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Social Vulnerability Evaluation of Natural Disasters and Its Spatiotemporal Evolution in Zhejiang Province, China

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Abstract: Natural disasters present a significant challenge to the productivity of Zhejiang Province. This paper is the first to evaluate social vulnerability to natural disasters in Zhejiang Province and provides a scientific foundation for disaster prevention, mitigation, and risk management. In this paper, we construct an indicator system for evaluating social vulnerability of natural disasters in Zhejiang Province through demand analysis, frequency analysis, and applicability analysis. The methodology employed in this paper reduces errors arising from subjective indicator selection and provides a reference for future international research on evaluating social vulnerability to natural disasters. This study analyzes the spatiotemporal evolution of social vulnerability to natural disasters in 11 cities from 2011 to 2020. The results indicate an overall downward trend of social vulnerability to natural disasters in Zhejiang. Social vulnerability to natural disasters exhibits significant spatial variability. The evaluation can help to bridge the knowledge gap regarding the social vulnerability of Zhejiang Province to natural disasters. The analysis of the spatiotemporal evolution of social vulnerability provides insights into the contributing factors to vulnerability and the effectiveness of past disaster management strategies. The findings of this study can serve as a valuable reference for future research in Zhejiang Province and other regions facing similar challenges. The results can contribute to the advancement of comprehensive knowledge of social vulnerability to natural disasters, which can inform the development of policies and strategies aimed at mitigating disaster risk and promoting effective disaster management globally.

Keywords: natural disaster; social vulnerability; evaluation; indicator system; spatiotemporal evolution

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1. Introduction

In 2019, a total of 8,960,600 individuals in Zhejiang Province was impacted by various natural disasters, including floods, typhoons, storm surges, drought, and high temperatures, 62 of whom died, and the direct economic loss reached 7.98 billion US dollars [1]. These natural disasters seriously affect the economic and social development of Zhejiang Province and threaten people's lives, highlighting that this province is somewhat vulnerable to natural disasters.

Social vulnerability to natural disasters refers to the degree to which a system produces adverse responses when disasters strike [2]. Evaluating social vulnerability to natural disasters is essential for understanding the derivatives and trends of disasters, proposing risk-prevention measures for vulnerable areas, and formulating differentiated post-disaster relief and reconstruction programs. Evaluating social vulnerability and exploring the spatiotemporal evolution of natural disasters in Zhejiang Province are extensive tasks. It involves aspects of physical geography, causes of disasters, and social economy; departments of emergency, water conservancy, and statistics; and different regions and time nodes. All these make it challenging to develop evaluation methods and collect and collate data. In this context, it is of great theoretical and practical significance to evaluate social vulnerability and investigate the spatiotemporal evolution of natural disasters in Zhejiang Province, which can help understand the spatiotemporal evolution and characteristics of natural disasters, prevent natural disaster risks, and facilitate post-disaster relief and reconstruction.

The concept of vulnerability first appeared in disaster research in geoscience, characterizing the degree to which research objects were susceptible to external factors due to their exposure and sensitivity [2]. In 1999, Mileti and Ebrary [3] used vulnerability to evaluate natural disasters when studying the impact of natural disasters such as earthquakes, floods, and typhoons on population, ecology, and society. They defined natural disaster vulnerability as the possibility of a disaster-bearing system being damaged by natural disasters. In 2003, Cutter et al. [4] proposed an evaluation indicator system of social vulnerability to natural disasters and regarded social vulnerability to natural disasters as the product of social inequality; inequality factors affected the sensitivity of different groups to disasters to some extent, further impacting their coping ability/resilience. To sum up, social vulnerability to natural disasters in our study refers to the weak link of society when natural disasters attack it: the exposure of social systems, sensitivity to natural disasters, and coping ability/resilience of social systems [2–4]. Exposure refers to the nature of the public, properties, or other components located in a hazardous area that are vulnerable to natural disasters, and sensitivity refers to the degree of susceptibility of the disaster-bearing body to natural disasters [5]. Coping ability/resilience also addresses the ability of social systems to withstand natural disasters and return to their initial state after natural disasters [6]. The degree of social vulnerability to natural disasters depends on the combined influence of the above three factors.

