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Urban Planning and Construction of Beijing Area Based on Sponge City Theory

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Abstract:

This paper mainly discusses the theory of sponge city and its application in urban planning and construction in Beijing, so as to solve the problems of urban waterlogging and water shortage. By integrating green infrastructure, permeable pavements, and low impact development (LID) technologies, the sponge city approach enhances the resilience to extreme rainstorm events of cities. Taking Beijing Olympic Park as an example, the sponge city theory is realized through the construction of rain gardens and green roofs. The potential of urban water management and improving the quality of the ecological environment was demonstrated. In addition, this paper also gives a case simulation. The promotion of Beijing's sponge city construction provides a model for the development of sponge cities in China. As the capital, Beijing's experience in sponge city development can be shared with other arid regions in the north, boosting construction efforts nationwide. This initiative lays the foundation for the long-term sustainable development of the city.

Keywords: Urban planning and construction; sponge city; low impact development.

1. Introduction

The concept of sponge city, first introduced in 2013, addresses the issues of urban waterlogging and water scarcity that have emerged from China's rapid urbanization. This innovative approach is designed to foster sustainable development and safeguard the ecological environment. A sponge city employs urban stormwater management strategies to enhance a city's resilience to heavy rainstorms, elevate the quality of life for its citizens, and improve the ecological environment. This is achieved through the installation of various facilities, including green roofs, cisterns, permeable pavements, and pocket parks. For instance, when modernizing urban drainage systems, emphasis should be placed on conserving the precious resource of rainwater.

In January 2014, China's Ministry of Housing and Urban-Rural Development issued the "Technical Guide for the Construction of Sponge Cities—Construction of Rainwater Systems for Low-Impact Development," which mandates that all regions actively promote sponge city construction in accordance with the guide and tailored to local conditions [1]. As the capital, Beijing, with its dense population, significant water environmental challenges, and varied terrain, stands to benefit greatly from the implementation of sponge city principles. This development can significantly mitigate urban waterlogging, enhance the ecological environment, and reduce the heat island effect.

This paper expounds the basic concepts and core principles of sponge city theory, discusses the function of sponge city theory in urban rainfall water resources management, and analyzes the sponge city theory in combination with the unique geographical and human characteristics of Beijing. Finally, this paper puts forward some strategic suggestions for implementing sponge city in Beijing, in order to promote the sustainable development of urban water environment in Beijing.

2. Sponge City Theory

Sponge cities, as the term implies, are designed to mimic the sponge's ability to absorb, retain, filter, and recycle water resources. They are engineered to withstand the pressures of extreme climate conditions and heavy rainfall, thereby enhancing the efficiency of water resource utilization through the emulation of natural ecosystem functions. There are three pivotal components of sponge city theory.

2.1 Green Infrastructure

Green infrastructure encompasses urban facilities that harmonize with nature, such as parks, wetlands, and reservoirs. These elements enhance the ecological services of a city by purifying air, improving water quality, and regulating climate. They form the cornerstone of sponge city theory, facilitating the storage and reduction of rainwater runoff. Innovations in this area are crucial; for instance, the Green Wave Roof in Paris is equipped with sensors to monitor hydrological activities, collecting data on rainfall, soil moisture, temperature, and runoff to understand water's interaction with green infrastructure. Similarly, Singapore's Garden by the Bay, located by Marina Bay, has been meticulously planned to sustain an energy- and water-efficient cycle. The greenhouses cool only the lower levels, reducing the cooling requirement through displacement ventilation. Chilled water pipes in the floor slabs ensure that cool air settles in occupied areas while warm air rises and escapes from the upper levels. Additionally, the garden utilizes photovoltaic systems for the adjacent cooling greenhouse complex and other eco-friendly features.

2.2 Permeable Ground

Permeable ground materials allow rainwater to infiltrate the soil, reducing surface runoff, replenishing groundwater, and easing the burden on urban drainage systems. Pervious concrete, which lacks fine aggregates, creates larger pores for water passage. This type of ground also mitigates the urban heat island effect and decreases flood risks through evaporation. In Beijing, such pavements are visible in parks and roads, including the popular red running tracks and playgrounds. The larger pores make these surfaces less rigid than concrete, offering a more comfortable and cushioned walking and running experience.

