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Benefit Analysis of IoT-Based Smart Monitoring System for Stormwater Sewers: A Case Study of Taoyuan City

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Abstract: Addressing urbanization and extreme climate challenges that led to frequent flooding in Taoyuan City, exposing drainage system deficiencies, the Water Resources Bureau established the "Smart Sewer Monitoring System." Integrating IoT, AI image recognition, and data analytics enables real-time water level monitoring, waterlogging incident warnings, siltation and sewage mixing analysis, and pipeline service evaluation, providing accurate decision support. This project expands the monitoring coverage, constructing a multi-dimensional water situation monitoring and control mechanism, including expanding stations, optimizing waterlogging cause analysis, establishing a management decision support platform, and developing intelligent control mechanisms. It aims to enhance monitoring and flood diversion capabilities by strengthening the platform, improving waterlogging analysis accuracy, constructing a decision support system, and developing advanced control mechanisms. Integrating cutting-edge technologies, it achieves a reliable automated framework for real-time Taoyuan water situation monitoring, improving flood control, raising disaster risk awareness, and mitigating life and property threats through early warning and immediate response. System performance evaluation and formulating a climate change resilience strategy facilitate comprehensive disaster reduction and risk management.

Keywords: Decision Support Platform, Smart Sewer Monitoring System, Risk Management, Flood Warning System

I. Introduction

Facing the dual pressures of rapid urbanization and extreme climate, nearly 1,200 cases of flooding have occurred in the Greater Taoyuan area in recent years, exposing the shortcomings of existing flood control facilities and urban drainage systems. Although the planned length of Taoyuan City's rainwater drainage system has reached 523.65 kilometers with an implementation rate of 84.45%, it still needs to overcome the challenge of frequent rainfall exceeding design standards. Therefore, establishing the "Intelligent Sewer Monitoring System" by the Taoyuan City Water Resources Bureau plays a crucial role. AI technology and the Internet of Things, integrating rainwater and sewage monitoring, road photography, image recognition, and data analysis, can more accurately predict and warn of potential waterlogging incidents, providing clear indicators of abnormal water levels, siltation, and sewer network damage.

This research project will continue to expand the monitoring system in the Taoyuan metropolitan area and other areas prone to flooding by establishing more monitoring stations. The project aims to enhance monitoring and control capabilities by integrating advanced information and communication technologies, geographic information systems, the Internet of Things, artificial intelligence, and extensive data analysis. Through comprehensive multi-dimensional water situation analysis, in addition to tracking the spatial and temporal changes of waterlogging, it will also facilitate disaster cause research, support decision-making, and optimize flood diversion strategies, achieving the following goals: strengthening monitoring platform functions, improving the accuracy of waterlogging cause analysis, building an effective management decision support system, and developing intelligent control mechanisms.

The goal is to achieve a reliable and automated monitoring framework that can monitor and assess the water situation in Taoyuan in real time. This will improve the city's flood control challenges, enhance public awareness of disaster risks, and mitigate threats to life and property through early warning and immediate response. This research will evaluate system performance, including equipment accuracy, data transmission reliability, and the effectiveness of predictive models. It will also formulate strategies to strengthen the city's overall resilience in responding to climate change, taking into account ecological and socio-economic factors to achieve comprehensive disaster reduction and risk management.

II. Related Works

2.1 Efficiency Evaluation of Intelligent Joint Control System for Detention Ponds

This study takes the Gongzhi IV and Gongzhi I detention pond systems in the Guishan District of Taoyuan City as an example to explore the application of intelligent control technology combined with real-time water quality monitoring in urban flood control. The capacity of the Gongzhi I detention pond is designed using the 100-year return period rainfall inflow. In contrast, the outlet discharge of the detention pond is determined based on the current water conveyance capacity of the downstream receiving water body and the bottleneck section. To evaluate the regulation effect of the detention pond under different return period rainfall scenarios, this study simulated rainfall scenarios with return periods of 10 years, 25 years, and 100 years. Under the 10-year return period rainfall scenario, the peak inflow into the detention pond is 2.74 cm. After regulation by the detention pond, the peak flow is reduced to 1.56 cm, which is only 56.9% of the inflow. Under the 25-year return period rainfall scenario, the peak inflow into the detention pond is 3.14 cm. After regulation by the detention pond, the peak flow is reduced to 1.84 cm, which is only 58.6% of the inflow. Under the 100-year return period rainfall scenario, the peak inflow into the detention pond is 3.73 cm. After regulation by the detention pond, the peak flow is reduced to 2.29 cm, which is only 61.4% of the inflow.

