands that act as natural filters, improving water quality and providing habitats for biodiversity (Fletcher et al., 2014).

Nature-based solutions such as bioswales, rain gardens, and bio-retention cells help capture and filter stormwater before it enters drainage systems, reducing urban heat island effects and promoting ecological balance.

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2.4.1. Green Roofs

Green roofs, or rooftop gardens, help manage stormwater, reduce urban heat, improve air and water quality, enhance biodiversity, and provide recreational spaces (Mentens et al., 2006; Sailor, 2008; Shafique et al., 2018). First developed in Germany in the 1960s, they later spread to China and the U.S. (Zhang et al., 2011). A green roof has five layers: waterproof membrane, drainage, filter, soil, and vegetation (Zhang et al., 2018b). The four types—intensive, semi-intensive, multi-course extensive, and single-course extensive—vary in soil depth and maintenance needs. While extensive green roofs are the most popular for their cost-effectiveness and low maintenance, further research is needed for adaptation in diverse climates (Besir & Cuce, 2018).

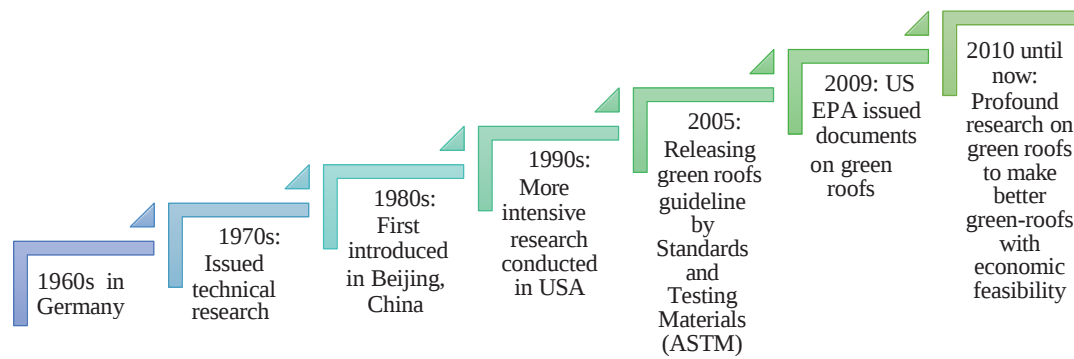


Figure 6. History of the development of green roofs around the world

2.4.2. Bio-Retention Systems

Bio-Retention Systems: A Sustainable Stormwater Solution

Bio-retention systems, also known as bio-filters or raingardens, are designed to filter stormwater, remove contaminants, and regulate water flow using vegetation and sandy loam layers (Davis et al., 2009; Fujita, 1997; Laurenson et al., 2013; Mangangka et al., 2015; Trowsdale & Simcock, 2011). These systems consist of five layers: drainage, transition, submerged zone, filter media, and detention—each tailored to site conditions (Muthanna et al., 2007). They effectively reduce runoff volume, enhance groundwater recharge, and maintain stream base flow, playing a key role in urban flood mitigation and water quality regulation (Jiang et al., 2017a; Wang et al., 2017a; Ryciewicz-Borecki et al., 2017).

Despite their benefits, limited research exists on their long-term performance, role in climate resilience, and computational modelling for efficiency forecasting (Wang et al., 2016; Liu et al., 2014). Further studies are necessary to optimize bio-retention for urbanization and climate adaptation.