2.3 Low Impact Development (LID)

LID is an innovative approach to rainwater management designed to mitigate the impact of urban development on the natural hydrological cycle. By integrating with the principles of sponge cities, LID focuses on strategies such as natural drainage, infiltration, rainwater harvesting, and green space creation to preserve and enhance the water ecosystem. This approach is underpinned by a combination of structural and non-structural measures. Structural measures involve the installation of facilities that recycle and utilize rainwater, including systems for treating it through infiltration and storage, thus amplifying its functional benefits. Non-structural measures, on the other hand, leverage various management tools to optimize stormwater utilization. A key aspect of LID is rainwater retention, where systems like green roofs and rain gardens are employed to slow the flow of rainwater during storms, managing peak discharge volumes and preventing flash floods. Additionally, rainwater infiltration is facilitated by using permeable pavements, which allow rainwater to seep into the soil, reducing river pollution and conserving water. These infiltration systems are equipped with carefully designed pipes and channels to ensure efficient flow and prevent sedimentation. Infiltration wells are also used to enhance the collection and absorption of rainwater. Lastly, LID promotes rainwater storage to minimize waste and provide a resource for irrigation, with common storage solutions ranging from rooftop cisterns to underground reservoirs. These strategies collectively contribute to a more sustainable and resilient urban water management system [2].

3. Sponge City Construction in Beijing Area

3.1 Geological and Hydrological Characteristics and Problems of Beijing Area

Beijing, with its temperate monsoon climate, experiences hot and rainy summers and cold, dry winters. The city's precipitation patterns, heavily concentrated in the summer months, make it susceptible to flooding during heavy rain events. The majority of Beijing's underlying surface

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consists of impermeable pavement, leading to significant surface runoff and rapid flow rates that can easily result in waterlogging. Over the past century, industrial over-exploitation has caused the ground to sink, the surface to harden, and the groundwater level to drop, leading to shortages. Additionally, the urbanization-driven daily sewage discharge from both industrial and residential sources has heightened the risk of water pollution.

Currently, Beijing grapples with several key water-related issues: urban waterlogging due to an inadequate drainage system, water scarcity stemming from the over-extraction of groundwater and the underutilization of surface water resources, and the degradation of the ecological environment in natural water bodies such as lakes and rivers. The city also faces water quality issues due to sewage discharge.

As of 2021, 70 percent of the 192 water quality monitoring sites in the Beijing-Tianjin-Hebei region and 75 percent of those in Beijing itself were rated at level 3,320, indicating a need for improvement. Despite a continuous improvement in surface water quality in recent years, there is still a significant gap between the current state and the target of 95% compliance by 2035, as outlined by the General Regulation. Among Beijing's five major river systems, the North Canal River and Ji Canal River are slightly polluted, with less than 60% meeting Class I-III water quality standards [3].

3.2 Planning and Construction of Sponge City in Beijing

The Beijing City Master Plan (2016-2035) outlines a strategic approach to systematically promote the prevention and control of water pollution, aiming for a comprehensive improvement in the water environment quality. The plan emphasizes the strengthening of source control, comprehensive planning for water and land use, and the construction of an all-encompassing water pollution prevention and control system. This system is designed to cover the entire river basin, the entire process, and all areas, ensuring a systematic control of water pollution. It intensifies the prevention and control of industrial and domestic sewage and comprehensively manages pollution from non-point sources in both urban and agricultural settings, while also strictly protecting drinking water sources. The plan sets ambitious targets within the evaluation index system for building a world-class harmonious and livable city, proposing that the water quality compliance rate of major river and lake functional areas should increase from 57% in 2015 to 77% in 2020, and ultimately to 95% by 2035 [4].

In recent years, in line with these objectives, the government has issued relevant policies for sponge cities, invested funds, encouraged technological innovation, and supported sponge city construction projects. These efforts have led to numerous urban park construction and improvement initiatives, significantly enhancing Beijing's environment. A prime example is Beijing's renowned Olympic Forest Park, situated in the Fourth Ring Road of Chaoyang District and spanning approximately 1,100 hectares. The park includes iconic structures such as the Bird's Nest and the Water Cube. It is equipped with excellent facilities for recreation, sports competitions, and large-scale events, offering Beijing's citizens a space to relax and connect with nature. The park also serves an educational purpose, with schools and communities organizing visits for students to learn about the ecological environment and understand the importance of sponge city concepts and water resources protection. Moreover, the park demonstrates the effectiveness of sponge city principles with a rainwater and floodwater utilization rate exceeding 80%. It can manage runoff from daily rainfall of up to 60mm without discharge, and in 2008, it utilized 400,000 square meters of rainwater for urban greening, road cleaning, and water system recharge. Even during extremely heavy rainfall events, such as the one on June 23, 2011 (which exceeded the once-in-20-years standard) the park's facilities continued to operate normally without any water accumulation on the ground [5].

