A Review of Multi Disaster Coupled Urban Risk Assessment

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Abstract. This article provides an overview of the current situation of urban safety risk assessment for multi disaster coupling. Firstly, the diversified characteristics of urban safety risks were analyzed, including natural disasters, accident disasters, and other aspects. Next, the application of the current risk assessment method framework was discussed, and problems in the assessment process were pointed out, such as inaccurate data and incomplete models. Subsequently, the current status of research on multi disaster coupling was discussed, and the correlation between multiple disasters was analyzed. The shortcomings of current research on coupling relationships were pointed out, and suggestions for urban safety risk assessment based on multi disaster coupling were proposed.

Keywords: Urban security;Multi disaster coupling;Risk assessment;Natural calamities

1. Introduction

Disasters have been present since the beginning of human origin and social development, and have caused distress to human society. Over the years, discussions on the constituent elements of disasters have never ceased, and researchers have put forward different perspectives, including the theory of disaster causing factors, the theory of disaster prone environment, and the theory of disaster bearing bodies. In the above three types of disaster theories, the emphasis on the dominant factors of disaster components is too much, ignoring the correlation between various factors in the system, which is relatively one-sided and cannot grasp the disaster system as a whole. Therefore, disaster systems theory comprehensively considers these three factors and believes that disasters are a surface variation system of the Earth composed of these three factors together. In a broad sense, the disaster prone environment refers to both the natural and cultural environment; Disaster causing factors refer to factors that threaten human life, cause economic and property losses, and damage the ecological environment, including natural, human, and environmental systems. The disaster bearing body refers to the object that bears the disaster, including human beings, buildings, ecological environment, and other factors. In urban disaster systems, the above three elements are equally important and indispensable. The urban disaster system is mainly composed of three primary subsystems: the disaster environment subsystem, the disaster causing factor subsystem, and the disaster bearing body subsystem, which also includes multiple secondary subsystems. The urban disaster system belongs to the regional disaster system, with complex energy and material inputs and outputs, involving the regional natural environment and socio-economic environment, and is an open and complex system.

Multiple types of disasters have a huge impact on the national economy and people's lives, and have a high degree of complexity in their interactions, making them the forefront of scientific research challenges. For example, in 2011, a catastrophic multi disaster earthquake occurred along the northeast Pacific coast of Japan, causing a chain tsunami, nuclear power plant meltdown, and radiation leakage. These multiple types of disasters have successively attracted high attention from the international community to related research[1]. In 2014, the UK experienced a series of major storms, with winds, floods, and avalanches causing severe damage to Scotland. In 2021, a "720" extremely heavy rainstorm disaster will occur in Zhengzhou, Henan Province. There will be a rare continuous precipitation in Henan Province, with an average cumulative precipitation of 449 mm, resulting in a total of 150 counties (cities, districts), 1663 townships, 14531600 people affected, 30106 households and 89001 houses collapsed; The affected area of crops is 8.72 million mu, and the area of crop failure is 3.8 million mu, resulting in a direct economic loss of 114.269 billion yuan. The catastrophic flood caused a total of 302 deaths and 50 people missing. This disaster is a particularly serious natural disaster caused by extreme rainstorm, which caused serious urban waterlogging, river floods, mountain torrents and landslides, and caused heavy casualties and property losses. From accidents, it can be seen that disasters in cities often do not occur in isolation, but rather multiple disasters occur simultaneously. The mutual influence and interaction between disasters make the disaster results amplified and complex, resulting in more serious losses.

2. Current Status of Urban Disaster Risk Research

2.1 Urban comprehensive risk assessment

Currently, research on urban disaster risk has become a hot topic both domestically and internationally. Domestic and foreign scholars have extensively conducted urban disaster risk assessments for different types of disasters and at different temporal and spatial scales. In 2005, the European Commission[2] evaluated the hazards, resilience, and exposure of four types of disasters: floods, droughts, forest fires, and high temperatures. Finally, the evaluation results were overlaid to create a comprehensive risk map. Petevilie et al. [3] conducted a comprehensive risk assessment of a city in India based on natural disasters, combined with factors such as population, architecture, and socio-economic factors, and applied GIS software to classify and partition urban risks. Gao Jiaojiao et al. [4] selected typical natural disasters in cities and conducted a comprehensive disaster risk assessment. They selected indicator factors from the perspectives of hazard factors, urban vulnerability, and regional defense, and constructed a fuzzy evaluation model for urban natural disaster risk. Huang Chongfu et al. [5-6] studied natural disasters and proposed first and second level models for urban natural disaster risk assessment based on fuzzy set theory. They also conducted empirical research using earthquake disasters as an example.

