# Research on the Current Status and Countermeasures of Sponge City Development in China

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**Abstract.** With the rapid advancement of urbanization in China, urban water problems such as frequent waterlogging, water shortage, and water environmental pollution have become increasingly prominent. Sponge city construction has become the core path for urban water system governance and high-quality development of new urbanization. This paper adopts research methods including literature analysis, case study, GIS spatial analysis, and a combination of quantitative and qualitative analysis to systematically sort out the theoretical system and development process of sponge city construction in China, analyze its spatial pattern, implementation effects and existing bottlenecks, and put forward targeted optimization countermeasures. The research results show that China's sponge city construction has gone through four stages and formed a systematic promotion mechanism. The 70 national pilot cities are mainly concentrated in the east of the Hu Huanyong Line. By the end of 2023, the cumulative built-up area of sponge cities nationwide had exceeded 18,000 km², and the number of waterlogging points in pilot cities had been reduced by more than 65% on average. However, the current construction still faces three core bottlenecks: excessive reliance on government finance, imperfect regional adaptive technical standards, and insufficient public participation. Based on this, this paper puts forward optimization paths from four dimensions: multi-scale planning coordination, regional technological innovation, diversified policy guarantee, and universal social participation, to provide theoretical and practical reference for the high-quality development of sponge cities in China, and also provide a research model for practical teaching of geography related majors.

**Keywords:** Sponge City; Construction Status; Spatial Pattern; Stormwater Management; Optimization Path; Urban Water Governance

## 1. Introduction

Against the backdrop of global climate change and rapid urbanization, the frequent occurrence of extreme precipitation events combined with the expansion of hardened urban surfaces has created a cumulative effect. Chinese cities are facing complex water-related challenges, including urban waterlogging, water scarcity, degradation of urban water ecosystems, and deterioration of water quality. Relevant IPCC reports indicate that over the past century, the global average temperature has steadily risen, and the intensity and frequency of extreme precipitation events such as heavy rainfall have significantly increased, with particularly pronounced impacts on densely populated and economically concentrated urban areas. Data show that the hardened surface rate in the built-up areas of large cities in China generally reaches 70% to 80%. More than 400 cities nationwide experience varying degrees of water shortages, among which over 100 are severely water-scarce cities. The management of urban water systems has thus become a core issue that needs to be addressed in the process of new urbanization.

Against this background, sponge cities have emerged as an innovative urban rain and water management model. At its core, it uses a six-dimensional technical system of 'infiltration, retention, storage, purification, utilization, and discharge' to enable cities to function like sponges: storing, infiltrating, and naturally purifying rainwater during rainfall, and releasing the stored water for use during droughts. This restores the urban hydrological cycle, enhances urban water security resilience, and stabilizes ecosystems. Since the concept of 'sponge cities' was officially proposed in 2012, China has launched two batches of national pilot cities, totaling 30 cities. By 2023, a demonstration system

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of 70 pilot cities has been established, making the construction of sponge cities an important lever for the development of urban ecological civilization in China.

### 1.1 Research Progress at Home and Abroad

Exploration of related concepts abroad began in the mid to late 20th century, forming three core technical systems: the United States' Low Impact Development (LID) concept, the United Kingdom's Sustainable Drainage Systems (SUDS), and Australia's Water Sensitive Urban Design (WSUD). These have established complete technical standards, policies, regulations, and market-based operating models, focusing on technological innovation, life-cycle cost analysis, and quantification of ecological benefits.

Although research on sponge cities in China started relatively late, it has developed rapidly, forming a theoretical and practical system tailored to the characteristics of Chinese urban development. At the theoretical level, scholars have constructed the framework and planning system for the concept of sponge cities, achieving deep integration with the new urbanization strategy; at the technical level, solutions suitable for different climates and topographies have been developed; at the practical level, differentiated construction experiences between northern and southern regions have been accumulated, while also revealing real issues such as insufficient planning coordination, weak financial sustainability, and low public participation.

