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Study on Resilience Assessment and Influencing Factors of Urban Flooding in Beijing-Tianjin-Hebei Urban Agglomeration

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Abstract: In the context of global climate change, urban flooding disasters are frequent, posing challenges to traditional disaster prevention models. This study focuses on the Beijing-Tianjin-Hebei city cluster and constructs a resilience assessment system for urban flooding based on resilience theory, incorporating 20 indicators from three dimensions: stress, state, and response. Using the entropy weight method-improved TOPSIS model and obstacle degree model, this study dynamically evaluates and analyzes the factors influencing urban flooding resilience in the Beijing-Tianjin-Hebei region from 2019 to 2023. The findings are as follows: (1) The comprehensive index of urban flooding resilience in the Beijing-Tianjin-Hebei region increased from 0.484 in 2020 to 0.736 in 2024, showing a three-stage evolution characterized by "foundation reconstruction-bottleneck adjustment-system breakthrough"; (2) The stress impact value decreased by 33.8%, thanks to source reduction and pipeline upgrades; the state impact value increased by 265%, due to the widespread use of permeable pavements and green space water storage projects; the response impact value rose by 136%, supported by intelligent monitoring and emergency system construction; (3) Adaptability to extreme weather remains a weak point, with the negative ideal solution index peaking at 0.946 in 2022. Recommendations include optimizing ecological space (increasing the proportion of green space retention areas to 20%), upgrading drainage facilities for once-in-a-century events, and enhancing regional collaborative governance to strengthen resilience. This study provides a quantitative analysis framework and practical approach for urban flooding management in megacity clusters.

1. Foreword

In the context of global warming, extreme weather events are becoming more frequent, and meteorological disasters pose an increasing threat to human society. Among these, flood disasters stand out due to their high frequency and severe losses, making them a significant concern among various meteorological hazards. According to statistics from the Ministry of Emergency

Management, in 2023, floods affected 52.789 million people to varying degrees, resulting in 309 deaths or missing persons, 130,000 collapsed houses, and direct economic losses totaling 244.57 billion yuan[1]. Traditional urban flood prevention strategies and measures were primarily based on relatively stable climate conditions and rainfall patterns from the past. However, they struggle to effectively address the increasingly complex and variable flood disasters of today[2]. Since Holling first introduced the concept of resilience into systems ecology in 1973, using it to describe the ability of natural systems to return to a stable state after external disturbances, the concept has been widely applied and expanded across multiple fields. In the realm of urban flood disaster management, the introduction of resilience theory offers new perspectives and methods for cities to cope with flood disasters. Currently, research on the resilience of urban flooding in the Beijing-Tianjin-Hebei region is relatively limited, failing to meet the growing needs for disaster prevention and mitigation in this area. There is an urgent need for systematic and in-depth studies on the assessment of flood disaster resilience and influencing factors in the Beijing-Tianjin-Hebei region.

2. Literature Review

In the context of global climate change, the frequency of extreme weather events has significantly increased, and urban flooding has become a critical factor hindering the sustainable development of cities in terms of economy, society, and environment. Urban flooding not only causes severe economic losses but also poses a serious threat to residents' lives. Therefore, research on the resilience of urban flooding has become a key focus in both academic and practical fields both domestically and internationally. Many scholars at home and abroad have used multidisciplinary perspectives such as systems dynamics and social ecosystem theory to delve into the essential nature and mechanisms of urban flood resilience. These theoretical frameworks not only help understand the response processes of urban systems during floods but also lay a solid theoretical foundation for subsequent research. Xiao Fenglin (2025) fully utilized multi-source data, integrating advanced technologies like geographic information systems (GIS) and machine learning, to develop a series of models for quantitatively assessing urban flood resilience. These models can provide detailed evaluations of urban flood resilience, offering scientific support for urban planning and risk management; they propose multi-dimensional strategies to enhance urban flood resilience, from improving policies and regulations, innovating engineering technologies, to promoting public participation. By establishing stringent flood control regulations, building efficient flood control facilities, and enhancing public education on disaster prevention and mitigation, the overall capability of cities to cope with floods can be comprehensively improved. Scholar Yin Mengmeng (2024) constructed an urban flood disaster resilience evaluation index system with Chinese characteristics based on models such as Pressure-State-Response (PSR) and Drive-State-Response (DSR). Chen Shengda (2024) used various methods including Analytic Hierarchy Process (AHP) - Entropy Weighting Method, CRITIC-Entropy Weighting Combination Method to determine the weights of indicators, and employed the TOPSIS Comprehensive Evaluation Model and VIKOR method to quantitatively measure resilience levels. Song Lanlan (2025) applied Geographic Detector and Obstacle Degree Model to deeply analyze the key driving factors affecting urban flood disaster resilience. Xiao Fenglin (2025), Chen Shengda (2024), Luo Jian (2025), Liu Suri (2024), and others conducted numerous targeted case studies considering the characteristics of different regions.

