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A Review of Research on Urban Disaster Resilience

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Abstract: With the acceleration of global climate change and urbanization, the risk of urban disasters is increasing, and the research on urban disaster resilience has gradually become an important direction in the field of disaster prevention and mitigation. This article systematically reviews the evolution of the concept of urban disaster resilience and its characteristic connotations, analyzes the current mainstream evaluation index framework and assessment methods, and summarizes the key factors affecting urban disaster resilience from aspects such as economic development, infrastructure, urban governance, social development, and the environment. Urban disaster resilience is the result of the coordinated action of multiple systems and has dynamic and complex characteristics. Future research should strengthen the application of dynamic simulation to enhance the capacity of urban disaster risk management and disaster prevention and mitigation.

Keywords: Urban resilience; Evaluation indicators; Assessment methods; Influencing factors

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1. Introduction

Entering the 21st century, the effects of global climate change have become increasingly prominent. The frequency and intensity of disasters such as extreme high temperatures, severe precipitation, and sea level rise have all increased exponentially. At the same time, with the largest urbanization process in human history, population, wealth, and infrastructure have been highly concentrated in a limited space, making the urban ecosystem extremely vulnerable. Modern cities not only face threats from traditional natural disasters such as earthquakes and floods, but are also deeply involved in the complex interweaving of public health incidents, cybersecurity risks, and cascading technological accidents, presenting a clear "multi-hazard coupling" characteristic.

In this context, the traditional disaster prevention and mitigation model centered on "hard defense" has gradually shown its limitations and is unable to cope with "black swan" events that exceed design standards. The academic community and decision-makers have begun to achieve a paradigm shift, shifting their focus from a single physical defense to the comprehensive concept of "urban resilience". Resilient cities emphasize that the system not only maintains basic functions after being impacted, but also possesses the dynamic ability to absorb disturbances, quickly recover, and learn and evolve from disasters.

Although the research on resilience has become a hot topic, it still faces problems such as generalized concept connotations, inconsistent quantitative evaluation standards, and unclear dynamic evolution mechanisms. This paper systematically explores the evolution process of urban disaster resilience, compares and analyzes the mainstream resilience assessment index frameworks and methods, and deeply discusses the factors influencing resilience, aiming to provide a reference for theoretical research on resilience cities and disaster prevention and mitigation practices.

2. Concept and characteristics of urban disaster resilience

2.1. Urban disaster resilience

The definition of urban resilience has gone through the stages of engineering resilience, ecological resilience, and social-ecological resilience.

The concept of engineering resilience originated from engineering science, mainly emphasizing the system's ability to return to its original stable state after being disturbed. The core focus is on the speed and efficiency of recovery. The resilience concept in this stage is mostly applied to the seismic performance of engineering structures and the reliability of infrastructure, emphasizing the stability and recovery ability of the system. Subsequently, ecologist Holling proposed the concept of ecological resilience, defining resilience as the system's ability to maintain its structure and function after being disturbed [1]. This stage broke through the limitation of engineering resilience only focusing on the recovery speed, emphasizing the system's ability to withstand disturbances and maintain operation. As cities are regarded as complex systems composed of social and natural systems, the resilience concept further expanded to social-ecological system resilience, emphasizing the system's adaptability and regulatory ability. This stage holds that cities not only need to resist and recover from disaster impacts, but also need to adapt to changing environments by adjusting their structure and functions (**Table 1**).

Table 1. The core concepts and key focuses of different stages of the resilience theory

Resilience stage	Core concept	Focus
Engineering resilience	Revert to original state	Recovery speed
Ecological resilience	Maintain system functionality	The ability to resist impact
Social-ecological resilience	Active system adaptation ability	Interactions among multiple systems

Urban disaster resilience is the practical application of resilience theory in the field of disaster prevention. Its definition can be summarized as: When the urban system is subjected to various natural or man-made disasters, through the coordinated interaction among internal systems such as material infrastructure, social economic organizations, and natural environment, it maintains basic functions, reduces post-disaster losses, quickly restores production and life, and continuously optimizes the system's defense capabilities throughout this process. Some scholars pointed out from a process perspective that it is the comprehensive resilience demonstrated by the city throughout the entire disaster life cycle [2].