In recent years, the rapid development of real-time water quality monitoring technology has brought revolutionary changes to urban water management. This study deploys various sensors, such as water level sensors, flow sensors, and rain gauges, to achieve real-time monitoring of water levels, flow rates, and rainfall. Integrating sensors with the Internet of Things (IoT) platform enables continuous data collection and real-time analysis, providing valuable information for urban water management decisions. Through intelligent control analysis of the Gongzhi IV and Gongzhi I detention pond systems, this study quantitatively evaluates the regulation effect of the detention pond under different return period rainfall scenarios. It explores the application of joint control mechanisms in mitigating urban waterlogging. The research results provide an essential basis for optimizing the design and operation of urban flood control facilities and have important implications for improving urban flood resilience.

Figure 1.Real-time Image Monitoring of Detention Ponds during Heavy Rainfall

Figure 2.Real-time Image Monitoring of Detention Ponds during Heavy Rainfall

2.2 Siltation Analysis

During the experiment implementation period, this study monitored more than 20 sedimentation monitoring stations, among which four stations repeatedly experienced sedimentation phenomena, all located in the Taoyuan District. These four stations are R1-013 (Shuren 2nd Street, Shuren 2nd Street Lane 194), R1-012 (Chunri Road, Chenggong Road Intersection), R1-008 (No. 249, Daxing Road), and R1-010 (No. 358, Yanping Road). The R1-013 station is located at the intersection of Shuren 2nd Street, Shuren 2nd Street Lane 194, and Dawan Ditch in the Taoyuan District. Sedimentation may occur at this location due to the continuous inflow of sediment from upstream irrigation channels, the obstruction of water flow, or construction gravel caused by the nearby Shuren 3rd Street detention pond connecting the waterway experiment. This study suggests that continuous monitoring is still required after the completion of the experiment and recommends annual dredging to ensure normal drainage function.

The R1-012 station is located at Chunri Road and Chenggong Road in the Taoyuan District, and it has experienced sedimentation in 109 and 111 years. In 109, the sedimentation height reached over 30 cm, and the sedimentation rise rate was relatively steep, possibly due to the reduced flow velocity caused by sediment obstruction, thus accelerating the sedimentation process. Although the estimated sedimentation height in 111 was only 10 cm, this study still recommends an early inspection and dredging to avoid the deterioration of sedimentation. The R1-008 station is located at No. 249, Daxing Road in the Taoyuan District, experiencing sedimentation phenomena in both 109 and 110 years, with an increasing trend in sedimentation height. This study suggests that the dredging frequency at this location should be increased to ensure smooth drainage. The R1-010 station is located at No. 358, Yanping Road, in the Taoyuan District, belonging to the Dawan Ditch watershed. This station experienced sedimentation in 110 and 111 years, with an increasing trend in sedimentation height. It is speculated that sedimentation may have occurred due to the nearby Shuren 3rd Street detention pond experiment, and it is recommended that the dredging frequency be increased to maintain drainage function.From the perspective of trunk lines, the upstream and downstream stations (R7-006, R7-007) of the Shanyinlu trunk line in the Guishan District showed possible sedimentation in 108 and 111 years, respectively, with a faster rise rate in 111. It is speculated that sedimentation may have occurred due to the large amount of sediment introduced by upstream irrigation and drainage, and it is recommended that relevant units promptly conduct dredging to avoid the escalation of sedimentation problems.

In summary, through long-term sedimentation monitoring, this study identified vital sedimentation areas in the Taoyuan and Guishan Districts. The results show that sedimentation problems are mainly concentrated in areas such as Shuren 2nd Street, Chunri Road, Daxing Road, Yanping Road in the Taoyuan District, and the Shanyinlu trunk line in the Guishan District. Factors causing sedimentation include upstream sediment input, nearby construction, and obstruction of water flow by sediments. For these critical areas, this study proposes recommendations such as increasing dredging frequency and continuous monitoring to maintain the regular operation of the drainage system and reduce the negative impact of sedimentation on urban drainage and flood control. The results of this study can provide a scientific basis for sedimentation management for relevant authorities, optimize the maintenance strategies of urban drainage facilities, and enhance urban flood resilience.