### 1.2 Research Content and Methods

The core research content of this study includes: systematically reviewing the theoretical foundations, functional systems, and development history of sponge city construction; analyzing the spatial distribution characteristics and construction patterns of pilot cities based on GIS spatial analysis; evaluating the comprehensive results of construction through typical cases and identifying the key development bottlenecks; and proposing optimization strategies for high-quality development from four dimensions: planning, technology, policy, and society.

The research methods mainly include: (1) literature analysis, summarizing relevant theories, policies, and practical achievements at home and abroad, and constructing a theoretical framework for the study; (2) case study method, selecting Xiamen and Jinan as typical cases to summarize differentiated construction models; (3) GIS spatial analysis, analyzing the spatial differentiation patterns of 70 pilot cities; (4) combination of quantitative and qualitative methods, quantifying the comprehensive benefits of construction and analyzing the deep causes of existing problems.

## 2. The Core Theoretical Basis of Sponge City Construction

### 2.1 Connotation and Core Functions

A sponge city refers to an urban water management model that, guided by the concepts of ecological priority and natural circulation, integrates buildings, roads, green spaces, water systems, and other ecosystems to create a city resilient to rainfall, floods, and other natural disasters. Its core lies in breaking away from the traditional 'rapid drainage' mindset of urban water management, implementing full-process control through source control, process regulation, and end-point treatment, restoring the urban hydrological cycle, and ultimately achieving construction goals such as no water accumulation during light rain, no flooding during heavy rain, clean water bodies, and mitigation of urban heat islands.

The core functions of a sponge city can be summarized in six dimensions: infiltration, detention, storage, purification, utilization, and discharge. These functions work synergistically to form a full-chain rainwater management system characterized by 'source reduction - process control - system governance,' providing threefold value in safety, resources, and ecology (Table 1).

### 2.2 Core support theory

Landscape ecology theory provides the core basis for optimizing spatial patterns in sponge city construction, emphasizing the identification of the spatial relationships among urban ecological patches, ecological corridors, and matrices to build a continuous and complete urban ecological network. This enables a networked and systematic layout of sponge facilities, overcoming the limitations of fragmented construction.

Table 1 Core Functions and Implementation Paths of Sponge Cities

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| Function | Core Connotation | Core Connotation |
|---|---|---|
| Infiltration | Enhance the infiltration capacity of surface rainwater, reduce surface runoff, replenish groundwater | Permeable pavement, sunken green spaces, bioretention basins, infiltration ponds |
| Retention | Slow down runoff, reduce peak flow, and relieve pressure on the drainage system | Rain gardens, green roofs, vegetated swales, vegetative buffers |
| Storage | Store rainwater runoff, alleviate water shortage, improve rainwater storage and regulation capacity | Rainwater storage tanks, ecological wetlands, modular water storage boxes, stepped ponds and dams |
| Purification | Remove pollutants from rainwater, improve water quality, reduce non-point source pollution | Constructed wetlands, multi-layer filtration systems, ecological riverbanks, microbial purification technology |
| Utilization | Achieve rainwater resource utilization, improve water use efficiency | Rainwater reuse systems, green landscape irrigation, street cleaning, landscape replenishment |
| Discharge | Safely discharge excess rainwater, prevent urban flooding risks during extreme rainfall | Combined/separate sewer networks, deep storage tunnels, river channel improvement, flood drainage channel optimization |

The natural water cycle theory is the core scientific basis for sponge city construction. Traditional urban development, through large-scale surface hardening, disrupts key components of the natural water cycle, leading to an imbalance in urban hydrological processes. Sponge cities, by simulating the natural water cycle, utilize techniques such as infiltration, storage, and evaporation to rebuild a healthy urban water cycle system and achieve a natural balance in the city's water system.

Sustainable development theory provides the fundamental value guidance for sponge city construction, establishing a comprehensive evaluation framework from environmental, economic, and social dimensions: the environmental dimension reduces the ecological footprint of urban development, the economic dimension achieves green and sustainable urban growth, and the social dimension ensures social equity in urban development.

