**Reasearch on Urban Flood Disaster Scenario Simulation Based on the Intelligent Planning Platform for Resilient Cities**

HU Bixia, YANG Jihong

（China Land Surveying and Planning Institute,Beijing,China,100035）

**Abstract:**The acceleration of the urbanization process has a remarkable influence on the global climate and ecological environment. Among them, extreme weather has led to the frequent occurrence of urban flood disasters, posing a threat to the safety of human life and property as well as the stable development of the economy and society. Enhancing the adaptability, resistance, and recovery capacity in response to disasters such as extreme weather has become a core topic in modern urban construction and management. This research establishes an intelligent planning platform for resilient cities and conducts a simulation study on urban flood disasters in Chongqing and Ningbo in China. This study makes full use of the integration of multi-source data and various algorithms, and undertakes unconventional rainstorm simulation and prediction based on terrain multi-source data. By setting rainfall data and rainfall regions, the rainstorm carrying capacity of different terrain areas can be quantified spatially, compensating for the insufficiency of single data information. The possible submerged road networks and existing dangerous points when the city encounters precipitation under different scenarios can be deduced. It can also determine the location of infrastructure needed in the city and improve the accuracy of extracting and classifying disaster-affected areas, improving the timeliness and accuracy of extracting and processing information on flood inundation and other disaster risks, supporting the formulation of emergency plans, and reducing the consumption of various resources and economic losses. The research results can enhance tenhance the early warning capability of urban flood risk, provide reference and guidance for realizing flood resilience and cross-disciplinary technology integration, and provide reference for regional flood disaster management and the construction of resilient cities in large cities.

**Key words:** Intelligent Planning Platform for Resilient Cities;Urban Flood Disaster ;Scenario Simulation;Resilient Cities

(Selected topics from the National Key Research and Development Programme special topics)

## 1 Introduction

Chronic stresses and acute shocks such as extreme weather, pandemics, wars and conflicts, and economic crises continue to threaten urban areas where more than half of the world's population resides, and the problems of modern cities in stably meeting the needs of urban residents for food and housing, infrastructure, energy and transport, healthcare, emergency shelter, and ecological and environmental protection have become more and more prominent, and the study of urban resilience is increasingly getting more attention from urban managers（Holling et al.,1973;Ahern et al.,2011;Shao et al.,2015;Sun et al.,2017;Zhao et al.,2020）.

With the development of China's urbanisation process, cities are increasingly becoming the centre of social activities, economy and population, and play a central role in economic and social development（Li et al.,2021;Fang et al.）. At present, China's urbanisation process has made remarkable achievements, with the proportion of urban population to the total population rising, and according to statistics, China's urbanisation rate has reached 65.22% in 2022. At the same time, the economic structure of urban and rural areas has also undergone obvious changes, the proportion of service and high-tech industries in cities has gradually increased, the centre of gravity of the urban economy has gradually shifted from the traditional manufacturing industry to the modern service industry and innovative industries, and an urban system consisting of city clusters, metropolitan clusters, various kinds of mega, large, medium-sized and small cities has been formed, with regional characteristics and spatial distribution. China's urbanisation process is characterised by the double driving force of population and economic agglomeration. Firstly, a large number of peasants have flocked to cities, resulting in a rapid growth of urban population, and secondly, cities have become the main engine of economic development, attracting a large number of enterprises and capital to gather. However, China's rapid urbanisation has also given rise to a number of problems and challenges, including urban traffic congestion, real estate bubbles, waste disposal and environmental pollution, etc. The large-scale influx of urban population has also led to indebtedness in urban infrastructures and increased pressure on the provision of adequate and equal public services（Wu et al.,2009;Kuang et al.,2016;Hu et al.,2018;Xu et al.,2022）.

Against the background of the demand for strengthening urban resilience and the construction of a new smart city governance system and capacity enhancement, intelligent planning, especially for urban resilience, has become one of the important research directions of smart city technology. The Proposal of the Central Committee of the Communist Party of China on the Formulation of the Fourteenth Five-Year Plan for National Economic and Social Development and the Visionary Goals for the 23rd Five-Year Plan, which was considered and adopted by the Fifth Plenary Session of the 19th CPC Central Committee, clearly puts forward the construction of resilient cities, the improvement of the level of urban governance, and the enhancement of the prevention and control of risks in the governance of megacities. In order to accelerate the construction of an integrated service system for intelligent planning of resilient cities, there is an urgent need to innovate and study China's theories and technologies in urban resilience assessment, monitoring and early warning, simulation, adaptive planning decision-making, etc., so as to realise the rapid monitoring of various types of disturbing factors and their impact assessment, as well as intelligently put forward planning suggestions and emergency response strategies by means of information technology, so as to increase the timeliness and accuracy of the urban system's response to risks. The study also aims to develop a comprehensive demonstration application of the resilient city intelligent planning platform for planning agencies, government natural resources management departments, emergency management departments and the public, and to carry out large-scale practice, so as to explore a scientific and feasible practice path for resilient city intelligent planning.

This study through the resilient city intelligent planning platform, based on the sample data of Chongqing Yuzhong District and Ningbo Haishu District, with ‘urban flood mitigation’ as the main line, starting from the realities of urban urban storm flood disaster management problems, for the city is currently facing the effect of sponge city is not significant, monitoring and emergency response technology bottlenecks and government governance. In view of the lack of significant sponge city effect, bottlenecks in monitoring and emergency response technology, and governmental governance dilemmas, we simulate and validate the formation process of heavy rainfall and flooding, with a view to providing a template for flood mitigation and response to the current status of the development and future planning of Chongqing and Ningbo, as well as other similar cities around the world.

