DEVELOPMENT AND APPLICATION OF FLOOD CONTROL AND WATERLOGGING PREVENTION INTELLIGENT MONITORING SYSTEM BASED ON SUBWAY "ONE MAP"

Luwei Li[1], Miao Yu[1], Haizhi Ma[1], Lei Meng[2], Zhiyuan Cui[1]

[1] Beijing Urban Construction Survey and Design Research Institute Co., Ltd.
[2] Beijing Metro Operation Co., Ltd., Geotechnical Technology Center

KEY WORDS: One map, Flood control Monitoring, Subway, Perception camera, Water level Recognition.

ABSTRACT:

Urban rainstorms and floods often occur, causing serious loss of life and property, and bringing great challenges to the safe operation of subways. In response to the need for prevention and control of urban subway floods and waterlogging, this project is based on geographic information technology, on the basis of "one map" of the subway, using intelligent sensing camera equipment, independent research and development of monitoring water level identification algorithms, and research and development of subway flood control and waterlogging prevention intelligent monitoring system It realizes the integrated management of sensing-transmission-analysis-knowledge-use monitoring of flood control and waterlogging prevention in subway stations. By integrating basic geographic information, monitoring points, real-time water level data and other information, the visualization of "one map" of flood control and waterlogging prevention is realized. The exhibition has greatly improved the management level of flood control and waterlogging prevention. The practical results and experience of this project can provide reference for related research in the same industry.

1. PREFACE

In recent years, with the continuous change of the global climate, the rapid urbanization process, and the frequent occurrence of extremely severe weather, heavy rain disasters have occurred frequently in large and medium-sized cities in my country. It is getting deeper and deeper, and it has affected the healthy development of urban economy in my country and the normal life of the people(Jianguo Li et al.,2015). The subway is the backbone of urban public transportation. Because of its advantages of convenience, punctuality and economy, it attracts a large number of ground passenger flow, which greatly alleviates the phenomenon of ground traffic congestion. However, the subway station has the characteristics of being closed, large passenger flow and mostly underground lines. In the event of a flood or other accident, the danger is extremely high. A large amount of rainwater pouring into the subway station in a short period of time can easily cause panic among people, cause congestion, stampede and drowning accidents. The equipment in the station is damaged due to accumulated water, which brings hidden dangers to the safe operation of the subway (Haiyan Zhu et al.,2018). On July 20, 2021, Zhengzhou continued to experience extreme heavy rain, causing serious water accumulation in the Wulongkou parking lot of Zhengzhou Metro Line 5 and its surrounding areas. At about 18 o'clock, the stagnant water washed away the retaining wall of the entry and exit lines and entered the main line section, causing a train on Line 5 to be besieged by the flood. After all-out rescue efforts, 14 passengers were unfortunately killed. Extreme weather and emergencies endanger people's lives and property.

Many foreign countries have carried out relevant research on the prevention and control of urban rainstorm and flood disasters. The urban storm and flood simulation model is a key technology for urban flood control and disaster mitigation simulation. At present, the urban storm and flood management model SWMM in the United States has a strong simulation and calculation function for urban storm and flood(Adams et al.,2000); Japan attaches great importance to urban storm and flood disaster system analysis in risk analysis. The system includes several sub-models suitable for the simulation of urban storm and flood disasters(M.H.Hsu et al.,2000). In China, experts such as Zhou Yuwen carried out monitoring and research on the process of urban rainstorm water accumulation based on GIS technology (Shuliang Zhang et al.,2004); Huang Guoru et al. simulated the inundation of Xinhepu Community in Guangzhou under different return periods through the integration of SWMM model and ArcGIS(Guoru Huang et al.,2011); Shanghai has developed a flood control early warning decision support system, which provides important technical support for the city's flood control and disaster mitigation(Yu et al.,2010). Domestic research on urban flood disaster monitoring and platform research mainly focuses on reservoirs, water conservancy, rainwater conditions, etc., with conventional flood control monitoring and early warning systems as the mainstay.