The following aspects primarily reflect the current research on the social vulnerability evaluation and spatiotemporal evolution of regional natural disasters.

- In terms of study areas, studies have evaluated the social vulnerability to natural disasters of landslides [7], floods [8], droughts [9], typhoons [10] et al. at the national level, such as in Malawi [11], Tonga [12], Sri Lanka [13], and Brazil [14]; at the provincial (state) level, such as the provinces of Sichuan [15], Fujian [16], and Anhui [17] and Liaoning [18] in China; and at the municipal level, such as Nanjing [19], Xi'an [20], Urumqi [21] in China, Mzuzu city Malawi [11], and the city of Mount Gambier [22] in Australia.
- Regarding the evaluation methods, existing studies have primarily used the indicator system method [11,15–21], the entropy-criteria importance through intercriteria correlation (CRITIC) method [23], and the fuzzy comprehensive evaluation method [24] combined with the mathematical models to evaluate the degree of social vulnerability to natural disasters in the study area. The indicators are usually selected in two ways. One way is to select indicators from sociodemographic, social structural, and socioeconomic perspectives based on the properties of the disaster-bearing body [17,18,21]. The other is to select indicators of exposure, sensitivity, and coping ability/resilience based on the intrinsic structural characteristics of social vulnerability to natural disasters [3–5]. Additionally, some studies employ system dynamics models to predict changes in social vulnerability to natural disasters [22].
- Through the evaluation, existing studies have mainly concluded the degree of social vulnerability to natural disasters, factors influencing social vulnerability to natural disasters, the spatiotemporal evolution of vulnerability, and suggestions for reducing vulnerability.

Generally, although there are many studies to utilize, there is still room for further improvement, primarily in the following aspects: (1) There is no subfield analysis of the demand for the evaluation indicators of social vulnerability to natural disasters in Zhejiang Province. (2) Limited studies have been conducted on the spatiotemporal evolution of social vulnerability to natural disasters in Zhejiang Province. Zhou et al. evaluated social vulnerability to natural disasters at the provincial level in China [25]. Their discussion focused on the spatial patterns but did not address the law of temporal evolution. Liao et al. conducted an analysis of heavy rain and flood disasters on the vulnerability of populations at the county level in Zhejiang Province [26]. However, they were limited by data availability issues and were unable to conduct a calculation analysis of the past decade.

(3) Some proposed evaluation indicators are weak in operability and high in management costs, making them difficult to apply in practice.

This paper aims to establish a system for evaluating social vulnerability to natural disasters. An analysis of the spatiotemporal evolution of social vulnerability to natural disasters in Zhejiang Province will be conducted, and the principal influencing factors will be identified. On this basis, we plan to identify some problems and propose corresponding countermeasures.

2. Materials and Methods

The detailed research process can be divided into the following steps: (1) Constructing an indicator system: Summarize and extract critical common indicators that are widely recognized and consistently applicable. Then, we establish an indicator system for evaluating social vulnerability to natural disasters in Zhejiang Province. (2) Calculation: The social vulnerability index is calculated, and evaluation criteria are designed. (3) Analysis of results: Analyze the evolution of social vulnerability to natural disasters in each city in spatiotemporal dimensions. To discover the patterns, we identify the problems and propose countermeasures. (4) Discussion and suggestions: Based on the research results, we draw conclusions and provide suggestions to offer a scientific basis and reference for evaluating social vulnerability to natural disasters in Zhejiang Province.

2.1. Selecting Evaluation Indicators

(1) Demand analysis: In terms of the three aspects of exposure, sensitivity, and coping ability/resilience of social vulnerability to natural disasters in Zhejiang Province, the demand for selecting the evaluation indicators of social vulnerability to natural disasters is analyzed.

(2) Frequency analysis: The critical common indicators are counted and summarized after collection and organization of vulnerability indicators in the relevant literature.

(3) Applicability analysis: First, we judge whether these indicators are applicable to the actual situation in Zhejiang Province through field research. Second, we determine the feasibility of these indicators without incurring significant additional management costs. Third, screen-relevant indicators based on principles such as data availability and quantifiability.

