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Social vulnerability assessment of earthquake disaster based on the catastrophe progression method: A Sichuan Province case study

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ABSTRACT

The identification of regions of social vulnerability to earthquake disaster and factors contributing to social vulnerability is significant for effective earthquake disaster risk management. To assess social vulnerability to earthquake disaster, this paper applied a rough set to construct an evaluation model of social vulnerability based on catastrophe progression. Following in-depth literature researches, an assessment model of social vulnerability to earthquake disaster in Sichuan Province, China, based on the catastrophe progression method was established. A rough set attribute reduction method was adopted to eliminate irrelevant social vulnerability indicators and optimize the proposed model. Finally, a catastrophe progression method for social vulnerability to earthquake disaster is developed to overcome the subjectivity of the index weight assignment of social vulnerability indicators in the currently used social vulnerability assessment method. The application of our method to Sichuan Province indicates large regional differences in terms of social vulnerability to earthquake disasters. The results show that the northeastern and central areas of Sichuan Province belong to the high social vulnerability category; in particular, Guangyuan is the most vulnerable region. These findings will provide policymakers with a scientific basis for their earthquake disaster risk management strategies.

1. Introduction

As a natural disaster, earthquake disaster has very strong destructive power, widespread range, and severe threat to human life safety [1,2]. China is in the Asia-Pacific and Pacific Rim seismic zone where the earthquake disasters occur frequently. According to the statistics, in China, from 2003 to 2008, there were 265 magnitude > 5 earthquakes, 59 magnitude > 6 earthquakes, and six magnitude > 7 earthquakes. Among these earthquakes, the 2008 earthquake in Wenchuan, Sichuan Province, resulted in 69,227 deaths, 17,923 people missing, 373,583 people injured and, a direct loss of 852.3 billion RMB [3].

It is very difficult to predict earthquakes accurately with the currently available technoligies. Vulnerability reduction is a core element of managing or reducing disaster risk and has been identified as the most significant prerequisite for resilience under degrees of exposure to disasters. Therefore, to reduce the damage caused by earthquake disasters, it is particularly important to study the assessment of social vulnerability to earthquake disasters. Timely and effective disaster risk management strategies not only rely on an adequate understanding of the disaster itself, but should also explore the sense of exposure and vulnerability in the society [4]. The probability of a natural disaster having effects that are more devastating in one place than in another deeply depends on the local vulnerability components of the affected society, such as its sociocultural and economic environment. Indeed, there is an important correlation between the potential risk and the social resistance and resilience of a specific place. Social vulnerability analyses aim to understand which population groups may be the most vulnerable to the impacts of natural hazards and identify the key factors that affect social vulnerability [5]. The results of social vulnerability study, can be used in future for risk management decisions, including risk reduction, prevention and mitigation [6]. Social vulnerability describes the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard. Socially vulnerable groups are victims who tend to be treated as groups with special needs, these people experience higher social vulnerability, which means that they are more at risk than others are [7]. Because of its complexity, scholars currently have different definitions for the concept of social vulnerability. Koks et al. [8] considered social vulnerability as the ability to deal with disasters. Chen et al. [9] indicated that social vulnerability influences people's ability to make full pre-disaster preparations under the pre-existing conditions, and to recover from post-disaster reconstruction. Clark et al. [10] discussed social vulnerability in references to the extent of damage caused by a disaster suffered by specific social groups,

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organizations or countries [10]. Bankoff et al. [11] noted that vulnerability is the key to understanding risk in an attempts to break away from the attitudes that have characterized relationships between human societies and their environment, Understanding vulnerability requires more than a simple understanding of societies and their environment; social vulnerability is also about people, their perceptions, and knowledge. However, vulnerability is not a property of social groups or individuals, but is embedded in complex social relations and processes. Several other definitions can also be found in the literature. For example, in their book, The Environment as Hazard, Burton et al. [12]emphasized that social vulnerability is related to all kinds of changes, including natural, social, and individual' changes, which expose people to the risk of disaster.

Some differences in these definitions of social vulnerability could be found in the literature; however, those social vulnerability researches have a common focus with an emphasis on individual, group, and social abilities to cope with disaster stress and disturbance. Thus, we could conclude that the theoretical connotation of social vulnerability should be understood from two aspects. On the one hand, social vulnerability emphasizes the sensitivity of the entire social system to the impact of disasters which involves two aspects. First, the potential factors contributing to the fragility of the system, including social, economic, political, cultural, and institutional factors, are reflected in the overall sensitivity of the social system. Second, under adverse effects of disaster events, the magnitude of the loss of elements in the social system is reflected in the sensitivity of its internal elements. On the other hand, social vulnerability also emphasizes the disaster response and adaptability, embodied in the social system within the elements of the state, which change through a feedback mechanism and influence the structure and function of the system. Social vulnerability is an existing state of the human social system, which refers to the extent to which the human social system manifests the degree of vulnerability, the magnitude of the disaster response and the ability to adapt, under the impact and disruption of existing or anticipated disaster events.

