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The advantages of sponge cities in urban flood prevention and control

Ziming Bian

School of Resources and Environment, Nanchang University, Nanchang, Jiangxi, 330000, China

wmorris83678@student.napavalley.edu

Abstract. Frequent occurrence of extreme precipitation is highly susceptible to flooding. The urbanization process has exacerbated the current situation of urban flooding. Sponge city technology has an important role in solving the problem of urban flooding. Since 2012, sponge city construction has been gradually launched in China. However, there are problems and challenges in China's sponge city construction. In this context, this paper explains the concept and advantages of sponge city. It attributes the main factors causing urban flooding to natural and social factors and discusses them separately. This paper uses the sponge city concept to construct the method of urban flood prevention and control system, and gives how to solve the problem of good articulation within the system. It also categorizes the existing sponge cities in China and puts forward the misunderstandings and deficiencies of the current state of construction of sponge cities. This study finds that sponge city construction is an important method to address the issue of urban flooding. It is also a necessary project to comply with the situation of urban development and plays a guiding role in the future urban construction project.

Keywords: Sponge Cities, Urban Flooding, "3M" System.

1. Introduction

In recent years, global warming has led to frequent extreme precipitation events. The combined effects of accelerated urbanization have made urban flooding a problem that cannot be ignored. According to the EM-DAT database of global flood events from 1950 to 2020, the region represented by Asia has shown a high frequency of abnormal rainfall in recent years [1]. Among them, China has the highest number of flooding events. Since 2008, more than 60% of China's cities have experienced floods of varying degrees of severity, resulting in several deaths and serious economic losses. Therefore, it is imperative to take active measures to reduce the hazards of urban flooding in cities.

In order to adapt to climate change, theories related to stormwater management such as water-sensitive urban design(WSUD), sustainable drainage systems(SUDS)and green infrastructure development(GI)have been continuously proposed. Among these, WSUD is a new approach to stormwater management that addresses the problems found in traditional water recycling systems. Considering the environmental, social impact and other factors, SUDS can collect, purify and reuse rainwater. GI makes full use of the disaster prevention and environmental purification functions through the rational use of green space, wetland and rainwater storage and infiltration system of plants in nature. However, these new types of stormwater management are costly, incomplete and limited by space and

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geography. As a result, sponge cities have emerged as an innovative urban planning and management concept. Sponge city is a comprehensive concept that combines various approaches such as SUDS, GI and so on. The core of "sponge city" is to combine multiple technologies to build water ecological infrastructure across scales [2]. Based on the concepts of source decentralization and sluggish release, it achieves the goals of reducing flood flow, absorbing rainwater resources and alleviating urban flooding. It ultimately serves to improve urban ecology.

In conclusion, sponge cities have the potential to play an important role in urban flood control. Consequently, the purpose of this essay is to examine the benefits of sponge city in urban flood prevention and control through in-depth discussion, which can further promote the role of sponge city concept in flood prevention and control. Firstly, it introduces the advantages of sponge city concept and analyzes the causes of urban flooding. Secondly, it discusses how to build the flood prevention and control system under the sponge city concept. Finally, it analyzes the existing sponge city construction problems with the existing city cases in China.

2. Sponge city

The term "sponge city" describes a city that has the good elasticity and ability to adapt to environmental change and natural calamities. Cities can absorb, store, infiltrate, and cleanse water when it rains. When necessary, the water that has been kept can be used. The concept of sponge cities aims to achieve effective stormwater management. It is designed to address the uneven distribution of water resources and urban flooding in China. It also serves a crucial function in purifying water resources in order to achieve the multifaceted goal of sustainable development.

2.1. Mitigate water resource imbalances

China is a typical monsoon climate zone. The vastness and complexity of the geographic environment have led to a serious uneven distribution of water resources between space and time in China. The main distribution pattern is more in the south and less in the north, so it is inevitable that some cities have insufficient water resources [3]. The construction of sponge cities can deal with this imbalance more effectively and make full use of water resources. The concept of sponge cities has been introduced into the construction of urban roads to make full use of rainfall through rational planning of water-stagnation and water-purification facilities. At the same time, retaining rainwater in urban road maintenance and green belt maintenance can achieve efficient use of water resources as well as alleviate the problem of water scarcity in China after effective treatment.