## 3.The Development Process and Spatial Pattern of Sponge City Construction in China

### 3.1 Development Stage Classification

Based on the dynamic changes in policy evolution, technological maturity, and implementation scale, the construction of sponge cities in China can be divided into four core development stages, fully reflecting the transformational logic from concept emergence to systematic governance.

The first stage is the Concept Exploration Period (2012-2014): The concept of 'sponge cities' was first proposed in 2012. In 2014, the Ministry of Housing and Urban-Rural Development issued the

'Technical Guidelines for Sponge City Construction,' establishing the core technical path of 'infiltrate, retain, store, purify, use, and discharge,' completing the theoretical framework.

The second stage is the Pilot Initiation Period (2015-2016): 30 national pilot cities were identified in two batches, with the central government arranging more than 60 billion yuan in special funds. The General Office of the State Council issued the 'Guiding Opinions on Promoting Sponge City Construction,' marking the transition of sponge cities from theoretical research to nationwide practical verification.

The third stage is the Large-Scale Promotion Period (2017-2020): The concept of sponge cities was fully incorporated into overall urban planning. Over 400 cities nationwide developed dedicated construction plans, expanding the construction scope to cover the entire country. At the same time, multiple national standards were issued, achieving a shift from 'single-point breakthroughs' to 'multi-dimensional collaboration' in deepening construction.

The fourth stage is the High-Quality Development Period (2021-present): The 14th Five-Year Plan incorporated sponge city construction into the core content of urban renewal and ecological civilization construction, setting an overall goal that 'by 2030, over 80% of urban built-up areas will meet sponge city construction requirements.' The focus of construction has shifted from scale expansion to quality improvement, integrating deeply with urban resilience building and the 'dual-carbon' strategy.

### 3.2 Spatial pattern characteristics

Through GIS spatial analysis of 70 national pilot cities from 2015 to 2023, their spatial distribution exhibits four core characteristics. The spatial distribution of the pilot cities is shown in Figure 1.

