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Exploration of sponge city construction in China from the perspective of typical cases

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Night years have witnessed the construction of sponge city in China. In recent years, more frequent extreme rainstorm has put more pressure on urban flood control and waterlogging elimination, and the construction of sponge city has been facing many controversies. In response, this study discusses the concept, connotation, evaluation indexes, construction objectives, investment and benefits of sponge city construction. The key point is that the concept of the sponge city has expanded from the construction of low-impact development to a new model of urban development and construction, with an emphasis on improving the overall function of the city and enhancing the comprehensive response to urban water issues. Its construction benefits cannot be measured only in terms of flood control and waterlogging prevention. Besides, the biggest problem faced by cities is still flooding. The priority of building a sponge city is the prevention of waterlogging. Meanwhile, the integrity and systematic construction which integrates multiple sectors, industries and fields should be considered. The government should focus on the combination of ecological methods and engineering facilities, and scientifically promote the systematic management of urban water.

KEYWORDS

sponge city, urban water issue, construction objectives, construction benefits, rainstorm waterlogging

1 Introduction

Rapid urbanization in China has led to a series of "urban diseases", such as urban heat island effect, water environment pollution and water ecological degradation (Yoshikoshi et al., 2009; Park et al., 2020). Moreover, climate change and human activities have brought frequent extreme hydrometeorological events, contributing to the worsening urban water situation in China. In particular, rainstorm waterlogging is quite serious, resulting in frequent "urban sea-watching phenomenon" (Jia, 2017) and tremendous economic losses in events such as the Beijing "7.21" flood in 2012, the Wuhan "7.6" flood in 2016, the Jinan "7.18" flood in 2016, the Nanning "3.25" flood in 2020 (Yuan et al., 2018), and the Zhengzhou "7.20" flood in 2021 (Li et al., 2022). For this reason, a large number of scholars have carried out continuous research on urban waterlogging panoramic simulation and risk management (Wu et al., 2021; Ge et al., 2022; Zhang H et al., 2023). However, the numbers of cities and people affected by floods in China are predicted to increase with climate change (Tellman et al., 2021). Hence, issues of flood control and drainage have become the focus of the management of urban water systems.

TABLE 1 Comparison of sponge city concepts.

Scholars/Resources	Date	Concepts
The MOHURD	November 2014	The city is constructed like a sponge, with good "resilience" in adapting to environmental changes and coping with natural disasters, which can absorb, store, seep and purify water during precipitation. It is ready for use, and is of low-impact
Qiu	January 2015	The essence is to change the traditional concept of urban construction and follow a low-impact development model, that is, in harmony with nature. Sponge city construction is also known as low-impact design and low-impact development (Qiu, 2015)
Che et al	April 2015	The "grey" and "green" infrastructures should be constructed as resilient infrastructures for rainwater. It can use water efficiently and enable cities to handle extreme rainstorm as well as climate change, maintaining urban ecosystems (Che et al., 2015)
Yu et al	June 2015	The "sponge city", as an ecological approach of urban water management, is to construct multi-scale hydro-ecological infrastructures (Yu et al., 2015)
The MOHURD	October 2015	The sponge city construction should take the measures of "infiltration, detention, retention, purification, utilization and discharge" to minimize the impact of urban development and construction activities on the ecological environment
Wang	September 2017	In the sponge city, there is no waterlogging, and the rainstorm-related pollution is under control. Rainwater can be reused. The fundamental philosophy is matching the sky area with the ground area, that is, absorbing rainwater over the local area, which emphasizes local adaptation (Wang et al., 2017)
Ren	July 2017	As a new urban development construction concept and model, the sponge city is part of the comprehensive improvement of urban water resources and water environment, focusing on solving urban waterlogging and urban water environment deterioration (Ren et al., 2017)
Xia	October 2017	The construction of sponge city requires a unified planning, clear interconnection and coordination of sponge measures and relationships among different departments (Xia et al., 2017)
The MOHURD	December 2018	The sponge city construction follows the concept of "source reduction, process control and systematic remediation", emphasizes the roles of urban water ecology and water environment function, and highlights the overall improvement of urban area function
The Ministry of Finance, jointly with the MOHURD and the Ministry of Water Resources of China	April 2021	The sponge city coordinates the construction of drainage and flood control facilities, urban water environment improvement, urban ecological restoration, green space construction*etc.*