Beijing is located on the northwestern edge of the North China Plain and is an inland city with heavy rains. Affected by climate change and human activities, extreme heavy rainfall has occurred frequently in Beijing in recent years, and the risk of floods has increased. "2012.7.21" torrential rain has caused serious economic losses and social impacts(Shuhan Zhang et al.,2021). As of December 2021, Beijing Metro has 27 operating lines with an operating mileage of 783 kilometers and 459 stations (including 72 transfer stations). In addition, the Beijing Metro still has 11 lines under construction. By 2025, the Beijing Metro will form a rail transit network with 30 operating lines and a total length of 1,177 kilometers. The large scale and frequent occurrence of subway water leakage accidents have brought huge challenges to flood control. It is urgent to use new technologies and new means to monitor the flood situation of urban subways to prevent accidents and ensure the safe operation of subways.

2. SYSTEM DESIGN

2.1 Overall design Ideas

The intelligent monitoring system for flood control and waterlogging adopts the B/S architecture, and the platform development adheres to the design concept of modularization, framework, clustering and service to improve the reliability, scalability and maintainability of the system, so as to meet the docking requirements of different systems. Integration, compatible applications and sustainable development needs. The system is a set of "integrated", "digital" and "intelligent" platforms, using the new generation of information technologies such as the Internet of Things, geographic information, Internet, and big data, based on video collection, Internet of Things data collection, standard industry equipment connection. Real-time collection and "one picture" display of water and rain information. The system automatically performs operation and maintenance diagnosis, and intelligently analyzes the images of front-end equipment, realizes full-time monitoring and intelligent early warning of subway flood and waterlogging conditions, and meets the needs of flood control and waterlogging prevention.

The system is built in the network of the existing CCTV system. The front-end, platform software, and clients of various departments involved in this system are independent into a set of systems, which run in the same network as the CCTV system, but the overall business is independent of each other. The new platform The integrated platform also operates independently of each other.

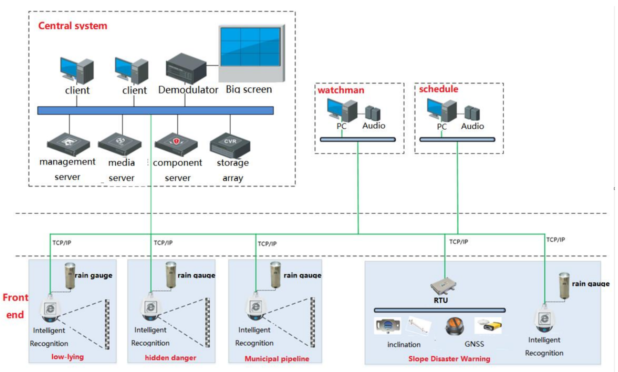

Figure 1. Overall topology of the system.

The intelligent monitoring system for subway flood control and waterlogging consists of four parts: front-end system, flood control business management platform, client and bearer network.

2.2 Functional Architecture

The system adopts advanced software and hardware development technology to realize the functions of centralized system management, multi-level networking, information sharing, interconnection, multi-service integration, etc., to meet the needs of intelligent visual management of subway flood control and waterlogging prevention monitoring. The functional architecture is shown in the figure below, which mainly includes functional modules such as video monitoring, water and rain monitoring, alarm monitoring, and network management.

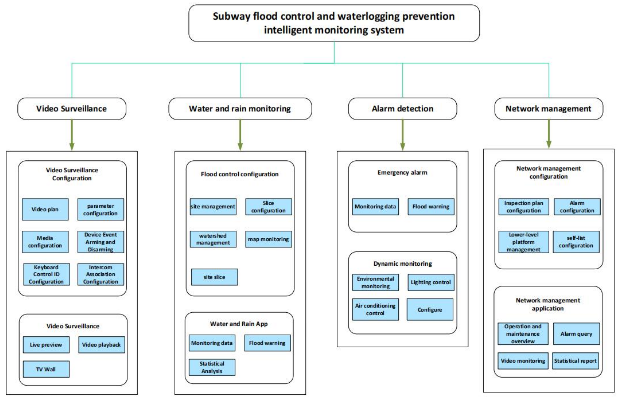

Figure 2. System functional architecture diagram.