(4) Correlation test: Verify the interrelationship between data and ensure the availability of indicators.

This paper uses the variance inflation factor (VIF) and SPSS software for correlation analysis. The VIF measures how much the variance of an explanatory variable increases due to multicollinearity [27]. A high VIF value indicates a high degree of multicollinearity. The formula for calculating the VIF of an independent variable x is:

$$VIF_i = \frac{1}{1 - R_i^2} \tag{1}$$

Empirical judgment methods indicate that when $0 < VIF < 10$, there exists no multicollinearity; when $10 \leq VIF \leq 100$, there is strong multicollinearity; and when $VIF \geq 100$, there is severe multicollinearity [28]. It is the coefficient of determination of the regression of other independent variables when X_i is the dependent variable.

2.2. Determining Weights of Evaluation Indicators

The entropy method is a weighting method that objectively determines the weight of indicators based on the size of information obtained from observed values of various indicators. According to the characteristics of entropy, using entropy as a tool, the weights of different indicators are calculated to provide a basis for the multi-indicator comprehensive evaluation method. Since the entropy method can overcome the shortcomings of the relatively low rationality and accuracy of the subjective weighting method as well as avoid the overlap of information between multiple indicator variables, this paper uses the entropy method to calculate the weight and assign values, with the following steps:

(1) Standardized treatment of indicators:

In the evaluation system, due to the difference in the dimensions of each evaluation indicator, when the difference level between the indicators is large, it will affect the final evaluation results. To ensure the accuracy of the evaluation results, this paper utilizes the range standardization method to process the original data:

Positive indicators represent higher social vulnerability for higher indicator values, and negative indicators indicate lower social vulnerability for higher indicator values.

Positive indicators are dimensionless and are defined as:

$$Z_{ij} = \frac{X_{ij} - X_{jmin}}{X_{jmax} - X_{jmin}} \tag{2}$$

Negative indicators are dimensionless and are expressed by:

$$Z_{ij} = \frac{X_{jmax} - X_{ij}}{X_{jmax} - X_{jmin}} \tag{3}$$

where Z_{ij}, X_{ij}, X_{jmax}, and X_{imin} are the standardized, original, maximum, and minimum values of the j-th indicator for the i-th city, respectively.

(2) Calculate the proportion Y_{ij} of the jth indicator of the i-th city as follows:

$$Y_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{m} Z_{ij}} \tag{4}$$

(3) Calculate the entropy value of the j-th indicator (E_j) as follows:

$$E_j = -K \sum_{i=1}^{m} Y_{ij} \ln Y_{ij} \tag{5}$$

where $K = \frac{1}{\ln m}$, $E_j \geq 0$.

(4) Calculate the coefficient of variation for the j-th indicator (G_j) as follows:

$$G_j = 1 - E_j \tag{6}$$

(5) Calculate the weight of the j-th indicator (W_j) as follows:

$$W_j = \frac{G_j}{\sum_{j=1}^{n} G_j} \tag{7}$$

where $i = 1, 2, 3, \ldots, m$, and $j = 1, 2, \ldots, n$.

2.3. Calculating Social Vulnerability Index

The hazard of place (HOP) model is adopted as a method to evaluate environmental risks. It integrates both natural and social factors, therefore overcoming the limitations of prior studies that focused exclusively on a single factor [29]. The HOP model can identify which cities show higher vulnerability. ArcGIS is used in this paper to visualize the results. Social vulnerability to natural disasters in Zhejiang Province is calculated based on the HOP model as follows:

$$VI = \sum_{i=1}^{n} Z_{ij} W_j \tag{8}$$

where VI indicates the social vulnerability index.

2.4. Social Vulnerability Grading Criteria

The natural breakpoint method is a statistical method that classifies and categorizes classes based on the pattern of the statistical distribution of values, maximizing the differences between classes. It is assumed that there are natural (non-artificial) turning points and breakpoints between any series that are statistically significant. By using these turning points, it is possible to divide the study population into clusters of similar nature. Thus, the natural breakpoints can effectively serve as boundaries for grading, reducing the influence of subjectivity on the criteria to some extent [24].