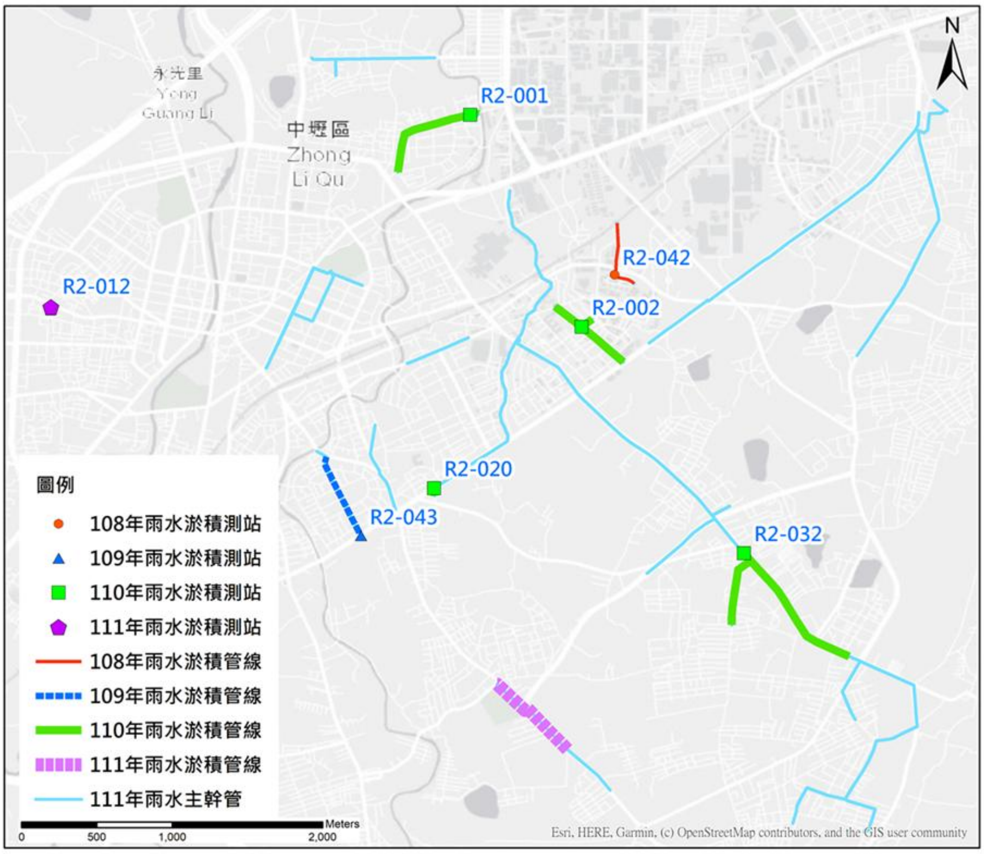

Figure 3.Stormwater Sewer Sedimentation Pipeline Diagram

III. Introduction to the Method

3.1 Flow Station Establishment Planning

In addition to evaluating the setup of measuring stations based on the monitoring results of existing stations and the review of historical disaster cases, this research also conducted detailed on-site surveys and comprehensive analyses of the urban planning area's rainwater sewer systems in Taoyuan District, Zhongli District, Guishan District, and Bade District to re-plan the locations of flow stations. To select the most suitable locations for setting up flow stations, this research prioritized maintenance holes on the main rainwater sewer trunk lines that are prone to flooding, have a history of flooding, and have complete sewer facilities.In Taoyuan District, this research focuses on monitoring the rainwater sewer system of the Nankan River basin. In contrast, Zhongli District mainly monitors the rainwater sewers of the Xinjie River and Laojie River basins. Through systematic on-site surveys and comprehensive evaluations, this research determines the priority of flow station setup based on the flood risk, historical disaster records, and the integrity of sewer facilities at each maintenance hole point.

This research conducted thorough on-site surveys of each potential flow station location. These results provide important references for the establishment of flow stations and lay a solid foundation for the planning and management of future rainwater sewer systems. This research hopes that through accurate flow monitoring and analysis, it can effectively enhance the city's flood prevention and disaster resistance capabilities and safeguard the lives and property of the public.

