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Spatiotemporal Changes in Social Vulnerability to Rainstorm-Driven Flood Disasters in Henan Province

Yiting Sun*

School of Emergency Management, Henan Polytechnic University, Jiaozuo, Henan, 454000, China

*2450232647@qq.com

Abstract

Rainstorm-induced flood disasters have intensified in Henan Province in recent years, magnifying social impacts and elevating social vulnerability. This study examines the spatiotemporal evolution of social vulnerability to rainstorm–flood hazards and develops targeted reduction strategies. Using the Vulnerability Scoping Diagram (VSD) framework, an index system incorporating sensitivity and social coping capacity was established, with indicator weights determined through the entropy method and vulnerability levels quantified via a comprehensive index. The results show that from 2014 to 2020, sensitivity steadily declined while coping capacity improved, leading to a gradual decrease in overall vulnerability. Spatially, sensitivity is lower in the north and west and higher in the south and east, whereas coping capacity strengthens from west to east; consequently, vulnerability increases from west to east and north to south, with river-adjacent areas exhibiting the highest levels. The study recommends prioritizing riverine zones, reducing agricultural dependence in high-sensitivity areas, and enhancing socioeconomic development in western regions.

Keywords

Social Vulnerability; Rainstorm–Flood Disasters; Spatiotemporal Evolution; Vulnerability Scoping Diagram (VSD); Entropy Weight Method.

1. Introduction

In recent years, the frequency of rainstorm-induced flood disasters has increased significantly in Henan Province due to the intensification of extreme weather events and rapid urbanization. These disasters are characterized by sudden onset, wide spatial impact, and severe losses. Beyond threatening human lives and property, they exert profound effects on regional socioeconomic systems, public service capacities, and vulnerable groups, thereby amplifying social vulnerability. Consequently, assessing social vulnerability to rainstorm–flood disasters is essential for enhancing disaster prevention and mitigation capacity, optimizing resource allocation, and formulating evidence-based governance strategies[1].

As a core component of disaster risk, social vulnerability reflects the sensitivity of a social system to external hazards and its capacity to respond and recover. Existing research has predominantly focused on hydrological simulation, hazard mechanisms, and physical exposure assessment, whereas studies on the spatiotemporal evolution of social vulnerability-particularly at the provincial scale-remain relatively limited. Henan Province, characterized by complex topography, dense population, and uneven regional development, exhibits typical and representative features in the formation and transformation of social vulnerability[2].

Therefore, this study constructs an evaluation index system comprising sensitivity and social coping capacity, grounded in the Vulnerability Scoping Diagram (VSD) framework. Using the entropy weight method and a comprehensive index approach, it systematically analyzes the

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spatiotemporal patterns of social vulnerability to rainstorm–flood disasters in Henan Province from 2014 to 2020[3]. Furthermore, the study proposes differentiated vulnerability-reduction strategies to provide scientific support for disaster risk governance and resilience enhancement in the province.

1.1. Research Area and Data SourcesSection Headings

Henan Province is located in central–eastern China, spanning 31°23′–36°22′ N and 110°21′–116°39′ E (Figure 1), with a total area of 165,700 km^2.

For the temporal analysis, this study draws on data from the Henan Statistical Yearbook (2014–2020) and selects indicators such as population density, economic density, and the proportion of primary industry in GDP.

For the spatial analysis, the equal-interval method is adopted, and the years 2014, 2017, and 2020 are selected as reference points. The spatial distribution characteristics of social vulnerability to rainstorm–flood disasters are examined across 17 prefecture-level cities in Henan Province and one province-administered county-level city, Jiyuan.