The natural breakpoint method is used to classify social vulnerability to natural disasters in Zhejiang Province under five levels: low vulnerability, mild vulnerability, medium vulnerability, moderate vulnerability, and high vulnerability.

2.5. Data Source

The data used in this study include primary economic data, urban construction data, healthcare data, sociocultural data, and population age structure data. Details of all these types of data required for the evaluation from 2011 to 2020 and their corresponding sources are tabulated in Table 1.

Table 1. The data source required for the evaluation from 2011 to 2020.

NO.	Data Type	Data Source
1	Primary economic data (e.g., economic density, gross domestic product (GDP), disposable income per capita, and the proportion of the primary industry to GDP)	National Economic Statistics Bulletin
2	Urban construction data (e.g., building footprint density and urbanization rate)	Social Development Statistics Bulletin
3	Healthcare data (e.g., the number of hospital beds per 10,000 people)	Local Chronicles and Historical Statistical Yearbook
4	Sociocultural data (e.g., the percentage of the population with higher education and unemployment rate)	Local Chronicles and Historical Statistical Yearbook
5	Data on the population age structure (e.g., the percentage of the population over 60 and under 14 years old and the percentage of the female population)	National Census Data

3. Results

3.1. Constructing Indicator System

3.1.1. Demand Analysis

The demand for the evaluation indicators of social vulnerability to natural disasters is clarified by subfields based on the actual situation of Zhejiang Province.

From the perspective of exposure, the population density of Zhejiang Province in 2021 was approximately 464.09 people/km^2, which is much higher than the level of developed countries such as the United States and European countries in the same period. In other words, a larger population is exposed to natural disasters in Zhejiang Province than in the USA or European countries. Therefore, more human and material resources are needed to ensure public safety in the face of natural disasters in this province. The economic density of Zhejiang Province in 2021 was approximately 1.004 million US dollars/km^2, much higher than China's average level in the same period. A high level of economic density is a double-edged sword. First, a strong economy is conducive to securing investments in disaster prevention and mitigation. Second, the concentration of social wealth may exacerbate city disaster losses. Regarding the exposure dimension, it is believed that the higher the regional economic density, the greater and more concentrated the social wealth of the affected area under the same causative factors, the higher the absolute value of disaster losses, and the more significant the social vulnerability to natural disasters [24].

Considering sensitivity, the percentage of the female population in Zhejiang Province has been approximately 47.7% since 2021, and the population under 14 years old and over 60 years old was roughly 33.5% of the total population. The vulnerability of women, the elderly, and children are higher in the face of natural disasters. Women's vulnerability is associated with their responsibilities for family care, reduced income, social constraints, and challenges in accessing resources. The vulnerability of the elderly and children is related to their physical and psychological well-being [30]. Therefore, more resources should be invested in guaranteeing their security. The unemployment rate continued increasing from 2019 to 2021 because of employment pressure and the impact of the COVID-19 pandemic. Unemployed people are a weak link in economic recovery and a destabilizing factor in natural disasters, which can lead to increased social vulnerability to natural disasters. First, the unemployed population is characterized by an unstable income and a lack of protection from medical and social insurance, among other factors. Second, unemployed individuals generally have a pessimistic mood and difficulty in adjusting their mental state, which are not conducive to natural disaster prevention [31].

From the perspective of the coping ability/resilience of Zhejiang Province, the number of hospital beds per 10,000 people was 55.9 in 2020, and the disposable income per capita was 8309.77 US dollars in 2021. Both figures are lower than the level of developed countries such as the United States and Japan in the same period. The former reflects the post-disaster relief capability, while the latter affects the ability of residents to respond to natural disasters. Both can characterize the strength of coping ability and resilience to some extent.

3.1.2. Domestic and International Indicators

The critical typical evaluation indicators in the relevant studies are sorted out and summarized. The feasibility of employing the indicators to evaluate social vulnerability to natural disasters in Zhejiang Province is judged according to the applicability, data availability, and quantifiability, as shown in Table 2. Frequency statistics refer to the accumulation of the number of times an indicator appears in the literature. Similar indicators can be grouped together, e.g., the proportion of elderly people and the proportion of people over 60 years old.