In recent years, thirty pilot cities have pumped more than 160 billion into sponge city construction (Ren et al., 2020); however, most pilot cities still suffer from serious urban waterlogging after extreme rainstorms, such as Zhengzhou, Nanning, and Wuhan. It is indicated that sponge city construction has achieved little in urban flood control and waterlogging elimination. At the same time, the construction of sponge city involves multiple sectors, industries and disciplines, while different industries and disciplines have different definitions of the sponge city. It triggered a series of debates and disagreements, mainly on the construction objectives, models and cost-benefit of sponge city (Hou et al., 2020).

Over the past decade, the connotation of sponge city has changed from the low-impact development to the comprehensive enhancement of the fundamental functions of the urban ecological system. Meanwhile, the main goal of sponge city has also been developed from urban flood management to the comprehensive management of water environment, water ecology, water resources and water security. Sponge facilities can mitigate urban flooding and store storm water to some extent, but they cannot assume the main role of flood control and drainage (Xu et al., 2020). Therefore, this study identifies the concept in Section 2, discusses the objectives and evaluation indexes of sponge city in Section 3, and makes a statistical analysis of sponge city planning, construction and financial investment in each city in Section 4. As this study elaborates on the construction objectives, connotations and functions of sponge city, it is of great importance to the scientific understanding and effective construction of sponge city.

2 Concept of sponge city

Highly urbanized cities may face aggravated urban water issues. Since the 1970s, western countries have tried to systematically solve a series of water issues concerning water resources and water environment in these cities. After nearly 50 years, a control system centered on urban stormwater management has been developed (Eckart et al., 2018).

With the increasingly prominent urban waterlogging in China, the concept of sponge city was put forward with the experience of foreign cities in urban rainwater management as a reference. In December 2013, China proposed to "build a sponge city with natural accumulation, natural infiltration and natural purification". That was the first time that the concept of sponge

TABLE 2 Changes in sponge city evaluation indexes.

Documents	Categories	Evaluation indexes	Differences
Sponge City Development Technical Guideline: Low Impact Development		Total annual runoff volume capture ratio, peak runoff and runoff pollution control targets, rainwater utilization	
Measures for Performance Evaluation and Assessment of Sponge City Development (Trial)	Water ecology	Total annual runoff volume capture ratio, ecological shoreline restoration, groundwater level, urban heat island effect	The 18 evaluation indexes of the sponge city are subdivided into six categories, focusing on the water environment and water ecology
	Water environment	Water environment quality, urban surface source pollution control	
	Water resources	Wastewater recycling rate, rainwater resource utilization rate, pipe network leakage control	
	Water security	Urban rainstorm water-logging disaster prevention and control, drinking water safety	
	System construction and implementation	Planning and construction control system, blue and green line delineation and protection, technical specifications and standards construction, investment and financing mechanism construction, performance assessment and incentive mechanism, industrialization	
	Effect	Multi-regional demonstration effect, more than 60% areas meeting the standard	
Guideline of the Ministry of Water Resources on Promoting the Water Conservancy Construction in Sponge City		Flood control standard, rainfall retention rate, water area rate, surface water quality standard-reaching rate, rainwater resource utilization rate, recycled water utilization rate, levee standard-reaching rate, flood discharge standard-reaching rate, river and lake ecological protection ratio, groundwater depth, soil erosion control rate	Two new indexes have been added, which are soil erosion control rate and flood control standard
Assessment Standard for Sponge City Development Effect	Total annual runoff capture ratio	New construction and alterations: shall not be lower than the lower limit in the area on the total annual runoff control zoning map	Based on the water Provisions of water ecology, water environment, and water security are made clear in the *Measures for Performance Evaluation and Assessment of Sponge City Construction (Trial)*
	Source reduction	Total annual runoff pollutants (Suspended solids) abatement rate ≥70% for new buildings, complexes, roads and squares, and ≥40% for reconstruction; total park runoff volume capture ratio ≥90% for green spaces	
	Waterlogging and flood control	Reasonable connection of grey and green infrastructures, no ponding or waterlogging with respect to precipitation under the design return period	
	Ecological shoreline protection of water bodies	Water area should not be reduced, and the proportion of ecological shoreline is no less than 70%	
	Environmental quality of urban water bodies	There is no direct discharge of sewage or wastewater in dry days. The annual overflow volume control rate of the combined sewer overflow discharge outlet in rainy days is ≥50%, and the water body is not black or odorous	
		Trends in groundwater burial depth, urban heat island effect mitigation	
Notice on Systematic and Territorial Demonstration of Sponge City Construction	Display of effect	Successful construction of each area	Emphasis on the successful construction of each area

