Innovative Solutions to Urban Water Resource Challenges and Sustainable Development: Taking Sponge Cities as an Example

Yiduo Tao[a]
Civil and Environment Engineering Department, HongKong Polytechnic University, Hong Kong, China

Keywords: Sponge City, Stormwater Management, Sustainable Development.

Abstract: With the acceleration of urbanization, issues such as urban waterlogging and water shortages are becoming increasingly severe, posing significant challenges to sustainable urban development. The concept of a sponge city emerges as a promising solution, aiming to enhance stormwater management by integrating natural and artificial systems. This paper delves into the foundational principles, applications, and significance of sponge cities in promoting urban sustainability. By analyzing the case of Pingxiang City in Jiangxi Province, the paper highlights the positive impacts of sponge city initiatives on improving urban water circulation and bolstering urban resilience against climate change. The findings suggest that sponge cities can effectively mitigate flooding and enhance water resource management. Finally, this paper proposes strategic recommendations for advancing sponge city construction across China, emphasizing the need for policy support, community engagement, and innovative design practices. These insights aim to provide a valuable reference for fostering green city development and addressing the pressing water-related challenges faced by urban areas.

1 INTRODUCTION

With the acceleration of urbanization, cities are facing increasingly severe water environment problems. In addition, the urban population and buildings are dense causing the surface impervious area to increase greatly, which leads to the rapid concentration of rainfall runoff and waterlogging. It is indicated that old urban drainage design designs are unable to meet the current precipitation conditions, and the drainage pressure in many cities has increased. After the occurrence of urban waterlogging, the drainage can not be discharged in time, and it will accumulate on the urban road, causing damage to the buildings. What's even more serious is that the city was flooded which seriously threatens the travel safety of residents, and greatly affects residents' water and electricity consumption. The occurrence of urban waterlogging will also cause damage to the urban environment because the water in the city will carry a lot of garbage. In an environment of long-term pollution, the urban geology will become fragile, and the short-term construction and long-term development of the city will be affected to some extent (Zhang, 2022).

A well-designed water supply and drainage system can not only meet the daily needs of urban residents but also effectively maintain and improve the environmental quality of the whole city. Firstly, a rationally designed drainage system can effectively prevent harmful substances from entering the water body and slow down the process of water quality deterioration. This helps protect the city's water. Secondly, through rational design of rainwater drainage systems, urban waterlogging can be effectively prevented and traffic chaos and infrastructure damage caused by extreme weather can be reduced. This helps to enhance the environmental adaptability and sustainability of cities. In addition, the good design of the drainage system can also reasonably collect and use rainwater to build ecological facilities such as rain gardens and green belts and promote urban greening (Song, 2024).

Under these severe challenges, the concept of sponge city was put forward and gradually received attention. The sponge city can absorb, store, seeps and purifies water when it rains, the stored water can be used when needed. Therefore, sponge city can effectively deal with many environmental problems

[a] https://orcid.org/0009-0004-3510-7550

Tao, Y.
Innovative Solutions to Urban Water Resource Challenges and Sustainable Development: Taking Sponge Cities as an Example.
DOI: 10.5220/0013326900004558

In *Proceedings of the 1st International Conference on Modern Logistics and Supply Chain Management (MLSCM 2024)*, pages 248-253
ISBN: 978-989-758-738-2

brought by urbanization, which is a sustainable urban construction concept.

The purpose of this paper is to discuss the necessity of sponge city and how to build sponge city. Firstly, the concept background of sponge city is proposed, and the necessity of sponge city is further demonstrated. Secondly, the concept of sponge city is introduced in detail, and its deep principle is analyzed. Thirdly, suggestions and prospects of sponge city are put forward. Finally, the construction of sponge city is deeply summarized.