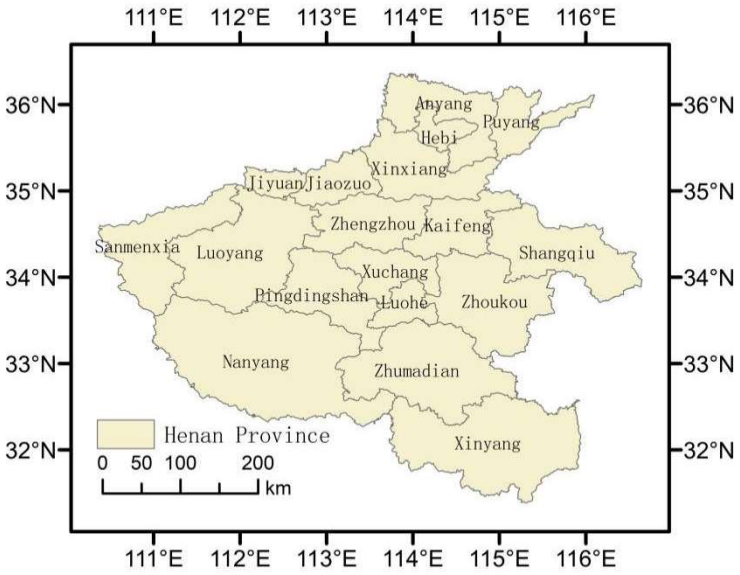

Figure 1. Overview of the Scope and Administrative Divisions of Henan Province

2. Evaluation Index System for Social Vulnerability of Rainstorm and Flood in Henan Province

2.1. Select Evaluation Indicators

This paper refers to the VSD framework and selects two dimensions, namely sensitivity and social response capacity, to measure the strength of social vulnerability. For sensitivity, four indicators are selected as references: population density, economic density, the proportion of the primary industry in GDP, and the proportion of the population engaged in the primary industry. Sensitivity refers to the degree to which a region's social system is affected or likely to be affected by external disturbances. After a rainstorm and flood event, the population and economy of the region are the two main aspects that may be disturbed by external factors; the primary industry mainly refers to agriculture, and Henan Province is a major agricultural province. Compared with other industries, agriculture suffers the most severe losses during rainstorm and flood events; the proportion of the population engaged in the primary industry can reflect the number of people in the region who are engaged in the primary industry and the

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number of people who may be affected during a rainstorm and flood event. Therefore, the four indicators of population density, economic density, the proportion of the primary industry in GDP, and the proportion of the population engaged in the primary industry are selected as references for sensitivity.

For social response capacity, three indicators are selected as references: urbanization rate, per capita GDP, and the proportion of expenditure on agriculture, forestry, and water affairs. Social response capacity refers to the ability of a region's society to defend against and respond to disturbances and pressures. The urbanization rate can reflect the distribution of the population between urban and rural areas in the region and show the management and development level of the region; per capita GDP is the per capita gross domestic product of the region, and through per capita GDP, the economic development situation of the region can be effectively understood. During a rainstorm and flood event, per capita GDP can reflect the response and recovery and reconstruction capabilities of individuals and the region; the proportion of expenditure on agriculture, forestry, and water affairs can reflect the expenditure and emphasis on the construction of modern agriculture development, rural infrastructure, and other expenses in the region. The construction of reservoirs, ponds, electric wells, irrigated areas at the end of the year, and drainage areas in the region can effectively prevent and reduce the losses caused by rainstorm and flood events. Therefore, the three indicators of urbanization rate, per capita GDP, and the proportion of expenditure on agriculture, forestry, and water affairs are selected as references for social response capacity.

2.2. Determine the Index Weights

This paper calculates the weights of the evaluation indicators of social vulnerability through the entropy method. The entropy method is a way to determine the weights of indicators by using entropy values (Table 1).