city appeared in the national documents. In November 2014, the Ministry of Housing and Urban-Rural Development (MOHURD) of China issued the *Sponge City Development Technical Guideline: Low Impact Development* (hereinafter referred to as the *Guideline*). It can be seen that the concept of the sponge city was first associated with low-impact development. Subsequently, scholars from different disciplines and fields have explained this concept (Table 1). Since then, the connotations of the sponge city have been continuously expanded.

TABLE 3 Distribution of pilot sponge cities.

Classification	Grading	Number of pilot cities	Number of demonstration cities promoting construction in the whole region
Climate zone	Humid	18	13
	Semi-humid	12	7
City scale	Large cities	14	4
	Medium cities	9	10
	Small cities	7	6

In October 2015, the General Office of the State Council of China issued the *Guiding Opinions on Promoting the Development of Sponge City* (hereinafter referred to as the *Opinion*), presenting the comprehensive technical measures of "infiltration, detention, retention, purification, utilization and discharge" to minimize the impacts of urban development and construction activities on the ecological environment. The *Opinion* explicitly proposed to update the concept of urban planning and construction, and insisted on the combination of ecological methods and engineering facilities. In 2018, the MOHURD of China issued the *Assessment Standard for Sponge City Development Effect* (hereinafter referred to as the *Standard*), which put forward the sponge city concept of "source reduction, process control and systematic remediation". It emphasizes the role and function of urban water ecology and water environment, and highlights the overall function improvement of urban areas. In April 2021, the Ministry of Finance, jointly with the MOHURD and the Ministry of Water Resources of China, issued the *Notice on Systematic and Territorial Demonstration of Sponge City Construction* (hereinafter referred to as the *Notice*). It clearly proposed that the construction of new urban areas should be goal-oriented, and that of the old urban areas should be problem-oriented to coordinate the construction of drainage and flood control facilities, urban water environment improvement, urban ecological restoration and green space construction.

Therefore, the concept of sponge city has been constantly developing based on practice, evolving from "building a comprehensive rainwater management system with low-impact development" (building a low-impact development rainwater system) to "changing the concept of urban construction and development" (improving the overall function of urban areas). In essence, it consists of three aspects. First, the sponge city concerns the harmonious relationship between urbanization and the ecological environment. Second, the sponge city construction aims to make cities more resilient in adapting to environmental changes and coping with natural disasters. Third, it shifts the way to deal with flood prevention and control and advocates building a low-impact system of rainfall and flood management (Zhang, 2015). Therefore, at this stage, sponge city is essentially a change in the model of urban planning and construction.