2.3 Business Architecture

The platform adopts a component architecture, and each component undertakes different capabilities, which are divided into common business components, general service components, and basic environment components in terms of capabilities. Each type of business is composed of components from their respective fields. Business components depend on the capabilities of common service components and basic environment components.

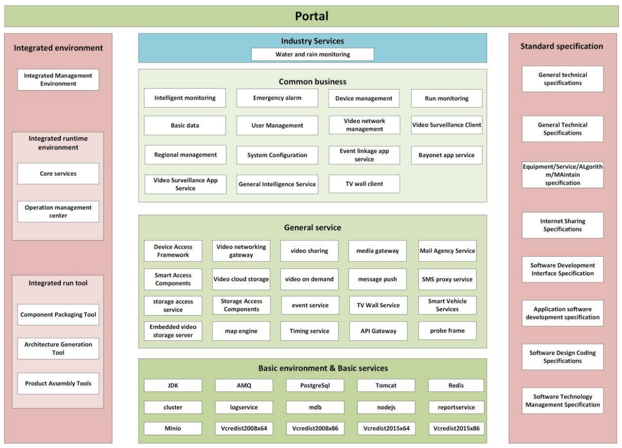

Figure 3. System business architecture diagram.

3. FLOOD CONTROL AND WATERLOGGING PREVENTION MONITORING "ONE MAP" KEY TECHNOLOGY

3.1 Water level Monitoring algorithm based on Image recognition

The water level recognition algorithm is the key technology of the system application. In addition to being affected by the image quality, the accuracy of the system's water level recognition is mainly determined by the water level recognition algorithm. The water level identification algorithm process proposed in this paper mainly includes the following steps: image preprocessing, water level positioning and water level identification.

Figure 4. Flowchart of water level identification algorithm.

3.1.1 Water ruler image Enhancement processing: The water level image is grayscaled, and the original image obtained by the water level monitoring system is a color image, including color information, which occupies a large storage space, resulting in a slow operation speed. In the preprocessing stage, the color image is converted into a grayscale image, which greatly reduces the amount of data and can greatly improve the operation speed. Color image grayscale usually includes component method, maximum value method, average method, and weighted average method. The grayscale effect is shown in the figure. The grayscale of the water level image in this paper adopts the weighted average method.

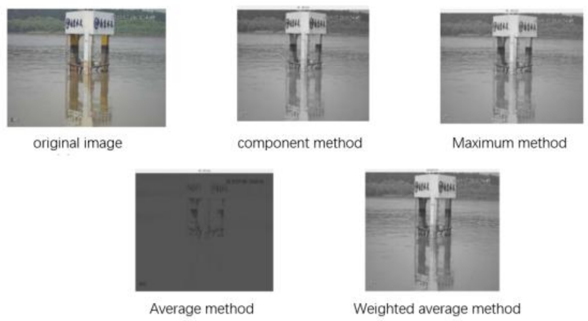

Figure 5. Comparison of grayscale effects.

Grayscale histogram equalization, because the grayscale distribution of the image is concentrated in a narrow range, which leads to the lack of clear details of the image. In order to make the image clear, it is necessary to make the difference of gray values larger, which means that the gray distribution becomes wider, so that the distribution of gray values becomes uniform. The number distribution is roughly the same, so that the contrast of the image can be enhanced and the details can be clearly seen. Histogram equalization is to stretch the image non-linearly, so that the histogram distribution of the transformed image is uniform. The equalization transformation algorithm used in this paper is:

$$s(\alpha_k) = T(\alpha_k) = \sum_{j=0}^{k} p_r(\alpha_j) = \sum_{j=0}^{k} \frac{\beta_j}{\beta} \quad (1)$$

The equalization histogram range [0,1] is all stacked by the formula, and the brightness of the image is obviously enhanced.