2.2. Urban disaster resilience characteristics

This article integrates the research findings of multiple scholars and the international practice framework to summarize the main characteristics of urban disaster resilience as follows [3–5].

2.2.1. Robustness

Robustness refers to the ability of a city system to withstand disturbances and maintain the stable operation of key functions under disaster impacts. It is the fundamental characteristic of urban disaster resilience. A city system with strong robustness can reduce functional losses under disasters such as floods and earthquakes, maintain the basic operation of infrastructure and social economic systems, and thereby reduce the impact of disasters.

2.2.2. Redundancy

Redundancy refers to the existence of structures or components in the urban system that have alternative functions, enabling the system to maintain its overall functionality even when some elements are damaged. For example, multi-path transportation networks and backup power supply systems can keep the system running when some nodes fail. The presence of redundancy enhances the city system's ability to withstand disaster impacts and maintain functional continuity, and is an important guarantee for the city's disaster resilience.

2.2.3. Resourcefulness

Resourcefulness refers to the ability of the urban system to rationally allocate and mobilize resources during a disaster, including material distribution, emergency response, and organizational coordination. Strong resource allocation capabilities can improve the efficiency of disaster response in the city and promote the recovery process after the disaster, which is an important manifestation of the city's disaster resilience.

2.2.4. Timeliness

Timeliness of recovery refers to the ability of the urban system to quickly control losses and restore functions after a disaster occurs. The faster the recovery speed, the smaller the long-term impact of the disaster on the city's social and economic system. Timeliness of recovery reflects the emergency management capabilities of the city system and the efficiency of post-disaster recovery, and is one of the key indicators for measuring the city's disaster resilience.

2.2.5. Flexibility

Flexibility refers to the ability of a city system to adjust its structure, optimize its strategies, or introduce new technologies to adapt to shocks from disasters or environmental changes. Cities with strong flexibility can promptly adjust their response measures based on the characteristics of disasters and enhance the system's adaptability, thereby strengthening the overall disaster resilience.

2.2.6. Holism

Holism refers to the ability of various subsystems in a city to operate in coordination through effective coordination and resource integration. The disaster resilience of a city not only depends on the disaster resistance capabilities of a single system, but also on the synergy among infrastructure systems, social systems, and management systems. Effective integration among systems can enhance the city's overall ability to respond to disasters.

2.2.7. Reflectiveness

Reflectiveness refers to the ability of a city system to summarize disaster experiences, optimize urban planning, management mechanisms, and infrastructure construction, and improve future disaster response capabilities. Cities with strong reflective ability can continuously optimize the system structure and management model to achieve continuous improvement in disaster resilience.

In summary, the essence of urban disaster resilience is the overall adaptability of the city system under the influence of disasters, which can be summarized into four aspects, as shown in **Table 2**.

Table 2. The core capabilities and characteristics of urban disaster resilience

Resilience core capabilities	Characteristics
Resistance capability	Robustness
Absorption capability	Redundancy flexibility
Recovery capability	Timeliness resourcefulness
Adaptability	Reflectiveness holism

3. Urban disaster resilience assessment model

3.1. Evaluation index framework

Establishing a scientifically sound and reasonable evaluation index system is the foundation for quantifying urban disaster resilience. Through in-depth review of the literature, it can be observed that scholars often adopt different entry points when constructing the index system based on specific research objects, research stages, and theoretical foundations.