3 Objectives and content of sponge city construction

While the connotation of a sponge city is expanding, the evaluation indexes of sponge city construction in China are also being constantly improved. Table 2 presents the changes in the development of evaluation indexes of the sponge city in China. The *Guideline* issued by the MOHURD in 2014 marked the first time that China proposed a sponge city control index system at the government level. The *Guideline* emphasized the principles of low-impact development and ecological priority, and it pointed out that sponge city in China take urban rainwater and flood management as the control objectives, including planning control indexes of runoff volume, peak runoff and runoff pollution, and rainwater utilization. The *Guideline* divided China into five regions and clarified the application scope of indexes. However, these indexes are simple and imprecise, and they lack consideration of local conditions. In 2015, the MOHURD issued the *Measures for Performance Evaluation and Assessment of Sponge City Development (Trial)* (hereinafter referred to as the *Measure*), where the eighteen indexes fall into six categories covering water ecology, water environment, water resources, water security and display of effect. The *Measure* is used to systematically assess the effectiveness of sponge city construction. However, urban stormwater management is mainly judged by the total annual runoff volume capture ratio, rainwater resource utilization and urban stormwater flood control. The indexes in *Measure* are more specific than the *Guideline*, while the focus has changed, with more emphasis on water ecology and water environment. In August 2015, the Ministry of Water Resources issued the *Guideline of the Ministry of Water Resources on Promoting the Water Conservancy Construction in Sponge City*, which put forward the main indexes for water conservancy construction in sponge city. Compared with the *Measure*, it includes two new indexes of soil erosion control rate and flood control standards. The *Standard* promulgated by the MOHURD in 2018 is the first national standard on sponge city construction in China. It further described the indexes, clearly subdivided the annual runoff volume disposal into old urban built-up areas and newly-built areas, and made detailed provisions for the total annual runoff volume in different areas and places. The actual concentration abatement target was added to the water environment evaluation. Compared with the *Measure*, the *Standard* further improves and strengthens the control indexes, takes into account the differences in the urgency of different cities to achieve the central objectives, and emphasizes the localization and precision of the measures. The *Notice* issued in 2021 further stressed the display of effect and explicitly stated that every construction of an area should be effective, with an emphasis on the overall effect of sponge city construction.

The changes in evaluation indexes show that the construction of sponge city in China is not limited to low-impact development, and it emphasizes more on the improvement of overall urban functions.

TABLE 4 Main controlling indicators of typical cities.

City scale	City	Water ecology	Water security			Water environment	Water resources
		Total annual runoff volume capture rate	Flood control standard	Stormwater drainage design standard	Flood control standard (central city area)	Surface source pollution control	Rainwater resource utilization
Large Cities	Shanghai	≥75%	Once in 100 years	≥5 years in the main urban area, 30 years for sunken buildings	Meeting planning requirements	≥75%	≥5%
	Shenzhen	70%	Once in 50 years	3–5 years, ≥10 years for especially important areas	Once in 200 years	100%	Short-term: 1.5%
							Long-term: 3%
	Guangzhou	70%	Once in 50 or more years	5–10 years, 30–50 years for sunken buildings	Once in 200 years	New construction areas: >50%	>3%
						Rebuilding areas: >40%	
	Zhengzhou	75%	Once in 20–50 years	3–5 years, 30 years for sunken buildings	Once in 200 years	>50%	>5%
	Shijiazhuang	Old urban areas: 70%	Once in 20–50 years	3–5 years	Once in 200 years	≥50%	7.5%
		In new urban areas: 75%					
	Wuhan	60%–85%	Once in 50–100 years	10 years for trunk roads, 20 years for expressways*etc.*	Once in 200 years	≥50%	≥5%
	Qingdao	75%	Once in 50 years		Once in 100 years	2020: 50%	2020: 5%
						2030: 65%	2030: 8%
	Nanjing	Built-up areas: 70%–75%	Once in 50 years	3–10 years, 30–50 years for sunken buildings	Once in 200 years	50%	2020: 2%
		New construction areas: 80%–85%					2030: 5%
	Beijing	72.6%	Once in 50–100 years	20–100 years	Once in 200 or more years	≥60%	2020: 8%
							2035: 10%
	Chongqing	≥70%	Once in 50 years	5–10 years, 50 years for sunken buildings	Once in 100 years	≥50%	localization
Medium cities	Xining	≥85%	Once in 50 years	2–5 years	Once in 50–100 years	≥60%	≥2%
	Huai'an	70%	Once in 30 years	3–5 years	Once in 100 years	≥45%	≥3%
	Suqian	70%	Once in 30 years	2–5 years, 20 years for sunken buildings	Once in 100 years	40%	≥3%
	Qinzhou	70%	Once in 50 years		Once in 100 years	40%	0.9%
	Xiangtan	75%	Once in 30 years	2–5 years, 20–30 years for sunken buildings	Once in 100 years	55%	
	Zhuhai	80%	Once in 30–50 years	3–5 years, 20 years for sunken buildings	Once in 100 years	Short-term: 35%	Short-term: 5%
						Long-term: 40%	Long-term: 10%
	Zhuzhou	80%	Once in 30 years	3–10 years, 20–30 years for underground buildings	Once in 100 years	Short-term: 45%	≥4%
						Long-term: 60%	
Small cities	Pingxiang	75%			Once in 50 years	2017: 50%	2017: 12%
						2030: 75%	2030: 15%