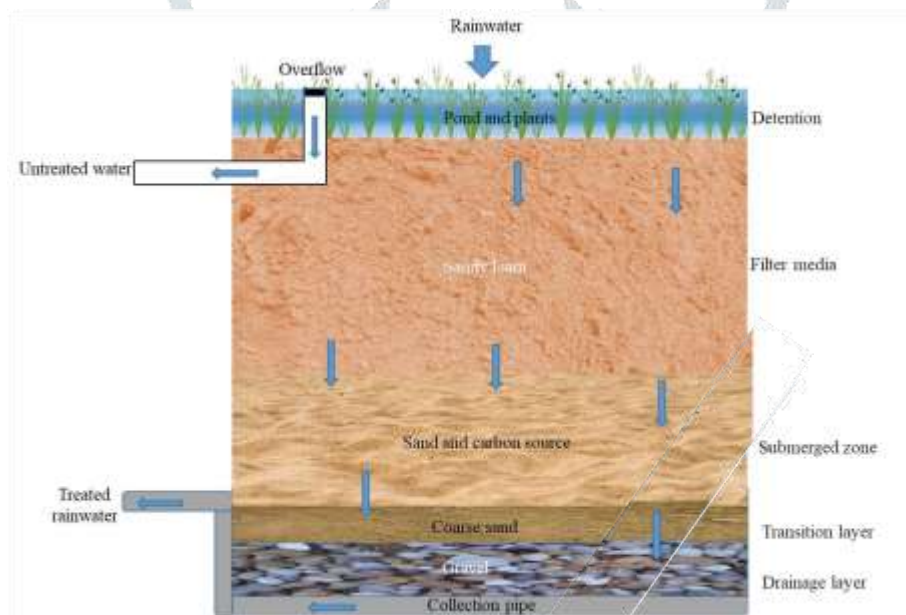


Figure 7. Bio-retention design

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2.4.3. Urban Permeable Pavement

Sponge Cities absorb rainwater, reduce runoff, and enhance groundwater recharge, improving urban water management by mitigating floods, cooling cities, and restoring ecosystems (Hu et al., 2018; Liu et al., 2018). Permeable pavement further aids in noise reduction and water purification, making it a sustainable infrastructure solution (Scholz & Uzomah, 2013; Yu et al., 2017). Commonly used in roads, walkways, and parking lots, its design varies based on traffic load and local conditions (Kamali et al., 2017).

The four main types of permeable pavements include:

- Grass Pavement (GP) – Uses vegetation to absorb water and provide green space.
- Permeable Asphalt (PA) – A porous asphalt mix that allows water to seep through.
- Permeable Concrete (PC) – A highly porous concrete material with excellent infiltration capacity.
- Permeable Interlocking Concrete Pavers (PICP) – Modular pavers with gaps for water infiltration (Woods Ballard et al., 2015).

Permeable concrete (PC) offers superior infiltration capacity if clogging is managed (Hu et al., 2018). A study at Tianjin University, China, showed permeable pavements reduced runoff by 35.6%, aiding flood control (Huang et al., 2014). However, effectiveness

depends on soil permeability and pollution levels, as clogging can reduce efficiency (Yu et al., 2017). Despite challenges, permeable pavement remains vital for sustainable urban water management.

2.4.4. Vegetation and Green Roofs in Water Absorption

Vegetation is a key element in Sponge Cities, improving stormwater absorption, reducing runoff, and enhancing air quality (Jia et al., 2017). Green roofs, in particular, provide multiple environmental benefits, including:

- i. Intercepting rainfall and reducing direct runoff.
- ii. Enhancing evapotranspiration, which helps manage urban temperatures.
- iii. Filtering pollutants from rainwater before it enters drainage systems.
- iv. Increasing insulation, reducing energy consumption in buildings (Fletcher et al., 2014).
- v. Green roofs, coupled with urban forests and green walls, significantly reduce urban flooding risks and contribute to sustainable urban development (Liu & Jensen, 2018).

The design and implementation of Sponge Cities rely on a holistic approach that integrates green infrastructure, permeable surfaces, rainwater harvesting, and vegetation-based solutions. By adopting these strategies, cities can enhance flood resilience, improve water quality, and promote ecological balance.

2.5. Overview of Current Implementation

Hard engineering remains dominant in urban flood management, but China introduced the Sponge City Program (SCP) in 2014 to promote nature-based solutions. The goal is to absorb and reuse 70% of stormwater by improving permeable surfaces, restoring ecosystems, and mitigating urban heat islands (Li et al., 2018).