## 2 Application to urban flooding in Chongqing and Ningbo

### 2.1 Status of the smart planning platform for resilient cities

The Resilient City Intelligent Planning Platform is an online cross-scale virtual fusion simulation-based Resilient City Intelligent Planning Platform composed of the platform's business function module, non-business function module, security module, and the corresponding database group, which, through the support of the Internet of Things, deep learning and other intelligent technologies, more accurately monitors and predicts the spatial needs of human beings for resisting, absorbing, and adapting to external disturbances in the face of a variety of perturbation scenarios of the urban system. The platform realises real-time monitoring of various key indicators of the city, quickly discovers potential risks and problems, carries out intelligent dynamic configuration and optimal adjustment of multi-system spatial and temporal resources before, during and after a disaster, and provides intelligent decision-making support to help make urban planning more scientific and efficient.

The business function module of the platform consists of a simulation and projection sub-platform, a monitoring and early warning basic information management sub-platform and an adaptive planning and decision-making sub-platform. Among them, the simulation and prediction platform is responsible for simulating the normal operation state of the city, disturbance triggering, and planning programme implementation. This platform interacts with the adaptive planning and decision-making platform, transmits simulated sections to the adaptive planning and decision-making platform for planning scheme generation and optimisation, and accepts planning schemes transmitted by the platform to simulate the implementation effect of the planning scheme to further optimise the planning scheme. The monitoring and early warning basic information management platform consists of sub-functional modules such as urban information monitoring, urban warning information management and basic information management. The platform transmits real-time monitoring data and warning information to the simulation and prediction platform so that it can update the simulation status in real time. The adaptive planning decision platform consists of a planning model modelling module, an urban resilience assessment module, a planning decision optimisation module and an optimisation result display module. This platform interacts with the simulation and prediction platform to make planning decisions based on the simulated sections and returns the decision sections containing planning decision data to the simulation and prediction platform. Each sub-platform interacts with each other to realise the business functions of the Resilient City Intelligent Planning Platform.

The non-business function module is divided into three sub-function modules: user service, operation and maintenance management, and background management. Among them, the user service module consists of data statistics, information retrieval, planning and decision-making reports and results display, user guide and other functions, while the operation and maintenance management includes micro-service management, system settings, system logs, system monitoring and other functions, which guarantee the stable operation and continuous optimisation of the whole system. The background management implements the platform's model management, user management, knowledge management, file management and other functions. The synergy of these three sub-functional modules ensures the efficient operation and intelligent management of the whole system.

The security module of the platform is used to protect system information from malicious invasion and modification. This functional module consists of application security, data security, platform and network security protection. According to the security protection requirements of the city where the system is deployed, hardware configuration, network environment, etc., corresponding security policies are configured for each functional module and relevant management regulations are formulated.

The core functions of the platform include resilience assessment, monitoring and early warning, simulation and rehearsal, and planning and decision-making. This application mainly uses the monitoring and early warning function and the simulation and projection function of the platform.

This study mainly uses the monitoring and early warning, simulation and rehearsal, and planning and decision-making functions. (1) The data enhancement module of the monitoring and early warning function of the platform contains the optical satellite image missing data repair function, which can achieve the de-clouded optical remote sensing image based on the cross-domain guidance of the SAR image, and provide high-quality data support for the disaster monitoring and early warning based on remote sensing images. The function has a risk and disaster monitoring and early warning module based on anomaly characterisation, which can realise the function of early warning for urban flooding risk points and disaster points, the function of detecting urban flood disaster points, the function of detecting areas of abnormal changes in urban buildings, the function of monitoring basic information on the distribution of urban vehicles, the function of monitoring the density of crowds in key urban areas, and the function of searching based on the WiFi positioning of drones. Among them, the function can achieve accurate prediction of major flooding risk points and disaster points covering more than 90% of the city based on the data provided for major urban risk points and disaster points under heavy rainfall and flooding scenarios; based on the accurate monitoring of major flooding risk points and disaster points covering more than 90% of the city based on the data provided for remote sensing imagery of the city; and the function also has a data management module, which mainly achieves the followingThe function also has a data management module, which mainly realises data description, city management and document management functions. To sum up, this function completes urban risk and disaster monitoring/warning and basic information management based on perception technology, and can achieve accurate monitoring and early warning covering more than 90% of the major risk points and disasters in the city by means of data enhancement and anomaly character analysis. (2) The simulation function can generate disaster simulation models based on the model parameters set by users for two types of daily risks and disasters (flooding and infectious diseases), simulate and predict the development process of the disaster, and integrate them into the joint prevention and control module for the purpose of projecting the level of resilience of the urban services and the degree of impact by the disaster. At the same time, the platform has a joint prevention and control module, which can generate a joint prevention and control plan proposal text for two types of daily risks and disasters, complete case analysis and risk assessment (supporting the generation of a joint prevention and control plan for rainstorms and flooding), and increase the efficiency of case analysis and risk assessment by more than one times compared with the efficiency of the user's baseline work. (3) The planning decision-making function of the platform has a basic layer data module, a planning scheme generation module, a planning decision analysis module and a knowledge base analysis module. In the planning scheme generation module, the long-term planning function can solve the spatial layout scheme of public service facilities such as hospitals and schools for the urban resilience measurement; the emergency planning function can solve the spatial layout scheme of emergency material storage, first aid stations and temporary sheltering and resettlement places for the flooding scenario of torrential rain. The platform can make use of basic data such as road networks and buildings of the whole city to solve the spatial layout planning scheme of temporary evacuation and resettlement places, emergency material reserves and first-aid stations within the whole city, and the average time spent is expected to be about 20 hours, which is comparable to the baseline efficiency of 4-5 months provided by the experts, so that the platform can solve the spatial layout planning scheme of the emergency service facilities within a relatively short period of time, and the working efficiency can be improved by twice. The efficiency of the work can be increased by more than a factor of one and 100 per cent of the urban area can be covered.