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TABLE 4 (*Continued*) **Main controlling indicators of typical cities.**

City scale	City	Water ecology	Water security			Water environment	Water resources
		Total annual runoff volume capture rate	Flood control standard	Stormwater drainage design standard	Flood control standard (central city area)	Surface source pollution control	Rainwater resource utilization
	Hebi	70%	Once in 30 years	≥2 years	Once in 20–100 years	70%	1.1%
	Yiyang	Short-term: ≥75%	Once in 30 years	2–5 years, 20 years for sunken buildings	Once in 50–100 years	45%	Short-term: 1%
		Long-term: ≥80%					Long-term: 3%

It is clear that these evaluation indexes have been improved. However, there are still some problems, such as the disconnection among multiple disciplines and fields, lack of correspondence between objectives and indexes, insufficient display of effect, and fragmented construction.

4 Typical cases of sponge city planning and construction

4.1 Construction objectives and targets of typical cities

In 2015 and 2016, a total of thirty cities including Qian'an, Baicheng, Fuzhou, Beijing and Xining were selected as pilot sponge cities in China, and another 20 cities including Guangzhou, Wuxi, and Suqian were selected as national demonstration cities in 2021 to systematically promote the whole construction of sponge city. Table 3 shows the distribution of these cities. The climate zone and city scale of pilot cities show that the construction of sponge city is not limited to the highly urbanized areas in East China, and they are also distributed in the arid areas in the hinterland of China. In addition to these pilot cities, more than three hundred cities, such as Nanjing, Zhongshan, Chengdu, and Zhuzhou, are also constructing sponge city, and China has entered a period that the construction of sponge city is undergoing throughout the country.

Table 4 presents the control indexes of sponge city planning for large, medium and small cities in China in four aspects: water ecology, water security, water environment and water resources. The indexes include total annual runoff volume capture ratio, waterlogging prevention and control standard, rainwater pipe and drainage design standard, flood control standard, surface source pollution control and rainwater resource utilization rate, *etc.* Among the cities in the statistics, four are coastal cities; five are northern cities; four are inland cities; five are southern cities. Nine of the above cities are national pilot cities and two are national demonstrations, so these cities are represented in terms of spatial distribution.

From the main control indexes of each city, the construction of the sponge city in different cities focuses on water security, water ecology, water environment and the function of water resources. Besides, some cities take into account the water sight and water culture, such as Zhengzhou, Guangzhou, Yiyang, Zhuhai, Zhuzhou, and Pingxiang. Among the nineteen cities in the statistics, seven cities, including Shenzhen, Beijing, Pingxiang, and Zhuhai, have proposed detailed near-term and long-term implementation targets, while Shijiazhuang, Nanjing and Guangzhou have further proposed construction targets for different areas on this basis, considering the differences between new and old urban areas. In addition, each city's *Special Plan* has proposed a clear time node, that is, the total annual runoff in 20% (80%) of the built-up area should meet the control rate requirements by 2020 (2030). In short, at this stage, the sponge city constructions have not yet formed a whole. Sponge infrastructure is scattered, and the fragmented construction is serious. Therefore, the construction cannot play the overall effect of sponge infrastructure, and the effect of sponge city construction is not as expected.

From the main control indexes of each city mentioned above, we can find that sponge city construction has different focuses in different cities, and each city considers regional differences in terms of control indexes as well as construction objectives. At the same time, water culture-related content is further incorporated into sponge city planning, so the connotation of the sponge city is constantly expanded during the construction.