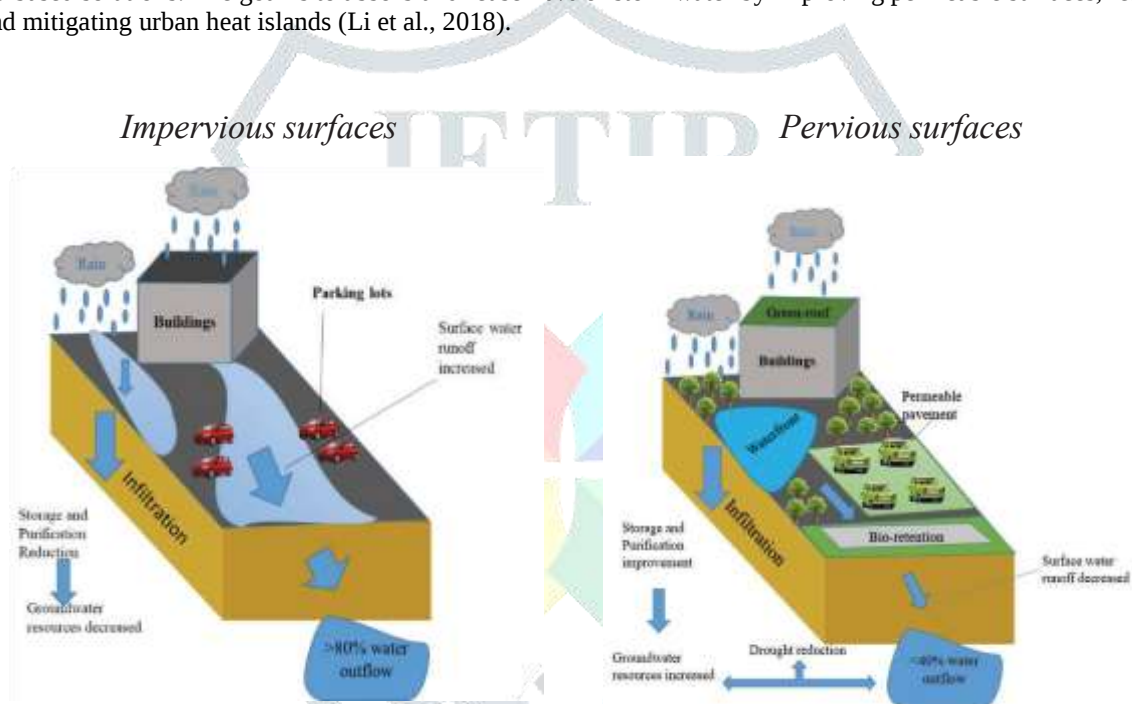


Figure 8. Difference between impervious surfaces and pervious surfaces

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The Chinese government initially invested \$50–100 million per pilot city, with future funding expected from private-public partnerships (PPP)—50% from private investors, 40% from local governments, and 10% from the central government (Liang, 2018). However, 72.63% of the public believes SCP should be mainly government-funded (Wang et al., 2017b). China's 2014 Sponge City technical guidelines emphasized cost-effective solutions like rain gardens and bio-swales over artificial ponds and green roofs (Chan et al., 2018). By 2016, 30 cities were piloting SCP projects, managed through collaboration between central and local governments. Key agencies include:

- i. NDRC – Strengthens financial support
- ii. Ministry of Finance – Manages funds
- iii. MOHURD – Issues guidelines & supervises projects
- iv. Ministry of Water Resources – Oversees water conservation

Successful implementation relies on coordination across government levels, ensuring Sponge Cities are resilient and sustainable.

