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Research Article

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Analysis and Evaluation of Urban Waterlogging Emergency Response Capability based on AHP

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Abstract: In recent decades, under the background of global warming, urban waterlogging disasters have occurred frequently, causing serious economic losses and casualties. In order to evaluate the emergency response capacity of cities in the face of waterlogging disasters, this paper uses the AHP analytic hierarchy method to construct an evaluation system for urban waterlogging emergency response capacity from three aspects: pre-disaster monitoring and early warning ability, disaster response ability and post-disaster recovery ability, and puts forward a mathematical model for urban waterlogging emergency response capacity assessment. At the same time, taking Zhengzhou City as an example, the results show that Zhengzhou City shows insufficient command and coordination ability and post-disaster investigation ability in the face of urban waterlogging disaster.

Keywords: AHP; urban flooding; emergency response capability; emergency management; mathematical model

1. Introduction

In recent years, due to the impact of global climate change and human activities, urban flooding disasters have occurred frequently in my country [1]. According to statistics from the Ministry of Water Resources and the National Disaster Reduction Center of the Ministry of Emergency Management, from 1991 to 2020, an average of 2,020 people died or went missing each year due to floods in my country, with a total of more than 60,000 deaths, an average annual direct economic loss of 160.4 billion yuan, and a total of about 4.81 trillion yuan. The "July 20" rainstorm in Zhengzhou in 2021 caused 380 deaths and disappearances, and direct economic losses of 40.9 billion yuan. Urban floods have become an emerging challenge threatening regional public security and socioeconomic development and have attracted widespread attention [2].

Controlling urban flooding is related to the safety of people's lives and property. In order to solve the problem of urban flooding, the General Office of the State Council issued the "Notice on Doing a Good Job in the Construction of Urban Drainage and Flood Control Facilities" in 2013. In 2014, the Ministry of Housing and Urban-Rural Development issued the "Technical Guidelines for Sponge City Construction - Construction of Low-Impact Development Rainwater System (Trial)", and in 2015, it jointly with the Ministry of Finance and the Ministry of Water Resources started the pilot construction of sponge cities. In April 2021, the General Office of the State Council issued the "Implementation Opinions on Strengthening Urban Waterlogging Control", which clearly put forward the goal of urban waterlogging control, that is, by 2025, cities across the country will basically form a drainage and flood control system of "source reduction, pipeline discharge, storage and drainage, and emergency response in case of excess". The problem of urban waterlogging has been highly valued by government departments and has risen to the national strategic level [2]. In academia, the concept of resilient cities has been proposed to address the ability of cities to respond to emergencies. Scholars Huang Hong and others define resilient cities as: cities that can effectively respond to external and internal economic, social, technological systems and infrastructure shocks and pressures, maintain the basic functions, structure and systems of the city after suffering a major emergency, and can quickly recover, make adaptive adjustments, and develop sustainably [3]. Scholar Bing Qiliang proposed that the first task of building a resilient city is to assess and zon the risk of urban disasters, determine the risk level, and then formulate corresponding planning measures from the perspectives of disaster prevention, mitigation, and relief. Only by rationally allocating resources can the impact of disasters on cities be effectively reduced and the city's response and self-healing capabilities be improved [4]. In November 2020, the "Proposal of the CPC Central Committee on Formulating the 14th Five-Year Plan for National Economic and Social Development and the Long-Term Goals for 2035" reviewed and approved by the Fifth Plenary Session of the 19th CPC Central Committee proposed for the first time to build a "resilient city".

At present, domestic and foreign scholars mainly achieve the purpose of quantification by constructing an indicator system, selecting corresponding mathematical methods, and establishing an operational model. The most commonly used method is the analytic hierarchy process. Jiang Yuxiao used the AHP-comprehensive fuzzy analysis method to construct a community waterlogging disaster resilience evaluation system [5]. Tan Yinan used the AHP analytic hierarchy process to construct an urban resilience evaluation system from three directions: pre-disaster resistance, disaster response, post-disaster recovery, and adaptability [6]. Based on the simulation results of the Donghai Group under the standard rainstorm conditions of flood prevention using Infoworks ICM software, Jin Zhisen used the analytic hierarchy process (AHP) to study the waterlogging risk assessment and high, medium and low risk zone zoning of the Donghai Group [7]. These studies mainly evaluated urban resilience from the perspective of overall urban planning but gave less consideration to the emergency response capabilities of cities in the face of waterlogging disasters. This paper mainly evaluates the emergency response capabilities of cities in the face of flood disasters from three aspects: pre-disaster monitoring and preparation, disaster response and rescue, and post-disaster recovery and reconstruction, in order to analyze the weaknesses of cities in the face of flood disasters and improve the level of urban emergency response capabilities.