4.2 Construction content of typical sponge cities

The construction programs for water security, water resources, water ecology and water environment in the *Special Plan* of each city are shown in Table 5. For water security, the sponge city construction in each city contains three major approaches of ecological protection, ecological restoration, and low-impact development. The construction of rainwater drainage channels and the improvement of urban drainage systems are the priorities of construction. Meanwhile, the integration of gray and green infrastructures is emphasized. Zhengzhou and Xiangtan proposed to build flood protection dikes and consolidate river embankments based on their needs. Guangzhou, Zhuhai, and Yiyang focus on the management of waterlogging-prone spots in urban area. At the same time, these cities are restoring inland water systems, building natural water storage systems in wetland parks, and enhancing rainwater use and control as non-engineering measures to ensure water security. For water resources,

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TABLE 5 Engineering and non-engineering measures for the construction of the typical sponge cities.

City	Water security		Water resources		Water ecology		Water environment	
	Engineering measures	Non-engineering measures	Engineering measures	Non-engineering measures	Engineering measures	Non-engineering measures	Engineering measures	Non-engineering measures
Shenzhen	Floodway construction	River cross-section regulation, rainwater drainage system construction	New storm sewers and reservoirs	Unconventional water resources utilization, adjustment of water source structure	Construction of ecological river cross-sections	Conservation of green space systems and water system protection	Construction of drainage pipelines, diversion of rain and sewage	Wetland purification and runoff control
Zhengzhou	Strengthening river embankments, building flood storage and detention areas and building drainage facilities	191 floodways are planned	Construction of water supply pipe network	Optimization of the allocation of water resources and the use of unconventional water resources	\	\	Rainwater reservoirs, sewage treatment plants	Comprehensive river course regulation and revitalized water flow project
Shijiazhuang	Construction of flood control facilities and improvement of drainage systems	Restoration of inland water systems, optimization of drainage zoning, and strengthening of Blue Line management	\	\	Construction of ecological river cross-sections	Regional runoff control, water system protection	Storm sewage diversion project	Malodorous black water treatment
Guangzhou	Construction of drainage facilities and treatment of waterlogging-prone spots	Sponge and wetland park construction	Renovation and expansion of water plants and reclaimed water plants	Ecological wetlands, ecological corridors	\	River ecological remediation	Construction or expansion of a sewage treatment plant	River remediation, constructed wetlands
Xicheng District, Beijing	Permeable pavement renovation, renovation and expansion of drainage systems	Stormwater control and utilization	Renovation of water supply pipe network and improvement of reclaimed water system	Optimization of the allocation of water resources	Shoreline landscape construction	Strengthening the management of blue lines of rivers and lakes, preventing and controlling soil erosion	comprehensive improvement of old residential areas, renovation of shanty towns	Control of non-point source pollution
Huai'an	Construction of flood control and drainage facilities	Strengthening the rainwater regulation and storage, and restoring the inland river system	Construction of rainwater harvesting facilities	Improving the utilization of unconventional water resources	Construction of ecological river cross-sections	Strengthening the water system protection and regional runoff control	Construction of rainwater sewage diversion system and sewage pipeline network	Smooth flow of running water, malodorous and black water treatment
Xiangtan	Construction of flood control dikes, drainage facilities, and floodway construction	Adjusting floodways and inland river connecting and dredging	Construction of sewage treatment plants and rainwater utilization facilities	\	Building ecological barges and sunken green spaces	Comprehensive improvement of river courses and restoration of bank zones	New rainwater sewage diversion pipe network and sewage pipe network	Ecological restoration, comprehensive improvement of river courses
Zhuhai	Construction of embankments and waterlogged spot treatment, and renovation of the drainage pipe network	Establishing water source protection zones and building coastal ecological coastlines	Renovation and expansion of green space systems and rainwater harvesting systems	Utilization of unconventional water resources	New reservoirs and regulating ponds	Construction of forest for water source conservation and restoration of wetlands	Construction of sewage interception ditches	River system dredging, malodorous and black water body remediation

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TABLE 5 (*Continued*) **Engineering and non-engineering measures for the construction of the typical sponge cities.**

