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A Review of Advances in Stormwater Resilience Research

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Abstract

Against the backdrop of the double overlap of climate change and urbanization, stormwater hazards are seriously threatening the safety and operation of cities. Resilient cities, as a new idea to cope with disaster risks, have been applied to urban stormwater risk management. From the perspective of resilience, the definition and research status of urban stormwater resilience are explained, four methods of urban stormwater resilience assessment are systematically sorted out: comprehensive index method, scenario simulation method, GIS analysis method, and machine learning method, and the strategies for improving urban stormwater disaster resilience are summarized in terms of pre-disaster prevention and post-disaster reflection, with pre-disaster needing to emphasize planning, strong assessment, remediation of shortcomings, whole process, and wisdom, while post-disaster is the resilience improvement The post-disaster period is an important opportunity period for resilience enhancement, with a view to providing theoretical support for stormwater resilience enhancement.

Keywords

Resilient City; Stormwater Resilience; Evaluation Methodology; Improvement Strategy.

1. Introduction

China is one of the countries with the most serious rain and flood disasters in the world. Rain and flood disasters are spread over a wide area, occur frequently, cause heavy losses, threaten people's lives and property, and have become an obstacle to China's sustainable development[1,2]. According to the "China Flood and Drought Disaster Prevention Bulletin 2021", in 2021, rain and flood disasters of varying degrees occurred in 30 provinces (autonomous regions and municipalities) across the country. A total of 59.01 million people were affected by rain and floods, 590 people were dead and missing, 152,000 houses collapsed, crops were affected in an area of 4760.43 thousand hectares, and direct economic losses were 245.892 billion yuan, accounting for 0.22% of the GDP that year. Affected by global climate change, the frequency of extreme weather has increased dramatically[3]. In addition, the new situation brought about by China's rapid urbanization process has put forward higher requirements for the prevention and control of rain and flood disasters in my country[4]. The 14th Five-Year Plan for the National Economic and Social Development of the People's Republic of China and the Outline of the Long-term Goals for 2035 propose that “conforming to new concepts and trends in urban development, we must carry out pilot demonstrations of urban modernization and build a livable, innovative, smart, green, "Humanities, Resilient City", building a "resilient city" has been elevated to a national plan, and stormwater resilience is also called flood-bearing resilience[5], which has become an important perspective for cities to deal with stormwater disasters.

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2. Definition and Characteristics of Stormwater Resilience

Canadian ecologist Holling first introduced the concept of resilience into ecosystem research in 1973, defining it as "the ability of an ecosystem to return to a stable state after being disturbed"[6]. Swedish ecologist Carl Folke later divided the development order of the concept of "resilience" into three concepts: engineering resilience, ecological resilience, and social-ecological resilience[7].

Table 1. The development sequence of the concept of "resilience"

Name	Features	Focus	Situation
engineering resilience	recovery time, efficiency	restore, fix	close to steady state equilibrium
ecological resilience	buffering ability, withstanding shock, maintaining operation	Durable, strong	multiple balance and stability
socio-ecological resilience	cross interference and recombination	adaptability to variability, learning, innovation	comprehensive system feedback, cross-scale dynamic interaction

The concept of resilience emphasizes the ability to absorb external shocks and disturbances, and quickly restore the city to its original state or reach a new equilibrium state through learning and reorganization[8]. As the concept of resilience gradually becomes more and more popular, it provides ideas and help for solving urban problems. In order to solve specific urban problems, classified "resilience concept groups" have been proposed by scholars one after another. It is under such conditions that the concept of stormwater resilience is It came into being.

Stormwater resilience is based on the further deepening and development of the sponge concept, providing a newer and more comprehensive idea for the planning and design of urban flood control and drainage. After a disaster-bearing body encounters a rain and flood disaster, its own functions will be damaged to a certain extent, and it will take a period of time to return to the pre-disaster state[9]. By improving the resilience, the degree of damage to the disaster-bearing body can be reduced and shortened. Its recovery time, and during the post-disaster reconstruction process, the city's flood prevention and drainage level can be further strengthened to better cope with possible future risks[10]. Without any active intervention, urban risks will gradually increase over time. Through resilient design, urban risk levels can be effectively reduced so that they are always within an acceptable range.

3. Current Status of Research on Flood Resilience

In cities, when stormwater disturbance is strong, it can be regarded as a stormwater disaster. It will form a flood peak in a short period of time and bring about a series of secondary hazards. Even when the disturbance is weak, it may cause urban water accumulation and surface area. source pollution. The relationships between various lifeline systems in the city are closely connected. Once the city's drainage system is damaged, catastrophic chain reactions may occur within and between systems[11]. In order to cope with future uncertainties, improving stormwater resilience has become a necessary measure for cities to achieve sustainable development, and stormwater resilience assessment is a prerequisite for improving stormwater resilience.