Table 1. Evaluation Index System for Social Vulnerability of Rainstorm and Flood in Henan Province

Criterion layer	Index level	Entropy value method weight	Criterion Attribute
sensibility	Population Density (persons/km^2)	0.1786	Positive
	Economic Density (10,000 yuan/km^2)	0.4261	Positive
	Proportion of Primary Industry in GDP (%)	0.3040	Positive
	Proportion of Employed Persons in Primary Industry (%)	0.0913	Positive
Social Response Capacity	Urbanization Rate (%)	0.1296	Negative
	GDP per Capita (yuan)	0.5730	Negative
	Percentage of Expenditure on Agriculture, Forestry, and Water Conservancy (%)	0.2974	Negative

2.3. Data Processing

Due to the different units of various indicators for sensitivity and social coping ability, this will have an impact during data analysis. Therefore, it is necessary to perform appropriate dimensionality normalization on the data, while retaining the relative meaning of the numbers. This paper considers sensitivity as a positive indicator and social coping ability as a negative indicator. To make the data easier to analyze, this paper performs dimensionality unit processing on the data, converting the data of positive indicators to positive and the data of negative indicators to negative [4].

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2.4. Evaluation Method

This study employs the comprehensive index method to calculate the sensitivity index and the social response capacity index, thereby constructing an evaluation model for social vulnerability to rainstorm and flood disasters in Henan Province.

3. Temporal and Spatial Evolution Patterns of Social Vulnerability to Rainstorm and Flood Disasters in Henan Province

3.1. Temporal Evolution of Social Vulnerability to Rainstorm and Flood Disasters in Henan Province

Based on the evaluation model of social vulnerability, the social vulnerability index for the period 2014–2020 was calculated, and a line chart illustrating the temporal evolution pattern of social vulnerability was plotted (Figure 2).

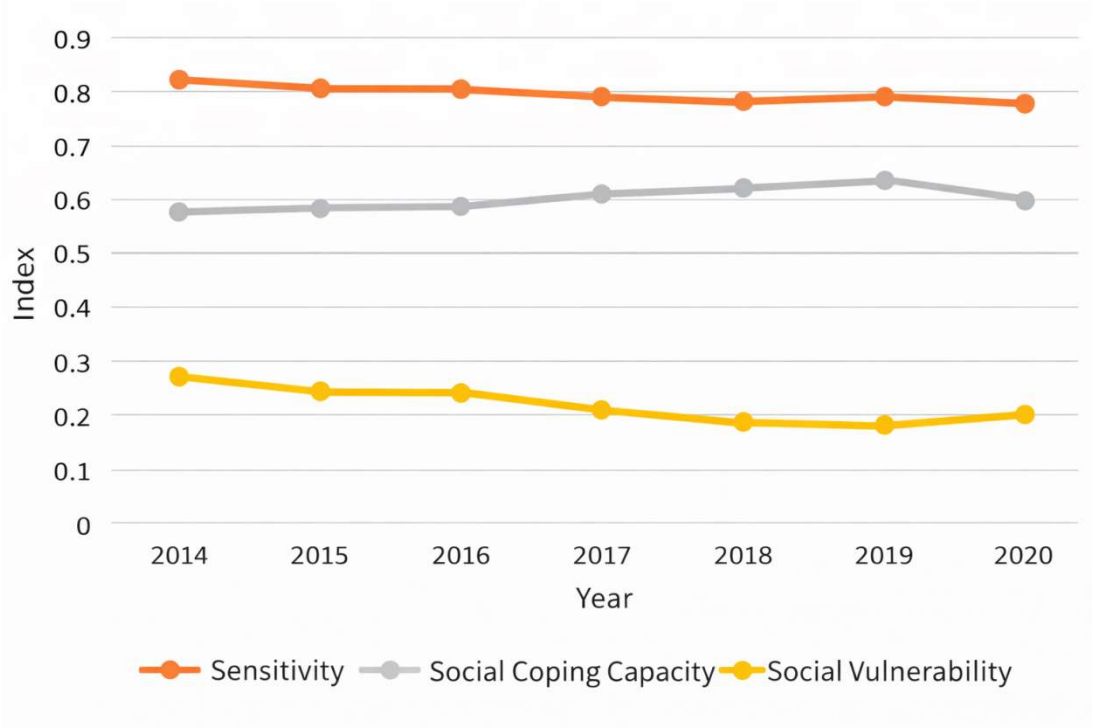

Figure 2. Trend of Social Vulnerability Index to Rainstorm and Flood Disasters in Henan Province, 2014–2020