Table 2. The critical common indicators reported in the relevant studies.

Primary Indicator	Secondary Indicator	Frequency	Applicability	Data Availability	Quantifiability	Source
Exposure	Population density (A1)	12	√	√	√	[6,11,18,19,21–23,31–34]
	Economic density (A2)	7	√	√	√	[11,13,18,21–23,27]
	Building footprint density (A3)	5	√	√	√	[11,12,21,22,34]
Sensitivity	The percentage of the population over 60 years old (B1)	14	√	√	√	[4,7–13,18,19,21,22,31,34]
	The percentage of the population under 14 years old (B2)	12	√	√	√	[4,7–13,19,22,31,34]
	Impoverished people (B3)	9	×	√	√	[7–11,13,19,21]
	Unemployment rate (B4)	9	√	√	√	[7–11,13,19,21,24]
	The percentage of the female population (B5)	9	√	√	√	[8–11,13,31,33,34]
	The percentage of minority groups (B6)	6	×	√	√	[8–11,31,34]
	The proportion of primary industry to GDP (B7)	5	√	√	√	[11,19,22,24,32]
Coping ability/resilience	Disposable income per capita (C1)	11	√	√	√	[4,7–11,19,23–25]
	The number of hospital beds per 10,000 people (C2)	7	√	√	√	[11,18,19,21,31,32,34]
	The percentage of the population with higher education (C3)	5	√	√	√	[8–11,34]
	The number of teachers per 10,000 people (C4)	5	√	√	√	[11,18,19,21,33]
	GDP (C5)	5	√	√	√	[6,13,23,24,34]
	Urbanization rate (C6)	4	√	√	√	[11,13,23,24]

Note: Applicability indicates whether the indicator is suitable for the current actual situation in Zhejiang Province; Data availability implies whether the indicator data are publicly available; Quantifiability indicates whether the indicator data can be expressed numerically. The symbol √ denotes that the indicator satisfies the selection principle, while the symbol × indicates that it fails to satisfy the selection principle. Economic density is the ratio of the regional gross national product (GNP) to the regional area, representing the output per square kilometer of land, and GDP represents the gross domestic product of Zhejiang Province.

3.1.3. Correlation Test

A collinearity analysis is performed on indicators in three aspects of exposure, sensitivity, and coping ability/resilience. In exposure indicators with the population density as the dependent variable, the VIF values are 1.203 and 1.203. In sensitivity indicators with the proportion of the primary industry to GDP as the dependent variable, the VIF values are 1.899, 2.090, 3.099, and 2.873. In coping ability/resilience indicators with the disposable income per capita as the dependent variable, the VIF values are 2.708, 4.641, and 4.072.

All VIF values between the indicators are less than 10, indicating that there is no multicollinearity between them: that is, there exists no correlation between the indicators. Therefore, all indicators can be used in our study.

3.1.4. Constructing the Indicator System

On this basis, the evaluation indicator system of social vulnerability to natural disasters in Zhejiang province is constructed. It includes three primary indicators of exposure, sensitivity, and coping ability/resilience; thirteen secondary indicators; and the weights of the secondary indicators in 2020, as listed in Table 3. The collinearity analysis of the indicator system shows that most coefficients of correlation between the secondary indicators are less than 0.8, indicating no collinearity between the indicators. The coefficient of correlation between economic density and GDP is 0.877. Since they are subordinate to different primary indicators and have opposite effects on social vulnerability to natural disasters, both can be used.

Table 3. The evaluation indicator system of social vulnerability to natural disasters in Zhejiang Province.

Primary Indicator	Secondary Indicator	Satisfy the Demand of Zhejiang Province			Incorporate Existing Research Findings	Weight
		Exposure	Sensitivity	Coping Ability/Resilience		
Exposure	Population density (people/km^2)	√	√		A1	0.103
	Economic density (10 thousand USD/km^2)	√		√	A2	0.169
	Building footprint density (m^2/km^2)	√	√		A3	0.054
Sensitivity	The percentage of the population over 60 years old (%)	√	√		B1	0.045
	The percentage of the population under 14 years old (%)	√	√		B2	0.053
	Unemployment rate (%)		√		B4	0.048
	The percentage of the female population (%)	√	√		B5	0.046
	The proportion of the primary industry to GDP (%)		√	√	B7	0.087
Coping ability/resilience	Disposable income per capita (USD)			√	C1	0.057
	The number of hospital beds per 10,000 people			√	C2	0.051
	The percentage of the population with higher education (%)			√	C3	0.115
	GDP (USD)	√		√	C5	0.123
	Urbanization rate (%)	√	√	√	C6	0.048