3.1.1. Framework based on urban system composition

This framework regards the city as a complex system and divides the evaluation dimensions by dissecting its internal subsystems. For instance, Li *et al.* improved the internationally recognized BRIC model based on local needs and divided the evaluation dimensions of domestic cities into six aspects: economic resilience, social resilience, environmental resilience, community resilience, infrastructure resilience, and organizational resilience [6]. Xu *et al.* from the perspective of disaster prevention focused more on the attributes of disaster prevention and extracted four core dimensions for index construction: infrastructure resilience, economic resilience, social resilience, and organizational institutional resilience [7]. Mu *et al.* proposed the ReCOVER system, where COVER represents the five dimensions of the city: community and population, government and management, housing and facilities, economy and development, and environment and culture [2]. Fang *et al.* established the "three-dimensional space" framework, dividing the urban system into three coupled subsystems: physical space, social space, and information space [8].

3.1.2. Framework based on disaster evolution

This framework breaks away from the limitations of purely material elements, focusing on the temporal sequence of disaster occurrence and emphasizing the dynamic response status of the city at different stages of the disaster. Zhou *et al.* specifically for specific sudden disasters such as floods, divided the assessment framework into three stages: the pre-disaster stage, the disaster-in-progress stage, and the post-disaster stage [9]. Mu *et al.* proposed the

ReCOVER system, where the "Re" refers to the four stages of post-disaster recovery, namely the rescue stage, the refuge stage, the rebuild stage, and the revival stage. Jiao *et al.* decomposed the impact of disturbances on the city from the perspective of dynamics before and after the disaster occurrence, using the PSR model framework [10]. The evaluation system consists of "pressure resilience" brought by the triggering factors, "state resilience" demonstrated by the affected body, and "response resilience" made by the urban subsystem.

3.1.3. Framework based on urban resilience capacity

This framework focuses on evaluating the dynamic capacity attributes of the internal systems of a city when it is confronted with external shocks. Zhao *et al.* combined five urban resilience influencing factors, namely the severity of urban disaster events, the vulnerability of the affected body, adaptability, resilience, and recovery ability, to construct a multi-factor comprehensive assessment model for urban resilience [11]. Hu *et al.* took into account both short-term disaster prevention and long-term evolution, and divided the indicators into two major dimensions: "survival resilience" and "development resilience" [12]. Among them, "development resilience" was further decomposed into five specific ability dimensions: the city's predictive ability, innovation ability, decision-making ability, transformation ability, and cooperation ability. Chen *et al.* constructed an urban resilience assessment framework under rainstorm and flood scenarios from three aspects: resistance, adaptability, and recovery ability [13].

3.2. Evaluation method

3.2.1. Comprehensive index method

After the indicator system has been constructed, the first step is to determine the significance of each indicator to the overall urban resilience.

The most commonly used subjective weighting method is the analytic hierarchy process (AHP), which constructs a judgment matrix through expert scoring and calculates the maximum eigenvalue and the corresponding eigenvector as the weights. It can fully incorporate the macroscopic experience and professional judgment of experts, but it is highly subjective. In the research of disaster prevention perspectives and post-disaster recovery processes, many scholars have used the AHP method to calculate the weights for management indicators that are difficult to quantify purely, such as infrastructure, economy, and society. The currently commonly used objective weighting methods include the entropy weight method and the CRITIC method. The entropy weight method assigns weights based on the degree of dispersion of the indicator data; the greater the data difference, the higher the weight. The CRITIC method not only considers the intensity of data comparison but also takes into account the conflict between indicators. When dealing with urban resilience data, these methods can effectively eliminate human interference and solve the problem of multicollinearity.

The comprehensive index method is the comprehensive weighted index obtained by weighting each indicator after calculating the weights of the indicators, and it serves as the quantitative result of urban disaster resilience. Mu *et al.* used the comprehensive index method to obtain the urban resilience score [2].

3.2.2. Multi-criteria decision-making method

The VIKOR method is a typical multi-criteria decision-making approach, mainly used for the comprehensive evaluation and ranking of the disaster resilience levels of multiple cities or regions. This method aims to maximize the group utility and minimize individual regret, and achieves the optimal ranking under multi-index conditions by constructing compromise solutions. Due to the fact that urban disaster resilience involves multiple interdependent indicators, the VIKOR method can effectively coordinate the conflicting relationships among the indicators. Zhou *et al.* used the VIKOR method to study the spatial pattern assessment and ranking of flood disaster resilience of 21 prefectures in Guangdong Province [9].

