Application of Distributed Water Storage Systems In Urban Water Hazards Management Under the Concept of "Sponge City"

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Abstract. Management of waterlogging-dominated water hazards is a critical issue in contemporary urban development. The introduction of the "sponge city" concept provides a new paradigm for addressing urban water hazard challenges, with the integrated and adaptive approach emerging as a key solution. This paper explores urban water hazards management within the framework of the sponge city concept and draws on distributed network technology, commonly employed in managing internet congestion, to propose a design framework for distributed water storage systems. Compared to traditional water hazards control methods, distributed water storage systems exhibit superior drainage efficiency and enable precise regulation of urban water resources. By integrating big data and artificial intelligence technologies, these systems can facilitate intelligent spatial and temporal scheduling of water resources, effectively addressing urban water hazarding while simultaneously promoting the sustainable and efficient utilization of water resources.

Keywords: Sponge City; Distributed Systems; Water Storage; Urban; Water hazards Management.

1. Introduction

In recent years, rapid urban population growth and continuous urban expansion have significantly altered the hydrological characteristics of cities. Traditional urban planning frameworks are no longer adequate to meet the demands of contemporary water hazards management. Effective urban water hazards management requires a holistic approach that accounts for multiple factors, including climate conditions, topography, geomorphology, and the state of existing infrastructure. By integrating the principles of sponge city construction into traditional water hazards management strategies, cities can achieve scientifically informed spatial and temporal regulation of water resources, thereby enhancing the overall efficiency and effectiveness of urban water hazards management.

The traditional centralized water resource management model has increasingly revealed numerous limitations. In response, the distributed water storage system, a key component of sponge city development, offers a novel approach to addressing these challenges. Sponge city is an innovative concept in urban stormwater management, focusing on enhancing the retention and infiltration capacities of urban areas to achieve scientific management and recycling of water resources. This approach is particularly suitable for water-scarce regions, where modifications to surface structures increase infiltration rates of surface water, thereby reducing surface runoff. Additionally, methods such as grooving, sand filling, and creating sunken water collection spaces shift the traditional paradigm of water hazards management, increasing urban water retention capacity. These strategies enable cities to adapt to changes in the water ecological environment, reduce the frequency of urban water hazardsing, and provide residents with a safer and more stable living environment [1].

This study focuses on urban water hazards management by systematically introducing the design principles and functions of distributed water storage systems within the framework of the "sponge city" concept. Considering the characteristics of traditional urban water hazardsing and the limitations of conventional management approaches, which often fail to ensure effective water hazards mitigation, distributed water storage systems provide an innovative solution. By optimizing urban pipe network designs and enhancing the allocation of spatial resources, these systems leverage distributed warning nodes to dynamically monitor water resources. This approach offers a practical reference for improving urban water hazards management strategies and achieving more effective and sustainable outcomes.

2. Characteristics of Urban Water Hazards and Conventional Mitigation Measures

With the continued growth of the global urban population, the original design frameworks of most cities have become inadequate for addressing current water hazards challenges. Effective urban water hazards management requires selecting measures tailored to the specific characteristics of urban water hazardsing, ensuring the effectiveness and sustainability of mitigation efforts.

2.1. Characteristics of urban water hazardsing

Water hazards refer to the adverse impacts on human production and daily life caused by the disruption of spatial hydrological balance. For example, when intense or prolonged rainfall exceeds the capacity of urban drainage systems, it can lead to waterlogging and other forms of inundation-related disasters [2]. The specific causes of urban water hazardsing give rise to three prominent characteristics: high suddenness, significant destructive potential, and a wide range of impact.

Urban water hazards are often closely associated with natural precipitation, which is characterized by significant unpredictability. Intense short-term rainfall imposes immense pressure on urban drainage systems, frequently exceeding their design capacity. In such scenarios, prolonged heavy rainfall poses a severe threat to the safety of lives and property for a broad population.

First, it is sudden. Urban water hazardsing is predominantly linked to natural precipitation, which is inherently unpredictable. Intense short-term rainfall exerts substantial pressure on urban drainage systems, often surpassing their design capacity. In such conditions, if heavy rainfall persists for an extended duration, it poses significant threats to the safety of lives and property on a large scale.