3.1 Stormwater Resilience Assessment Method

The stormwater resilience assessment method is a method used to measure the response and adaptability of a city or region in the face of stormwater disasters[12]. Through quantitative or qualitative methods, we examine the performance of various aspects of a city or region when rainwater disasters occur, including physical facilities, social economy, environmental management, emergency response, etc.[13]. It focuses on the disaster resilience, resilience, adaptability, and disaster risk reduction capabilities of a city or region[14].

Through stormwater resilience assessment, we can understand the vulnerability and resilience of a city or region to stormwater disasters and improve its shortcomings. The assessment results can provide scientific basis for stormwater disaster risk management, emergency response planning and urban planning, and help formulate and optimize stormwater disaster prevention and control strategies[15]. Currently commonly used rain resilience assessment methods include comprehensive index method, scenario simulation method[16], GIS technical analysis method[17], machine learning method[18], etc.

Table 2. Summary of Stormwater Resilience Assessment Methods

Assessment Method	Advantage	Shortcoming	Application Scenarios
comprehensive index method	comprehensiveness, flexibility, comparability	subjectivity	multi-faceted and multi-level assessment
scenario simulation method	consider dynamic changes	high model complexity	evaluate under specific events or conditions
GIS analysis	visual display	data management difficulties	assessment based on spatial analysis
machine learning method	automate, predict and optimize	limited interpretability	assessing the potential impacts of future stormwater disasters

3.1.1 Comprehensive Index Method

The composite index method is a commonly used assessment method for assessing stormwater resilience. It derives a comprehensive resilience index by comprehensively considering the weights and scores of multiple evaluation indicators to reflect the city's response and adaptability in the face of stormwater disasters[19]. Based on the assessment results, the city's strengths and weaknesses in stormwater resilience can be identified. These results can provide guidance for developing and improving measures and strategies for resilience.

Moghadas et al.[20] developed a hybrid multi-criteria decision-making method based on a comprehensive index of six dimensions: society, economy, institution, infrastructure, community capital and environment, and evaluated the flood resilience of various districts in Tehran, Iran; Qasim et al.[21] selected resilience indicators based on four dimensions: social, economic, institutional, and physical to evaluate the ability to withstand flood disasters in three communities in Khyber Pakhtunkhwa Province, Pakistan; Nahin et al.[22] used multi-criteria decision analysis Conduct stormwater vulnerability assessment on the Jamuna River floodplain area; Ling et al.[23] constructed a comprehensive assessment system of stormwater resilience throughout the disaster cycle covering pre-disaster resistance capabilities, disaster response and recovery capabilities, and post-disaster adaptive capabilities. An empirical study was conducted on five cities on the southeastern coast of China.

3.1.2 Scenario Simulation Method

The scenario simulation method simulates the impact of different stormwater disaster events on cities by establishing simulation scenarios, and evaluates the city's resilience level in coping with and adapting to these scenarios. Chang et al.[24] used a 3D hydrodynamic model to simulate time-varying inundation conditions under an extreme rainfall (799mm rainfall in 72 hours) in Tainan to evaluate the impact of LID on stormwater disaster resilience; Zhang et al.[25] developed a Systematic urban stormwater resilience assessment model, covering runoff simulation, flood estimation and resilience assessment; Vojinovic et al.[26] established a 1D-2D model of Ayutthaya, Thailand through MIKE

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to analyze nature-based flood control measures and their relationship with gray infrastructure Combined with the control effect on rainwater disasters; Rosa et al.[27] used SWMM to establish a model to evaluate the hydrological response of the Belo Horizonte City Water District in Brazil to rainfall runoff events under different land use scenarios.

3.1.3 GIS Analysis Method

The GIS analysis method uses geographic information system (GIS) technology to collect, organize, analyze and visually display data related to urban stormwater disasters, thereby helping to understand and evaluate stormwater resilience[28]. Through GIS technology, we can further understand the spatial distribution of urban stormwater disasters, potential risk areas, affected populations and facilities, and evaluate the effects of different prevention and control strategies[29]. In addition, GIS technology can also support spatial decision analysis, such as determining the best flood evacuation path and selecting the appropriate location of flood control facilities. Waghwala et al.[30] used GIS spatial analysis tools to draw a flood management map for Surat City, helping to reduce and transfer flood risks and enhance the flood resistance of flood-prone areas; Wakhungu et al.[31] used GIS technology to conduct a flood management map in Florida. Pa City conducted an environmental vulnerability assessment when encountering flood risks; Wang Ying and others studied the visualization technology of waterlogging disaster values in sponge cities based on GIS technology, which provided a reliable analysis basis for the prevention and control of rain and flood disasters in the city.