3.3 Technology and Method of Sponge City Construction

At present, according to the sponge city theory, Beijing adopts the rainwater runoff regulation and control technologies of initial rain diversion at the source, seepage promotion and emission reduction and storage regulation, including roof storage and discharge, structural permeable pavement and inverted biological retention, etc. In the process of excessive rainfall runoff pollutant transport. The rainwater runoff regulation and pollution interception purification integrated technology based on the principles of hydraulic cyclone control drainage, interception and pollution control, filtration and purification has been developed, including multi-functional rainwater inlet, high hollow penetration pipe and universal pollution interception hanging basket. In the process of runoff pollution discharge, ecological purification and other technical schemes are studied by using nodes such as local catchment area outlet, plot area outlet and water discharge area [6].

4. Case Application

At present, Beijing still needs to control black water bodies, renovate old residential areas, and protect the environment of natural water areas. Regarding the naturalization, ecologicalization and sustainability of the urban water cycle, this study suggests that more green roofs and rain gardens can be adopted in the half-height residential building communities of the second and third ring roads to purify rainwater, increase vegetation and reduce net flow. Fig. 1 is a schematic diagram of the transformation of Longtan Area in Beijing, which was completed by Adaptation Support Tool.

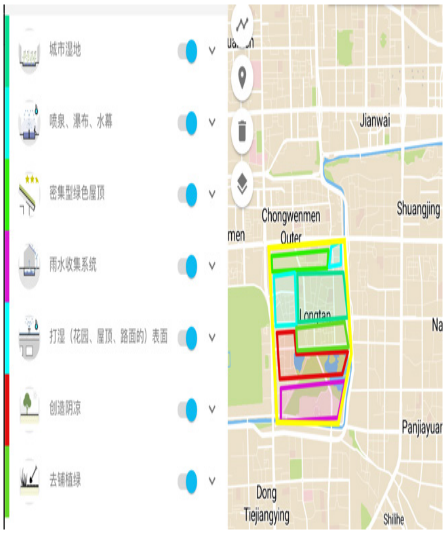

Fig. 1 Schematic diagram of the transformation of Beijing Longtan Area

Table 1. Model prediction coefficient

Measure	Area (m^2)	Runoff return period improvement factor	Recharge groundwater (mm/ year)	Heat reduction (c)	Cool place
Urban wetlands	761.036.43	21	0	0	0
Fountain	364.993.51	1	0	0.23	1
Green Roof	314.671.15	1.6	0	0.2	0
Rainwater harvesting system	711.602.76	158.187.244.81	5	0	0
Wet the surface	78.723.15	1	0	0.05	0
Create shade	655.040.82	1	0	0.41	1
Go lay the greenery	404.124.7	2.07	30	0.26	0

As shown in Table 1, trees have been added to this modified community to provide landscape, shade and water storage functions. The blue area of the community, which is a pond, can regulate the climate of the small area while beautifying the community landscape. The light green area above is an urban wetland for sewage treatment and water quality improvement. Next to the wetland are eco-lofts with green roofs for residential buildings, planted with locally appropriate plants to maintain good water retention and heat absorption. The green area on its left is a grassy area that can be used as a park to enrich the recreational activities of the surrounding citizens. The purple area to the south of the community is a pavilion with a rainwater collection system on the roof for irrigation and toilet flushing. The blue area below is a sprinkler system for humidification, as well as a fountain for landscaping and localized drought relief.

Although there are still many loopholes in the concrete implementation of this model, it provides a way of thinking for community transformation. Beijing has built 18 characteristic parks with a total of 700 km^2 of forest land and 35.33 km^2 of wetland. These newly built urban sponges can intercept surface runoff during rainfall, absorb rainfall by under forest vegetation, absorb underground flow by root system, and store flood in wetland, thus effectively reducing the probability of flood.

5. Conclusion

This paper highlights the successful implementation of the Sponge City principle in Beijing Olympic Forest Park, demonstrating enhanced resilience under extreme weather conditions. The strategy adopted not only enhances the ecological service function of the park, but also provides quality leisure space for the citizens.

Technically, Beijing has integrated advanced stormwa-

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ter management techniques. For example, water source can be controlled by initial rainwater diversion, water seepage can be promoted and runoff can be reduced. In addition, the city has implemented retention regulations and integrated technologies for stormwater regulation and pollution interception, including hydro cyclone control, filtration and purification systems. These measures are aimed at effectively managing the flow of stormwater and mitigating the dispersal of pollutants.

This paper also puts forward a simulation strategy to improve the environment of old residential areas and natural water bodies in Beijing by using the concept of sponge city. By integrating green roofs, rain gardens, and other sponge city elements, the urban water cycle can be naturalized, ecologically, and made more sustainable.

In conclusion, the sponge city construction in this study provides a robust urban planning and development strategy for Beijing. It has the capacity to address the challenges posed by climate change and shape a trajectory for sustainable urban growth. With the continuous research, development and deployment of innovative technologies and methods, Beijing will develop towards a greener, more ecological and more sustainable urban model in the future.

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