2 CANALYSIS OF THE URBAN WATERLOGGING

2.1 Urban Waterlogging and Water Resources Problems

The supply of urban water resources plays a vital role in the operation of the city. In addition to domestic and industrial water, the ecological environment and urban resilience also require a strong water supply. Adequate water resources security is the premise of urban development. What's more, under climate change and extreme weather events, the supply security and emergency management of urban water resources are particularly important. However, with the process of urbanization, large areas of cultivated land and natural vegetation have been replaced by buildings such as streets, factories and houses. Water retention, permeability and thermal state of the underlying surface have all changed significantly, and the natural storage capacity of the catchment area has weakened. What's worse, the discharge of urban industrial wastewater and domestic sewage into rivers and acid rain formed after industrial waste gas discharged into the atmosphere lead to serious pollution of urban water bodies (Zhang, 2012).

In the past, the function of the drainage system was focused on drainage and sewage, ignoring the nature of water regeneration and the fragile nature of the water environment, which lacks the function of purifying sewage and creating a healthy water cycle. In addition, past planning principles for stormwater harvesting and drainage systems focused on discharging stormwater immediately into river systems and quickly downstream into the ocean instead of enhancing the surface seepage of rainwater and recharging groundwater, leading to water waste (Zhang, 2001). What's worse, the drainage and water supply systems of the past still have many deficiencies. Such include insufficient drainage capacity, unreasonable water supply distribution, inadequate network coverage, low intelligence level, and weak emergency management capabilities.

At the same time as climate change and rapid urbanization, urban waterlogging has become an urban water problem that cannot be ignored. There are two main reasons for urban waterlogging. First, The extreme weather caused by climate change, especially the rain island effect, has caused the heavy rainfall and rain intensity in the urbanization area to break through the historical meteorological records. Second, The rapid development of urbanization and the expansion of construction land have greatly increased the rainwater runoff and peak discharge in the urbanization area (Liu, 2020).

2.2 The Drainage Concept of Sponge City

The concept of sponge city comes from the industry and academia used to use Sponge to compare a certain adsorption function of the city in recent years, more scholars use Sponge to compare the rain and flood regulation and storage capacity of the city or land. Sponge refers to the water ecology with the landscape as the carrier infrastructure. It is stated that to build a Sponge City, we must extend the research object from the water itself to the water ecosystem, regulate the structure and function through ecological approaches, and enhance the overall service function of the ecosystem (Yuan, 2015). In order to build sponge cities, it is necessary to give full play to the accumulation effect of original topography on rainfall, the infiltration effect of the natural underlying surface and ecological background on rainwater, and the natural purification effect of vegetation, soil and wetland on water quality.

Sponge Cities have many advantages that can bring huge benefits to the city. First, through the use of permeable pavement, rain garden and other measures to improve the surface water permeability, enhance the infiltration capacity of rainwater. It can increase groundwater recharge, which is conducive to alleviating the problem of groundwater overdrawing. Second, Sponge Cities constructed rainwater storage ponds, wetlands, and other facilities to temporarily store rainwater and relieve storm flood peaks. It effectively reduces the risk of urban rain water and alleviate urban waterlogging problems. In addition, green space, ditches, and other slow-release facilities should be used to delay the speed of rainwater runoff and reduce flood hazards. What's more, the collected rainwater is treated and used for urban greening, road washing, etc. , which can realize the utilization of

rainwater resources. Planting a large number of vegetation and the formation of water bodies also can reduce the urban heat island effect and improve the urban microclimate. Finally, Sponge City construction is conducive to maintaining the urban ecosystem's virtuous cycle and promoting the ecological environment's restoration. Vegetation restoration, wetland construction and other natural system restoration can improve the ecological adjustment capacity of the city. To put it in a nutshell, Sponge facilities play a comprehensive role in flood control, water supply, and ecology. Moreover, integrating natural elements such as vegetation and water in planning sponge cities can beautify the urban landscape and improve the quality of human settlements. By decentralized stormwater management, the construction investment of centralized stormwater pipe network is reduced. These aspects of the application reflect the multiple value of urban infrastructure.