3.1.2 Water level detection algorithm based on Dictionary learning: Since the images obtained by the camera can be clearly divided into water scale and water surface, the main idea of the water level detection algorithm is to use dictionary learning to classify each image into two categories: water scale and water surface. The water level value can be easily calculated by searching the boundaries of these two categories. In short, the water level detection algorithm can be divided into three steps. First, convert all training images into a training matrix Y, where each column of the training matrix Y represents a training sample and corresponds to a specific class label; then, the training matrix Y is input into the dictionary learning model, after continuous iterative training The trained dictionary D is obtained; finally, by having a compact and discriminative dictionary D, the images captured in real time from the camera are classified into water gauge and water surface to calculate the water level value. These three steps are shown in the figure below:

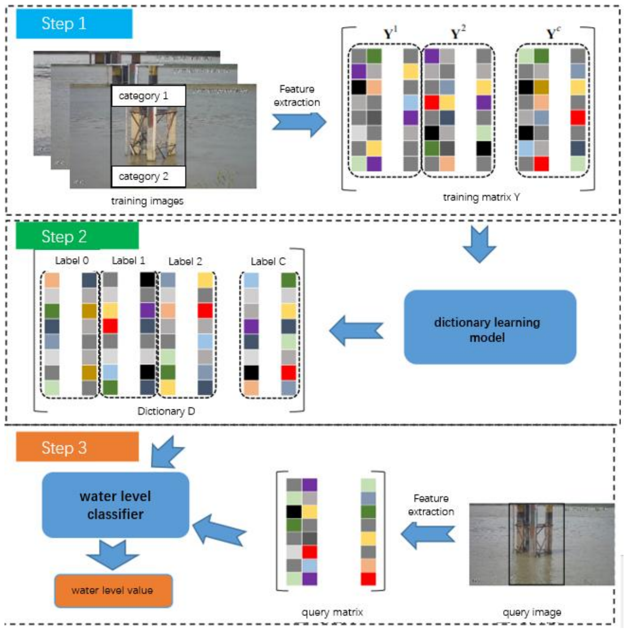

Figure 6. Water level detection algorithm steps.

1) Training image preprocessing

The specific steps of image preprocessing are as follows:

(a) First, grayscale the training image to convert it to a grayscale image;

(b) Extract the area of interest from the water level image and remove the area we are not interested in;

(c) classification of samples for our region of interest;

As can be clearly seen from Figure 9, the black straight line in the figure can easily divide our area of interest into the water ruler class and the water surface class. According to the internal structure and texture information of these two categories, we divide them into C1 and C2 sub-categories respectively. As shown in the figure, we divide the water ruler class into C1 subclasses with blue lines, and the water flow class into C2 subclasses with yellow lines. Therefore, the entire region of interest is divided into C=C1+C2 categories in total.

(d) Extract training samples in each subclass separately;

(e) Synthesize several training samples into a training sample matrix Y and obtain the corresponding category label vector L.

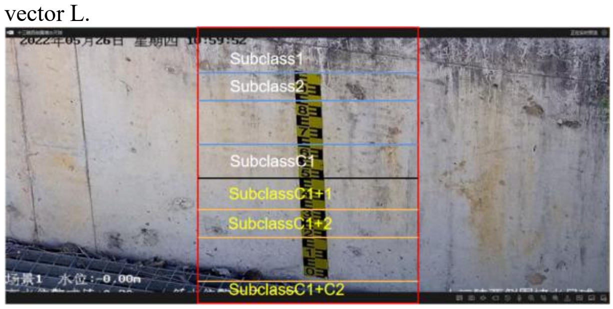

Figure 7. Classification of water level information images.