2.2. Mitigate urban flooding

As the number of hardened roads in the city increases, so does the problem of flooding in the city. Building a hierarchy of large, medium, and small sponges allows for cascading stormwater runoff to relieve municipal drainage pressures. It is also possible to pre-treat natural water bodies to lower the water level. Improved control in both areas can help to greatly increase the city's resistance to flooding. Severe weather such as continuous rainfall or typhoons often lead to urban flooding, which is the main reason for building sponge cities.

2.3. Clean up water resources

Water resources and the water environment are deteriorating as a result of the industrialization of cities. Some pollutants are inevitably present on urban roads. These pollutants will be carried into the city's drainage system or directly introduced into the river as rainwater washes away, thus increasing the pollution of water bodies [4]. In the urban road construction into the sponge city concept, the use of green plants, soil or some new materials to intercept some of the pollutants, can do the first filtering of rainwater, which can purify the rainwater, is conducive to remediation of black-smell water bodies.

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3. Analysis of the causes of urban flooding

Urban flooding is a phenomenon in which waterlogging occurs in a city as a result of heavy rainfall in a localized area that exceeds the water storage and drainage capacity of the area. When analyzing the causes, it can be divided into natural and social factors.

3.1. Natural factor

On one hand, global climate change has led to frequent rainstorms. According to the 2020th report of the World Meteorological Organization, global concentrations of major greenhouse gases are still on an upward trend. The average temperature is the second-highest in recorded history and has risen by 1.2°C from the pre-industrial era. The global average temperature increases year by year, resulting in a rise in the concentration of water vapor and a gradual rise in the energy stored in the atmosphere. To a certain extent, it will inevitably need to be released, manifesting itself in lightning, thunderstorms and heavy rain [5].

On the other hand, the natural pattern water circulation system has been destroyed. As urbanization has accelerated, some natural water storage sites, including lakes and ditches, have been replaced by structures, causing the natural water cycle system to be destroyed. Failure of the original network of water systems such as rivers and wetlands are not conducive to the internal digestion of stagnant water in the city. In the event of a short period of heavy rainfall or a sudden downpour, serious waterlogging can occur within the city. In addition, the large number of underground parking lots, underground shopping malls, overpasses, and other infrastructure built within the city can alter the original water circulation process and contribute to the pooling of rainwater to form waterlogging [6].

3.2. Social factor

Firstly, rapid urbanization has led to the intensification of the "rain island effect" and the "heat island effect". The heat island effect is a phenomenon in which the temperature inside a city significantly exceeds that of its immediate surroundings as a result of changes in the characteristics of the city's subsurface, air pollution and artificial waste heat when the city grows to a certain size. This phenomenon not only contributes to hot weather, but also triggers anomalies within the city, such as warm winters and abnormally heavy rainfall. In addition, the urban heat island effect negatively affects the annual, seasonal and monthly average precipitation, mainly in the form of increased rainfall in urban centers and their downwind zones, which increases the probability of urban flooding significantly [7]. As a result, under the same weather conditions, the frequency of rainfall in cities is much higher than in the surrounding areas, and the frequency of heavy rainfall is much higher than in the suburbs, thus creating the "rain island effect".

Secondly, there is insufficient capacity to build social water recycling systems. According to data, funds for the construction and maintenance of urban drainage systems in China account for a low proportion of municipal infrastructure, and the coverage of the pipe network is only about 60 per cent, which greatly affects the city's flood-drainage capacity [8]. Additionally, there are issues with the current drainage system, including old drainage pipe network system facilities, debris clogging, and insufficient over-water capacity. Once encountered heavy rainfall, especially the attack of extremely heavy rainfall, the urban drainage system will face a severe test. Furthermore, compared with developed countries, Chinese urban flooding early warning system and response measures still need to be improved. For a long time, China has had a tendency to "emphasize construction and neglect management" of urban flooding, with an inadequate management system and a lack of regular maintenance and inspection of the relevant infrastructure, which has led to ineffective response to disasters and caused huge losses. In recent years, although the early warning system for urban flooding has been developed and some substantial progress has been made, there is still room for improvement in terms of accurate early warning.