3 ANALYSIS OF THE SPONGE CITY

3.1 The Application of Sponge City

The application of Sponge City principles is evident in various aspects. Firstly, sponge road design involves using permeable paving and sponge pavement materials to enhance water seepage, storage, and runoff management on roads. Permeable paving refers to the use of permeable materials with good gaps to lay the pavement, which lead rainwater to enter the pavement surface structure, through the base with water storage capacity to penetrate into the soil foundation, so that rainwater reduces in the ground and purify water quality (Ying, 2016). Secondly, sponge-type garden green spaces, such as parks and squares, incorporate features like concave green spaces and ecological ditches to improve rainwater infiltration and provide temporary storage. Additionally, sponge design for building roofs and walls increases water storage capacity through roof greening and rainwater harvesting systems. Lastly, a sponge pipe network system employs rainwater collection networks and distributed storage to facilitate local filtration and controlled release of rainwater. Through the above design, Sponge City can effectively alleviate urban waterlogging.

The Sponge City concept can greatly enhance the city's drainage capacity in bad weather. In bad weather, the chance of a storm will increase significantly. Suppose there is no corresponding drainage system in the city. In that case, the waterlogging water cannot be effectively discharged outside the city, and it will be deposited in the urban road, which will aggravate the problem of urban environmental pollution and soil erosion. These ecological problems will affect the ecological balance and the natural ecosystem's original disaster resistance and climate regulation ability. And then it triggers a vicious cycle. In the management of urban waterlogging, it is necessary to fully consider various factors, improve the existing urban drainage system, and adapt to the sustainable development of the natural environment. Sponge city needs to use natural tools to solve the problem of natural waterlogging. Moreover, the construction of sponge city can increase the proportion of permeable road surface and reduce the proportion of hard road surface, and the urban surface conditions will also be improved. Under the premise of the same amount of precipitation, sponge cities have a stronger ability to resist waterlogging than traditional cities (Liu, 2020).

3.2 Citations of Case Studies

In April 2015, Pingxiang City, Jiangxi Province was successfully selected.

The country's first batch of sponge city construction pilot cities, Sponge city pilot construction was launched to solve urban waterlogging and water environment problems. Pingxiang City, Jiangxi Province is an old urban area, and the current drainage system is mainly intercept-type combined drainage system. Considering the difficulty of the current transformation and the short-term construction target, the current drainage system should be retained, the current drainage zoning form should be adjusted and optimized, and the damaged canals should be determined and repaired according to the current investigation and model analysis. Urban waterlogging can be controlled by combining construction districts, park squares, road LID transformation, end overflow regulation and storage, and comprehensive regulation of Wufeng River. The overall idea of the scheme considers all links of the sponge construction engineering system, including LID transformation link of source emission reduction, process control link, system governance link, etc. This project is mainly to transform LID of the existing building district, and the process control link is mainly to upgrade and restore the municipal administration district. The system management link is mainly through the upstream flood interception and regulation and storage project, the internal gate

station project, pumping station, river and lake regulation and storage, regulation and storage pond regulation and storage projects to achieve the regulation and storage of excessive rainwater and the control of the end pollution.

As of June 2017, the comprehensive regulation project of Wanlong Bay waterlogged area has completed 15 LID renovation projects at the source. Through the integration of permeable pavement, sunken green space, biological detention facilities and other facilities, and the integration of landscape, municipal affairs, architecture and other professional fields, the source can control high-frequency light rainfall through renovation. The renovation project basically achieved 75% of the total annual runoff control rate, corresponding to the design rainfall of 22. 8 mm. The process control project has completed the construction of three new drainage pipes and pollution interception main pipelines, and the system regulation project has completed the upstream flood interception, Yuhu regulation storage and ecological transformation, Geese Lake regulation storage and ecological wetland construction, Wofeng He-Geese Hu-Pingshui River drainage sluice station construction, and the construction of two regulation storage ponds.