Second, it is high destructive potential. Urban water hazardsing can inundate extensive infrastructure, including underground garages, shopping malls, and other facilities, while also triggering large-scale secondary disasters. Prolonged submersion of urban structures compromises the stability of building foundations. Additionally, urban water hazardsing can lead to the spread of diseases, which, if not controlled effectively, may result in severe consequences.

Third, it is wide impact range. In recent years, the continuous expansion of urban areas, coupled with higher density of roads and buildings, has exacerbated the impact of urban water hazardsing. Water accumulation during water hazards events cannot be rapidly drained through urban drainage systems, leading to its spread towards surrounding areas due to water flow dynamics. Consequently, the affected range is significantly broadened. Furthermore, the cascading effects of urban water hazardsing disrupt daily life, such as causing shortages of essential goods and spikes in commodity prices [3, 4].

2.2. Conventional Urban Water Hazards Management Measures

Urban water hazards management is directly tied to the quality of life of residents and significantly influences the safety of lives and property. To effectively address urban water hazardsing, urban planning departments often employ underground drainage networks to manage water resources. These networks are integrated with urban water hazards discharge channels, which divert water from the drainage systems to mitigate urban waterlogging. In addition to these measures, some cities utilize artificial lakes, reservoirs, and similar infrastructures for water storage. This dual approach not only addresses urban waterlogging caused by heavy rainfall but also helps alleviate seasonal water shortages, enabling flexible temporal allocation of water resources.

At present, urban water hazards management predominantly adopts a "preparedness and timely response" strategy. This involves proactively conducting risk assessments and ensuring adequate preparedness for potential water hazards events during non-emergency periods. When water hazards occurs, relevant human and material resources are promptly mobilized to address the situation, minimizing associated losses to the greatest extent possible.

3. Challenges in Urban Water Hazards Management

Water hazards management remains a significant challenge in urban development. Over an extended period, considerable experience has been accumulated in addressing urban water hazardsing. Currently, urban water hazards management primarily focuses on optimizing drainage system designs, including urban drainage networks, water hazards discharge channels, and water storage reservoirs or lakes. However, these approaches often exhibit a degree of lag in implementation, and their practical effectiveness remains suboptimal [5].

3.1. Inefficient Urban Construction Planning

In recent years, the increasing density of urban construction has exacerbated issues within urban water management systems. Common problems during urban development include improper connections in stormwater drainage systems, such as misaligned, mixed, or missing connections. Additionally, untreated wastewater is often discharged directly into rivers and lakes, resulting in widespread environmental pollution. The capacity of newly installed drainage networks is frequently insufficient to meet the current urban drainage demands, especially during large-scale and prolonged rainfall events. This leads to the overloading of urban drainage systems and frequent occurrences of urban waterlogging. Moreover, some water hazards discharge channels have been obstructed during urban construction, resulting in a loss of their water hazards mitigation capacity. These factors collectively increase the complexity and difficulty of urban water hazards management.

3.2. Insufficient Water Storage Capacity

Water storage capacity is a critical metric for evaluating the effectiveness of urban water hazards management. Compared to the design of drainage networks and water hazards discharge channels, the planning of water storage reservoirs and lakes holds even greater significance [6]. However, improving water storage capacity requires adequate spatial resources. The continuous expansion of urban development has resulted in limited internal space, with many original water Storage Rivers and lakes being filled in or relocated to relatively remote areas. This severely undermines the effectiveness of urban water hazards management. Moreover, poorly planned water storage designs can exacerbate urban water hazardsing issues [7].

4. Distributed Water Storage Systems and Their Application in Urban Water Hazards Management

4.1. Introduction to Distributed Water Storage Systems

The traditional centralized water resource management model has increasingly revealed numerous limitations. In response, the advent of distributed water storage systems within the sponge city framework offers a novel approach to addressing these challenges. Departing from the conventional centralized water storage paradigm, distributed systems are designed based on the spatial distribution of urban hydrological ecosystems. They strategically allocate water storage nodes and capacities within drainage networks, enabling efficient water management. Furthermore, by employing automated control systems, these nodes facilitate the dynamic scheduling of water resources. This approach provides a modern and innovative framework for urban stormwater management, enhancing resilience and sustainability in contemporary cities.