Finally, the issue of long-term planning for urban development is also prominent. The construction of urban drainage systems is characterized by high investment, long development cycles and slow returns. It is often overlooked by managers. The establishment of urban flooded drainage networks is an

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ongoing iterative process that requires continuous construction and optimization by multiple subsequent generations of managers. In addition, there may also be cases where plans developed by previous decision makers are shelved or modified by subsequent managers, resulting in inadequate urban drainage systems. It is particularly evident in the construction of Chinese cities.

4. Construction of flood prevention system and case study under the concept of sponge city

4.1. Flood control system construction

The traditional urban drainage model mainly relies on gray facilities to achieve rapid drainage, which can easily to induce flooding problems. Sponge city aims to build an urban water management system based on the combination of green and gray, which is a green way to solve urban water problems. Its core technology system includes Micro System, Minor System and Major System, referred to as the "3M" systems [9]. The systemic nature of sponge city theory requires that the "3M" systems are fully connected in planning and design, standard application, vertical control to play a comprehensive role in dealing with water ecology and water safety issues.

The solution to waterlogging needs to start from the root of the problem. By using stagnation, storage, drainage and other technical means, the efficiency of "3M" system based on the concept of sponge city can be fully played, so as to achieve comprehensive management. Therefore, relying on the "3M" system to solve problems caused by internal causes, should clarify the role of each subsystem in the process of flood prevention and control. As shown in Figure 1, this is a diagram of the components of the "3M" system with the linkage of the structures.

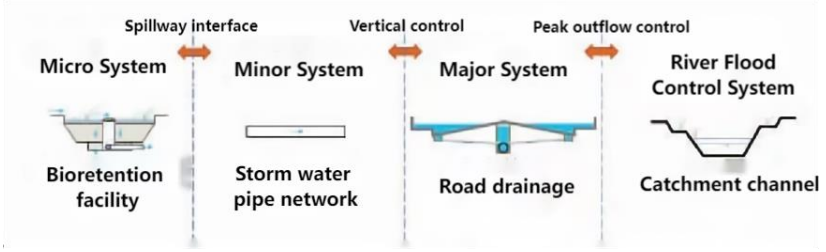

Figure 1. Components and linkages of the 3M system [9].

(1) Micro System

The objective of the Micro System is to restore the natural hydrologic characteristics of the site prior to development in response to low-intensity, high-frequency, small to medium rainfall events. However, the current design objectives are limited in their abatement effectiveness when responding to rainfall events with return periods greater than one year. To achieve the return period requirement for flood control (20 to 100 years),the maximum feasible storage space possible on the source parcel needs to be provided. For example, measures such as decentralized delayed conditioning ponds and multi-functional storage ponds can be installed to achieve peak runoff reduction.

(2) Minor System

The Minor system focuses on solving the problem of rapid increase in runoff caused by short-term heavy rainfall, coping with higher probability of short-term heavy rainfall events, and realizing the goal of no accumulation of water on the ground. In view of the relatively low standards prevailing in China, the design of the micro-drainage system should be carried out in new areas in strict accordance with the requirements of the Code for Design of Outdoor Drainage. Close integration with upstream micro-drainage systems to enhance safety. In China's older urban areas, where the standard of underground pipeline networks is low and there are problems such as aging and disrepair, re-breaking the ground and repairing the system will lead to huge investment and social impacts. Therefore, the strategy of "source micro-drainage system renovation + part of the network maintenance + part of the network construction" should be adopted. Balancing economic and environmental considerations in order to realize the normative requirements.

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(3) Major System

The Major system focuses on the rational storage and discharge of excess runoff to cope with lower probability of excessive rainfall events and to ensure that heavy rainfall does not result in flooding. The main objective of the design of large drainage systems is to meet, first and foremost, flood control and control criteria. Ensure that rainfall runoff in excess of drainage capacity is safely removed within the design return period, while stormwater is reasonably stored and retained. Secondly, through a reasonable "storage and drainage" strategy, combined with the basin drainage plan, to determine the maximum discharge flow limit, to reduce the flood control pressure of the basin. The design should take into account the location of waterlogging, storage facilities, the arrangement of large drainage channels, and the vertical connection with the urban topography, to protect the original storage areas, such as rivers, lakes, wetlands, pits, ponds, ditches, and make full use of natural forces to achieve the effect of water storage and drainage.

