Rainwater Management Strategies from the Perspective of Urban Flood Resilience

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Abstract: This article examines rainwater management strategies for enhancing urban flood resilience, focusing on rising flood risks due to urbanization and the need for effective responses. It critiques traditional management limitations and proposes a comprehensive framework integrating green infrastructure with resilience theory. Strategies are explored across four key dimensions: infrastructure, institutions, economy, and society, with multi-level measures like source control, process control, economic support, and community engagement. Using domestic and international case studies, the article demonstrates these strategies' practical effectiveness, aiming to improve cities' resistance, recovery, and adaptability to flooding and waterlogging.
***Keywords*:** rainwater management; strategies; urban flood resilience

1. Introduction

According to the World Cities Report 2022 by the United Nations, 56% of the global population lived in urban areas in 2021, a figure expected to reach 68% by 2050[1]. Urbanization has driven rapid development and population concentration[2], increasing greenhouse gas emissions and altering surface characteristics. The spread of impermeable areas has intensified rainwater runoff, raising peak flow and flood volume, especially in low-lying areas, exacerbating flood risks. As cities grow, concentrated populations and assets increase land value, resulting in substantial economic losses from flooding[3]. The 2022 Global Natural Disaster Assessment Report indicates floods are 14% more frequent than the historical average and have caused 8,049 deaths, 20% above the average. These trends underscore floods' expanding impact on urban health, safety, and quality of life.

Existing infrastructure struggles with flood challenges in complex urban environments. To mitigate flood-related losses, a new integrated urban system is essential. The concept of resilient cities offers practical solutions for enhancing flood resilience and has become a prominent research area. Emphasizing interdisciplinary, multidimensional, and multi-scale approaches, resilient cities aim to strengthen urban systems' adaptive capacity to climate and disaster risks. This concept not only enhances resistance and recovery from floods but also proposes new perspectives on disaster adaptation for extreme urban events.

2. Literature Review

Recent years have seen a surge in research on flood management. Traditional rainwater management relies heavily on "grey" infrastructure, such as pipes, canals, and pump stations, aiming to control runoff by "rapid elimination" and "end concentration." However, urban drainage systems (UDS) are typically only designed for specific rainfall periods, leading to flooding when overwhelmed by excessive runoff[4]. Additionally, this approach lacks resilience and overload capacity, aggravating groundwater depletion, soil moisture loss, and pollutant spread, thereby intensifying conflicts between artificial and natural water cycles[5].

To counter these issues, green infrastructure—such as rain gardens, permeable pavements, and green roofs—has gained attention as an innovative solution that can reduce runoff, curb urban water pollution, and enhance water quality[6]. The concept of resilience adds a further dimension, addressing flood management by enhancing cities' adaptability to climate and disaster risks. First introduced in 2002 by the ICLEI, urban resilience emphasizes a comprehensive approach that integrates social, infrastructural, and ecosystem interactions for disaster preparedness[7]. Researchers highlight that true flood resilience relies on robust infrastructure, institutional readiness, economic stability, and social cohesion, as Jha identified as the four pillars of resilience[8]. A holistic management approach incorporating community engagement, disaster preparedness,

and ecosystem services enables cities to achieve a dynamic balance and turn flood risks into opportunities for transformation.

3. Conceptual framework for urban flood resilience

Resilience theory suggests a multidimensional approach to evaluating urban flood resilience, focusing on four key indicators: infrastructure, institutional, economic, and social resilience.

(1) Infrastructure resilience: Enhances the ability of cities, transport systems, and critical infrastructure to withstand and adapt during extreme weather, ensuring drainage and stormwater systems remain effective.

(2) Institutional resilience: Involves robust disaster response policies, flexible emergency management, and collaborative governance across departments and communities.

(3) Economic resilience: Ensures cities can recover quickly after floods, with adequate funding and comprehensive insurance to support swift return to normal operations.

(4) Social resilience: Emphasizes community engagement in disaster response, including education, risk awareness, resource sharing, and public participation to strengthen local response capabilities.

4. Rainwater and flood management strategy

To strengthen urban flood resilience, management strategies should integrate infrastructure, institutions, economy, and society, using multi-level approaches like source control, process control, economic support, and community participation to build robust flood response capabilities.