Pingxiang has a high rainfall in June every year, and the accumulated rainfall of 2 hours on June 1, 2017 was 84 mm. According to the rainfall conditions before the project's construction, Wofeng River generally overflowed, and different degrees of waterlogging occurred in Wanlong Bay and Wofeng River areas. Due to the emission reduction at the source, the pre-empting storage capacity of Yuhu and Yue Hu, and the linkage effect between the rainwater storage tank and the Wofeng River drainage pumping station, the water level monitoring data and the actual situation show that Wofeng River has not reached the warning water level, and no obvious waterlogging has occurred in Wanlong Bay area. The online monitoring of water level meter in the vulnerable waterlogging area opposite Wanlongwan Building on Park Road shows that the maximum water level value of the day is 0. 58 m, and the peak water level does not exceed the top line of the pipe 0. 80 m, affected by rainfall, the maximum water level increased by 0. 44 m, did not exceed the early warning line, there is no risk of waterlogging in the case of heavy rain. The water level meter monitoring of the Wufeng River section of Kangzhuang Road shows that in the case of this heavy rain, the maximum water level is 1. 82 m, the maximum water level increased by 1. 63 m, the water level has not exceeded the early warning line, no overflow and waterlogging. The rainstorm level was close to that of July 8, 2016, but although the rainfall level was close to the warning level, it did not overflow. On July 8, 2016, the Wofeng River overflowed, and the average depth of the overflow water reached 0. 5 m, indicating that the waterlogging control effect is beginning to show. (Xu, 2017)

In this case,the project's remediation plan focuses on reducing emissions at source, using permeable pavements, sinking green Spaces, and bioretention facilities to manage light rain and improve runoff. In addition, process control was emphasized. Improving municipal infrastructure and laying new drainage and interception pipes have played a major role. Moreover, system management is also an essential part of the overall remediation program. It included upstream flood interception, construction of regulation and storage facilities, and ecological transformations, which realized the control of excessive rainwater storage and end pollution. As a result, The construction of Sponge City in Pingxiang City, Jiangxi Province has realized the effective elimination of waterlogging in the area and the effective reduction of water pollutant discharge.

4 SUGGESTIONS AND PROSPECTS

The future construction of sponge cities requires comprehensive planning and design, emphasizing the combination of nature and city, increasing green Spaces, rivers and wetlands, and promoting natural water circulation. According to different regions' climate and terrain characteristics, it is particularly important to develop tailor-made design solutions. In terms of multi-functional infrastructure, it is recommended to use materials such as permeable bricks and permeable concrete to reduce runoff, while promoting green roofs, increasing the amount of urban green, and improving the microclimate. Technological innovation is also key, using sensors and iot technology to monitor water flow and water quality in real time and developing new materials to improve water absorption and water purification efficiency. In terms of public participation and education, community residents are encouraged to participate in constructing and maintaining sponge cities, and public awareness of sponge city concept is raised through publicity activities. The support of policies and regulations is indispensable, and the government can formulate incentive mechanisms to support sponge city projects, while establishing unified construction standards and evaluation

systems. In terms of international cooperation, through the exchange of experience, sponge city construction experience is shared with other countries and regions, and advanced technologies and concepts are introduced. Looking forward to the future, sponge cities will significantly improve the city's flood control and drainage capacity, improve residents' quality of life, achieve ecological restoration, improve the water environment and ecosystem, and thus realize the harmonious coexistence of cities and nature. In addition, it can reduce urban flood disaster losses and bring long-term economic benefits. These measures will promote sponge city to become an important direction of future urban development.

At present, sponge city construction, as an important measure of urban water management in China, needs strong theoretical support, technical support and data guarantee. Therefore, it will be the main research direction in the future to build a perfect meteorological and hydrological monitoring and forecasting system, in-depth analysis of urban hydrological effects and mechanism of runoff production and confluence under changing environments, especially the hydrological and hydraulic response mechanism of sponge facilities, and coupled with multidisciplinary theories to build urban water system models suitable for complex urban underlying surfaces (Zongxue, 2019).

5 CONCLUSION

Based on the shortage of urban water supply system and the harm of urban waterlogging, this paper puts forward the innovative concept of sponge city. The aging and inadequate design of traditional water supply systems has led to frequent water shortages and waterlogging, seriously affecting residents' lives. Through the combination of natural and artificial systems, sponge cities can absorb, store, permeate and purify rainwater, thereby reducing waterlogging, improving water utilization efficiency and improving the urban ecological environment.