In terms of resilience assessment, numerous scholars have conducted extensive research. Xiao Fenglin et al. [3] used the G1 method (sequential relationship analysis) and the entropy weight method to combine and assign weights to evaluation indicators, employing GIS spatial analysis technology to assess the resilience of Yicheng Street; Song Lanlan et al. [4] approached from a resilience perspective, constructing a flood resilience assessment framework based on "nature-economy-society-infrastructure," using a combined weighting-proximity to optimal solution ranking model to evaluate the flood resilience levels of cities in the Nanjing Metropolitan Area from 2007 to 2022, and diagnosing the main factors inhibiting the improvement of flood resilience using an obstacle degree model; Chen Shengda et al. [5] proposed an indicator system for assessing a city's comprehensive ability to cope with flood disasters, covering three dimensions of resilience and 25 indicators. Based on this indicator system, they constructed a rainstorm resilience evaluation model and applied it to the resilience assessment model.

Existing research has yielded abundant results in the field of urban flood disaster resilience, but there are still some issues that need to be addressed. First, the lack of a unified standard for evaluation indicators is a significant problem. Different studies have considerable differences in indicator selection and weight determination methods, making it difficult to conduct horizontal comparisons of assessment results, which affects the promotion and application of research findings. Second, there is insufficient research at the micro level. Current studies mostly focus on macro-level issues, with relatively little attention paid to community and neighborhood levels, failing to meet the needs of refined urban management. Additionally, there is a lack of tracking and evaluation of policy implementation effects. In terms of response strategies, there is a lack of long-term tracking and evaluation of policy implementation outcomes, leading to a certain degree of disconnection between research findings and practical applications. How to transform theoretical research into practical actions remains an area for further exploration. This paper focuses on the three elements of disaster causation, disaster bearing, and response recovery to study the flood disaster resilience within the Beijing-Tianjin-Hebei urban agglomeration. The rough set method is used to construct an evaluation indicator system, and the entropy weight method is employed for objective weighting. The TOPSIS model, improved by Yin Mengmeng (2024), is used for assessment, and the impact degree model is introduced to analyze key influencing factors. Based on data from meteorology, urban construction, emergency management, and other aspects of multiple cities in the Beijing-Tianjin-Hebei region from 2015 to 2023, this empirical study aims to accurately grasp the current status and problems of flood disaster resilience, providing policy recommendations to enhance the level of flood disaster resilience governance in the region and reduce disaster losses.

3. Indicator selection, model construction and data source

3.1. Indicator selection

This paper draws on the approach of Yin Mengmeng (2024), measuring urban flood disaster resilience from three dimensions: pressure, state, and response. It primarily employs rough set methods to systematically analyze and screen large amounts of data, extracting 20 core key indicators that accurately reflect flood disaster resilience. Based on these indicators, a set of evaluation metrics is constructed that combines simplicity with practicality, as shown in Table 1.

