Integrated Analysis of Smart Stormwater Storage and Drainage Strategies for Extreme Rainfall Events

Minfeng Xu

Hefei Beicheng Industrial Investment Co., Ltd., Hefei, Anhui, 230000, China

Keywords: Extreme rainfall; Wisdom rainwater storage; Wisdom drains water; Policy integration; Urban rainwater management

Abstract: Under the background of global climate change, extreme rainfall brings great challenges to urban rainwater management. Traditional strategies can't meet the demand. This article focuses on the integration of intelligent rainwater storage and drainage strategy for extreme rainfall. By analyzing the limitations of traditional rainwater storage and drainage strategies, introducing the intelligent concept and technology, this article discusses the intelligent transformation of traditional facilities and the application of new facilities in the intelligent rainwater storage strategy, as well as the real-time monitoring, intelligent dispatching and plan optimization in the intelligent drainage strategy, and deeply analyzes the principles, difficulties, solutions and benefits of their integration. The research results show that the integration of smart rainwater storage and drainage strategy can effectively improve the city's ability to cope with extreme rainfall, reduce the negative impact of waterlogging disaster on all aspects of the city, realize efficient management and utilization of rainwater, provide theoretical and practical guidance for the city to build a more scientific and intelligent rainwater management system, and have great significance for ensuring the sustainable development of the city.

1. Introduction

As the core area of human activities, cities are facing the increasingly severe threat of extreme rainfall. Under the background of global climate change, the frequency and intensity of extreme rainfall events have increased significantly, which has brought unprecedented challenges to the urban rainwater management system [1]. When dealing with such extreme situations, the traditional rainwater storage and drainage strategy gradually exposes its limitations and is difficult to meet the needs of sustainable development of modern cities [2]. Under this background, it is of great practical significance to study the integration of intelligent rainwater storage and drainage strategy for extreme rainfall.

Extreme rainfall often leads to frequent waterlogging disasters in cities. Urban waterlogging will not only cause serious damage to urban infrastructure, affect the normal operation of transportation, electric power, communication and other systems, but also threaten the safety of residents' lives and property and trigger a series of social problems [3]. At the same time, waterlogging may also lead to the spread of water pollution and have a long-term negative impact on the urban ecological environment [4]. Based on this, how to effectively deal with extreme rainfall and improve the city's rainwater storage and drainage capacity has become a key issue in the field of urban planning and management.

With the rapid development of information technology, the intelligent concept has gradually penetrated into the field of urban rainwater management [5]. Smart rainwater storage and drainage strategy realizes real-time monitoring, accurate prediction and intelligent regulation of rainwater system by integrating advanced technologies such as Internet of Things, big data and artificial intelligence, which provides new ideas and methods for solving urban waterlogging problems [6]. Smart rainwater storage facilities can automatically adjust the storage capacity according to real-time rainfall data and water level information, and improve the storage and utilization efficiency of rainwater; The intelligent drainage system can optimize the drainage path, quickly

  DOI: 10.25236/icacel.2025.087

eliminate stagnant water and reduce the impact of waterlogging disasters by intelligently dispatching drainage equipment.

However, at present, the intelligent rainwater storage and drainage strategy still faces many problems in practical application. On the one hand, there are differences in technology application and system construction in different regions, and there is a lack of unified standards and norms, which makes it difficult for different systems to effectively integrate and work together [7]. On the other hand, the implementation of smart strategy needs a lot of capital investment and technical support, and it is difficult to popularize and apply it in some economically underdeveloped areas [8]. In addition, the public's low awareness and participation in the smart rainwater management system has also affected the implementation effect of the strategy to some extent. Based on this, it is needed to systematically analyze the integration of intelligent rainwater storage and drainage strategy for extreme rainfall. Through in-depth study on the principles, technologies and methods of intelligent rainwater storage and drainage strategy, this article analyzes the key problems and challenges in the integration process, and puts forward targeted solutions, with a view to providing theoretical support and practical guidance for the city to build a more scientific, efficient and intelligent rainwater management system, thus effectively improving the city's ability to cope with extreme rainfall and ensuring the sustainable development of the city.