The fundamental principle of distributed water storage systems in sponge cities lies in endowing urban areas with sponge-like resilience, enabling them to respond more effectively to the challenges posed by rainfall. By scientifically and strategically integrating various water storage facilities within urban environments, these systems achieve decentralized rainwater collection, storage, and utilization [8].For instance, in newly developed urban areas, wetland parks with water storage functions can be constructed to simultaneously beautify the environment and store rainwater. In older districts, existing drainage systems can be retrofitted to include additional water storage nodes and expanded pipelines, transforming the traditionally linear drainage network into a more robust system with enhanced storage capacity. Additionally, unused urban spaces can be repurposed to install multiple rainwater collection modules, such as small-scale rainwater storage tanks. The harvested rainwater can then be utilized for urban landscaping, firefighting, and other purposes.This distributed water storage system not only effectively mitigates urban waterlogging but also provides a stable supplementary water resource for the city. Furthermore, it reduces urban reliance on external water sources and enhances the city's water self-sufficiency. In doing so, the system plays a vital role in safeguarding urban water ecological security.

4.2. Urban water hazards Management Strategies Based on Distributed Water Storage Systems

Urban water hazards management is closely tied to the design and construction of water storage and drainage systems. Although the introduction of the sponge city concept has effectively alleviated urban water hazardsing, it still falls short of achieving the goals of "integrated storage and precise control." In this context, enabling the dynamic allocation of water resources through urban pipeline networks has become a key research focus in sponge city construction. Distributed water storage systems offer a viable solution to this challenge by leveraging advanced technologies such as big data, the Internet of Things (IoT), and 3D visualization. These systems facilitate the intelligent management of urban water resources, thereby reducing the likelihood of urban water hazardsing [9].

4.2.1. Enhancing Spatial Allocation of Resources

Urban water hazards management is a complex and systematic endeavor requiring the integrated use of urban resources. Within the framework of the sponge city concept, distributed water storage systems leverage existing urban drainage networks, water hazards discharge channels, and storage units. Using historical rainfall data, urban water hazards management models can be constructed to simulate precipitation intensity and volume, identifying specific water hazards-prone locations and analyzing the underlying causes. Based on these analytical results, designers can dynamically adjust spatial resource allocation plans to improve the effectiveness of water hazards management [10]. Distributed water storage systems under the sponge city concept do not rely solely on traditional river and lake resources. These systems also incorporate wetlands, reservoirs, and high-permeability water storage zones, utilizing underground runoff as a key platform for water hazards-pronemanagement. This approach reduces the drainage burden caused by surface runoff. For instance, data analysis might reveal areas within residential neighborhoods with significant surface runoff. In such cases, internal water storage units can be added, provided safety is ensured. This strategy addresses issues such as urban waterlogging caused by reduced water storage capacity while simultaneously providing sufficient water resources for uses like landscaping and irrigation, thus minimizing wastage [5].

Analysis of various urban water hazardsing scenarios reveals that resource allocation centered on water storage platforms should adhere to the principles of "scalability" and "systematization."First, for cities prone to frequent water hazards the construction scale of water storage platforms, such as wetlands, rivers, and lakes, should be expanded based on local conditions. Where feasible, surrounding farmland can be utilized as emergency water storage platforms and integrated with agricultural irrigation systems to mitigate the damage caused by urban water hazardsing. Second, water hazards management based on water storage platforms requires systematizing dispersed resources. All storage nodes should participate in the comprehensive allocation of water resources. Through systematic management, the full potential of water storage platforms in water hazards mitigation can be realized, reducing the pressure on individual regional storage platforms [11].

The construction of distributed water storage systems under the sponge city concept does not imply that a greater number of water storage platforms is always better. Instead, the focus is on ensuring that the city's overall water storage capacity meets demand. This involves determining the optimal number, capacity, and location of water storage platforms based on historical water hazards data for each urban area.In cases of large-scale rainfall, the entire network of water storage platforms must dynamically adjust their storage levels to facilitate cross-regional allocation of water resources. This approach ensures efficient use of storage platforms while maintaining the balance between water storage capacity and urban water hazards management needs.