Although there has been real progress in the theoretical underpinnings of social vulnerability over the past two decades, this advancement in developing methods for measuring social vulnerability is insufficient. Cutter et al. [13–15] created social vulnerability index to understand society's responsibilities when disasters occur, and several scholars have cited Cutter et al.'s thoughts about social vulnerability. The weight assignment of social vulnerability indicators is still a major challenge for social vulnerability assessment, and there seems to be no consensus in the literature. Koks et al. [16] combined disaster, exposure, and social vulnerability to explain the social vulnerability to flooding disasters in Rotterdam, the Netherlands. They analyzed six indicators extracted from the previous literature: total population, single parent family, non-European immigrants, population under 14 years old and above 65 years old, average monthly income, and average construction age. The same weight is assigned to each social vulnerability indicator to create comparative results for each social vulnerability variable. Box et al. [17] utilized a mixed-methods approach including a quantitative questionnaire and qualitative interviews to research flood risk responses in Brisbane, Australia, and understand what factors helped or hindered the response and adaptation to flood risk. Zebardast [18] used a factor analysis with Analytic Network process model to evaluate the social vulnerability to earthquake disasters in Iran. They applied spatial data analysis to reveal the spatial patterns in Iran to provide the theoretical basis for earthquake disaster risk management. Arias et al. [19] highlighted the necessity of developing a vulnerability-centered risk management framework based on social cohesion and integration principles. Zeng et al. [20] focused on Luogang District in Guangzhou, the capital of Guangzhou Province in China. Because of the restriction of unavailable data, they proposed a new social vulnerability assessment method for natural disasters based on remote sensing technology. After analyzing three indices, i.e., land use of population density, age structure, and family household distance to the hospital, Zeng et al. used an expert evaluation method to determine the index weights, and finally demonstrated that this method would provide a reasonable theoretical basis for natural disaster risk management. Rufat et al. [21] indicated that a significant challenge in measuring social vulnerability to hazards is identifying influencing factors that to reflect better the context in which vulnerability occurs. They identified demographic characteristics, socioeconomic status, and health as the leading empirical drivers of social vulnerability to damaging flood events. In the previous literature, the most commonly used methods for the analysis of social vulnerability were the Analytical Hierarchy Process (AHP), Principal Component Analysis (PCA), and Geographic Information System (GIS), which helped manage, identify, and visualize the social vulnerability index of a specific area [22]. For instance, to explore the local social vulnerability to natural disasters in Henan Province, China. Liu and Liang [23] applied PCA and AHP to establish a social vulnerability assessment model for natural disasters. The results of the assessment were obtained and using ArcGIS for the regionalization mapping. To understand the abilities of individuals, households, communities, and societies to anticipate, cope with, resist, and recover from the impact of natural disaster, Frigerio et al. [24] used a GIS to identify the spatial variability of social vulnerability to seismic hazards in Italy. They used a qualitative social vulnerability exposure map to show the importance of the integration of social vulnerability studies into seismic risk mitigation policies. Zhang and You [25] selected 45 indicators for social vulnerability to natural disaster from demographic and socio-economic aspects of Shanghai, China. They applied PCA to these selected variables and produced 16 indicators. Social vulnerability scores for the 18 Shanghai counties were calculated by applying the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) method, where a higher social vulnerability score indicated higher social vulnerability. Finally, Zhang and You [25] analyzed the regional characteristics for the social vulnerability to natural hazards in Shanghai, to provide a scientific basis for urban natural disaster risk management and regional disaster prevention and mitigation.

It can be concluded that there is a great variety of classifications for large number of social vulnerability indicators. Because of the abstract and complex nature of social vulnerability itself, social vulnerability assessments are currently facing two challenges. The first challenge is the construction of the social vulnerability index system. Index systems are usually based on subjective experience. However, although it can be proven that the index system is scientific and rational, the evaluation system for index information may show overlaps, thus redundancy index may easily cause evaluation error. The second challenge is to assign weights to the social vulnerability index. Previous studies on weight assignment methods, such as AHP, and expert consultation method, are strongly subjective. This subjectivity defect greatly reduces the credibility of social vulnerability assessments, and even leads to incorrect evaluation results.

The increasing importance of measuring social vulnerability has triggered many attempts to provide solutions in recent years. Several significant attempts were made to study social vulnerability in different nations, such as America [26,27], Italy [28], and Australia [29,30]. Sichuan Province has the highest probability for earthquakes and related economic losses, however, no studies have assessed its social vulnerability to date. Therefore, the goal of this paper is to construct a catastrophe progression model for social vulnerability assessment in combination with rough set theory, and then apply it to Sichuan Province. A 486 000 km^2 region in southwestern China. Sichuan Province is located in the Himalayas-Mediterranean seismic belt. The mainly mountainous in Sichuan Province includes four kinds of terrain: mountains, hills, plains, and plateaus. Sichuan Province is divided into 21 administrative regions, including a deputy provincial city, 17 prefecture-level cities, and three minority autonomous prefectures. Earthquake disasters not only occur extremely frequently, but also their effects spread widely throughout Sichuan Province. According to the