Note: The symbol √ indicates that the secondary indicator satisfies the demand of Zhejiang Province in the three dimensions of vulnerability analysis. One indicator can satisfy multiple needs at the same time. For example, economic density as an exposure indicator implies that the higher the economic density, the more severe the damage per unit area once a disaster strikes. Meanwhile, this indicator is related to evaluating coping ability/resilience.

3.2. Calculation Results

The social vulnerability index of natural disasters for 11 cities in Zhejiang Province from 2011 to 2020 can be calculated (Table 4).

Table 4. The social vulnerability index in Zhejiang Province.

City Name	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hangzhou	0.3576	0.3993	0.4097	0.3970	0.4006	0.4050	0.3982	0.4227	0.4013	0.1567
Ningbo	0.4549	0.4328	0.4352	0.4311	0.4342	0.4332	0.4296	0.4466	0.4183	0.1852
Wenzhou	0.4503	0.4532	0.4618	0.4600	0.4643	0.4665	0.4682	0.4459	0.4636	0.2370
Jiaxing	0.5220	0.5010	0.5030	0.4958	0.5050	0.4978	0.4910	0.4248	0.4776	0.2580
Huzhou	0.6155	0.6098	0.6115	0.6017	0.5901	0.5880	0.5969	0.5457	0.5662	0.3897
Shaoxing	0.5804	0.5153	0.5280	0.5014	0.5005	0.4926	0.4807	0.4612	0.4684	0.2422
Jinhua	0.5209	0.5108	0.5147	0.5112	0.5179	0.5178	0.5118	0.4740	0.4912	0.2787
Quzhou	0.7963	0.6767	0.7843	0.7772	0.8045	0.7994	0.7720	0.7118	0.7570	0.7186
Zhoushan	0.6562	0.7372	0.6740	0.6677	0.6964	0.6890	0.7148	0.6837	0.7052	0.5745
Taizhou	0.5720	0.5715	0.5842	0.5604	0.5610	0.5501	0.5596	0.5561	0.5555	0.3588
Lishui	0.8162	0.8242	0.8207	0.8307	0.8375	0.8320	0.8282	0.7563	0.8171	0.7299
Zhejiang Province	0.6382	0.6297	0.6276	0.6203	0.6294	0.6263	0.6231	0.5888	0.6117	0.4552

Based on the calculation results, the natural breakpoint method is used in ArcGIS to classify social vulnerability to natural disasters in Zhejiang Province into five levels, as tabulated in Table 5.

Table 5. Social vulnerability rating scale for natural disasters.

Category	Low Vulnerability	Mild Vulnerability	Medium Vulnerability	Moderate Vulnerability	High Vulnerability
Criteria	0.1567–0.2787	0.2788–0.4807	0.4808–0.6017	0.6018–0.7372	0.7373–0.8375

3.3. Analyzing Temporal Evolution of Social Vulnerability to Natural Disasters

Based on the analysis results from Tables 4 and 5, the temporal dimension demonstrates that the vulnerability level of all 11 cities in Zhejiang Province remained constant from 2011 to 2019. The average vulnerability percentage was approximately 36.7%, but the overall trend of social vulnerability to natural disasters decreased with the largest decrease from 2019 to 2020. In 2020, only the cities of Lishui, Quzhou, and Zhoushan remained in moderate vulnerability, while the remaining cities reached mild vulnerability and below. The year of 2020 is the closing year of China's 13th Five-Year Plan, with Zhejiang Province reaching the level of full prosperity in 2020. First, the comprehensive strength is stronger. The economy in Zhejiang Province exhibits medium to high growth and has a more reasonable industrial structure and improved modern infrastructure. Second, urban and rural areas become more coordinated. Urbanization has accelerated significantly, and the gap between urban and rural areas has been further reduced. Third, the ecological environment is getting better. The rate of energy exploitation is increased while pollution is reduced, and environmental quality is substantially improved. Fourth, people's lives are happier. Education is modernized, people's life quality is generally improved, and the quality of employment is constantly enhanced. Public service systems such as culture, health, sports, and social security systems become more comprehensive.