2. Construction of an Evaluation Index System for Urban Waterlogging Emergency Response Capabilities

The analytic hierarchy process (AHP) is a multi-scenario or multi-objective decision-making and evaluation method proposed by American operations researcher TLSaaty at the University of Pittsburgh in the early 1970s [8]. It can model and quantify complex problems by combining qualitative and quantitative analysis. Its basic idea is to analyze the various factors and their relationships contained in the complex problem, classify all the elements studied by the target layer, criterion layer, and benchmark layer (specific solutions, scenarios, measures, etc.), and mark the connection between the elements of the previous layer and the next layer. A multi-level structure is formed. At each level, the relative importance of the elements of the layer is judged according to a certain criterion, and a judgment matrix is constructed. The ranking weight of the elements is determined by solving the matrix eigenvalue problem, and finally the combined weight of the elements of each layer to the total goal is calculated.

After systematically analyzing the current status of its emergency response capabilities and reviewing the literature, the entire process of urban waterlogging emergency response was analyzed from three aspects: pre-disaster monitoring and early warning capabilities, disaster response capabilities, and post-disaster recovery and reconstruction capabilities. Through gradual in-depth and layer-by-layer decomposition, an evaluation index system for urban waterlogging emergency response capabilities was initially determined [9] .

Pre-disaster monitoring and early warning capability is the first stage of the entire emergency management, and its purpose is to minimize the losses caused by waterlogging disasters. The two secondary indicators are monitoring and early warning capability and emergency support capability. Monitoring and early warning capability corresponds to two third-level indicators, namely meteorological warning and the number of mobile phone users. Meteorological warning can monitor waterlogging disasters, keep abreast of relevant dynamics, and strive for precious emergency response and escape time for residents. The more complete the system construction, the more effective it can be in avoiding risks and reducing losses caused by waterlogging disasters. The number of mobile phone users represents the ability of residents to receive flood information. Emergency support capability preparation corresponds to three third-level indicators, namely material support, medical support and shelter.

Disaster response capability is mainly composed of two secondary indicators, namely emergency rescue capability and command and coordination capability. Among them, emergency rescue corresponds to four third-level indicators, namely emergency evacuation, fire rescue, medical rescue and traffic maintenance. Command and coordination capability corresponds to three third-level indicators, namely command, coordination and decision-making.

Post-disaster recovery and reconstruction capability corresponds to two secondary indicators, namely accident aftermath and accident summary. Accident aftermath consists of three indicators, accident site handling, recovery and reconstruction and social assistance. The accident summary consists of two indicators: accident investigation and accident analysis.

By calculating the combined weight of each layer of elements to the total target, the importance level of elements in the same layer is judged according to the 9 importance levels given by Saaty in the hierarchical analysis method (see Table 1) [7].

Table 1: Saaty element importance levels

Scale a_{ij}	**definition**
1	Factor i is equally important as factor j
3	Factor i is slightly more important than factor j
5	Factor i is more important than factor j
7	Factor i is very important than factor j
9	Factor i is absolutely more important than factor j
2、4、6、8	It is the scale value corresponding to the intermediate state between the above judgments
reciprocal	If factor i is compared with factor j, the judgment value is: $a_{ij}=1/a_{ji}$

Determined by referring to data from a large number of literature. The weight value of each indicator is calculated using the software yaahp (Figure 3). Taking the pre-disaster monitoring and early warning capability as an example, the indicator weight is calculated by the sum-product method, as shown in Tables 2 to 5.

Table 2: Calculation results of the weights of each scenario of pre-disaster monitoring and early warning capacity

B1	**Importance Judgment Matrix**		**Weight**
	C1	**C2**	**ω_j**
C1	1	2	0.667
C2	1/2	1	0.333

Table 3: Calculation results of the weight of each scenario of monitoring and early warning capability

C1	**Importance Judgment Matrix**		**Weight**
	D1	**D2**	**ω_j**
D1	1	2	0.667
D2	1/2	1	0.33

Table 4: Calculation results of weight of each scenario of emergency support capability

C2	**Importance Judgment Matrix**			**Weight**
	D3	**D4**	**D5**	**ω_j**
D3	1	1	2	0.40
D4	1	1	2	0.40
D5	1/2	1/2	1	0.20

Table 5: Calculation results of the weight of the benchmark layer

A	Importance Judgment Matrix			Weight
	B1	B2	B3	ω_j
B1	1	1	2	0.40
B2	1	1	2	0.40
B3	1/2	1/2	1	0.20

The weight of each third-level indicator is calculated based on the criterion layer weight and the corresponding scenario weight.