## 2.2 Description of the application demonstration area

2.2.1 Yuzhong District of Chongqing Municipality

Yuzhong District of Chongqing is the mother city and birthplace of Chongqing Municipality, located in the southwestern part of Chongqing Municipality, is the confluence of the Yangtze River and the Jialing River, surrounded by water to the east, south and north, and open to the land to the west, as a narrow peninsula in an east-west direction. It is bordered by the Yangtze River in the east and south, adjacent to the waters of Nanan District; the Jialing River in the north, connected to the waters of Jiangbei District; and Shapingba and Jiulongpo Districts in the west.

In 2023, Yuzhong District has 11 streets under its jurisdiction, with an area of 23.25 square kilometres. According to the seventh census, Yuzhong District has a resident population of 588,700, with a population density of 25,300 per square kilometre, making it the most densely populated district in Chongqing. The rivers in Yuzhong District belong to the Jialing River and Yangtze River systems. The Yangtze River flows through the district from the south, while the Jialing River enters the district from the west to the east and joins the Yangtze River at Chaotianmen. The Yangtze River enters the area at Huangshaxi, and flows northward through Caiyuanba and Chaotianmen. The Jialing River enters the area at Dishuiyan, Hualongqiao, and flows east through Liziba and Niujiaotuo to join the Yangtze at Chaotianmen.

2.2.2 Haishu District of Ningbo City

Haishu District of Ningbo City is located in the central and western part of Ningbo City, with a total area of 595.2 square kilometres, east of Fenghua River and Yinzhou District, north of Yuyao River and the Jiangbei District, west of Yuyao City border, south of Fenghua District connection. Located in the monsoon climate zone in the transition region of the northern subtropical and central subtropical, belonging to the maritime monsoon humid climate, Haishu District, five mountains, one water and four fields, the land belongs to the Ningshao Plain, the terrain is generally high in the southwest and low in the northeast, the streams and rivers circling. As of 2023, it has jurisdiction over 9 streets, 7 towns and 1 township, with a total of 101 communities and 165 administrative villages. As of the end of 2023, the district had a resident population of 1,065,000, and the urbanisation rate of the resident population was 88.9%.

**2.3 Application Demonstration Content: Simulation and Rehearsal, Monitoring and Early Warning and Assisted Decision-making**

2.3.1 Yuzhong District, Chongqing Municipality

Chongqing pilot demonstration using heavy rainfall and flooding simulation, uploading DEM, buildings, rivers and lakes and other hydrological data, as well as road network data to build a city intelligent body, establish an urban flooding model, simulate and analyse the inundation scope, inundation elevation, inundation depth of the study area in the production of convergence formed under rainfall at different time scales, and identify the inundation area (depth of water greater than or equal to 40 cm), inundation road network (inundation coefficient greater than 0.8 road network) and hazardous areas (water depth less than 40 cm, greater than or equal to 20 cm). coefficient is greater than 0.8 of the road network) as well as hazardous areas (water depth less than 40cm, greater than or equal to 20cm) and hazardous road networks (inundation coefficient in the inundated area is less than or equal to 0.8, greater than 0.4 of the road network). The model algorithms are also validated against actual rainstorms to analyse the accuracy and reliability of the model algorithms in different rainfall events.

Upload the required data for simulation in ‘Simulation’, and set the rainfall levels of 1 in 5 years, 1 in 10 years, 1 in 50 years and 1 in 100 years for simulation of heavy rainfall and flooding. Table 1 below.

Table 1 Simulation of heavy rainfall and flooding

| Simulation level | 24-hour average rainfall (mm/h) | Number of inundated areas at 24 moments (number) | Area of inundated areas at 24 moments (square kilometres) |
|---|---|---|---|
| Once in five years | 11.47 | 17 | 0.008 |
| Once in ten years | 14.32 | 18 | 0.009 |
| Once in fifty years | 20.93 | 431 | 0.2 |

| | | | |
|---|---|---|---|
| Once in a hundred years | 23.78 | 1210 | 0.57 |

The result of one in five years shows that there are 17 inundated areas in Yuzhong District at 24 moments, with a total inundated area of 0.008 square kilometres, and the main inundated areas are near South District Road and Daping Medical College Road, which have not produced any hazardous points for the time being. As Figure 1 and Figure 2.

Figure 1 Flooded area (moment 24) as a result of modelling a 1 in 5 year rainstorm

Figure 2 Localised map of the inundation area as a result of the simulation of a 1 in 5 year rainstorm (moment 24)

The results of the one in ten years show that there are 18 inundation areas in Yuzhong District at 24 moments, with a total inundation area of 0.009 square kilometres, and the main inundation range is basically the same as that of the one in five years, with an increase in the inundation area, which has not produced any hazardous spots for the time being, as shown in Fig. 3.

Figure 3 Flooded area (moment 24) as a result of the simulation of a 1-in-10-year rainstorm

The result of one in fifty years inundation shows that there are 431 inundated areas in Yuzhong District at 24 moments, with a total inundated area of 0.2 square kilometres, and the main inundated areas are the sections of Jialingjiang River Riverside Road, Yangtze River River Riverside Road, and the low-lying sections of the roads within the ranges of Jiefangbei, Qixinggang, Daxigou, Daping, etc., generating a total of 733 dangerous points, as shown in Figs. 4, 5, and 6.