The Near Ideal Solution Ranking Method (TOPSIS) is based on the construction of positive and negative ideal solutions, and calculating the distances between each evaluated object and the ideal and negative ideal solutions, then calculating the proximity coefficient to conduct comprehensive evaluation and ranking of the disaster resilience levels of cities. This method can fully utilize the indicator information and achieve objective comparison of the disaster resilience of multiple cities. Chen *et al.* used the TOPSIS model to conduct comprehensive measurement of the urban resilience of the Har-Tang City Cluster [14]. Meng *et al.* used the TOPSIS method to assess the urban regional resilience under flood disasters [15].

3.2.3. Modeling and simulation of complex systems

Due to the high randomness and fuzziness of disaster events, the cloud model utilizes three numerical characteristics, expectation, entropy, and super-entropy, to successfully convert qualitative concepts into quantitative assessment data. Jiao used the cloud model to conduct an empirical analysis of 31 provinces across the country and calculated the comprehensive resilience levels of these 31 provinces [10].

This method focuses on the feedback and delay of macro systems. By constructing “causal loop diagrams” and “stock-flow diagrams”, it seeks nonlinear feedback relationships among various subsystems of the city. This method can simulate the dynamic changes of urban disaster resilience during the disaster impact and recovery process, reflecting the long-term evolution characteristics of the urban system. Huang *et al.* simulated the dynamic changes of Nanjing’s flood resilience under four scenarios from 2009 to 2025 based on the system dynamics model [16]. Yang *et al.* utilized the information feedback feature of system dynamics to construct a simulation model of the urban tourism environment system resilience under multiple scenarios and measured the tourism environment system resilience of Lanzhou City [17].

4. Influencing factors of urban disaster resilience

4.1. Economic development factors

Economic development factors are an important fundamental condition influencing urban disaster resilience. A higher level of economic development significantly enhances the ability of a city to withstand disaster impacts and recover. Existing studies typically analyze these factors from aspects such as macroeconomic strength, industrial structure, innovation capacity, fiscal capacity, and disaster losses. Macroeconomic strength is mainly reflected through indicators such as GDP total, per capita GDP, and per capita disposable income of residents. The industrial structure and employment structure are usually characterized by indicators such as the proportion of the tertiary industry, unemployment rate, the number of large-scale enterprises, and the proportion of private and individual employees, to reflect the stability and shock-resistance capacity of the economic structure. Urban innovation capacity is measured through indicators such as the proportion of research and development funds in GDP, the number of patent authorizations, and unit GDP energy consumption, reflecting the potential of the city to adapt to disasters and recover. Additionally, local fiscal revenue and fixed asset investment reflect the government’s fiscal guarantee capacity for disaster prevention and post-disaster recovery. The direct economic losses caused by disasters can reflect the vulnerability level of the urban economic system.

4.2. Infrastructure construction factors

Infrastructure construction is an important material foundation for the resilience of cities in the face of disasters, directly influencing the city's ability to resist disasters, respond to emergencies, and recover after disasters. Existing studies usually analyze aspects such as transportation facilities, municipal vital infrastructure systems, medical rescue facilities, information communication facilities, and flood control and drainage facilities. Transportation facilities are typically measured by indicators such as per capita road area, public transportation ownership, and goods turnover volume, reflecting the ability to evacuate personnel and transport rescue materials during disasters. Municipal vital infrastructure systems include basic support facilities such as water supply, power supply, and gas supply, often characterized by the penetration rate of water and gas supply and pipeline density, reflecting the city's ability to maintain basic operations. Medical rescue facilities are typically measured by the number of hospital beds and doctors per 10,000 people, reflecting the post-disaster medical treatment capacity. Information communication facilities are reflected by indicators such as internet penetration rate and communication equipment ownership, reflecting the ability of disaster warning and emergency information transmission. Moreover, indicators such as drainage pipe density, flood control engineering facilities, and disaster prevention community numbers reflect the city's flood control, drainage, and disaster prevention and mitigation capabilities.