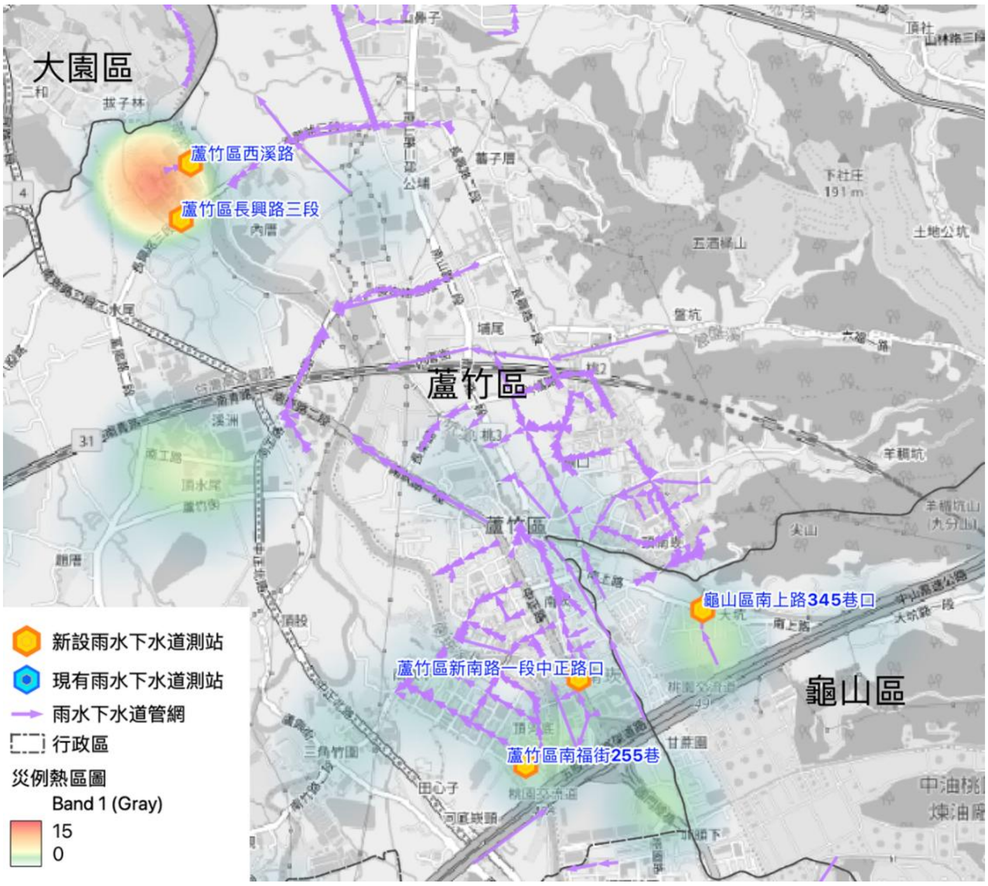

Figure 4.Rainfall Station Location Planning Map

3.2 Rainfall Monitoring Station Establishment Planning Establishing

Rainfall monitoring stations is a crucial component of urban flood management systems. The real-time data these stations provide can be used in flood prediction models, enhancing the city's ability to respond promptly to heavy rainfall events. This research aims to provide a comprehensive and rigorous methodology for the strategic planning and implementation of rainfall monitoring stations in Taoyuan City, focusing on the urban areas of Taoyuan District, Zhongli District, Guishan District, and Bade District.

3.2.1 Station Selection Criteria

To ensure the optimal layout and functionality of rainfall monitoring stations, this research has established a comprehensive set of station selection criteria, including:

1. **Historical flood data analysis:** This research conducted an in-depth analysis of historical flood events in Taoyuan City, identifying high-risk areas that frequently experience flooding. Priority is given to setting up rainfall monitoring stations in these areas to ensure timely data collection and implementation of response measures.
2. **Evaluation of existing sewer systems:** This research conducted detailed field surveys and assessments of Taoyuan City's existing rainwater sewer systems. Key maintenance holes along the main rainwater sewer trunk lines and flood-prone sections are selected as monitoring station sites to effectively monitor and manage the operation of the urban drainage system.
3. **Urban planning considerations:** This research reviewed urban planning documents and development blueprints for Taoyuan, Zhongli, Guishan, and Bade Districts. By assessing future urban expansion and land use changes, this research ensures that the layout of monitoring stations comprehensively covers the entire metropolitan area and adapts to future development needs.
4. **Interoperability with existing infrastructure:** This research emphasizes the seamless integration of monitoring stations with the existing rainwater drainage system. Selected sites must be compatible with the existing infrastructure for better coordination and data collection. This research also evaluated the interoperability of monitoring stations with other urban management systems (such as transportation and emergency response) to enhance overall urban resilience.