2) Dictionary training

First, perform grayscale processing on several training images and convert them into grayscale images. We convert the training images into a training matrix Y by performing a series of image preprocessing on several training images. Each column of the training matrix Y is represents a training sample with a specific class label. Therefore, the training matrix Y can be expressed as Y=[Y1,.....,Yc], which is consistent with the algorithm in the previous section, select the appropriate coefficients β, a and y, and input the training matrix Y into the previous section proposed In the cross-suppression dictionary learning model using group regularization, Algorithm 1 is used for continuous iterative training to obtain a discriminative structured dictionary D after training.

3) Calculation of water level value
The calculation of water level value mainly includes the following four steps:

(a) Extract test samples from the images to be tested.

(b) Use a classifier to classify each test sample in the form of a column vector extracted from the water level information image.

(c) Find the interface between the water gauge class and the water surface class, that is, the pixel water level value.

(d) Convert the pixel water level value to the actual water level value.

Assuming that the actual water level of 1 meter corresponds to h pixels on the water level information image, and the position of w meters on the water level corresponds to the pixel water depth lw in the water level information image, the actual water level value R can be calculated from lr:

$$R = w + \frac{l_w - l_r}{h} \tag{2}$$

Therefore, using the above four steps, the water level value of each water level information image can be calculated in real time.

3.2 IoT Information access Technology

Supported by the Internet of Things, big data and cloud computing, through the integration of video surveillance, water level analysis and other technical means, a more "smart" model is used to improve the way of personnel management and interaction, so as to achieve informationization, refinement and intelligence. Control. Perception device data is divided into temporal data and historical data, and historical data is the accumulation of temporal data. The collected data is only saved locally, and the platform uses socket to transmit the data to the server and parse the data.
Socket is a middleware abstraction layer that communicates between the application layer and the TCP/IP protocol suite. It is a set of interfaces. The English meaning of Socket is "hole" or "socket". As the process communication mechanism of BSD UNIX, take the latter meaning. Also commonly referred to as a "socket", it is used to describe IP addresses and ports, and is a handle to a communication chain that can be used to implement communication between different virtual machines or between different computers.

Advantages: 1) The transmission data is byte-level, the transmission data can be customized, and the amount of data is small (for mobile phone applications: low cost); 2) The data transmission time is short, and the performance is high; 3) It is suitable for both client and server. 4) It can be encrypted, and the data security is strong.

Disadvantages: 1) The transmitted data needs to be parsed and converted into application-level data; 2) The development level of developers is required to be high; 3) Compared with Http protocol transmission, the amount of development is increased.

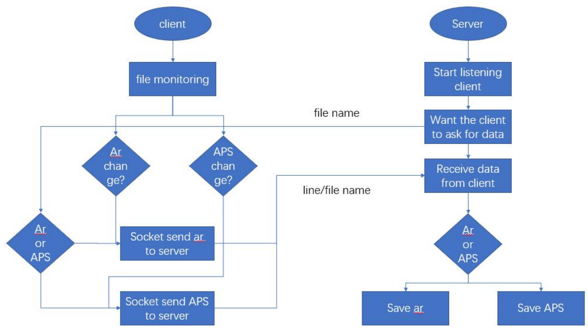

Figure 8. Flowchart of data transmission

For this constant connection mode, the platform has the function of automatic connection between the client and the server. In order to transmit data faster and more accurately, the system has added a series of technologies such as breakpoint upload, file splicing, and MD5 verification. The server can send commands to the client to clear logs, obtain logs, and obtain data of any slice.

Socket transmission standard: line+FileNameLength+FileName+FileSize+Index+md5+ specific content; where line is the identification code of the left and right lines, FileNameLength is the length of the file name, FileName is the file name, FileSize is the file size, and Index is The offset position transmitted by the current Socket, md5 is the md5 code of the file.

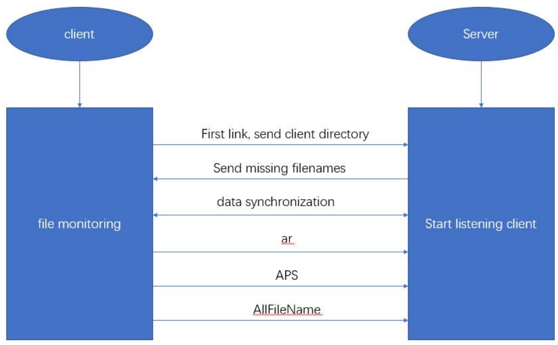

Figure 9. Connection process.