3.1.4 Machine Learning Method

The machine learning method is a data-driven method for assessing stormwater resilience. It uses machine learning algorithms and models to analyze and predict the potential risks, impacts and response capabilities of urban stormwater disasters[32]. Common machine learning models include decision trees, support vector machines, neural networks, random forests, etc. Li et al.[33] studied the application of machine learning in urban surface water stormwater risk assessment, showing that machine learning can help quickly draw flood risk maps and contribute to urban stormwater risk assessment and management; Sankaranarayanan et al.[34] used depth The neural network method predicts the possibility of rainwater disasters based on temperature and rainfall to reduce the losses caused by rainwater disasters; Wang et al.[35] established a model based on support vector machines to predict the water level of rainwater pipe networks, and It has good accuracy and running speed; Cheng Pengen and others used the random forest algorithm to analyze the correlation between rainwater disaster risk factors and rainwater disasters, and improved the quantitative analysis of indicator weight evaluation.

3.2 Research on Strategies to Improve Stormwater Resilience

The stormwater risk prevention and control system includes flood control and drainage-related infrastructure, stormwater monitoring, forecasting, early warning, and dispatch decision-making support systems, etc. The connotation of stormwater resilience refers to the three capabilities that cities have when facing the above water problems[36]. That is, the ability to avoid rain and flood disasters, the city's recovery ability after rain and flood disasters occur, and the city's self-organization, learning and adaptability. Through a series of pre-disaster and post-disaster measures, the impact of rain and flood disasters on the city can be effectively reduced.

3.2.1 Pre-disaster Prevention

(1) Focus on planning: Integrate the concept of resilience into planning, determine a scientific and reasonable urban stormwater prevention and control standard system, and establish an interconnected comprehensive stormwater and flood prevention and control infrastructure system.

(2) Strong assessment: Use multiple methods to evaluate the city's stormwater resilience to provide decision-making basis and technical support for the city's drainage management, flood early warning, flood control emergency response, and operation dispatch.

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(3) Make up for shortcomings: Investigate and analyze the current infrastructure related to flood control and drainage, find out the lags and weaknesses of the existing infrastructure, and sort out the priorities for infrastructure renovation on this basis, and strive to improve the current foundation. Flood control and drainage effects of facilities.

(4) Whole process: The management and control of rainwater should focus on "source emission reduction, process control, and system management", and control the entire process of rainwater cycle "water collection, water seepage, water purification, and water storage".

(5) Intelligence: Deeply integrate Internet technology and water technology, carry out research on urban stormwater forecast and early warning, improve the information sharing and coordination linkage mechanism of relevant departments, and build a reliable urban stormwater disaster forecast and early warning system.

3.2.2 Post-disaster Response

After being hit by rain and flood disasters, cities can quickly recover through three methods: failure prevention, accelerated recovery, and conversion performance. As the area of urban built-up areas continues to expand, the requirements for flood control and drainage standards are also constantly increasing. The actual level of flood control and drainage is mostly lagging behind. Post-disaster reconstruction is an important period of opportunity for improving urban resilience. Post-disaster reconstruction work is not just about repairing the city. The reconstructed urban flood control and drainage standards should be as high as possible higher than the original standards, strengthening the integration of the urban flood control and drainage system with transportation, water supply, power supply, gas supply, ecology, environment and other subsystems. The correlation between accidents can be transformed into adaptive learning, and "blood transfusion" reconstruction can be transformed into "organic recovery", so that the city's stormwater resilience can be continuously improved.

4. Conclusion

The interconnectedness, reliability, and disaster adaptability of the urban flood control and drainage system and other subsystems together constitute the city's resilience. In view of the increasing frequency and degree of rainwater damage faced by urban development, this article takes the opportunity of resilient city construction to clarify the definition of stormwater resilience from the perspective of resilience, and summarizes the key aspects of stormwater resilience from the aspects of resilience assessment and resilience improvement strategies. Current status of research. At present, domestic research on stormwater resilience is still in the development stage. The definition and core mechanism analysis of stormwater resilience in existing research are not clear enough, and various theoretical technologies still need to be further improved.

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