The exposure of Zhejiang Province rose slightly from 2011 to 2020. The population density increased, and the potential casualties might be significant under the same intensity of natural disaster attacks. Hence, more resources must be invested in disaster prevention and mitigation, which means that increased population density leads to increased social vulnerability to natural disasters. From 2011 to 2020, the economic density of Zhejiang Province soared at an average annual growth rate of 8.2%. In this process, some areas experienced massive consumption of resources, environmental pollution, and ecological damage, reducing the disaster-bearing capacity of the cities. Meanwhile, the high economic density led to high exposure, so the social vulnerability to natural disasters in Zhejiang Province showed an increasing tendency.

The susceptibility of Zhejiang Province continuously declined from 2011 to 2020, so the social vulnerability to natural disasters was on a downward trend. The reason may be that the proportion of primary industry to the GDP of municipalities in the province decreases year by year, and the economic losses caused by natural disasters are mainly in the primary industries, such as agriculture, forestry, and fishery. Nonetheless, this indicator has the opposite effect on the social vulnerability to natural disasters in the cities of Hangzhou and Ningbo. Since the real estate industry in the tertiary industry of these two cities shows a swift and overheated development, the excessively high prices lead the public to invest more money in housing, increasing sensitivity.

The coping ability/resilience of Zhejiang Province significantly rose during 2011–2020. The GDP increases year by year, and the government's economy strengthens. Social security, especially in disaster prevention and mitigation, receives more financial resources, improving coping ability and resilience during natural disasters. The urbanization rate of Zhejiang Province rapidly increased from 2011 to 2020, significantly reducing social vulnerability to natural disasters. The reasons may be as follows: (1) Urbanization improves the public infrastructure, including transportation, water supply, power supply, and other system elements closely related to the city operation, reducing the likelihood of derivative disasters brought by natural disasters. (2) In the urbanization process, the surplus rural labor can be absorbed, which promotes the transfer of primary industry to secondary and tertiary industries and drives rural development. It helps enhance the regional industrial structure and the overall development of the region.