2. Smart rainwater storage strategy

In the face of extreme rainfall, traditional rainwater storage facilities have limitations in capacity and regulation flexibility. Smart rainwater storage strategy relies on advanced technology to upgrade traditional facilities and introduce new facilities to improve storage efficiency. Traditional rainwater storage facilities, such as reservoirs and wetlands, are designed with fixed capacity based on historical rainfall data. However, when the extreme rainfall exceeds the design standard, the storage capacity will be stretched [9]. Moreover, its regulation is mostly manual operation, and its response speed is slow. Taking a traditional reservoir in a city as an example, in an extreme rainfall, due to limited capacity and failure to timely control, water accumulated in the surrounding area.

Intelligent transformation aims to give "wisdom" to traditional facilities. With the help of Internet of Things technology, sensors are installed in storage facilities to monitor water level, water quality and other parameters in real time. Use big data to analyze and predict rainfall trends, and provide a basis for facility regulation [10]. Taking a reconstructed reservoir as an example, through the intelligent control system, the water inlet is automatically opened at the initial stage of rainfall to store water quickly; When approaching the warning water level, according to the real-time rainfall data, if the accumulated water will exceed the capacity, the outflow will be automatically adjusted to ensure safety. Table 1 shows the differences between them in real-time monitoring, regulation response time and storage efficiency.

Table 1 Performance Comparison Between Traditional and Smart Rainwater Storage Facilities

Comparison Item	Traditional Rainwater Storage Facilities	Smart Rainwater Storage Facilities
Real-time Monitoring	Not available	Equipped with real-time monitoring of water level, quality, etc.
Response Time	Manual operation, slow response	Automatic response, completes adjustment within seconds
Storage Efficiency	Fixed capacity, inflexible	Flexible capacity adjustment based on real-time data

New smart rainwater storage facilities have emerged. Like intelligent permeable pavement, it consists of permeable materials and intelligent sensing devices. When it rains, rainwater quickly seeps into the underground water storage layer, and the infiltration speed is controlled by intelligent devices to avoid surface water accumulation. During drought, stored rainwater can be extracted for

irrigation. For example, the intelligent rainwater garden uses an automatic irrigation system and rainwater collection system to intelligently allocate rainwater according to the water demand of plants. Table 2 lists the working principles, applicable scenarios, and advantages of different new facilities.

Table 2 Features of New Smart Rainwater Storage Facilities

Facility Name	Working Principle	Application Scenarios	Advantages
Smart Permeable Pavement	Combines permeable materials with sensors to control infiltration/storage	Sidewalks, plazas	Rapid drainage, groundwater recharge, surface runoff regulation
Smart Rain Garden	Integrates automatic irrigation with rainwater collection systems	Urban green spaces, residential gardens	Aesthetic enhancement, rainwater purification, smart distribution

3. Smart drainage strategy

The urban drainage network system is often overwhelmed under extreme rainfall. The intelligent drainage strategy achieves real-time monitoring and intelligent scheduling through new technologies, optimizes drainage plans, and improves drainage capacity. The design of rainwater runoff diversion facilities is shown in Figure 1.