In the construction process of sponge city, many measures can be applied, such as increasing urban green space, building sunken green space, permeable pavement, roof greening, rain gardens and so on. These facilities not only absorb and store rainwater but also purify it through natural filtration processes, improving water reuse. In addition, sponge city also emphasizes the infiltration and recharge of rainwater, through seepage pavement, open drainage systems and reservoirs and other facilities, so that rainwater can effectively penetrate into the ground, replenish groundwater resources, and alleviate the problem of urban groundwater level decline.

In this paper, a practical case of Pingxiang city in Jiangxi Province is cited to analyze in detail the important role of sponge city in improving urban flood disasters. Through the implementation of the Sponge city project, Pingxiang City adopted a series of green infrastructure and ecological measures to effectively improve the drainage system of the city and reduce the frequency of waterlogging. When the rainstorm comes, the phenomenon of water accumulation in the urban area is significantly reduced, the travel of citizens is more convenient, and the environmental quality of the city has also been significantly improved. This successful practice provides valuable experience and reference for other cities, proving the feasibility and effectiveness of the sponge city concept in practical operation.

Looking to the future, the construction of sponge cities needs the dual promotion of technological innovation and policy support. Through the development and application of advanced materials and technologies, the efficiency of stormwater management can be further improved. At the same time, the government's policy guidance is also crucial, and reasonable policy support can accelerate the promotion and popularization of sponge cities. What's more, the government's policy guidance is also crucial, and reasonable policy support can accelerate the promotion and popularization of sponge cities. Public participation is also a key factor in the construction of sponge cities. The active participation of community residents can not only enhance the public's awareness of environmental protection, but also provide more targeted opinions and suggestions for urban planning. By strengthening public education and community activities, the concept of sponge city will be more deeply rooted in people's hearts, forming a good atmosphere for the participation of the whole society, thus promoting sustainable urban development. In short, the concept of sponge cities is expected to be expanded globally to address the dual challenges of climate change and urbanization. By restoring natural ecosystems, enhancing biodiversity and improving the urban environment, sponge cities will create a healthier and more livable living environment for humans, ultimately achieving sustainable urban development and improving the quality of life of residents. In the future, with the progress of technology and policy support, the construction of sponge cities will be more mature and perfect, providing a strong guarantee for the global urbanization process.

REFERENCES

Liu, J., Wang, J., Wang, H., & Mei, C. 2020, Effectiveness of Urban Inundation Control System in Sponge City Construction. Progress in Water Science, 31(4), 611-618.

Song, Y. 2024, Study on Rational Improvement Measures of Urban Water Supply and Drainage Design. Engineering Construction, 7(2), 166.

Xu, H., Zhao, C., Lv, M., Guo, Y., Ma, H., Huang, C., & Xu, Z. , Comprehensive Regulation Practice of Sponge City in Waterlogging Area of Wanlongwan, Pingxiang City. Water Supply and Drainage in China, 33(18), 11 – 12.

Ying, J., & Zhang, Q. 2016, Application Research of Urban Permeable Pavement under the Concept of Sponge City. Modern Urban Research, 31(7), 42 – 43.

Yuan, H., Fu, W., & Wang, S. 2020, “Sponge City”: Theory And Practice. City Planning Review, 39(6), 29.

Zhao, L., Wang, Y., & Zhang, H. 2021, Evaluating the Performance of Sponge City Design in Urban Stormwater Management. Water Resources Management, 35(12), 4231-4245.

Zhang, J. 2012, Discussion on the construction of urban waterlogging control system under the concept of sponge city. International Journal of Architecture, 4(2), 212.

Zhang, J. 2022, Problems Facing Urbanization and Urban Hydrology. Hydro-science and engineering, 35(1), 2.

Zhang, J. 2024, Modern View of Urban Drainage System. Engineering Science, 3(10), 34.

Zong, X., & Tao, C. 2019, The Theoretical Basis of Urban Water Management and Sponge City Construction – Research Progress of Urban Hydrology. Journal of Hydraulic Engineering, 50(01), 53 – 61.