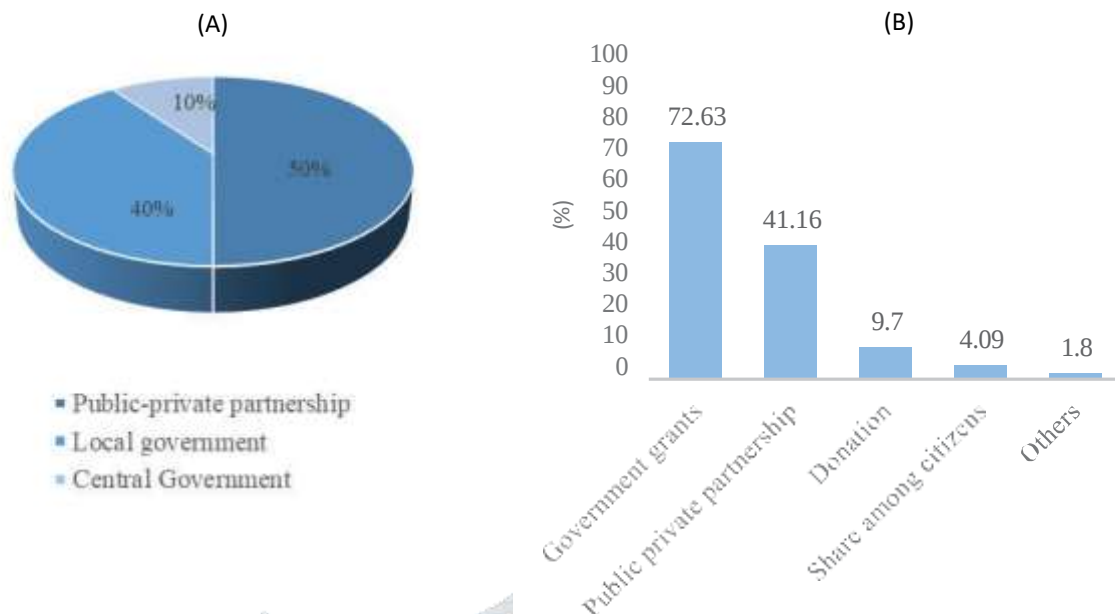


Figure 9. (a) Investments by different stakeholders in Sponge City projects from the Chinese government perspective, (b) the main sources for Sponge City projects from public perspectives

(Adapted from Wang et al., 2017b.)

2.6 Case Study Analysis of Sponge City Pilot Cities in China

China's Sponge City Program (SCP) was initiated in 2014 to tackle urban water management issues through green infrastructure and Low-Impact Development (LID) measures. This case study provides an in-depth analysis of the pilot cities selected for the program, highlighting their geographical diversity, climate conditions, urban water challenges, and the effectiveness of sponge city initiatives.

2.6.1. Selection Criteria and Geographic Distribution

China is a vast country with highly diverse climatic and geographical conditions, which directly impact the design and implementation of Sponge City strategies. The selection of pilot cities was based on several factors:

- i. Climate and Precipitation:
 - a. Southern and Central Regions: These areas receive 410 mm to 1830 mm of annual precipitation and have average temperatures between 4.6°C and 25.5°C. They were prioritized due to frequent flooding and waterlogging issues.
 - b. Northeastern Cold Regions: Pilot cities were chosen to test Sponge City solutions in sub-zero temperatures, ensuring infrastructure resilience against frost and snowmelt flooding.
 - c. Arid and Semi-Arid Areas: Selected cities in north-central China were included to explore how green infrastructure could enhance stormwater retention and water reuse in water-scarce regions.
- ii. Urban Water Issues: Cities facing challenges such as poor drainage systems, high flood risks, and water shortages were prioritized.
- iii. Governance and Financial Support: Cities with strong municipal governance and technical capabilities were chosen to ensure effective implementation and innovation.
- iv. Pilot Area Designation: Each pilot city established a designated pilot area (≥ 15 km²) to test and monitor LID measures. This approach helped streamline project management while allowing for potential city-wide expansion.

2.6.2. Comparative Analysis of Key Pilot Cities

i. Wuhan – A Water-Rich Metropolis

Geographical Context: Located in central China, Wuhan has a monsoon-influenced humid subtropical climate with annual precipitation of 1269 mm. The city is prone to severe urban flooding due to its extensive river network and rapid urbanization.