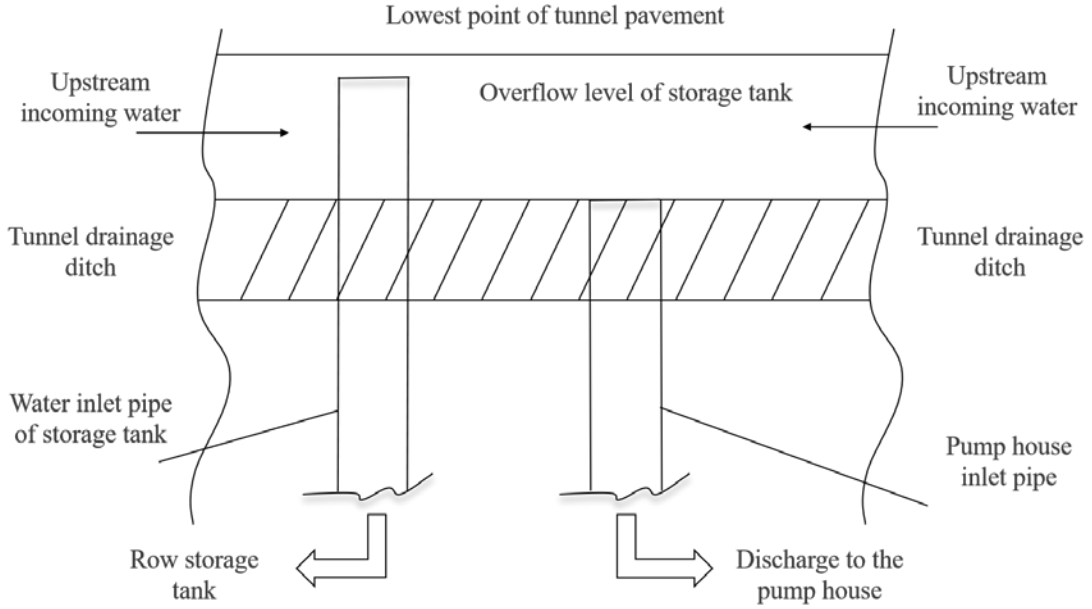

Figure 1 Design of rainwater runoff diversion facilities

The urban drainage pipe network system is complicated, some of which are aging and have insufficient drainage capacity. In extreme rainfall, the pipeline is easy to be blocked and the drainage is not smooth. Real-time monitoring is the basis of intelligent drainage. Install water level sensors, flow sensors and other equipment at key nodes of the drainage pipe network to collect water level and flow data in the pipe network in real time. Using geographic information system (GIS) technology, the data is presented directly on the electronic map. Staff can monitor the real-time operation status of the pipeline network. If during a certain rainfall process, it is detected through real-time monitoring that the water level in a certain section of the pipeline network is abnormally high, the problem area can be located in a timely manner, providing a basis for subsequent scheduling. Intelligent scheduling is the core component. Based on real-time monitoring

data, big data analysis and artificial intelligence algorithms are used to predict the drainage trend of the pipeline network and intelligently dispatch drainage equipment. Like an intelligent pump station, it automatically adjusts the frequency and quantity of water pump operation based on water level and flow data to improve drainage efficiency. At the same time, it is needed to optimize the drainage path and avoid excessive drainage pressure in local areas. Table 3 shows the significant improvements brought by intelligent scheduling in drainage time, water depth, and other aspects.

Table 3 Drainage Efficiency Comparison Before/After Smart Scheduling

Comparison Item	Before Smart Scheduling	After Smart Scheduling
Drainage Time	Long (~4-6 hours)	Significantly reduced (~2-3 hours)
Waterlogging Depth	Average 30-50 cm	Average 10-20 cm

It is very important to formulate and optimize the drainage plan. Combined with urban topography, pipe network layout and other factors, make a scientific and reasonable drainage plan. It can simulate waterlogging scenes under different rainfall intensities and evaluate the feasibility of the plan. According to real-time monitoring and intelligent scheduling feedback, the plan is optimized in time. For example, after several extreme rainfalls in a city, by analyzing the waterlogging data, the evacuation route and emergency drainage point setting in the drainage plan are adjusted to improve the coping ability.

4. Strategic integration analysis

4.1 Principles and objectives of integration

Strategy integration should follow the systematic principle, regard rainwater storage and drainage as an organic whole, and make overall planning from urban planning, facility layout to operation management. At the same time, it also adheres to the principle of adaptability and flexibly adjusts the integration strategy according to the geographical environment, climate conditions and urban functional requirements of different regions. The principle of cost-effectiveness can not be ignored. While pursuing efficient response to extreme rainfall, it is needed to reasonably control the input cost and ensure the optimal allocation of resources. The main goal of integration is to improve the resilience of cities to extreme rainfall. By integrating intelligent rainwater storage and drainage strategies, rainwater can be collected, stored, utilized and discharged efficiently, and the negative impact of waterlogging disaster on urban infrastructure, ecological environment and residents' lives can be minimized to ensure the normal operation of the city.

4.2 Integration difficulties and solutions

In the process of integration, the difference of technical standards is a big problem. Monitoring equipment and intelligent control systems produced by different manufacturers often follow different technical standards, resulting in inconsistent data formats and incompatible interfaces, making it difficult to achieve effective docking and data sharing. In this regard, it is needed to establish unified technical standards and specifications, clarify the data transmission formats, communication protocols and interface standards of various devices, and ensure the interconnection between systems.

Data fusion and analysis are also quite challenging. Advanced data mining and machine learning algorithms can be used to build a data fusion platform to realize automatic collection, cleaning, fusion and analysis of multi-source data. Table 4 summarizes the above difficulties and corresponding solutions.