The research methods for urban disaster risk assessment at home and abroad mainly include indicator system based urban risk assessment, GIS software based mathematical modeling assessment, scenario simulation based urban disaster risk assessment, and risk probability based modeling and assessment. Li Yiwei et al. [7] started from the perspective of urban resilience and protection capacity, and selected a total of 22 indicators from six aspects: natural disasters, accident disasters, public health events, social security events, disaster bearing capacity, and disaster resistance capacity to construct a risk assessment model for urban resilience and protection capacity. However, they did not consider the coupling factors of multiple types of disasters in urban disasters. Yin Jie et al. [8] considered the composite factors of multiple types of disasters and selected indicators from disaster causing factors, material risks, exposure, and resilience to construct an urban disaster assessment model. However, Yin Jie chose the probability and severity of natural and man-made disasters to reflect the level of urban disaster risk, and did not deeply analyze the interaction between the two, making the assessment results unable to accurately reflect the comprehensive risk level of urban disasters. Luo Pei et al. [9] developed the Chongqing Geological Disaster Risk Assessment Information System based on GIS software, which is used to accurately assess the danger and vulnerability of regional geological disasters. Wang Qiao et al. [10] identified typical urban disasters and considered urban vulnerability factors. They applied GIS software to weight the evaluation results of urban disaster risk and exposure, and created a comprehensive risk map of urban disasters. Han S R et al. [11] took strong wind, rainstorm and flood as composite disaster factors, estimated strong wind and flood using scenario simulation, and assessed the comprehensive disaster risk of Incheon in combination with disaster risk, exposure, vulnerability and resilience. Through the study of the above literature, it has been found that current research on urban comprehensive risk assessment mostly focuses on the study of a single disaster risk, without considering the coupling effect between multiple disasters on urban safety.

2.2 Urban Comprehensive Risk System Framework

The term risk has a vague and controversial origin. The definition of risk was first proposed in the field of insurance, which defined risk as the probability of damage caused by an event. In the 20th century, risk assessment was established as a formal discipline in the fields of engineering and science, and the concept of risk theory was introduced and applied to disaster research.

The risk framework is a conceptual model that highly summarizes the risk elements and their interrelationships considered in a risk system, and is the theoretical basis for conducting risk assessment work. In the field of disaster risk research, many scholars have proposed various forms of risk system frameworks based on a single type of disaster. The mainstream viewpoints include the following two categories.

(1) Emphasize the relationship between disaster and damage.

This type of research suggests that disaster risk refers to the loss and probability of a certain area experiencing a certain intensity of disaster in a certain period of time in the future[12]. This definition elucidates the two essential attributes of disasters, namely non profit and uncertainty. Among them, quantifying uncertainty is the key to the entire risk assessment work, including calculating the probability of the occurrence of a certain intensity of disaster causing factors and the loss under certain probability conditions. Generally speaking, there is a clear inherent relationship between the probability and intensity of disaster causing factors. Based on understanding the mechanism of disaster causing factors, their exceedance probability and regression period can be calculated based on historical data. At the same time, disaster losses are closely related to the intensity of the causative factors, and factors such as disaster intensity/intensity, impact range, and duration are all determining factors of losses. Therefore, this type of research mainly focuses on the interrelationship between the probability of disaster occurrence, disaster intensity, and losses. Through statistical analysis of historical disaster situations, disaster loss curves are established to obtain the relationship function between disaster characteristics (probability or intensity, etc.) and disaster losses, in order to evaluate future disaster risks and possible losses.

The general risk assessment model that emphasizes the relationship between disaster and damage is R=f (L, P), where R is the risk, L is the loss, P is the probability of disaster occurrence, and f represents the functional relationship between the two. This model highlights the nature of disasters, but its focus is on the risk analysis of disaster causing factors, and it lacks consideration of other elements in the disaster risk system (such as disaster pregnant environment, disaster bearing body, etc.). The construction of such models requires analysis and fitting of a large amount of historical disaster data, therefore, the quality of historical disaster data has a significant impact on the accuracy of risk assessment results. In the context of global climate change and rapid urbanization, the evolution of disaster prone environments is accelerating, and the frequency of disasters caused by the coupling of natural and human factors increases nonlinearly. The amplification effect of disaster losses is more complex, which puts higher demands on the quantification of uncertainty in risk assessment.

(2) Emphasize the relationship between risk factors.