3. Establishment of Evaluation Levels

In order to make the evaluation results more accurate, the author consulted experts and read a large amount of literature and referred to the grading table in the "Emergency Preparedness Capability Assessment Report" published by the National Emergency Management Association (NEMA) of the United States6. Each capability score in the airport emergency capability structure can be divided into 5 levels, represented by "5, 4, 3, 2, 1" respectively. In practical applications, the intermediate values can be used to more accurately describe the actual score [10].

Table 6: Grades and scores

Grade/Score	Description
5	Completely meets the requirement (just need to maintain)
4	Able to meet the requirements well (only limited effort required)
3	Medium meets the requirement (requires greater effort)
2	Barely meets the requirement (requires great effort)
1	Unable to meet the requirement

The score of urban waterlogging emergency response capability is a comprehensive performance of all indicators in the indicator system. Each single indicator reflects the urban waterlogging emergency response capability from different aspects. The higher the score, the better the resilience of urban waterlogging prevention and control.

The comprehensive evaluation method is the most widely used indicator integration method at present. It aims to integrate the indicator values with different dimensions into a value with a unified dimension that can reflect the resilience level of urban waterlogging prevention and control. It is mainly calculated by the sum of the product of the quantitative indicator value of each indicator and its weight. The overall evaluation result is expressed as the urban waterlogging emergency response capability P. Its calculation formula is as follows:

$$P = \sum_{j}^{i} \omega_j P_i$$

Where: P is the total score of urban waterlogging emergency response capability, the corresponding indicator weight of ω_j is shown in Figure 2, P_i is the score of the corresponding indicator, i=1, 2,…, 17. If P_i is known, the above model can be used to comprehensively score the emergency response capability of urban waterlogging.

4. Evaluation of Emergency Response Capability of Urban Waterlogging in Zhengzhou

Zhengzhou City is selected as an example to verify the validity of the model in this paper. Through extensive literature reading and data collection, the evaluation scores of various indicators of Zhengzhou City are shown in Table 7.

Table 7: Scores for each indicator

Index	D1	D2	D3	D4	D5	D6	D7	D8	D9
Score	3.1	3.35	3.07	3.24	3.12	3.O6	3.08	3.11	2.93
Index	D10	D11	D12	D13	D14	D15	D16	D17	
Score	2.88	2.85	3.0	2.76	3.03	3.5	2.8	3	

The data in Table 7 are introduced into the mathematical model for evaluating urban waterlogging emergency response capabilities. The comprehensive score of Zhengzhou's urban waterlogging emergency response capabilities is 3.43. It is between "well able to meet the requirements" and "generally able to meet the requirements" and is biased towards the latter. In addition, analysis of the scores shows that Zhengzhou's command and coordination capabilities in the face of urban waterlogging, as well as its accident investigation capabilities after the disaster, need to be improved. From the "7.20" incident in Zhengzhou, it can be seen that Zhengzhou did not stop work or school when it issued a series of heavy rainstorm warnings, resulting in many people going out in the rain, and its emergency command and coordination capabilities were insufficient [11]. After the disaster, the number of deaths and missing persons was unclear, and the real data was not released until the second year, proving that Zhengzhou lacked post-incident investigation capabilities.

It can be seen from this that, on the one hand, during the emergency rescue process, there was a lack of coordination and cooperation between government departments and civil groups, making it difficult to achieve unified dispatch, which seriously affected the efficiency of emergency rescue. On the other hand, there have long been problems such as insufficient, inaccurate, and untimely information, which is the basis and premise of emergency management [12].

5. Conclusion

1) Based on the systematic analysis of urban waterlogging emergency rescue, an urban waterlogging emergency capacity evaluation index system was established. The establishment of the emergency capacity evaluation index system provides a new idea for the research on emergency capacity evaluation.
2) A mathematical model for urban waterlogging emergency capacity evaluation was proposed to achieve quantitative evaluation of urban waterlogging emergency capacity.
3) The weak links of Zhengzhou's emergency capacity in the face of urban waterlogging were analyzed. And the common problems in my country when facing urban waterlogging disasters.

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