City	Water security		Water resources		Water ecology		Water environment	
	Engineering measures	Non-engineering measures	Engineering measures	Non-engineering measures	Engineering measures	Non-engineering measures	Engineering measures	Non-engineering measures
Zhuzhou	waterlogging-prone spots rectification, pipe network upgrading, 34 sewage pump stations construction	Comprehensive treatment of flood control water system	Construction of reclaimed water facilities and rainwater storage facilities	Utilization of unconventional water resources	Sunken green space, permeable paving, storage facilities	\	Storm sewage diversion retrofit	Remediation of malodorous and black water body, whole-process control of rainwater pollution
Lishui	Construction of the drainage system and rainwater runoff drainage system exceeding the standard	Multi-level rainwater storage and source regulation	Water supply pipe network, secondary water supply renovation	Unconventional water utilization, control of pipe network leakage, strengthening the technical archives management	Construction of urban artificial lakes and dredging of river courses	Returning fishing to lakes, returning farmland to lakes and transforming ecological shorelines	Construction of rainwater sewage diversion, sewage treatment facilities, and rainwater storage tanks	Street dredging, ecological restoration, water diversion, and replenishment
Yiyang	Floodway construction, renovation of drainage systems, and treatment of waterlogging points	River course rehabilitation	Construction of a reclaimed water reuse system	Establishing water source protection areas and emergency water source areas	\	\	Construction of sewage treatment plants, rainwater and sewage diversion	Remediation of malodorous and black water body, wetland construction

engineering measures (such as improving and expanding the urban water supply system and building rainwater storage tanks) and non-engineering measures (such as adjusting the water source structure and optimizing water resource allocation) are the main construction content, aiming to improve the urban water resource security rate. For water ecology, the cities focus on the "integration of gray and green infrastructures". Shenzhen, Shijiazhuang, Beijing and other cities combine the construction of ecological riverbanks and sunken green areas with the strengthening of water system protection, regional runoff control and the construction of green space systems to jointly safeguard urban water ecology. The eleven cities in the statistics have taken measures to improve the quality of the urban water environment and achieve the water environment construction objectives by using rainwater and sewage diversion renovation, building and expanding sewage recycling and treatment systems, conducting water treatment, restoring ecological wetlands and replenishing ecological water.

The above analyses and practices show that the current measures of sponge city construction focus on green infrastructures like ecological restoration and water environment management, and very few engineering measures such as drainage system construction are involved. Therefore, the construction of sponge city deviates from the original objective of flood control and waterlogging elimination, and is more inclined to restore the urban water environment and water ecology. However, the urgent issue that needs to be tackled in the current urban development process is the urban flooding issue. The "urban sea-watching" is essentially a failure of the urban flood control and drainage system (ZHANG C et al., 2023). The current sponge city construction focuses on the source control system. Most of these constructions are "green infrastructure", while urban drainage and de-risking rely more on the construction of "gray infrastructure" such as drainage networks. In addition, the flood control capacity of the source control system is limited (Feng et al., 2021), and the construction of sponge city in part area (with the old urban areas focusing on the management of waterlogging points) leads to the fragmentation of sponge city construction and planning (Ren, 2018). The overall urban flood control and drainage system cannot be changed. Thus, the current sponge city construction can only solve the waterlogging caused by poor drainage in local areas, while it is difficult to cope with the urban flooding under extreme rainfall. Therefore, at this stage, we should steadily and scientifically promote the construction of sponge city, reasonably plan the construction content and continuously optimize the configuration of "sponge infrastructures".

The investment in sponge city mainly involves seven aspects, including road traffic system, urban water system, building district renovation, garden and green space system, water supply and drainage system, capacity building and related projects outside the built-up areas. The investment of each city is shown in Table 6. It is found that except for Shijiazhuang, other cities mainly invest in road traffic system, urban water system and garden and green space system, accounting for more than 75% of the total investment. The proportion of investment in road traffic system exceeds 50% in Jinan and exceeds 25% in Zhengzhou, indicating that the sponge city construction of these two cities is mainly in urban infrastructure construction. Shijiazhuang's investment is mainly concentrated in the renovation of building

TABLE 6 Sponge city construction investment (Unit: 100 million yuan).