Sponge City Initiatives:

- i. Constructed permeable pavements, bio-retention systems, and artificial wetlands to improve stormwater retention.
- ii. Enhanced urban lakes and reservoirs to manage flood peaks.
- iii. Retrofitted existing drainage infrastructure with sustainable urban drainage systems (SUDS).

Results:

- i. 35% reduction in urban runoff within pilot areas.
- ii. Improved groundwater recharge and urban cooling effects.
- iii. Better public perception of green spaces and ecological sustainability.

ii. Shanghai – High Urbanization, High Flood Risk

Geographical Context: As a highly urbanized coastal city, Shanghai experiences 1520 mm of annual rainfall, increasing flood risks due to high population density and impervious surfaces.

- i. Sponge City Strategies:
- ii. Integrated green roofs and vertical gardens to absorb rainfall in densely built environments.
- iii. Expanded permeable public spaces and rainwater harvesting systems to optimize water reuse.
- iv. Strengthened flood storage capacity in urban lakes and channels.

Outcomes:

- i. 25% decrease in waterlogging incidents during heavy rains.
- ii. Enhanced urban aesthetics and biodiversity through green infrastructure.
- iii. Challenges in retrofitting older drainage systems due to high costs and spatial constraints.

iii. Beijing – Water Scarcity and Flooding Coexist

Geographical Context: Beijing has a semi-arid climate with 600 mm of annual precipitation, but also faces seasonal flooding due to sudden heavy rainfalls.

Implemented Measures:

- i. Created sponge parks to capture and store rainwater for urban use.
- ii. Developed rainwater harvesting and wastewater recycling systems to address water shortages.
- iii. Installed porous asphalt and detention basins to slow stormwater flow.

Impact:

- i. 20% improvement in water retention and local water supply.
- ii. Reduced dependence on external water resources.
- iii. Issues with sediment clogging in permeable pavements affecting long-term performance.

iv. Xiamen – Coastal Resilience Against Flooding

Geographical Context: Xiamen, located along China's southeastern coast, receives 1300 mm of rainfall annually and faces typhoon-induced flooding.

Key Solutions:

- i. Designed multi-functional coastal buffer zones to mitigate storm surges.
- ii. Constructed mangrove forests and urban wetlands for flood absorption.
- iii. Developed hybrid green-gray infrastructure, including reinforced embankments.

Results:

- i. 40% increase in stormwater retention compared to traditional drainage systems.
- ii. Enhanced coastal biodiversity and ecological stability.
- iii. Economic challenges in maintaining green infrastructure due to high costs.

2.6.3. Challenges and Lessons Learned

Common Challenges

- i. High Initial Investment Costs: Government funding of US\$50-100 million per city was not sufficient for full-scale implementation. Future reliance on public-private partnerships (PPPs) is necessary (Liang, 2018).
- ii. Policy and Regulatory Gaps: Early pilot cities lacked clear guidelines on stormwater pollution control and wastewater recycling (Wang et al., 2017b).
- iii. Maintenance and Performance Issues: Some sponge infrastructures faced issues like clogging in permeable pavements and higher maintenance costs for green roofs (Yu et al., 2017).
- iv. Public Awareness and Participation: 72.63% of surveyed residents believed SCP funding should be government-subsidized, revealing a lack of community engagement and investment incentives (Wang et al., 2017b).