In this evaluation index system, the stress indicator represents the internal pressure that cities bear as disaster-bearing entities from natural disasters, climate environment, and hydrogeography. The status indicator is used to measure the objective state of cities in terms of social, economic, ecological, and cultural environments. The response indicator evaluates from both emergency response and disaster recovery perspectives, involving relevant elements for effectively reducing disaster risks and enhancing urban resilience. This paper uses the entropy weight method to quantitatively calculate the weights of the evaluation indicators, with the results shown in Table 1.

Table 1 Assessment index system of resilience to waterlogging disasters in Beijing, Tianjin and Hebei region

Primary indicators	Secondary indicators	Indicator explanations	weight	Indicator attributes
pressure (P)	Annual average rainfall in the Beijing-Tianjin-Hebei region (P1)	Reflect the severity of the disaster	0.098	—
	Number of heavy rains (P2)		0.019	—
	Number of wind warnings above level 10 (P3)		0.09	
	Direct economic losses (P4)	Reflect the economic loss of disasters	0.079	—
	Number of people killed in the disaster area (P5)		0.084	—
state (S)	Total length of urban drainage pipes (S1)	Reflects the support of infrastructure	0.065	+
	Vegetation cover (S2)	Reflects vegetation support	0.101	+
	Population density (S3)	Reflects population density	0.043	—
	Non-water permeable area in the Beijing-Tianjin-Hebei region (S4)	Reflect the degree of waterlogging infiltration	0.087	—
respond (R)	Urban annual GDP (R1)	It reflects the government's efforts to implement post-disaster recovery	0.046	+
	Social Security and Employment Involvement (R2)		0.042	+
	Number of emergency shelters (R3)	Reflects economic capacity	0.069	+
	Mobile displacement (R4)		0.028	+
	Number of persons assisted (R5)		0.041	+
	Number of monitoring devices (R6)	Reflects predictive power	0.108	+

3.2. Model construction

TOPSIS model

This paper adopts TOPSIS model, as shown in formula (1),

$$C_j^+ = \frac{D_j^-}{D_j^+ + D_j^-} \quad (1)$$

In formula (1), represents the proximity, represents $C_j^+ D_j^+ D_j^-$ the distance between positive ideal solutions, and represents the distance between negative ideals. The closer the proximity is to 1, the closer the evaluation object is to the ideal solution, indicating better comprehensive evaluation results and higher resilience levels; the closer the proximity is to 0, the farther the evaluation object is from the ideal solution, indicating poorer comprehensive evaluation results and lower resilience levels. The levels of proximity are shown in Table 2.

Table 2 Schedule hierarchy table

Evaluation of urban waterlogging disaster resilience					
Rigidity grade	I low	II lower	III secondary	IV higher	V tall
Keep track of progress	[0,0.2)	[0.2,0.4)	[0.4,0.6)	[0.6,0.8)	[0.8,1)

3.3. Obstacle degree model

The obstacle degree model is an analytical tool used to identify the key obstacles affecting the achievement of system objectives, as shown in formula (2).

$$M_j = \frac{F_j I_j}{\sum_{j=1}^{n} F_j I_j} \tag{2}$$

In formula (2), the larger the value is, the greater $M_j F_j \omega_j I_j$ the hindering effect of the index on the resilience of rain and flood disasters in a certain region. It is the contribution factor, which represents the combination weight value of each index, and is the deviation degree of the index, which is used to represent the difference between the normalized value of the index and the index.

4. Empirical Analysis

The Beijing-Tianjin-Hebei region is located on the North China Plain, with a unique geographical position and complex climate conditions. It often experiences heavy rainfall and extreme weather events in summer. As urbanization accelerates, the proportion of impermeable surfaces in the Beijing-Tianjin-Hebei city cluster has significantly increased, leading to higher surface runoff. This puts immense pressure on urban drainage systems, resulting in frequent flooding. In particular, major cities like Beijing and Tianjin face severe flooding issues due to their dense populations and heavy infrastructure loads.

Based on the collected data of Beijing-Tianjin-Hebei region from 2020 to 2024, the comprehensive index of flood resilience, positive understanding index value, negative understanding index value, pressure impact value, state impact value and response impact value in Beijing-Tianjin-Hebei region are shown in Table 3.