After the service is started, the client sends all file names to the server, and the server selects the content to be synchronized according to the names. After the file transfer is completed, calculate whether the file is correct according to md5. If there is a problem, delete the file on the server and upload it on the client again.

4. SYSTEM APPLICATIONS

The subway flood control and waterlogging prevention intelligent monitoring system is a set of "integrated", "digital" and "intelligent" platforms, including video/image monitoring, water and rain monitoring and other subsystems. Under one platform, the unified management and interconnection of multiple subsystems can be realized, which can truly achieve "integrated" management and improve the user's ease of use and management efficiency. The system is a self-developed integrated multi-system networking platform based on SOA system architecture. It adopts advanced software and hardware development technology to realize functions such as centralized system management, multi-level networking, information sharing, interconnection, and multi-service integration to meet the needs of subway flood control. The demand for intelligent visualization management of waterlogging. Key features include:

4.1 "One Map" for Flood Control and Waterlogging Prevention Monitoring

Using geographic information technology, the base map, line/station data, camera points, water level monitoring data and other elements are integrated and integrated to visually display the monitoring points and the water level of the station mouth, and realize the "one map" management of subway flood and waterlogging conditions. Provide technical support for managers to analyze and judge, and ensure the safe operation of the subway. This project has carried out monitoring applications in subway Jin'anqiao Station, Coking Plant Station, Ming Tombs Station, Universal Studios North and other stations.

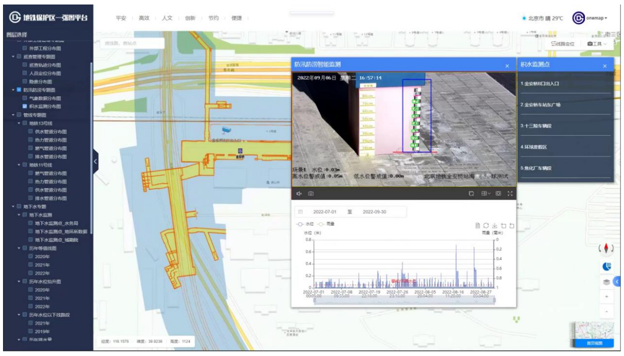

Figure 10. Thematic map of flood control and waterlogging prevention monitoring.

4.2 Flood control Intelligent scene simulation

Using BIM technology and GIS technology, the subway station, the surrounding environment of the station, flood control surveillance cameras, flood control materials, etc. are integrated and integrated in the three-dimensional scene, so as to truly restore the on-site situation and improve the level of flood control management.

Figure 11. Flood control intelligent scene simulation.

4.3 Data management and analysis

The monitoring data displays the real-time monitoring data of water and rain conditions in the form of a list, and realizes the standardization and information management of monitoring data. Combined with the monitoring historical data, the monitoring data can be automatically analyzed, such as the relationship between rainfall, drainage and stagnant water. It can be known that the rainfall is proportional to the drainage, and the comparison of the historical data can also provide a reference for the current water level monitoring.

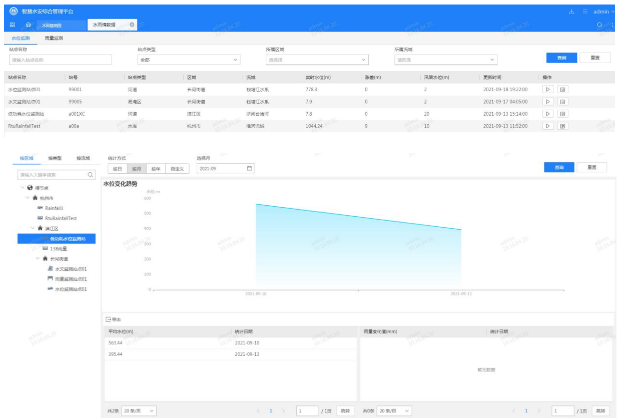

Figure 12. Monitoring data management

4.4 Monitoring data statistics and Early warning

The system connects to the monitoring data of the intelligent sensing camera in real time, and automatically generates a water level monitoring curve. By setting the water level height warning control value, if the water level reaches the warning value, the system will automatically warn and remind, effectively improving the level of flood prevention and control.