Fig. 4 Simulation results of 1-in-50-year rainstorm (moment 24)

Figure 5 Localised map of the inundation area as a result of the simulation of a 1 in 50 years rainstorm (moment 24)

Fig. 6 Localised map of hazardous points (moment 24) as a result of the simulation of a 1 in 50 years rainstorm

The result of one-in-a-century inundation shows that: 24 moments Yuzhong District has a total of 1,210 inundation areas, inundation area of a total of 0.57 square kilometres, the main inundation range in the range of one-in-fifty-years and then a significant increase, from the Jiabin Road Visionary Centre section, the Changbin section of the road, such as the local Jialingjiang River road section, the Yangtze River road section of the road to expand to the vast majority of the region along the river road section, as well as the liberation of the monument, the Qixinggang, the Daxigou, Daping and other low-lying road sections within the range, generating a total of 1,554 hazardous points. As shown in Figures 7, 8 and 9.

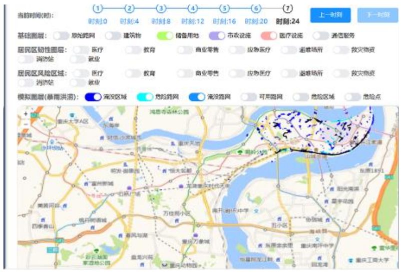

Figure 7 Simulation results of a 100-year rainstorm (moment 24)

Figure 8 Localised map of the inundation area as a result of the simulation of a 100-year storm (moment 24)

Figure 9 Localised map of hazardous points (moment 24) as a result of the simulation of a 100-year rainstorm

The conclusions of the above four types of heavy rainfall and flooding simulations show that the difference between the simulation results for the 1 in 5 years and 1 in 10 years is relatively small. The area of the inundation zone, road sections and hazardous points for the 1-in-50-year and 1-in-100-year events increased exponentially, as shown in Table 2 below.

Table 2 Comparison table of simulation results of heavy rainfall and floods

| Simulated rainfall level | Number of inundated areas at the 24th hour (number) | Increase in precipitation from the previous level (%) | Area of inundated area at the 24th hour (km$^2$ ) | Increase in precipitation from the previous level (%) | Number of hazardous points at the 24th hour (number) | Increase in precipitation from the previous level (%) |
|---|---|---|---|---|---|---|
| Once in five years | 17 | - | 0.008 | - | 0 | - |
| Once in ten years | 18 | 5.88 | 0.009 | 12.50 | 0 | - |
| Once in fifty years | 431 | 2294.44 | 0.2 | 2122.22 | 733 | - |
| Once in a hundred years | 1210 | 180.74 | 0.57 | 185 | 1554 | 112.01 |

In order to verify the accuracy of the simulation results, a rainfall of 20 mm/h (i.e., one in fifty years) was used for the simulation based on the actual situation of the heavy rainfall in Chongqing on 21 July 2023 as shown in Fig. 16, and the situation of severely flooded road sections in Yuzhong District in the news was collected (Fig. 10).


今晨重庆多地暴雨致道路严重积水 21日白天巴南等10个区县暴雨持续

凤凰网重庆 关注
2023年07月21日 10:35:12 来自重庆
2人参与 1评论

重庆市气象台发布消息，据实况监测显示，7月21日06时至07时，重庆北碚区、沙坪坝区、渝北区、渝中区、江北区、九龙坡区、南岸区、大渡口区、巴南区、璧山区、铜梁区、永川区、合川区、江津区、长寿区等15个区及两江新区、重庆高新区的115个雨量站超过20毫米，达短时强降雨标准，**其中北碚区人和村雨量最大，为87.9毫米。**

Figure 10 News Screenshot of Actual Rainfall in Chongqing

The known severely inundated road sections were compared to the modelled results. The module functional accuracy tests are shown in Table 3 below:

Table 3 Comparison of simulation results for heavy rainfall and flooding

| Actual flooded area | Modelled result flooded or not |
|---|---|
| Changbin Road, Yuzhong District Traffic Patrol Detachment | Yes |
| Niu Jiao Tuo Overpass on Sixin Road | Yes |
| Vision Centre, Jiabin Road | No |
| Jiefang West Road | Yes |
| Medical College Road | Yes |
| Hongyadong Road | Yes |
| Qianlianmen Tunnel | No |
| Huanghuayuan Interchange, North District Road | Yes |
| Caiyuan Road | Yes |
| Daxigou LRT Station, Jiabin Road | Yes |
| Dahuang Road | Yes |
| Minzu Road | Yes |

| | |
|---|---|
| Wuyi Road | Yes |

There are 12 actual severely inundated road sections and 10 severely inundated road sections simulated by the platform, with an accuracy rate of about 83 per cent. Error analysis of simulation results: The parts of the platform's simulation results that do not match the actual situation are mainly along the river and inside the tunnels. The reason for this is that the platform test data lacks data related to the drainage network and drainage pumps in Yuzhong District, which cannot accurately simulate the drainage carrying capacity of Yuzhong District, and this has a certain impact on the simulation results.

The simulation results show that the model can accurately control the inundation range and water depth of the disaster area after the occurrence of urban rainstorm and flooding disaster, and improve the efficiency of effective decision-making during flood rescue. The simulation results are compared with the actual situation as shown in Figures 11, 12 and 13. (Note: The real-life pictures are from media reports such as Upstream News, Chongqing Publishing, and Surfing News.)