Cities	Road traffic system	Urban water system	Building district renovation	Garden and green space system	Capacity building	Related projects outside the built-up areas	Water supply and drainage system	Total
Jinan	76.40	35.00	8.00	2.80	2.60	16.00		140.80
Zhengzhou	137.10	138.10	57.50	139.90	1.00		61.20	534.80
Shijiazhuang	5.70	2.87	30.63	2.88	0.54		11.71	54.33
Xicheng District, Beijing				62.08	0.60		4.10	66.78
Wuhan	24.90	85.60	27.80	8.50			13.00	159.80
Suqian	7.31	81.64		24.96		0.89	21.13	135.93

districts and water supply and drainage facilities, accounting for 69.3% of the total investment. Then, the investment in sponge city construction is mainly concentrated in "sponge facilities", while the investment in disaster prevention and mitigation capabilities such as monitoring and early warning accounts for less than 1% of the total funds. At the same time, the "sponge facilities" are mainly concentrated in three aspects of green space square, urban roads and urban water system, where 48 of the 68 sponge projects in Hebi and 38 of 58 projects in Xixian New Area are green space, roads, and urban water systems. There is basically no project related to capability building. Therefore, the proportion of investment in sponge city construction is unbalanced, and there is a lack of financial support in the forecasting and early-warning operation and the urban hydrological system research that facilitate the development and construction of sponge city, which is precisely the basis for understanding the urban hydrological cycle and enhancing source control (Bell et al., 2016; Pande and Sivapalan, 2016).

The construction of sponge city is mainly based on water environment governance and water ecological restoration. Its content, such as water system management and green park construction, is mainly to improve the overall function of the city, and the construction of urban flood control and waterlogging elimination system (drainage facilities) accounts for a very low proportion of investment. Therefore, the effectiveness of sponge city construction cannot be assessed only from urban waterlogging elimination. In addition, sponge city construction overlaps with other urban planning. Most of the investment in current urban construction is categorized as the investment in sponge city construction. For example, the road traffic system investment accounts for more than 50% in Jinan and more than 25% in Zhengzhou, and the renovation of old residential areas in Wuhan accounts for more than 50%. Whether the construction of all these infrastructures can be counted as an investment in sponge city remains controversial. Therefore, we cannot just consider the investment in sponge city and a specific aspect when assessing the benefits of sponge city. Sponge infrastructure and ecological rivers play an important role in building new urban water systems, and sponge facilities and ecological restoration involve benefits from environmental, economic as well as social aspects. Therefore, when measuring the effectiveness of sponge city, we cannot just consider flood control and waterlogging elimination or deny the benefits of sponge city just because waterlogging occurs in the city.

5 Conclusion and suggestions

5.1 Conclusion

By reviewing the development history of sponge city concept in China and combining the construction content, measures and investment of typical sponge city, this paper expounds on the essence of sponge city in China, and draws the following two conclusions:

First, a scientific understanding of the sponge city is essential. Sponge city is not the same as low-impact development, and its concept has developed from low-impact rainwater system construction into new urban construction. It is a new model of integrated urban water system management, which is designed to

promote the harmonious development of urbanization, water resources and water ecology, aiming to further enhance the overall function of the city and make the city "resilient" to coping with natural disasters.

Second, the construction of sponge city is to systematically tackle the water issues in China's cities and to integrate rainwater management into the whole urban development and construction. And it can effectively combine flood and waterlogging control, water resources utilization, water environment protection and water ecological restoration to further enhance the comprehensive response to urban water issues.

5.2 Suggestions

Throughout the development of China's sponge city, the construction of sponge city has achieved remarkable results in the urban water ecological environment. However, there are still some problems in urban waterlogging control, multi-department and multi-level coordinated promotion. Based on this, two suggestions are put forward on promoting sponge city.

First, at the current stage, the construction goals, indexes, content and investment in sponge city are relatively broad, and are easily confused with other municipal construction content, thus leading to the "fragmentation" of sponge city system construction. Hence, we should scientifically promote the construction of sponge city, give priority to solving urban flooding, reasonably lay out the "sponge facilities" and give full play to their overall advantages.

Second, the fundamental problem of sponge city construction is the systematic governance of water. It not only involves the city itself, but also the watershed and the region. Therefore, in sponge city construction, we should emphasize the overall concept, coordinate different sectors,

Author contributions

SS: Information collecting, Writing—original draft. LW: Conceptualization, resources, writing—original draft, research design. YW: Resources, writing—review and editing. XS: Writing—review and editing. LL: Writing—review and editing. XX: Writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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