At the same time, the "3M" systems should be well connected to the watershed flood control system. Enhanced meridian channel allocations and rationalization of outfall elevations are needed to minimize the impacts of watershed flooding on the city.

In addition, the "3M+ Basin Flood Control" system to deal with flood prevention and control, for heavy rainfall during the recurrence period, needs to be supplemented by early warning and forecasting and rescue and relief and other non-engineering measures. Through the intelligent water platform, can be analyzed in advance may be affected by the flooding of the region, to achieve timely warning. At the same time, it coordinates with all relevant departments, such as housing construction, water conservancy and meteorology, to develop high-precision city-scale flood risk maps, to prejudge potential risks and to develop transfer plans.

Overall, the sponge city concept focuses on mitigating the impacts of flooding on cities by coordinating and integrating the "3M" system with the watershed flood control system. In this concept, the "3M" system, on the one hand, functions to reduce the pressure on the watershed flood control system by reducing discharges, cutting peak flows, and staggering discharges. On the other hand, the "3M" system allows stormwater runoff to be regulated at the appropriate time and location, thus effectively addressing urban flooding. This coordinating role helps to realize the dual benefits of urban flood control and flood management.

4.2. Case study of sponge city construction in China

Since 2015, the state has launched two batches of 30 sponge city pilot cities, considerably advancing the growth of sponge city building. However, it has also become a pressing issue to figure out how to fully exploit regional traits and build sponge city construction spots in keeping with the local natural and societal conditions.

The plains river network area has issues including a high water table and limited soil infiltration capacity, is heavily inhabited, is subject to monsoon climate, and is prone to excessive rainfall in a short period of time. Jiaxing [10]concentrates on reducing runoff pollution and encouraging water environmental conservation throughout the construction of the sponge city. On the one hand, using intricate bioretention strategies increases soil infiltration capacity. On the other hand, the impact of a high water table can be mitigated by proper planting. Changde [11, 12]focuses on river training as well as park renovation at the end to solve the water pollution problem in the case of urban rainwater and sewage combined flow. At the same time, the urban flooding problem in case of heavy rainfall is mitigated through neighborhood renovation and new road construction projects.

At the confluence of inland streams and the sea are coastal cities. Conditions related to hydrology and water quality are more complicated. Seawater backup problems are a common occurrence in unique situations. To store rainfall, save freshwater, and create a flood protection and drainage system, Xiamen [13] adopts sponge city construction. Three issues are prioritized in the creation of Ningbo's sponge city [14]. The first is to lessen the strain on urban drainage and flood management. The second is to safeguard and enhance the ecosystem of urban water. The final step is to increase the pace at which rainwater resources are utilized [15].

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Mountainous cities are affected by natural terrain, meteorological and hydrological conditions and urban construction conditions. The goal and process of building sponge cities in this region also has its special characteristics. Jinan [16-17] not only stores rainwater through sponge facilities to break through the urban spatial limitations, but also collects rainwater, conserves water, protects vegetation, and conserves soil and water through the natural sponges such as ponds, valleys, and mountain forests near the city.

The Northwest Dry and Early Region is subject to a continental climate with low rainfall. The region is perennially dry and early, and regional soil erosion is severe due to overdevelopment. Xixian [18], on the other hand, strengthens the control and protection of ecological protection zones and protects ecologically sensitive areas such as water sources. The utilization of non-conventional and renewable water resources is improved by maintaining hydrological characteristics and water conservation methods. Guyuan [19] focuses on the planning and control of rainwater collection, recycling and reuse, with a view to alleviating regional water scarcity.

In conclusion, the construction of sponge cities in China needs to be designed according to the differences in terrain conditions, water sources and precipitation, and so on. The appropriate sponge city design plan should be designed according to the actual situation.

5. Problems and challenges of sponge city construction in China

(1) Complex operation and maintenance system

At present, although some cities in China to build sponge city effect is outstanding. However, there are a small number of cities have little effect. Operation means and maintenance efforts need to be improved. First of all, the construction of sponge city is not just a drainage system, but an extremely large system. It involves the joint operation of gardening and greening, urban roads, drainage systems, environmental protection facilities and other systems. Its management and operation system are complex and complicated. It is more difficult to coordinate in the division of labor and collaborative work [20].