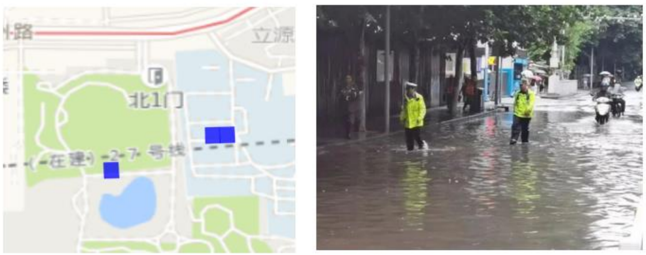


Figure 11 Comparison of simulation results and actual situation (medical school section)

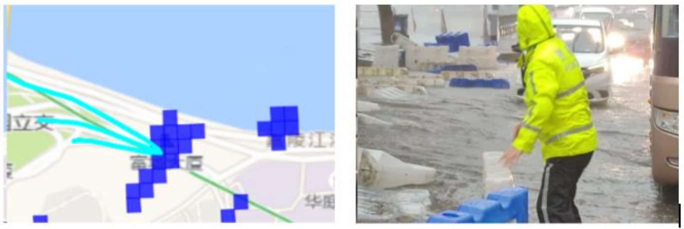

Fig. 12 Comparison between simulation results and actual situation (Hongyadong section)

Fig. 13 Comparison between simulation results and actual conditions (National Road section)

Model Early Warning Application: The platform simulation provides self-setting of rainfall parameters, display of inundated areas and spatial distribution of hazardous areas at various moments. By presetting the level of impending rainfall, locking the key areas of disaster prevention in advance, combining the collection of meteorological information, carrying out patrols along the two rivers to check the risk, the investigation of flooding points and other conventional emergency response measures, to improve the efficiency of effective decision-making during flood rescue.

Planning recommendations: First, reset the design return period of stormwater drains in mould flood risk points. According to the simulation results, Changbin Road, Niujiaotuo Interchange, Daping Main Street, Hongyadong road section and other areas are prone to flooding risk points, in order to avoid urban roads in heavy rainstorms when the water pooling, should improve the design standards of stormwater drains, high-quality development of stormwater infrastructure; Second, the location of the simulation results of the flooding point to take the pipeline's functional deficiencies of the renovation, pressure drainage, the installation of sponge facilities, the transformation of low-lying terrain, stormwater grate and pipe maintenance and dredging and other targeted measures. At the same time to strengthen the regional inspection and check and preventive response, strengthen the water flood control emergency rescue team construction, enrich the rescue equipment and materials, and strengthen risk management.

**2.3.2 Haishu District, Ningbo City**

Ningbo City intends to demonstrate the application of the relevant functional modules of the Resilient City Intelligent Planning Platform's storm-flood simulation and planning decision-making, and apply the platform's simulation results to urban flood risk monitoring and early warning, urban flood prevention and control, emergency response decision-making, and planning decision-making.

1.Planning decision-making

For the pre-disaster planning and site selection under flood disaster, first of all, according to the natural geographic profile of a city, the preliminary screening of a city centre meets the screening criteria for alternative disaster avoidance areas, such as parks, playgrounds, golf courses and so on. Assuming that there are M alternative disaster avoidance areas, K suitable formal disaster avoidance areas need to be selected from the M alternative disaster avoidance areas according to the disaster prevention and risk avoidance criteria. The site selection criteria can be to rescue as many and as fast as possible affected people, reduce casualties and property damage under limited time and space conditions. In the process of picking out K formal disaster avoidance zones from M alternative disaster avoidance zones, the involvement of reinforcement learning is required to give the optimal site selection of disaster avoidance zones based on the appropriate reward function using the intelligences. The adaptive planning decision-making platform implements a distributed multi-decision-making intelligence collaborative decision-making method based on the multi-intelligence deep reinforcement learning algorithm MAPPO, which is an application of the PPO algorithm in multi-intelligence scenarios, and the whole algorithm adopts a Centralised Training, Decentralized Execution (CTDE) framework, and a centralized training, distributed execution (CTDE) framework, and a centralized training, distributed execution (CTDE) framework. The whole algorithm adopts the framework of Centralised Training, Decentralized Execution (CTDE), which can achieve distributed decision-making of multiple intelligences.

Taking the integrated rainstorm disaster scenario as an example, the main objective function of the corresponding site planning decision problem includes maximising the number of people to be covered, minimising the evacuation time and minimising the cost, so the current mathematical modelling of the site selection problem in this scenario takes the optimisation of these three objectives as the site selection objective. The specific modelling is as follows.

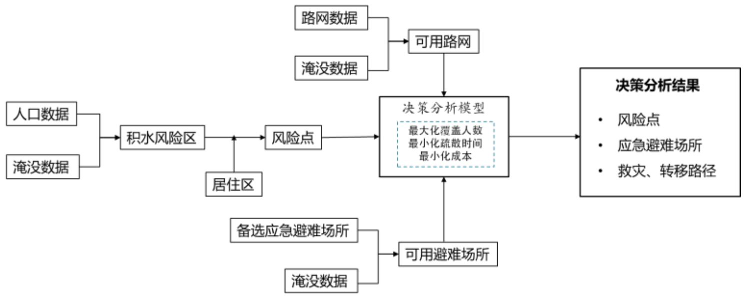


Fig. 14 Schematic of the modelling algorithm

(1) Data preparation

According to the data requirements of the platform, building surface data, medical facility data, educational facility data, park data, superstore data, sports facility data, and population distribution data within the scope of Haishu District, a demonstration area, were collected and uploaded to the platform after standardisation.

For medical data, important general hospitals, specialist hospitals and other facility point elements within the scope of Haishu District were collected, with data sourced from Ningbo POIs, and data attributes, formats and coordinates were standardised.

Stadium data, collected important stadiums, sports venues and other facility point elements within the scope of Haishu District, data from Ningbo POI, data attributes, format and coordinates were standardised.

Educational facilities data, collected important primary schools, secondary schools, adult education and other facility point elements within the scope of Haishu District, data from Ningbo POI, data attributes, format and coordinates were standardised.

Residential population distribution. Population grid data within the boundaries of Haishu District was collected, with data sourced from Baidu Population Data, and data attributes, format, and coordinates were standardised, with the number of resident population associated with each grid.

Park data, collected park point elements within the scope of Haishu District, data from Ningbo POI, data attributes, format, coordinates were standardised.

Superstore data, collected elements of commercial points within the scope of Haishu District, data attributes, format and coordinates were standardised.