Table 4 Technical Challenges and Solutions for Strategy Integration

Technical Challenge	Specific Manifestation	Solution
Technical Standard Discrepancies	Inconsistent data formats/incompatible interfaces	Establish unified technical standards for data protocols

Data Fusion & Analysis	Difficulties in multi-source heterogeneous data integration	Build data fusion platforms with machine learning algorithms

4.3 Integrated benefit analysis

The benefits brought by strategy integration are manifold. From the perspective of economic benefits, by optimizing the rainwater storage and drainage system, the economic losses caused by waterlogging disasters, such as infrastructure repair costs and business interruption losses, can be reduced. At the same time, rainwater recycling can replace some urban water supply and reduce the cost of water resources procurement. In terms of environmental benefits, it can effectively reduce the pollution of waterlogging to urban water bodies and protect the urban water ecological environment. Reasonable rainwater storage is helpful to maintain groundwater level and improve urban microclimate. The social benefits are also remarkable, which enhances the confidence of urban residents in coping with extreme rainfall and enhances their sense of security and happiness. At the same time, it also enhances the image of the city, attracts investment and talents, and promotes the sustainable development of the city.

5. Conclusions

This article discusses the integration of intelligent rainwater storage and drainage strategy for extreme rainfall. In terms of smart rainwater storage strategy, traditional facilities have been intelligently transformed, and real-time monitoring and intelligent regulation have been realized with the help of technologies such as Internet of Things and big data, which has improved the storage efficiency; The application of new intelligent rainwater storage facilities, such as intelligent infiltration pavement and intelligent rainwater garden, further enhances the ability of rainwater collection, storage and utilization. The intelligent drainage strategy improves the urban drainage capacity by installing sensors at key nodes of the drainage network for real-time monitoring and optimizing the drainage plan in combination with the urban reality.

The integration of smart rainwater storage and drainage strategy follows the principles of systematicness, adaptability and cost-effectiveness. Although it faces difficulties such as differences in technical standards, data fusion and analysis, it can be overcome by establishing unified standards and norms and building a data fusion platform. The integration strategy has brought remarkable economic benefits, reduced waterlogging loss and water resources procurement cost; In terms of environmental benefits, protect water ecology and improve microclimate; Social benefits, enhance residents' sense of security, enhance the image of the city, and promote sustainable development.

The integration of intelligent rainwater storage and drainage strategy is an effective way to improve the city's ability to cope with extreme rainfall. In the future, we should further improve technical standards, deepen multidisciplinary integration, strengthen public participation and continuously optimize this integration strategy.

References

[1] Wang Dongying, Wang Wei, Zhang Hui. Optimization of storage capacity and quantity of stormwater detention tanks based on SWMM model[J]. Water & Wastewater Engineering, 2022, 48(10): 84-88.

[2] Wang Shen. Engineering design of fully underground stormwater pumping station and initial rainfall detention tank[J]. China Water & Wastewater, 2024, 40(2): 82-86.

[3] Li Wenyu, Hou Jingming, Li Xuan. Research on optimal operation scheme of urban stormwater detention tanks based on rainfall-runoff numerical model[J]. Journal of Water Resources and Water Engineering, 2024, 35(5): 82-89.

[4] Wang Yanfang, Duan Meng. Process design and optimization of multifunctional detention tank

at Zhenjiang Border Inspection Station[J]. China Water & Wastewater, 2023, 39(6): 83-87.

[5] Tang Lei, Zhou Feixiang, Wang Weiwei. Systematic solution to typical urban waterlogging issues in northern cities[J]. China Water & Wastewater, 2020, 36(13): 139-144.

[6] Yang Yingxue, Hu Xiaofeng, Yuan Fang. Case study on drainage and flood control system planning strategies for hilly county towns in southeastern coastal areas[J]. China Water & Wastewater, 2022, 38(12): 119-124.

[7] Hong Wei, Gao Xujun, Du Yingen. Simulation study on the benefits of sponge city reconstruction on stormwater runoff reduction in old urban areas of Xi'an[J]. Journal of Water Resources and Water Engineering, 2021, 32(5): 70-77.

[8] Zhou Yi, Zhou Yundi. Numerical simulation of unit area storage depth for initial rainfall detention tanks[J]. Water Resources and Power, 2024, 42(4): 43-46.

[9] Xi Mufan, Wang Xianfeng, Li Shixing. Simulation-based optimization design of urban initial rainfall detention facilities using SWMM model[J]. Industrial Water & Wastewater, 2023, 54(3): 42-46.

[10] Li Hongyan, Zhang Chong, Hao Jingkai. Application of GT-GRA-TOPSIS in site selection and quantity optimization of stormwater detention tanks[J]. Journal of Taiyuan University of Technology, 2024, 55(5): 832-840.