(2) Difficulty of maintenance facilities

In low-impact development technology, China commonly utilizes the porosity of materials such as green plants, soil, and multigrade materials to intercept and preliminarily filter pollutants for initial purification. However, in sponge city construction, these facilities must be maintained in a timely manner . Otherwise, it will lead to the blockage of pore space by pollutants, which in turn will lead to the inability of rainwater to be discharged in a timely manner, and eventually induce other water conditions [21]. The role of the facility itself and the original purpose of building a sponge city is lost.

(3) Design program and material problems

Currently, the construction of sponge cities in China mainly focuses on "drainage, purification and utilization". The design of sponge cities is carried out individually by drainage or landscape personnel. However, sponge city construction is a comprehensive system, relying only on the design of the above personnel may have limitations. Often, many aspects are not well considered, resulting in a program that is not reasonable enough to give full play to the benefits of sponge city construction.

A variety of different types of sponge city facilities and materials exist in the market. Purchasing suitable materials has become a difficult problem. Currently on the market sponge facilities and materials of various types, quality varies. If you choose materials that do not match the program, it will affect the expected effect of sponge city construction. For example, porous lightweight permeable concrete is characterized by water permeability, water retention and air permeability, and is suitable for reducing environmental loads. Permeable asphalt, on the other hand, is semi-permeable and is suitable for reducing vehicle noise. If permeable asphalt is used on roads that need to be paved with permeable concrete, it will result in rainwater not being able to quickly seep into the ground, causing water to accumulate on the road and affecting the smooth flow of traffic. At the same time, it affects the rainwater collection of downstream water storage devices, resulting in failure to meet the requirements of sponge city construction standards.

(4) Geographical complexity

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In parts of China's developed cities and areas, the construction of sponge cities has recently begun. The sponge city construction program is also different due to China's vast territory, climate and geographical conditions and the water environment in different regions. For example, in the northern and western regions where rainfall is low and evaporation is high, how to effectively recycle rainwater is the key to building sponge cities. How to manage and abate runoff flooding and water pollution is the focus of southern cities with high rainfall and abundant rainwater resources, which are prone to urban flooding during the flood season.

6. Conclusion

This essay primarily examines how sponge cities are used to lessen the effects of urban flooding. Then, it makes use of the "3M" system to build a preventative and control system using the idea of a sponge city to examine the need to address the root causes of urban floods. The true situation of China's cities, including those on the plains, the coast, and the mountains, is also classified and examined in this essay. The paper concludes by summarizing the issues that China's building of sponge cities is experiencing, including the difficulty of facility maintenance and the complexity of the operation and maintenance systems.

This study find that the concept and measures of sponge cities have a positive impact on flood prevention and control, and that there are still problems with the construction of sponge cities in China. Sponge cities can alleviate the imbalance of water resources, purify water resources and alleviate the problem of waterlogging. Due to global climate change, frequent heavy rainfall and rising average temperatures, and the impact of the construction of social water circulation systems and inadequate flood warning systems, the phenomenon of urban waterlogging is serious. "3M" system requires a good connection between the source emission reduction system, the drainage system, and the drainage and removal system of each system in terms of planning and design. It focuses on peak runoff control, so that the runoff is in an adapted position at the right time, thus achieving the purpose of preventing and controlling flooding. Compared with the traditional drainage method that relies solely on gray facilities for fast drainage, the system is a combination of green and black urban water management system. It has the advantages of low risk of flooding, improved water utilization, protection of the water environment and ecosystem, improvement of urban quality and sustainable development.

The sponge city construction technology that China has perfected is currently in its early stages, and there are still issues that need to be fixed. On the one hand, there are still issues with the construction of sponge cities, such as insufficient care being taken, inconsistent material quality, imperfect guardianship mechanisms, and inability to perform operations and maintenance in a timely manner. However, there are still a lot of short boards in the technology for building sponge cities, and in order to find the loopholes and compensate for the short boards, more sophisticated low-impact development technology and facilities are required.

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