As can be seen from Figure 2, the sensitivity index shows a steady decline, with a decrease of 3.69% in 2017 compared to 2014, and a decrease of 5.66% in 2020 compared to 2014. The social response capacity generally exhibits an upward trend, increasing by 6.19% in 2017 compared to 2014, and by 3.01% in 2020 compared to 2014. Overall, social vulnerability displays a downward trend, decreasing by 26.61% in 2017 compared to 2014, and by 25.81% in 2020 compared to 2014.

3.2. Spatial Distribution Characteristics of Social Vulnerability to Rainstorm and Flood Disasters in Henan Province

The spatial distribution maps of social vulnerability to rainstorm and flood disasters in Henan Province for the years 2014, 2017, and 2020 are presented in Figure 3. It can be observed that social vulnerability generally increases from west to east and from north to south[5]. Over time,

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social vulnerability to rainstorm and flood disasters in Henan Province has shown a gradual decrease.

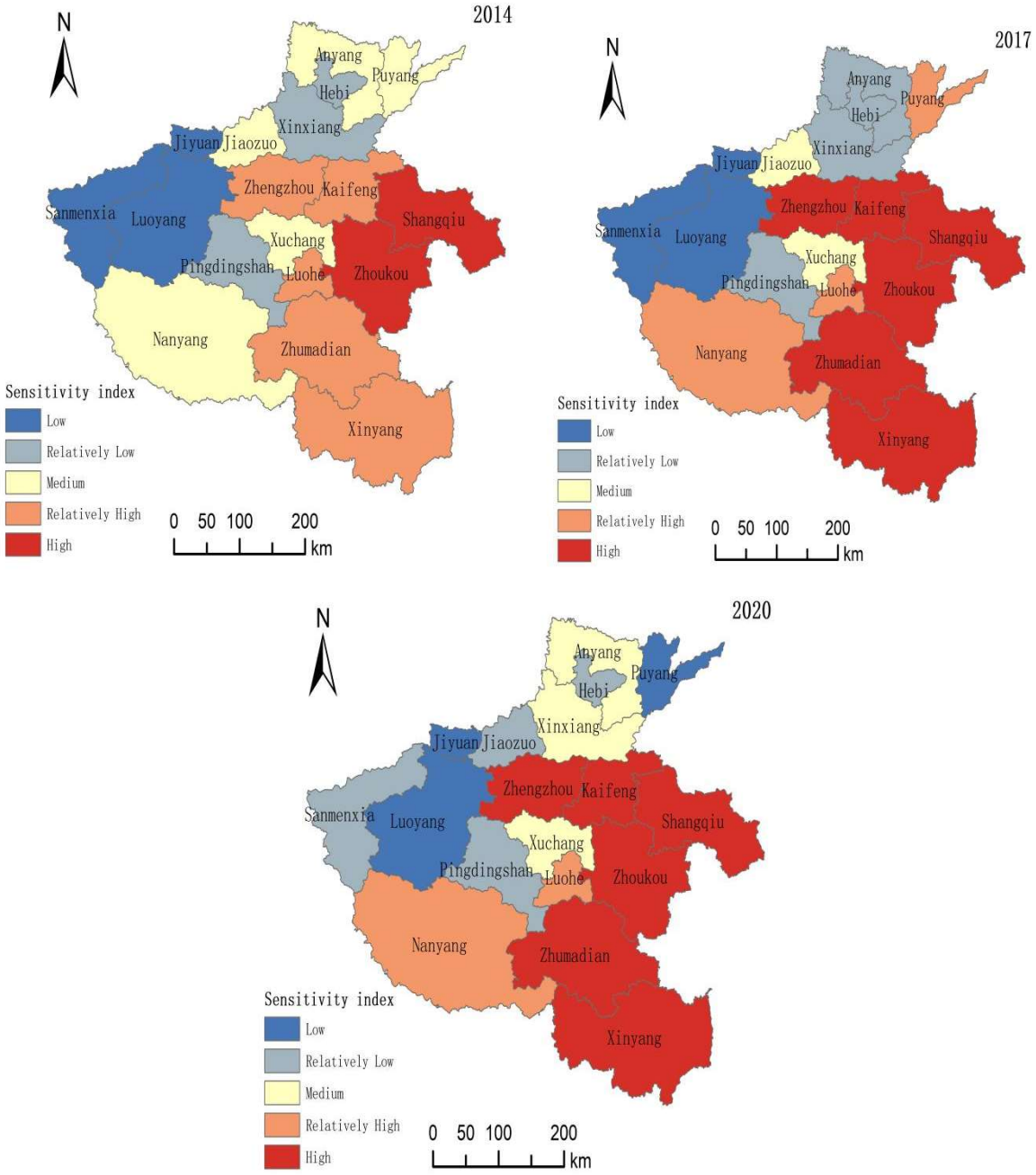

Figure 3. Distribution Characteristics and Dynamic Evolution of Social Vulnerability to Rainstorm and Flood Disasters in Henan Province

Areas located in the southeastern part exhibit higher social vulnerability. Although the southeastern regions demonstrate relatively high social response capacity to rainstorm and flood disasters, their sensitivity is also elevated, resulting in greater social vulnerability in these areas.

Riverside areas show higher social vulnerability. The topography and terrain in these regions are relatively flat, leading to rapid water level rise during floods and comparatively weaker flood resistance capacity. Consequently, social vulnerability is higher in riverside areas.

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Over time, the sensitivity to rainstorm and flood disasters in Henan Province has gradually decreased, while social response capacity has steadily improved. As a result, social vulnerability to rainstorm and flood disasters in the province has been continuously declining.

4. Conclusion