4.3. Urban governance and management factors

Urban governance and management capabilities reflect the management efficiency of the government and relevant organizations throughout the entire process of disaster prevention, emergency response, and post-disaster recovery. Existing studies usually analyze these factors from aspects such as emergency preparedness capabilities, social security capabilities, emergency resource allocation capabilities, and institutional and financial support capabilities. Among them, emergency preparedness capabilities can be measured by indicators such as the number of disaster warnings, the frequency of emergency drills, and the situation of risk investigations, reflecting the government's ability to identify and prevent risks. Social security capabilities are typically characterized by indicators such as medical insurance coverage rate, unemployment insurance coverage rate, and minimum living security level, reflecting the city's social buffering capacity against disaster impacts. Emergency resource allocation capabilities can be reflected by indicators such as the number of fire stations, the number of emergency shelters, and the scale of emergency personnel, reflecting the city's emergency response capabilities. Furthermore, government fiscal expenditure levels, disaster prevention and mitigation investment, and public safety expenditures reflect the government's resource guarantee capabilities for disaster prevention and control.

4.4. Social development factors

Social factors mainly reflect the demographic characteristics of the urban population, social vulnerability, and social adaptability. Usually, analysis is conducted from aspects such as population structure, population exposure, educational level, socio-economic conditions, and social capital. Among them, population structure can be measured by indicators such as age structure and gender structure, reflecting the vulnerability of different groups to disasters. Population density, population growth rate, and the number of affected people reflect the exposure level of the urban population. The higher the population density, the greater the potential loss from disasters.

Educational level is usually measured by indicators such as the prevalence of higher education and the number of students in school, and the higher the educational level, the stronger the public's awareness of disaster prevention and response capabilities.

4.5. Environmental factors

Environmental factors reflect the level of natural disaster risks faced by a city and the regulatory and recovery capabilities of the ecosystem. Usually, this is analyzed from aspects such as the intensity of disaster-causing factors, ecological buffering capacity, environmental quality, and ecological carrying pressure. Among them, indicators such as precipitation and the frequency of extreme precipitation reflect the intensity of flood disaster risks faced by the city. Indicators such as green coverage rate, forest coverage rate, proportion of water area, and proportion of natural reserve area reflect the absorption and regulation capabilities of the ecosystem for floods. In addition, indicators such as air quality level, water resource utilization intensity, and pollutant emission level reflect the health status of the ecosystem and environmental carrying pressure.

5. Conclusion

This paper systematically reviews the concept evolution, characteristic connotations, assessment framework, assessment models, and influencing factors of urban disaster resilience. Urban disaster resilience research has advanced from engineering resilience and ecological resilience to the stage of social-ecological integrated resilience, emphasizing active system adaptation and multi-system coupling. Currently, the academic community has constructed multi-perspective evaluation frameworks and employed advanced methods such as subjective and objective combination weighting, multi-criteria decision-making, and system dynamics for quantitative measurement and simulation. Research shows that the level of urban resilience is profoundly influenced by comprehensive factors such as economic strength, infrastructure, governance efficiency, social structure, and ecological environment. However, resilience assessment still faces challenges such as inconsistent standards and unclear dynamic evolution mechanisms. Future research should focus on as follows:

(1) Constructing a universal and standardized quantitative system for disaster resilience;

(2) Deepening the dynamic simulation of complex urban network cascading failures under multiple disasters;

(3) Strengthening the transformation of theory to planning practice, integrating facility redundancy, economic support, and government strategic governance, and effectively enhancing the comprehensive response efficacy of cities throughout the entire disaster life cycle.

Disclosure statement

The author declares no conflict of interest.

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