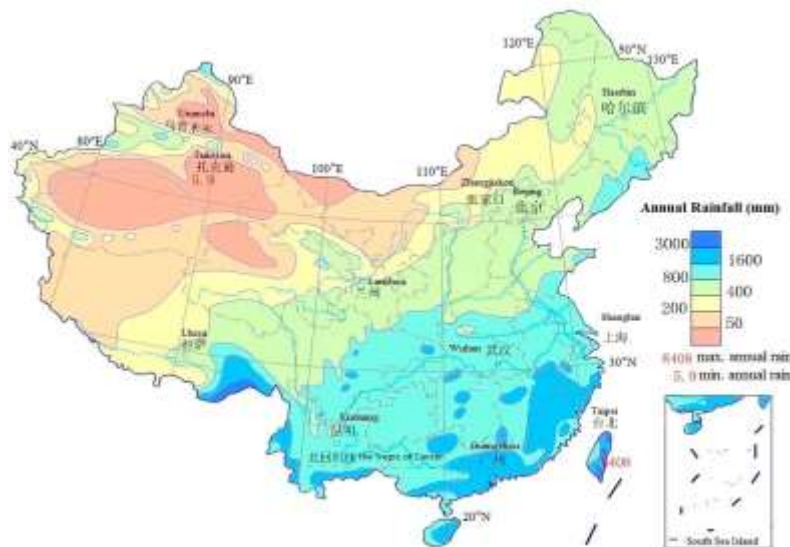


Figure 3. Annual precipitation distribution in China.

ii. Key Takeaways for Future Implementation

- i. Customized Strategies for Different Climates:
 - i. Water-scarce regions should prioritize rainwater harvesting and underground reservoirs.
 - ii. Flood-prone areas need expanded wetlands and improved drainage infrastructure.
- ii. Stronger Financial Models:
 - i. A 50-40-10 funding model (50% private investment, 40% local government, 10% central government) is proposed for long-term sustainability.
 - ii. Encouraging corporate green investments through tax incentives.
- iii. Integrated Urban Planning:
 - i. SCP should be embedded into city master plans rather than as standalone projects.

- ii. Coordinated efforts between the Ministry of Urban Development, Finance, and Water Resources are essential for scalability.
- iv. Advanced Monitoring Systems:
 - i. IoT-based water sensors to track infiltration rates in real time.
 - ii. AI-driven climate modeling tools for predictive flood management.

The Sponge City pilot projects in China offer valuable insights into sustainable urban water management. While cities like Wuhan and Shanghai have demonstrated successful flood reduction through LID measures, challenges such as financial sustainability, maintenance costs, and policy gaps remain. The future success of Sponge Cities depends on stronger public-private collaborations, advanced technology integration, and localized design approaches tailored to each city's climate and urban characteristics. If properly scaled, Sponge Cities can serve as a global model for climate-resilient urban development.

3. Benefits and Challenges of Sponge Cities

Sponge Cities provide significant environmental, social, and economic advantages by integrating green infrastructure into urban water management. Environmentally, they help control urban flooding, improve water quality, and support biodiversity by promoting stormwater absorption and groundwater recharge (Li et al., 2018). Measures such as rain gardens, wetlands, and permeable pavements reduce surface runoff and mitigate urban heat island effects, making cities more climate-resilient. Socially, these initiatives enhance public health by reducing waterborne diseases and air pollution while also improving urban aesthetics and increasing property values (Wang et al., 2018). Economically, Sponge Cities lower long-term infrastructure costs by reducing dependence on traditional drainage systems and optimizing water resource management.

However, the implementation of Sponge Cities faces several challenges. High initial investment costs, policy gaps, and maintenance issues can hinder their success (Jia et al., 2017). Effective governance, public-private partnerships, and long-term maintenance strategies are essential for sustainable urban water management. Addressing these challenges will determine the long-term success of Sponge Cities in promoting climate resilience and sustainable urban development.

Key Benefits

- i. Environmental Benefits:
 - i. Flood control and reduced surface runoff
 - ii. Improved water quality and groundwater recharge
 - iii. Enhanced biodiversity and urban climate resilience
- ii. Social and Economic Benefits:
 - i. Better public health through cleaner water and air
 - ii. Increased property values and improved urban aesthetics
 - iii. Lower long-term infrastructure and maintenance costs
- iii. Challenges
 - i. Financial: High initial investment and long-term maintenance costs
 - ii. Policy and Planning: Gaps in regulations and governance structures
 - iii. Technical Issues: Risk of system clogging and the need for proper maintenance
 - iv. Public Awareness: Limited knowledge and acceptance of Sponge City initiatives

By addressing these challenges through innovative policies, public engagement, and strategic investments, Sponge Cities can play a crucial role in sustainable urban development.