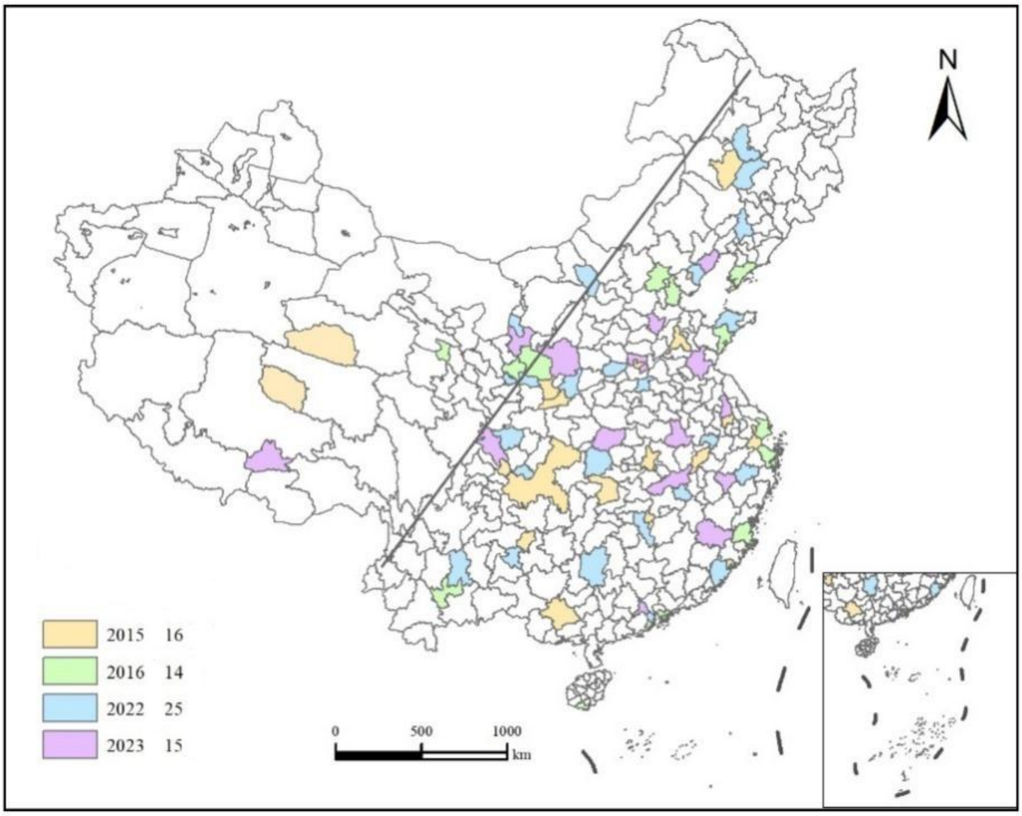


Figure 1. Spatial Distribution Map of China's Sponge City Pilot Cities

First, showing the differentiation characteristics along the Hu Huanyong Line. Over 90% of pilot cities are concentrated east of the Hu Huanyong Line, forming five major contiguous regions: Shaanxi-Gansu-Ningxia, Chengdu-Chongqing, middle Yangtze River, eastern coastal areas, and the Northeast; areas to the west are limited by factors such as terrain, climate, and economic development, resulting in few pilot projects.

Second, significant clustering in economically developed areas. Six provinces—Guangdong, Fujian, Jiangsu, Zhejiang, Shandong, and Sichuan—account for over 40% of the total number of pilot projects nationwide. These areas have strong economic foundations, prominent water issues, and possess the financial, technical support, and urgent demand for sponge city construction.

Third, coverage across all city levels: large, medium, and small. Among the 70 pilot projects, there are 19 large cities, 23 medium cities, and 26 small cities, accounting for 27.1%, 32.9%, and 37.1% respectively. This allows exploration of two differentiated approaches: high-density built-up area renovation and new area-wide construction, forming replicable construction experiences.

Fourth, achieving full coverage of multiple landform types. The pilots cover six major landform types, including northern plains, mountainous valleys, and densely rivered plains, fully considering the diverse natural geographical conditions across China. This enables the exploration of adaptive construction models suitable to local conditions, ensuring that pilot experiences are applicable nationwide.

### 3.3 Policy and Standards System Development

China has established a three-in-one policy and regulatory system of 'national top-level design - local implementation rules - technical standards and specifications.' Core documents such as the "Technical Guidelines for Sponge City Construction" and the "Evaluation Standards for Sponge City Construction" have been issued successively. In 2024, the "Water Conservation Regulations" officially incorporated sponge city construction into legal norms, providing a legal basis for its long-term advancement.

At the level of promotion mechanisms, a mature model of 'national guidance, local implementation, scientific and technological support, and market participation' has been formed: the national level coordinates policies, funds, and assessments; local governments, as the responsible entities, promote project implementation; research institutions provide technical and theoretical support; and market players participate deeply in investment, construction, and operation through PPP models and other means, creating a multi-party collaborative promotion framework.