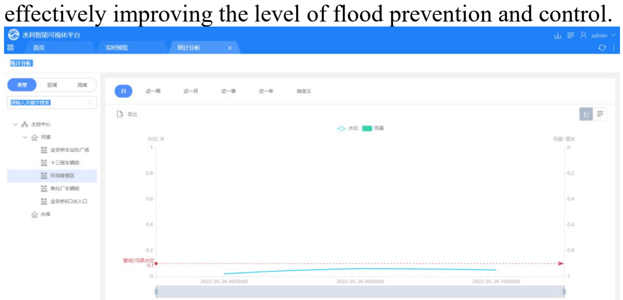

Figure 13. Monitoring data statistics and early warning

5. CONCLUSION AND OUTLOOK

As the global climate continues to change, extreme weather frequently occurs, and urban rainstorms and floods frequently occur. The huge amount of rainfall brings challenges to the safe operation of subways. This project uses geographic information technology, installs intelligent sensing cameras at key locations of subway stations, and integrates automatic water level reading algorithms to monitor flood control and waterlogging. The main conclusions are as follows:

(1) This project is based on intelligent sensing equipment, and realizes real-time dynamic monitoring of subway water and rain conditions through key links such as sensing-transmission-storage-analysis-integration;

(2) Using geographic information technology to integrate basic geographic information, flood control monitoring, surrounding environment and other elements, realize the "one map"

management of flood control and waterlogging monitoring, and improve the level of flood control management;

(3) Through the flood control application demonstration at the 4th station of Beijing subway at 5:00, practice has proved that the system can effectively monitor the water and rain conditions, prevent the occurrence of subway flood disasters, and ensure the safety of subway operation.

Due to factors such as the project cycle, the system has initially realized the early warning function of monitoring data, and in the later stage, further research can be done on the formation of a monitoring and early warning system.

REFERENCES

Adams, B. J. and Papa, F. Urban Stormwater Management Planning with Analytical Probabilistic Models. John Wiley Sons, Inc. (2000).

Guoru Huang , Jing Huang , Haijun Yu , et al. Research on SWMM Secondary Development of Urban Stormwater Model Based on GIS [J]. Hydropower and Energy Science, 2011, 29(4):4.

Haiyan Zhu . Study on vulnerability assessment of rainstorm and waterlogging of subway stations in Beijing [D]. Capital University of Economics and Business.

Jianguo Li . Design and Implementation of GIS-based Flood Control Information Monitoring and Analysis System [D]. Shandong University, 2015.

M.H. Hsu, S. H. Chen and T. J. Chang. Inundation Simulation for Urban Drainage Basin with Storm Sewer System [J]. Journal of Hydrology, 2000, 234(1-2): 21-37.

Shuhan Zhang , Fandong Zheng , Suchuang Di , et al. Thinking about Beijing's urban waterlogging prevention and control from the "2021.7.20" rainstorm and flood in Zhengzhou [J]. China Flood Control and Drought Relief, 2021.

Shuliang Zhang , Qiaoling Zeng , Yongfa Jiang , et al. Visualization of urban rainstorm water accumulation supported by GIS [J]. Journal of Hydraulic Engineering, 2004, 35(12):0092-0098.

Yu D. Parallelization of a two-dimensional flood inundation model based on domain decomposition [J]. Environmental Modelling & Software, 2010, 25(8): 935-945

https://doi.org/10.5194/isprs-annals-X-3-W1-2022-93-2022