After the data were uploaded to the platform, the situation is shown in the following figure:

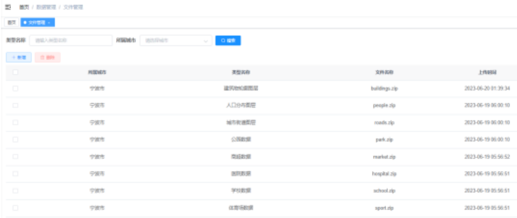

Figure 15 Platform data list screen

(2) Decision-making model establishment

The decision-making model of Ningbo City is established in the platform.

Figure 16 Planning Decision Module Data Presentation

(3) Planning decision-making results

The results of planning decision-making after the platform has been run include: the location of the emergency shelter, the line from the point of risk to the emergency shelter, the point of risk requiring emergency shelter, and the straight line from the point of risk to the emergency shelter.

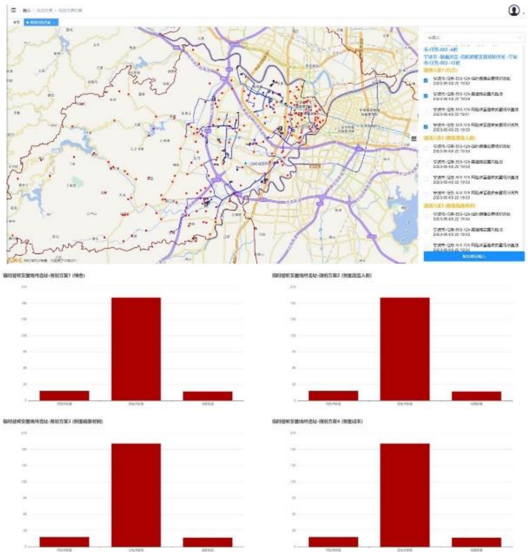

Figure 17 Display of planning decision results

(4) Demonstration application of results

①Emergency deployment decision-making

Taking the current emergency supply facility locations as alternative point inputs, for the inundation situation in the simulation of heavy rainfall and flooding, the decision-making analysis model is set up to output the siting plan of the emergency supply facility as well as the line from the risk point to the emergency supply facility, which can provide emergency decision-making information support for the heavy rainfall and flooding scenarios, and assist the emergency department in deploying flood prevention and flood control strategies.

②Siting of emergency supply facilities

The initial layout of the emergency supply facilities as an alternative point input, the flooding simulation for heavy rainfall flooding simulation, the establishment of decision analysis model, the output of the emergency supply facilities siting plan and the risk point to the emergency supply facilities line, you can analyze the optimal layout of the facilities planning from the emergency supply facilities siting point, the emergency supply facilities siting planning to provide technical support to assist in Facility siting preparation.

2. Early warning of urban flooding to assist the deployment of flood prevention

The urban flood early warning system constructs a data-driven multi-dimensional time series neural network model, and establishes a prediction model for the distribution of urban flooding and the degree of damage by fitting the correlation between the city's historical precipitation data and the depth of waterlogging, so as to effectively improve the early warning capability of urban flooding risks and disasters. The specific modelling is as follows.

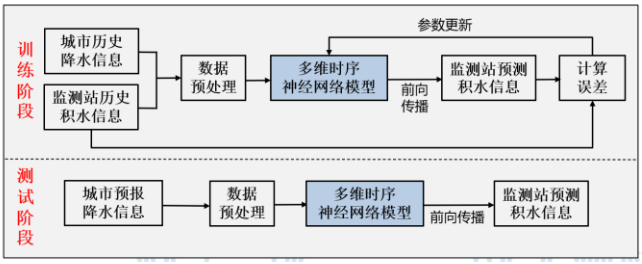


Fig. 18 Workflow of a data-driven early warning system for urban flooding points

The main consideration is the intrinsic relationship between precipitation and waterlogging, which is learnt through a big data neural network. Intuitively, precipitation and waterlogging are many-to-many relationships, and a waterlogged point will be affected by the surrounding precipitation, which converts the information of the surrounding precipitation into the influence of the precipitation point on the waterlogged point, and measures the strength of the influence by the distance between the two. Assuming that there are M precipitation points and N waterlogged points, then the neural network model needs to establish M×N correspondences and learn the intrinsic connections through big data. Eventually, the water accumulation information is predicted based on the precipitation information.

(1) Data preparation

According to the data requirements of the platform, precipitation data and, inland flooding inundation data are obtained. The specific data situation is shown below:

Table 4 Inland flooding inundation data

| File format | No. | Column name | Data type and format | Data type and format Remarks |
|---|---|---|---|---|
| xlsx/csv | 1 | stnm | str | Location Name |
| | 2 | STCD | int | Station Code |
| | 3 | TM | object | Time |
| | 4 | Z（积水深度m） | float | Depth of water |
| | 5 | lgtd | float | Longitude |
| | 6 | lttd | float | Latitude |

Table 5 Rainfall data

| File format | No. | Column name | Data type and format | Data type and format Remarks |
|---|---|---|---|---|
| xlsx/csv | 1 | stnm | str | Location Name |
| | 2 | STCD | int | Station Code |
| | 3 | TM | object | Time |
| | 4 | DRP | float | Time period rainfall |
| | 5 | DYP | float | Daily rainfall |
| | 6 | LJ | float | LJ |
| | 7 | lgtd | float | Longitude |
| | 8 | lttd | float | Latitude |

After uploading the data, in the data processing module it will be automated to combine the flooding data with the precipitation data and generate the neural network model input file.

(2) Neural network model training

Build the flood warning prediction model in the platform. Train the weights file for each waterlogged point.

(3) Model training results


Figure 19 Model training data

(4) Model prediction results

The prediction results after running the platform include: waterlogged point data categorised on a map (maximum value for the predicted time period), detailed csv files.