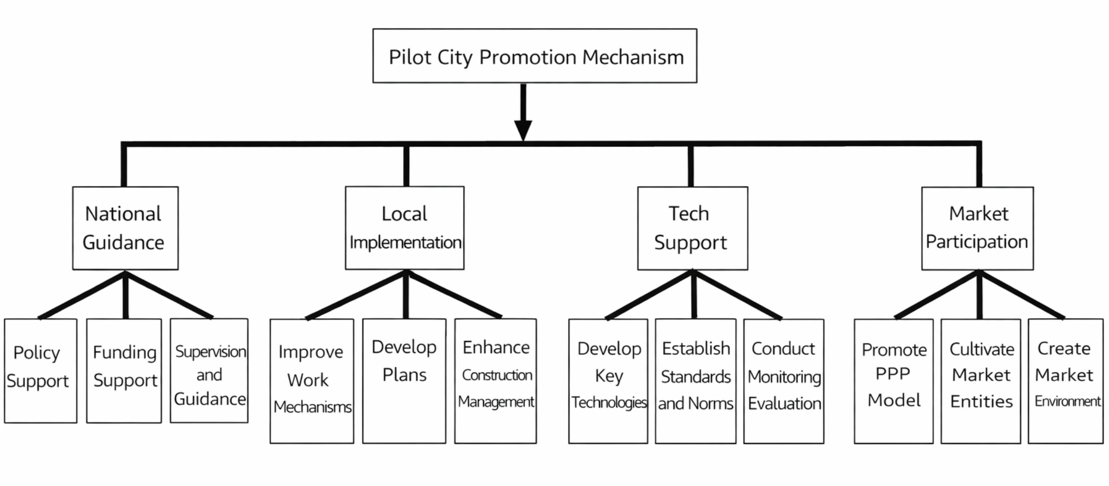


Figure 2. Framework of the Promotion Mechanism for Pilot Sponge Cities in China

## 4. The Practical Outcomes and Existing Problems of Sponge City Construction

### 4.1 Typical construction case

Xiamen, as one of the first pilot cities in the rainy southern region, has an average annual rainfall of 1,400 mm, and the issue of urban waterlogging caused by short-term heavy rainfall during typhoon season is prominent. During the pilot construction, Xiamen developed a construction model of "planning-led, diversified financing, technological innovation, and public participation," deeply integrating the sponge city concept into various urban plans. Through the PPP model, social capital was introduced, local technical standards were formulated, and public science education was

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strengthened. By 2023, the total annual runoff control rate in the pilot area reached 82%, all urban waterlogging spots were eliminated, and the water quality of urban rivers stabilized at Class III standard, achieving a win-win outcome for both ecological and economic benefits.

Jinan, as the second batch of pilot cities in the water-scarce northern region and known as the "City of Springs," faces three major challenges: urban waterlogging prevention, spring water protection, and water resource shortage. Jinan innovatively built an integrated sponge city system of "mountains, springs, lakes, rivers, and city," forming a three-dimensional management approach of "upper storage, middle drainage, and lower discharge." A water source conservation system was established in the southern mountainous area, and the old city integrated sponge city construction with cultural heritage protection. Permeable materials suitable for the northern freeze-thaw climate were developed, and a smart management platform was established. By 2024, a total sponge city area of 265.4 $km^2$ had been completed, the standard for urban waterlogging prevention in the pilot area improved from a 1-in-1-year event to a 1-in-5-year event, the core waterlogging points were basically eliminated, continuous spring flow was ensured, and a replicable construction model for water-scarce northern regions was formed.

### 4.2 Overall construction achievements

First, the city's capacity to prevent and control urban waterlogging has significantly improved. By the end of 2023, the first batch of 30 national pilot cities had built more than 6,000 $km^2$ of sponge city areas. The total annual runoff control rate in pilot areas generally reached 70%-85%, and the number of waterlogging points decreased by an average of more than 65%. Cities like Beijing, Shenzhen, and Wuhan have significantly enhanced their ability to cope with extreme rainfall.

Second, the quality of urban water environments has continuously improved. Sponge cities, through full-process pollution control, have effectively reduced urban non-point source pollution. In pilot cities such as Beijing, Jinan, Xiamen, and Wuhan, surface water quality has improved from primarily Class IV-V before construction to predominantly Class III, and black and odorous water bodies have been basically eliminated.

Third, ecological and social benefits have been fully demonstrated. The construction of sponge cities has increased urban blue-green spaces, effectively alleviated the heat island effect, replenished groundwater, and improved urban biodiversity and living environment quality. At the same time, it has driven technological innovation and industrial upgrading in multiple sectors including environmental protection, construction, and landscaping. By 2030, the cumulative investment in sponge cities nationwide is expected to reach 7.6 trillion yuan.