Social vulnerability refers to the weaknesses and deficiencies within a social system when facing external shocks or internal changes, including its capacity to withstand stress, respond effectively, and recover. This may result in the system's inability to cope with and recover from crises efficiently, thereby leading to severe social issues and disasters. Reducing social vulnerability can enhance the ability to manage external pressures and internal changes, safeguarding the stability and development of individuals and society as a whole.

Drawing on the VSD framework, this study constructed a social vulnerability evaluation index system. The entropy method was applied to determine the weights of each indicator, and a social vulnerability evaluation model was established. Using the comprehensive index method, sensitivity and social response capacity indices were calculated, followed by the computation of social vulnerability indices for 18 cities in Henan Province. The main findings are as follows:

(1) Over time, the sensitivity to rainstorm and flood disasters in Henan Province has continued to decrease, while social response capacity has steadily increased. As a result, social vulnerability has shown a significant declining trend, indicating enhanced stability and sustainable development capacity of the social system.

(2) Spatially, sensitivity gradually increases from west to east and from north to south. Social response capacity strengthens progressively from west to east. Social vulnerability rises from west to east and from north to south. Additionally, social vulnerability in riverside areas is substantially higher than in other regions.

(3) Areas with high social vulnerability are typically characterized by high dependence on agriculture, location along rivers, and relatively high economic and population density. However, for rapidly developing regions such as Zhengzhou and Nanyang, high social vulnerability is primarily attributed to insufficient expenditure on agriculture, forestry, and water conservancy, leading to inadequate social response capacity. In contrast, for economically lagging regions such as Luohe and Kaifeng, high social vulnerability results from low urbanization rates, underdeveloped economies, excessive sensitivity, and insufficient social response capacity.

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