Fig. 20 Presentation of model prediction results

Based on the data of historical flooding events, the mapping relationship between rainfall and flooding distribution and flooding depth was constructed by building a data-driven multidimensional time-series neural network model. The test data covered 210 flooding monitoring points of key concern in Ningbo city, and the time range was from 1st September to 18th September 2022. Based on the Technical Standard for Prevention and Control of Flooding in Cities and Towns (Local Standard of Zhejiang Province), different warning levels (normal, risk, and disaster) are defined for different depths of flooded water points, so that different warning measures can be targeted. Among them, the threshold of waterlogging depth greater than 30cm is defined as a risk point, and the threshold of waterlogging depth greater than 100cm is defined as a disaster point.

In the testing process, the input data were rainfall data from rainfall monitoring stations in Ningbo from 1 September to 18 September 2022 (including rainfall time and monitoring station location, with a sampling interval of 5 minutes). Using the trained flood warning model, the input data are predicted and analysed one by one, and the peak depths of waterlogging at each day of the 210 waterlogging monitoring points of key concern in Ningbo are output in turn, and the warning levels are classified according to the depths of the waterlogging points. Finally, the warning level is visualised in a map.

The test shows that from 1 September to 18 September 2022, among the 210 waterlogging monitoring points focused on Ningbo, there were a total of 136 times of risk points with waterlogging depths of more than 30 cm, and a total of 32 times of disaster points with depths of more than 100 cm. Among them, the big data-driven urban flooding early warning platform provided by the partner, Northwestern Polytechnical University, accurately predicted 122 times of the risk points and 31 times of the disaster points, with a risk and disaster prediction accuracy rate of 91.07%.

$$\text{准确率} = \frac{\text{准确预测的风险点或灾害点}}{\text{真实的风险点或灾害点}} \times 100\%$$

The related methods are computationally efficient, have good portability and generalisation, and are of great significance for enhancing disaster monitoring and early warning capabilities.

## 3 Application Demonstration Features

### 3.1 Assisting in the physical examination and assessment of territorial spatial planning, identifying the state of urban resilience construction, and supporting resilience planning decision-making.

Chongqing has a wide variety of natural disasters, of which geological disasters, floods, meteorological disasters and fires are the main ones, featuring high frequency, wide impact and serious losses. Meanwhile, in the context of globalisation and the high frequency of public health emergencies, comprehensively improving the emergency medical response and support capacity of Chongqing's central city is also an important task in the construction of resilient cities. Using the simulation and projection capability of heavy rainfall and flooding provided by the Resilient City Intelligent Planning Platform, we carry out a series of prediction and prognosis on the normal operation status of the city, disturbance triggering, and the implementation of planning programmes, etc., to support the resilience monitoring and assessment of the city in the face of torrential rainfall, and to make up for the insufficiency of the urban medical examination and assessment in which only the number of points of waterlogging in the city and the coverage rate of municipal hospitals over 2km are used to measure the risk. The platform is used to set up different levels of risk environments, spatially quantify the carrying capacity of rainstorms in different topographic areas, and deduce the possible flooding of the road network, as well as the existence of danger points, when the city encounters heavy precipitation. The application simulates the rainfall scenarios of 1 in 5 years, 1 in 10 years, 1 in 50 years and 1 in 100 years respectively, and the simulation results obtained have been verified by the actual occurrence of heavy rainfall scenarios, and are capable of practical application. Unlike the medical assessment where the indicators only reflect the overall situation of the region as a whole, the platform identifies the vulnerable areas within Yuzhong District and the rainfall carrying capacity of each grid, which better refines the conclusions of the medical assessment.

**3.2 Dovetailing with the ‘One Map’ Implementation Supervision Information System for Territorial Spatial Planning and Exploring Deepening Paths for Planning Implementation Supervision**

At present, the ‘one map’ system is being constructed in accordance with the national standard ‘Technical specifications for the “one map” real-time monitoring information system for territorial spatial planning’, which was issued in March 2021, and the ‘one map’ system is being implemented in accordance with the national standard ‘one map’ for territorial spatial planning. The main construction content of the planning implementation monitoring, assessment and early warning part is as follows: relying on real-time collection and access to diversified data, conducting dynamic monitoring of land space development, protection and construction activities during the implementation of land space planning, and carrying out medical check-ups and assessments of the status quo of development and protection of land space in municipalities and counties and the implementation of the plan in accordance with the requirements of ‘one medical check-up in a year and one assessment in five years’, focusing on the red line for ecological protection and the plan implementation. In accordance with the requirement of ‘one medical examination per year, one assessment per five years’, the current situation of development and protection of national land space and the implementation of planning in cities and counties will be assessed by medical examination, focusing on the rigid control requirements of the ecological protection red line, permanent basic farmland, urban development boundaries, and other important control lines, as well as the binding targets of national land spatial planning to carry out timely warning. The monitoring and assessment of urban security and resilience has not been set up separately for early warning, and the integration of the resilient city intelligent planning platform into the ‘one map’ system has made up for the insufficiency of monitoring and early warning of urban resilience in the ‘one map’ system, which has helped to improve the capacity of supervision of the implementation of territorial spatial planning. It helps to improve the capacity of monitoring the implementation of territorial spatial planning, refine the content of urban resilience control in the management of planning implementation, expand the theoretical methods and technical system of monitoring and early warning, and promote the establishment of intelligent, refined, multi-scenario feedback decision-making mechanism (Figure 21).


Figure 21 Access to Chongqing Municipal Land Spatial Planning ‘One Map’ Information System

**3.3 Assisting emergency deployment decision-making**

The current emergency shelter locations that have been collected and standardised as alternative point inputs, in response to the inundation situation of the simulation of heavy rainfall and flooding, establish a decision-making analysis model, output the emergency shelter siting plan and the line from the risk point to the emergency shelter, which can provide information support for emergency decision-making for the heavy rainfall and flooding scenarios, and assist the emergency departments in the deployment of flood prevention and flood control strategies.