### 4.3 Existing core issues

First, the sustainability of funding is insufficient, with excessive reliance on government financial investment. The investment for building sponge cities reaches 100-150 million yuan per square kilometer, and the full lifecycle operation and maintenance costs are high. Currently, construction funds mainly depend on government financing, with relatively low participation from social capital. The promotion of the PPP model faces issues such as unclear profitability models, long return cycles, and imperfect risk-sharing mechanisms, with funding gaps being particularly prominent in the underdeveloped central and western regions.

Second, regional adaptability and technical standards are inadequate, and there are bottlenecks in technology promotion. There are significant differences in climate, topography, and hydrological conditions between southern and northern China, but the existing technical standards are mostly national general norms, with a lack of localized standards for areas such as northern freeze-thaw zones, northwest arid regions, and southwest mountainous regions. Meanwhile, core technological equipment and operation and maintenance costs are high, local low-cost technology research and development is insufficient, and some sponge facilities face problems such as clogging, freeze damage, or functional failure after construction, making it difficult to achieve long-term benefits.

Third, public awareness and participation are insufficient, and a social co-governance system has yet to be established. Currently, sponge city construction is mainly government-led, and the public lacks awareness of the core concepts, facility functions, and their own responsibilities, with some even having resistance to sponge transformation within residential communities. At the same time,

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channels for public participation are not smooth, making it difficult for people to be genuinely involved in the entire process of planning, construction, and operation, and the phenomenon of 'government acts, the public only observes' is widespread.

## 5. Optimization Strategies for the High-Quality Development of Sponge Cities in China

### 5.1 Planning Level

Build a multi-scale planning coordination system of 'region-city-community-plot.' At the regional level, delimit ecological protection red lines based on watershed hydrological characteristics and establish an integrated urban-rural sponge ecological network. At the city level, incorporate rigid indicators such as annual runoff control rates into the overall urban plan and regulatory plan, achieving deep integration with specialized plans for transportation, water conservancy, green spaces, etc. At the community and plot levels, formulate differentiated construction standards to ensure that planning requirements are implemented. Utilize GIS technology to carry out precise rainstorm and flood risk assessments, optimize the layout of sponge facilities, and achieve precise full-process management and control. Strictly adhere to the baseline of ecological protection, prioritize the protection of rivers, wetlands, and other natural sponge bodies, restore urban blue-green ecological networks, and realize the synergistic enhancement of artificial facilities and natural ecosystems.

### 5.2 Technical aspect

Develop localized, low-cost, and easy-to-maintain sponge city technologies based on the natural geographic characteristics of different regions. In the north, focus on breakthroughs in frost-resistant permeable materials; in the northwest, concentrate on efficient rainwater collection and utilization technologies; in the southwest, develop stepped rainwater retention and regulation technologies for mountainous areas. Accelerate the establishment of technical standards and regulations based on regional and geomorphic differences, and improve the full-process technical system for design, construction, inspection, and operation and maintenance. Integrate technologies such as the Internet of Things, big data, BIM, and artificial intelligence to build an intelligent sponge city platform that combines real-time monitoring, intelligent analysis, early warning, and coordinated management, thereby enhancing the refined management of urban water systems. Strengthen collaboration among industry, academia, and research institutions, promote the transformation and large-scale application of technological achievements, and enhance core technological competitiveness.

### 5.3 Policy level

Taking the implementation of the 'Regulations on Water Conservation' as an opportunity, improve the legal and regulatory framework for sponge city construction, incorporate construction requirements into the entire urban construction management process, and clarify the legal responsibilities of all parties involved. Establish a long-term assessment and evaluation mechanism, integrate construction outcomes into the evaluation of local governments' ecological civilization efforts, strengthen lifecycle assessments, and avoid 'focusing on construction while neglecting operation and maintenance.' Innovate diversified investment and financing models, increase the allocation of fiscal funds to underdeveloped areas in central and western regions, improve the PPP model's profit and risk-sharing mechanisms, and broaden financing channels through government service purchases, franchise operations, green bonds, REITs, and other methods, forming an investment and financing structure characterized by 'government guidance, market leadership, and diversified participation.' Establish a multi-department collaborative governance mechanism involving housing and urban-rural development, water resources, ecological environment, and others, breaking down departmental barriers and creating a synergy in work efforts.