4.2.2. Optimizing Intelligent Pipeline Network Design

Urban water hazards management requires the integration of multiple factors. Historical data shows that urban water hazardsing often occur in specific areas, primarily due to geographical factors. In particular, low-lying urban areas with poor drainage capabilities are more prone to water hazards during intense short-term rainfall events. To address this issue, distributed water storage systems under the sponge city concept can efficiently utilize resources such as drainage networks, water hazards discharge channels, and water storage platforms. By employing advanced technologies such as automated control systems and the Internet of Things (IoT), existing resources can be upgraded to improve management capabilities. A remote control platform can be used to monitor surface runoff, subsurface runoff, and the operational loads of drainage networks, water hazards discharge channels, and water storage platforms under varying rainfall conditions. This enables timely adjustments to resource deployment, ensuring the spatially optimized allocation of water resources. To achieve this goal, urban drainage network designs should incorporate features such as flow and level sensors, along with region-specific enhancements such as unidirectional shut-off valves and pumping equipment in areas with lower elevations. These additions allow for real-time monitoring of drainage network performance while enhancing the efficiency of cross-regional water resource allocation [9].

The design of intelligent pipeline networks transforms traditional urban water hazards management by optimizing water storage strategies. Adding water storage platforms at critical points effectively mitigates waterlogging issues caused by geographical factors.During implementation, the design of intelligent pipelines should consider the distribution of water storage capacities and select pipe diameters accordingly. Additionally, in the process of hydraulic resource allocation, parameters such as water flow velocity and the number of pipelines should be precisely controlled to enhance system efficiency and ensure optimal performance.

In addition to addressing waterlogging in low-lying areas, intelligent pipeline network design effectively mitigates water resource loss in higher-altitude urban regions. Water storage platforms can dynamically adjust the distribution of urban water resources, preventing resource loss and supporting the development of a new urban water ecological system. As the level of intelligence in urban pipeline networks continues to improve, the role of water storage platforms in water hazards management will become increasingly prominent. This advancement will promote the integrated utilization of various water storage resources, including subsurface runoff platforms, significantly reducing the likelihood of urban water hazardsing [12].

4.2.3. Developing a Node-Based Early Warning Model

With the continuous expansion of urban areas and increasing population density, sudden large-scale rainfall events have made urban water hazardsing increasingly unpredictable. Currently, the sponge city concept focuses primarily on enhancing urban infiltration, retention, and detention capacities. However, in the absence of effective early warning systems, the precision and efficiency of urban water hazards management remain insufficient. To address this limitation, urban water hazards management under the sponge city framework should prioritize not only the reinforcement of physical water storage infrastructure but also the development of a comprehensive water resource data management system. By implementing a more accurate node-based early warning model, it becomes possible to achieve precise control and management of all urban water storage units.

The node-based early warning model for distributed water storage systems under the sponge city framework enables dynamic acquisition of urban resource data under varying rainfall conditions. This facilitates predictions of potential water hazards scenarios over a specified period and provides corresponding mitigation strategies. The model design primarily consists of three units: the data collection unit, the data analysis unit, and the early warning unit. The data collection unit is responsible for gathering information on inflow and outflow volumes, water levels, and flow rates from drainage networks and water storage nodes. The data analysis unit uses urban water hazards simulation models to analyze and predict water hazards scenarios caused by the collected data. The early warning unit monitors the status of drainage networks and water storage platforms, issuing warnings and providing optimal solutions for resource allocation. This ensures scientifically informed water resource distribution among urban water storage platforms, enhancing the overall effectiveness of urban water hazards management [13].

The development of node-based early warning models enhances the intelligence of distributed water storage systems under the sponge city framework in managing urban water hazardsing. Compared to traditional water hazards management approaches, these models allow for proactive intervention before water hazards occurs, thereby overcoming the delays associated with conventional reactive methods. With ongoing advancements in technology, node-based early warning models can be integrated with intelligent control terminals. Based on early warning results and optimized solutions, the system dynamically allocates water resources within drainage networks, achieving the goal of scientifically informed water storage and efficient water hazards management [3].

5. Conclusion

This study employs survey methods, literature review, and experiential analysis to conduct an in-depth investigation of historical urban water hazardsing issues. Combining these insights with the principles of sponge city construction, it proposes a novel approach to urban water hazards management based on distributed water storage systems.The findings indicate that the fundamental cause of urban water hazardsing lies in inadequate regional capacities for water retention, drainage, and detention. The design of distributed water storage systems under the sponge city framework can efficiently utilize water storage nodes to enhance urban water hazards management capabilities. With the ongoing refinement of distributed water storage systems and the integration of technologies such as artificial intelligence, these systems are poised to become a vital component of smart city construction. As a result, urban water hazards management will become more scientific, intelligent, and precise, providing city residents with a safer, more hygienic, and more convenient living environment.

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