4.1 Source control

Improve urban planning to manage city expansion responsibly, balance urban growth with nature, and protect ecosystems. Implement 'blue-green-grey' infrastructure by promoting rain gardens, permeable pavements, and green roofs to increase water infiltration and reduce runoff. Establish retention areas such as wetlands and reservoirs to manage excess rainwater and reduce pressure on drainage systems, ensuring infrastructure is developed in alignment with city growth.

4.2 Process control

Improve the flood warning system, utilize big data and meteorological monitoring technology to achieve efficient warning and early evacuation, and reduce the losses caused by flood disasters. Develop flood emergency response plans, conduct regular drills, and strengthen the city's emergency management capabilities.

4.3 Economic support

By establishing a special fund for rain and flood management and improving the disaster insurance mechanism, losses can be effectively dispersed, the economic burden on municipal and residents can be reduced, and the city can quickly recover to pre disaster levels after encountering flood disasters.

4.4 Community participation

Through community education activities, enhance residents' awareness of flood risks, popularize self rescue and mutual aid knowledge, and improve disaster response capabilities.

5. Case Study

With accelerated urbanization and hydrological damage from high-density development, cities face increased flood risks during extreme rainfall. Using urban parks as examples, this section illustrates how resilience concepts can help mitigate urban flooding. Globally, flood resilience has been incorporated into park and city planning, integrating factors like infrastructure, institutions, economy, and society for comprehensive flood management.

5.1 Harbin Qunli Rainwater Park (Infrastructure Resilience)

Harbin's Qunli New Area, receiving 567mm of annual rainfall, experiences intense summer floods. To mitigate waterlogging, the Beijing Tu Ren design team established a rainwater wetland system to collect, purify, and store rainwater, while also recharging groundwater. This park, serving as both flood management and recreational space, integrates natural wetlands into urban infrastructure, enhancing resilience and promoting climate adaptation.

5.2 Kanagawa Prefectural Urban Disaster Prevention Park (Institutional Resilience)

Following the Great Hanshin Earthquake, Kanagawa, Japan, developed disaster prevention parks with robust emergency preparedness. Equipped as emergency shelters with ample supplies, these parks significantly improve residents' resilience to natural disasters, showcasing the value of institutional readiness in flood resilience.

5.3 Landscape Renovation of the Colmar River in South San Francisco (Social Resilience and Infrastructure Resilience)

The 3.2-kilometer Colmar River Landscape Corridor in San Francisco's Bay Area initially featured concrete banks that isolated it from nearby communities. Rising sea levels and frequent flooding revealed the limitations of rigid flood control. The "Kolma River Connector" project, developed collaboratively with local residents, restored the ecological link between the river and its surroundings. Community activities, including a fairy tale book about the river, were organized to engage residents and foster environmental awareness, reinforcing social resilience.

The renovation replaces rigid structures with greenery and stepped revetments, allowing closer human-nature interaction while establishing flood control areas and vegetation zones that enhance biodiversity. Rain gardens and wetlands help purify water, reduce flood risks, and demonstrate the effectiveness of green infrastructure in bolstering flood resilience.

5.4 Central Emergency Response Fund Climate Action Account (Economic Resilience)

The International Federation of Red Cross and Red Crescent Societies estimates a $20 billion annual increase in climate disaster funding needs by 2030. The UN's Climate Action Account under the Central Emergency Response Fund plays a vital role in delivering resources to vulnerable regions, offsetting economic and humanitarian impacts. Economic resilience is strengthened by proactive, flexible funding that equips countries to better cope with climate shocks, enhancing their adaptability and recovery capabilities.

6. Conclusion

In summary, urban flood management is a comprehensive and complex challenge. With the acceleration of urbanization and the frequent occurrence of floods, cities urgently need to establish resilient management systems to effectively respond to these risks. By combining green infrastructure and resilience theory, not only can cities enhance their response capabilities, but they can also strengthen their resilience and adaptability. Future research should focus on how to better integrate various urban resources, follow the pace of urban progress, promote technological innovation, and enhance social adaptability to ensure sustainable development of cities in the face of extreme weather conditions.

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