4. Policy and Governance for Sponge Cities

i. Strong Regulations and Policies

Effective policies are crucial for Sponge City success. Governments should establish clear regulations on stormwater management, green infrastructure, and urban planning. National policies must be adaptable to local needs to ensure proper implementation and long-term sustainability (Jia et al., 2015).

ii. Multi-Level Governance

Sponge City development requires coordination between national, regional, and local governments. Clearly defining roles and responsibilities can help avoid conflicts and ensure smooth execution. Collaboration with private stakeholders and communities is also essential for long-term success (Golden & Hoghooghi, 2018).

iii. Financial Support and Incentives

Governments should provide financial support, such as subsidies or tax incentives, to encourage investment in green infrastructure. Public-private partnerships (PPPs) can help share costs and responsibilities, making large-scale projects more feasible and sustainable (Liang, 2018).

iv. Data-Driven Decision Making

Reliable data on rainfall, water flow, and urban drainage is necessary for informed decision-making. Governments should establish monitoring systems and use advanced models to track Sponge City performance and adjust strategies accordingly (Bach et al., 2014; Zhang & Chui, 2019).

v. Public Awareness and Participation

Community involvement is key to maintaining Sponge City infrastructure. Public education campaigns can raise awareness about water conservation and the benefits of green infrastructure, encouraging citizens to support and participate in these initiatives (Butler & Schütze, 2005).

5. Future Prospects and Recommendations for Sponge Cities

i. Better Monitoring and Cooperation

Sponge City projects need continuous tracking to measure their success. Before construction, proper planning should include technology selection, funding sources, and long-term benefits. Different agencies must work together to share data and avoid conflicts (Hakimdavar et al., 2016).

ii. Smart Planning Tools

Advanced computer models can help design better water drainage systems. Existing models like SWMM and MIKE URBAN need improvements to predict rainfall effects, reduce pollution, and prevent flooding. Future tools should provide long-term forecasts and handle complex urban water problems (Golden & Hoghooghi, 2018).

iii. Understanding Economic and Environmental Benefits

Sponge Cities improve water management, biodiversity, and urban cooling, but these benefits are hard to measure. Cost-benefit analysis should include social, environmental, and economic factors to attract investment. Tools like W045 Best can help assess these benefits, though improvements are needed for long-term planning (Toran, 2016).

iv. Creating Local Guidelines

Each city has unique weather and urban planning needs, so national policies may not always fit. Localized rules should be developed to ensure green infrastructure, such as bio-retention systems and green roofs, works effectively for each region's conditions.

v. Expanding Sponge City Projects

To maximize benefits, Sponge Cities should be implemented on a larger scale, connecting individual projects into a full watershed system. This approach will improve water quality, reduce floods, and support biodiversity (Urich et al., 2013).

6. Conclusion

Sponge City is a sustainable urban water management approach that addresses issues such as flooding, water pollution, and declining groundwater levels. Cities can improve their resilience to climate change by incorporating green infrastructure like permeable pavements, rain gardens, and constructed wetlands.

An analysis of pilot cities reveals that Sponge Cities provide significant environmental, social, and economic benefits, such as flood control, improved water quality, biodiversity conservation, improved urban aesthetics, and increased property values.

However, obstacles such as high implementation costs, policy gaps, and maintenance concerns must be addressed in order to ensure long-term success. Strong governance, financial incentives, and public participation are critical for overcoming these barriers. Future advancements should prioritize improving monitoring and evaluation systems, developing decision-support tools, valuing ecosystem services, and developing localized policies that are tailored to different urban environments. Large-scale implementation at the watershed level will enhance the benefits of Sponge City initiatives, ensuring a comprehensive and integrated approach to urban water management. Sponge Cities, with continued investment, policy support, and community involvement, can play an important role in creating resilient, sustainable, and livable urban environments for future generations.

7. Reference

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