### 5.4 Social level

Promote a community co-construction and co-governance model, widely soliciting residents' opinions throughout the entire process of project planning, design, construction, and operation, and establish mechanisms for resident supervision and incentives to enhance their sense of participation and recognition. Build a comprehensive science publicity system combining "traditional media, new media, and offline activities" to popularize knowledge about sponge cities and raise public awareness. Guide the public to carry out micro sponge constructions at the household and community levels, practice a green and low-carbon lifestyle, cultivate grassroots environmental organizations and volunteer teams, and create a positive social atmosphere of 'co-construction by all, shared by all, maintained by all.

## 6. Conclusion and Outlook

### 6.1 Research Conclusion

This article systematically reviews the theoretical framework, development history, and spatial pattern of sponge city construction in China. Through the analysis of typical cases, it evaluates the construction outcomes and existing bottlenecks and proposes targeted optimization strategies, arriving at the following main conclusions:

First, the construction of sponge cities in China has gone through four stages: conceptual exploration, pilot initiation, large-scale promotion, and high-quality development. A systematic promotion mechanism has been established, with a technical system centered on "infiltrate, delay, store, purify, use, and discharge." The policy, legal, and standards systems have gradually improved, providing solid institutional and technical support for nationwide construction.

Second, the spatial distribution of 70 national pilot cities shows a significant Huhanyong Line differentiation feature, with a high concentration in economically developed eastern regions, while also achieving full coverage across cities of different sizes and various landforms, forming differentiated construction models between the north and south. By the end of 2023, the total area of sponge cities nationwide exceeded 18,000 km², achieving significant results in flood prevention, water quality improvement, and ecological restoration. Third, China’s sponge city construction currently faces three main core bottlenecks: excessive dependence on government funding with an incomplete market-oriented operation mechanism; lagging development of region-specific technical standards and low-cost technologies; and insufficient public participation, with a social co-governance system yet to be established.

Fourth, to promote the high-quality development of sponge cities in China, systematic efforts are needed in four dimensions: at the planning level, strengthen multi-scale spatial planning coordination and ecological baseline protection; at the technical level, advance localized technological innovation and intelligent system integration; at the policy level, improve diversified policy support and market-oriented operation mechanisms; and at the social level, build a community co-construction and co-governance system with public participation.

### 6.2 Limitations and Prospects

This study still has certain limitations: some data are only up to 2023, so tracking of the latest developments and policy updates since 2024 is not comprehensive; the case studies mainly focus on two typical cities, and the comparative analysis of construction experiences in cities of different regions and sizes is not in-depth; research on public participation mechanisms lacks quantitative analysis of the willingness of different groups to participate.

Future construction of sponge cities and related research can continue to be deepened in three directions: first, continuously carry out research and development on technologies to enhance sponge city resilience under extreme climate change, low-cost localized technologies, and intelligent management technologies, and improve regional technical standards systems; second, further innovate market-oriented investment and financing and long-term operation and maintenance mechanisms, improve cross-departmental coordination and public participation mechanisms, and form a pattern of co-construction and co-governance by the whole society; third, conduct a full-life-cycle quantitative assessment of the comprehensive benefits of sponge city construction, strengthen comparative research on construction models in different regions, and provide more comprehensive theoretical and practical support for high-quality development of sponge cities across all areas. At the same time, the research framework developed in this study can also serve as a reference model for undergraduate practical teaching in geography-related majors, helping students enhance their comprehensive ability to solve complex geographical problems.

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