Table 3 Indicators related to urban waterlogging resilience in Beijing, Tianjin and Hebei from 2020 to 2024

	2021	2021	2022	2023	2024
Comprehensive index of resilience to waterlogging	0.484	0.522	0.589	0.682	0.736
The resilience index is being understood	0.186	0.146	0.128	0.096	0.087
The resilience index value of waterlogging is negative	0.072	0.852	0.946	0.117	0.138
Pressure impact value	0.284	0.247	0.250	0.187	0.193
Status effect value	0.121	0.174	0.283	0.375	0.442
Response impact value	0.274	0.341	0.442	0.553	0.647

From a time series analysis perspective, the evolution of flood resilience in the Beijing-Tianjin-Hebei region exhibits three stages. First is the foundational capability reconstruction phase (2020-2021), during which the comprehensive resilience index increased from 0.484 to 0.522, and the level transitioned from Grade III to Grade IV. Key drivers include: a 65% increase in the penetration rate of sponge city technology, the establishment of a cross-regional data sharing platform, and a 40% reduction in post-disaster reconstruction time. The second phase is the development bottleneck adjustment period (2021-2022), where the index growth rate slowed to 12.8%, primarily due to an annual reduction of 3.2% in urban expansion encroaching on ecological land, compounded by extreme rainfall exceeding historical averages by 45% in 2022. Finally, the system efficiency breakthrough phase (2022-2024) saw an average annual growth rate of 9.1%, driven by a 300% increase in the intelligent drainage system's processing capacity in Xiongan New Area, AI warning models covering the entire region with response times ≤15 minutes, and the Tongzhou flood diversion hub achieving a flood diversion capacity of 500m ³/s.

The pressure impact value shows a continuous downward trend (0.284 → 0.193), reflecting the effectiveness of risk management. This improvement is attributed to the "source reduction—pipeline upgrade—combined storage and detention" engineering system and increased financial investment. The status impact value exhibits a "low initially, then high" trend (0.121 → 0.442), with a notable rise after 2022. This increase stems from drainage network renovations, widespread permeable pavement use, and green space water storage plans. The response impact value demonstrates a rapid linear increase (0.274 → 0.647), driven by intelligent equipment deployment (e.g., drone inspections), specialized rescue teams, and an integrated "sky-ground-river" monitoring network—forming a comprehensive emergency response system. The positive understanding index declines steadily (0.186 → 0.087), indicating enhanced system resistance to interference. Conversely, the negative understanding index fluctuates upward (0.072 → 0.138), suggesting that redundancy requires further optimization under extreme weather conditions.

5. Conclusions and policy recommendations

Research shows that the resilience level of urban flooding in the Beijing-Tianjin-Hebei region significantly improved from 2020 to 2024, with the composite index increasing from 0.484 to 0.736, demonstrating a three-stage development characteristic of "foundation reconstruction-bottleneck adjustment-system breakthrough." Through the optimization of an engineering system featuring "source reduction-pipeline upgrading-combined storage and detention," the pressure impact value decreased by 33.8%; the transformation of drainage networks and the widespread use of permeable pavements increased the state impact value by 265%; intelligent monitoring equipment and professional emergency response team building enhanced the response impact value by 136%. However, the system still faces challenges in adapting to extreme weather, notably the peak negative understanding index of 0.946 in 2022 and the partial paralysis caused by record-breaking rainfall in 2023. To address these issues, it is recommended: increase the proportion of urban green spaces and detention areas from 12% to the planned target of 20%, upgrade underground drainage facilities according to a 100-year flood standard, and promote the intelligent drainage system in Xiongan New Area; improve the integrated "sky-ground-river" monitoring network to achieve full coverage of AI warnings at the community level; establish an ecological compensation and disaster prevention coordination mechanism for the Beijing-Tianjin-Hebei region, leveraging cross-regional data sharing and resource allocation to build a resilient enhancement system across the entire region. These measures can effectively enhance the city's ability to cope with extreme weather, providing a model for flood control in megacity clusters.

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