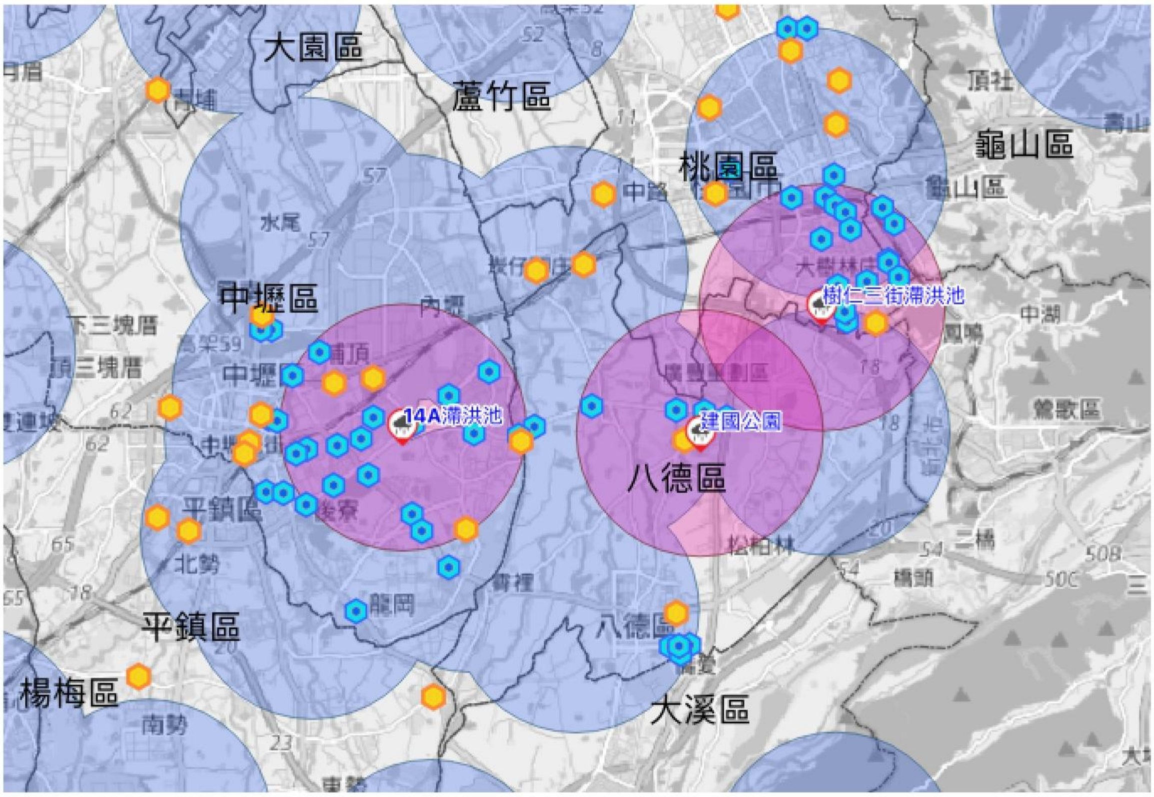

Figure 5. API for retrieving weather station list

IV. Results and Discussion

The successful implementation of the real-time monitoring system for storm sewers in Taoyuan City demonstrates the importance of advanced technology in urban water management. This project provides Taoyuan City with a comprehensive and effective flood monitoring and early warning system by integrating various advanced sensors and monitoring equipment.

High-precision AQUAS pressure-type water level sensors were selected to deploy water level monitoring stations. Their excellent measurement accuracy and range ensure the reliability of water level data. These sensors utilize durable materials, such as AISI 316L stainless steel and PUR cables, to resist the impact of harsh environmental conditions and extend the service life of the equipment.For low-lying areas prone to flooding, the project introduced VIVOTEK SD9384-EHL infrared high-speed dome cameras, providing high-resolution video surveillance and remote zoom capabilities. These cameras are equipped with intelligent infrared technology, ensuring precise imaging under various lighting conditions and providing critical visual information for real-time assessment and rapid response to flood events.

The flow velocity monitoring stations employ advanced radar flow meters, providing stable and reliable water flow velocity measurement data. These data are crucial for the accuracy of flood prediction models, ensuring that the models can obtain critical parameters promptly and improve the precision of predictions.

The rainfall monitoring stations are equipped with WINTEC (5H2B-NB-IoT) real-time water level data transmitters, which support the connection of various sensors, enabling comprehensive environmental monitoring. These transmitters feature low power consumption and a robust protective design, adapting to the challenges of outdoor environments. The built-in AES encryption function ensures the security of data transmission, protecting sensitive information from unauthorized access.