**3.4 Enhancement of Early Warning Capability for Urban Flooding Risks and Disasters**

By fitting the correlation between the city's historical precipitation data and the depth of waterlogging, a prediction model for the distribution of urban flooding and the degree of damage was established. Input precipitation data, after the neural network model to get the waterlogging data, visual display on the map, compared with the traditional method, rapid access to global information, and effectively improve the early warning ability of urban flooding risk and disaster.

## 4 Conclusion and Outlook

(1) Providing Innovative Perspectives and Ideas for the Management of Urban Disasters such as Rainstorms and Floods

At present, China's research on resilient cities is still in the exploratory stage, and the results are mostly focused on urban management and policy research, and there are no targeted and systematic research results in the field of urban planning for the prevention and control of rainstorms and floods and other common urban disaster scenarios. The platform's construction research applies the theory of resilient cities to the prevention and control of urban infectious diseases and storm waterlogging research, and provides practical platform tools, which help city managers and planners to deeply understand the mechanism of the impact of disasters on resilience, and put forward corresponding preventive and curative measures and specific methods, so as to reduce the impacts of disasters, recover a large number of economic losses, and create social benefits.

(2) Enhance the ability to regulate regional flooding and regional water security capacity

Strengthen the focus of the basin flood monitoring and protection of early warning capabilities, the platform flood warning and simulation of the application of the results of the deduction to improve the regional water hazards, monitoring and situational analysis capabilities to achieve timely prediction of flood changes in early warning to enhance the ability to carry out rapid disposal of sudden floods to safeguard regional water security and reduce socio-economic losses. Further grasp the basin flood carrying capacity, improve the management and scheduling of important water control projects, and improve the ability to deal with sudden water-related events. It further improves the timeliness of flood situation perception in the region, ensures water safety in the basin, rationally carries out project dispatching in the basin region based on the results of digital simulation, strengthens supervision and guidance in the basin, and provides technical support for water safety guarantee in the basin region.

(3) Provide direction and basis for government planning departments to promote resilient city construction through planning tools

Urban planning is an important means to enhance urban resilience and build livable, efficient, safe and resilient human space. By carrying out the application demonstration of urban flooding in Chongqing Municipality, it reduces the cost of disaster risk, makes up for the problem of insufficient information of single data and single evaluation method, improves the precision of extraction and classification of the city's disaster affected range, so as to improve the timeliness and precision of the extraction and processing of disaster risk information such as torrential rainfall inundation, etc., and through the simulation of the city's disasters, it can make a risk prejudgement in advance, support the formulation of the emergency response plan, and analyse the The causes of problems can be analysed, so as to formulate planning programmes in a targeted manner.

(4) Provide practical reference for the construction of urban resilience system

Through the application demonstration and empirical analysis of urban flooding and infectious disease prevention and control in Chongqing Municipality, we simulated the risk distribution and time change of heavy rainfall and waterlogging disaster scenarios, and initially verified the technical base of urban resilience system construction of ‘people-oriented’ with resilience assessment and metrics, simulated disaster scenarios as the background, and intelligent planning schemes as the goal. The technical base of urban resilience system construction has been preliminarily verified, and a basic framework has been set up for further deepening the technical research in the future. It also provides a practical basis and model demonstration for urban management departments and planning technical teams to familiarise themselves with the concept, characteristics and core elements of resilient cities, and gradually introduce the construction of resilient city system into the technical logic and management requirements of planning.

## Reference


[1] Holling C S. Resilience and stability of ecological systems [J]. Annual Review of Ecology and Systematics, 1973, 4(4): 1-23.

[2] Ahern J. From fail- safe to safe-to- fail: Sustainability and resilience in the new urban world [J]. Landscape and Urban Planning, 2011, 100(4): 341-343.

[3] Shao Yiwen, Xu Jiang. Urban resilience:A conceptual analysis based on an international literature review [J]. International Urban Planning, 2015, 30 (02): 48-54.

[4] Sun Yang, Zhang Luocheng, Yao Shimou. Evaluation of resilience of prefecture-level cities in Yangtze River Delta based on social-ecological system perspective [J]. China Population-Resources and Environment, 2017, 27 (08): 151-158.
[5] Zhao Ruidong, Fang Chuanglin, Liu Haimeng. Progress and prospect of urban resilience research [J]. Progress in Geoscience, 2020, 39 (10): 1717-1731.
[6] LI Zhigang,Chen Hongsheng,Xiao Yang,et al. Urban governance foresight in the new era: exploring the road to sustainable urbanisation [J]. Urban and Rural Planning, 2021, (05): 1-8.
[7] Fang Chenhao,Zhao Min. Urban development trend and planning response under the new pattern of 'double cycle' [J]. Journal of Urban Planning, 2022, (01): 18-26.
[8] Wu Zifang, Lu Zhangwei, Yang Zhirong, et al. An econometric study on the dynamic relationship between urbanisation and construction land growth in China [J]. China Land Science, 2009, 23 (02): 18-23.
[9] Kuang Bing, Lu Xinhai, Zhou Min. Dynamic evolution of the distribution of land economic density in Chinese cities [J]. China Land Science, 2016, 30 (10): 47-54.
[10] Hu Bixia, Li Jing, Kuang Bing. Evolutionary characteristics and influencing factors of urban land use efficiency differences under the concept of green development [J]. Economic Geography, 2018, 38 (12): 183-189.
[11] Xu G, Zheng Muchen, Wang Yaxing, et al. Population and land urbanisation in China: comparison of evolutionary trends, regional and scale differences and measurement methods [J]. China Land Science, 2022, 36 (05): 80-90.