Disaster risk is determined jointly by various participants in the disaster process. The "Risk Triangle" framework proposed by Crichton [13] and improved by Granger [14] points out that disaster risk is jointly determined by hazard (H), vulnerability (V), and exposure (E). Shi Peijun [15] believes that the disaster risk system consists of three elements, namely the stability of the disaster prone environment (ES), the hazard of the disaster prone factor (HR), and the vulnerability of the disaster prone body (SV). He also proposes that while emphasizing the study of disaster prone factors, it is necessary to also pay attention to the study of the spatiotemporal dynamic changes of the disaster prone environment and the disaster prone body. This viewpoint emphasizes the importance of the disaster environment in the disaster process, revealing that disasters are a dynamic process that changes with the environment. Other risk factors depend on the environment and are linked by their presence in the same environment. Subsequently, Zhang Jiquan et al. [16]

proposed a four element risk system framework, which considers hazard (H), exposure (E), vulnerability (V), and disaster prevention and mitigation capabilities (C) in risk assessment.

3. Current status of research on the coupling mechanism of multiple disasters

3.1 Basic Concepts of Multiple Disasters

The disaster system includes three key elements: the disaster environment, the disaster causing factors, and the disaster bearing body. In multiple disaster problems, the three can have multiple combinations in terms of space, time, and intensity. In order to clarify the combination relationship of multiple disasters, existing research describes the correlation between different disasters as cascading effects [16], domino effects [17], inducing effects [18], chain effects [19], etc., to represent the phenomenon of "one disaster triggering another disaster". Some scholars have also described this combination relationship as encountering events [20], coupling events [21], correlated events [22], etc., to represent the phenomenon of "one disaster causing a change in the state of another disaster". These descriptions to some extent reflect the complex combination relationship of multiple types of disasters, but there is overlap in the meanings of some concepts, and their use is also somewhat confusing. Ming Xiaodong et al. [23] summarized the complexity of multiple types of disasters from four aspects: interaction, occurrence time, impact range, and disaster causing effects. He believes that from the perspective of interaction, different disaster causing factors may be independent of each other or may be interrelated. The existence and degree of such correlation have a significant impact on the disaster situation; From the perspective of occurrence time, the causative factors may occur simultaneously or sequentially, and the order and time interval of occurrence will affect the final disaster losses; From the perspective of the scope of influence, it may be either separated from each other or overlapping, and the size of the overlapping area determines the final scope of influence; From the perspective of disaster effect, the disaster may be aggravated or mitigated, and there may be no obvious impact (for example, the successive rainstorm after the Wenchuan earthquake triggered landslides, further aggravating the disaster; on the contrary, the Yangtze River basin can effectively alleviate the drought when encountering typhoons in the summer drought period). Among the four aspects, interaction is the foundation of all relationships and plays a decisive role in the occurrence time, impact range, and disaster causing effect of multiple disasters. Shi Peijun et al. [24] summarized the complex multi disaster phenomena in disaster systems as disaster clusters, disaster chains, and disaster encounters, and systematically compared and discussed their scientific connotations. Based on this, they proposed a multi disaster conceptual model, which has been widely recognized in disaster risk research. Therefore, referring to its research, based on the concepts of disaster clusters, disaster chains, and disaster encounters, further explore the conceptual models of multiple types of disasters and their sources, properties, and consequences.

3.2 Current status of research on the interaction relationship between multiple disasters

The interaction between various disasters involved in urban safety is very complex. Some scholars have studied the interaction relationship between natural disasters and multiple types of disasters. Based on the research results of Kappes et al. [25], three types of multi disaster effects have been summarized: exposure of buildings to various disasters, simultaneous impact of disasters, and continuous occurrence of disaster events in the same area in a short period of time. According to the summary of WANG et al. [26], the typical complex interrelationships between multiple hazards are mainly composed of mutual amplification effects, no influence effects, and mutual exclusion effects. TILLOY et al. [27] classified the interrelationships between disasters into five categories: triggering, changing conditions, composite, independent, and mutually exclusive. By analyzing the magnitude of the interrelationships between disasters, they derived interactions and concluded that there are three levels of correlation between disasters: strong correlation based on causality before and after, weak correlation based on causative factors, and no correlation. In addition, Ba et al. classified multiple types of disasters into five categories based on their dynamic evolution process [28]: concurrent, superimposed, cumulative, cascading, and long-term, demonstrating the coupling relationship between typical multi hazard cases.

4. Research summary and trends

Through a review of the current research status of urban safety risk assessment models and multi disaster coupling, we have drawn the following conclusions:

At present, there has been some progress in the research of urban safety risk assessment models, and various models have been applied in different fields. However, existing models still have some limitations, such as insufficient adaptability to certain complex situations and high data requirements. The study of multi disaster coupling is gradually receiving attention, revealing the interrelationships and synergistic effects between different disaster types. However, the complexity of multi disaster coupling poses challenges for research and requires further in-depth exploration.

Future research should focus on the following aspects:

1. Further improve the evaluation model to enhance its accuracy and applicability.

2. Strengthen the research on the coupling mechanism of multiple disasters and gain a deeper understanding of the mutual impact of disasters.

3. Promote interdisciplinary cooperation and integrate knowledge and technology from different fields.

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