The project's remote monitoring architecture adopts IoT and MQTT protocols, realizing efficient communication between sensors and the central monitoring platform. This design allows real-time data transmission and remote control, significantly improving the flexibility and scalability of the system. At the same time, optimized communication protocols reduce the system's resource load, ensuring the stable operation of the monitoring network.

To ensure the long-term reliability of the monitoring equipment, the project has developed a comprehensive maintenance plan. Regular inspections, calibrations, and necessary component replacements ensure the equipment's performance is always in optimal condition. Furthermore, implementing data quality control measures, such as redundant data storage and transmission paths, further enhances the integrity and accuracy of the data, providing a reliable basis for decision-making.

Overall, the successful implementation of the real-time monitoring system for storm sewers in Taoyuan City showcases the tremendous potential of advanced technology in modern urban water management. Integrating various sensors and monitoring equipment provides comprehensive and accurate flood monitoring and early warning capabilities, significantly improving the city's resilience to extreme weather events. This project not only makes a significant contribution to the sustainable development of Taoyuan City but also provides valuable experience and inspiration for water management in other cities. With the continuous advancement and deepening application of technology, we can look forward to the emergence of more intelligent and efficient urban water management solutions in the future, contributing to the construction of safer and more livable urban environments.

V. Conclusions

5.1 Conclusion

The successful implementation of the real-time monitoring system for storm sewers in Taoyuan City has set a new benchmark for urban water management. The project has established a comprehensive flood monitoring and early warning system by integrating advanced Internet of Things (IoT) technology, high-precision sensors, and AI-driven data analytics. This innovative approach has greatly enhanced the city's ability to predict, monitor, and respond to waterlogging events, providing a solid guarantee for public safety and property protection.

The core of the system lies in its multi-dimensional monitoring and control mechanism. By deploying advanced equipment such as pressure-type water level sensors, high-speed dome cameras, radar flow meters, and real-time data transmitters, the system can accurately capture water levels, flow velocities, siltation conditions, and the overall status of the sewer network. This high-quality real-time data provides:

1. Solid decision support for flood control and disaster risk management.
2. Enabling city managers to develop effective response strategies promptly.
3. Minimizing the negative impact of floods.

The successful expansion of the project further demonstrates its outstanding scalability and adaptability. By increasing monitoring stations and optimizing waterlogging cause analysis algorithms, the system has achieved broader monitoring coverage and more accurate flood analysis. This comprehensive monitoring network not only improves the system's overall performance but also provides critical information for developing effective flood diversion strategies. As cities continue to grow and face new challenges brought about by climate change, this scalable design ensures that the system can keep pace with the times and continuously meet the needs of urban water management. From the perspective of technological innovation, the project has successfully integrated multiple cutting-edge technologies into a unified platform. Whether it is high-precision sensors, intelligent image recognition technology, or IoT-based real-time data transmission, each technology introduced has undergone rigorous evaluation and optimization to ensure its stability and reliability under adverse environmental conditions. This multi-technology fusion approach not only enhances the system's overall performance but also provides valuable experience and inspiration for the construction of future smart cities. From the sustainable development perspective, the project has set a new standard for urban water management practices in Taoyuan City. By combining advanced technology with existing infrastructure, the system demonstrates how to achieve intelligent upgrades in urban water management without large-scale reconstruction. This innovative approach improves the city's ability to cope with extreme weather events and lays the foundation for building a more resilient and sustainable urban environment. As global climate change intensifies, this innovative urban water management model will undoubtedly become a significant trend and direction for future urban construction.

Looking to the future, the successful experience of Taoyuan City's real-time monitoring system for storm sewers is worth learning from other cities. To further improve the performance and reliability of the system, future work should focus on several aspects:

1. Continuously optimizing data analysis algorithms
2. Introducing emerging technologies such as 5G and edge computing
3. Expanding the coverage of the monitoring network
4. Strengthening regular maintenance and updates of equipment

These measures will ensure the system can operate stably in the long term and continuously provide accurate and timely decision support for urban water management.In summary, successfully implementing the real-time monitoring system for storm sewers in Taoyuan City has set a new benchmark for urban water management and explored a viable path for applying innovative technology in urban governance. This project fully demonstrates the enormous potential of combining advanced technology with traditional infrastructure, providing valuable experience and inspiration for building safer, more resilient, and livable intelligent cities. More and more cities will soon learn from Taoyuan City's successful model and work together to create a better urban future.

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