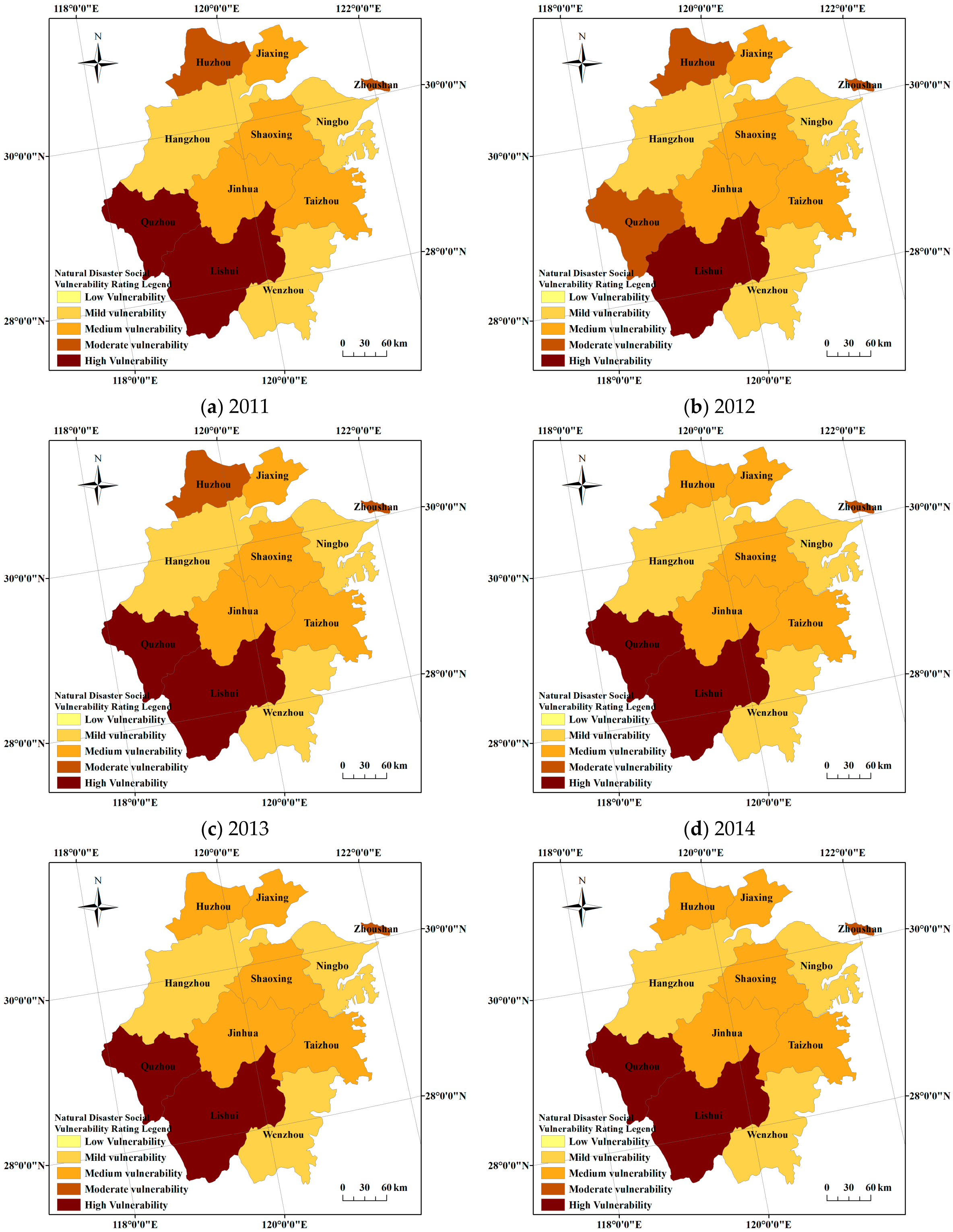
3.4. Analyzing Spatial Evolution of Social Vulnerability to Natural Disasters

To further analyze the spatiotemporal characteristics of social vulnerability to natural disasters in Zhejiang Province, ArcGIS is employed to portray Figure 1. Figure 1 depicts the evolution of the spatiotemporal distribution of social vulnerability to natural disasters in all cities of Zhejiang Province from 2011 to 2020.

The spatial dimension demonstrates that the distribution pattern of social vulnerability to natural disasters in Zhejiang Province was high in the south and low in the north in 2020. The trend of the gradient distribution is evident. Social vulnerability to natural disasters is the highest in the southwest and gradually decreases from Lishui to the north, while social vulnerability to natural disasters is the lowest in the northwest.

From the perspective of exposure, the social vulnerability to natural disasters is higher in Lishui, Quzhou, and Zhoushan than in the other cities. The reasons may be as follows: Lishui and Quzhou are mountainous areas with fewer plains and abundant precipitation, and the percentage of mountains in Quzhou and Lishui is 85.44 and 85.42, respectively. The precipitation in Quzhou and Lishui in 2020 was 2132.4 mm and 1421.2 mm, respectively. An annual precipitation of 800 mm or more in a specific area is considered a wet zone, making them more prone to secondary hazards such as flash floods and a higher probability of being attacked by natural disasters. Their location factors affect the layout of transportation routes and limit the development of the regional economy, thereby increasing social vulnerability to natural disasters. The higher population density of Zhoushan also indicates the higher exposure of the population to natural disasters. Moreover, comprising several archipelagoes, Zhoushan is surrounded by the sea and often attacked by typhoons. In other words, it has a greater probability and regional scope of exposure to natural disasters than the other cities, increasing the social vulnerability to natural disasters.

Considering sensitivity, the cities of Zhoushan, Lishui, Shaoxing, Huzhou, and Jiaxing have a higher social vulnerability to natural disasters than the others, which may be because of the following. Both Zhoushan and Lishui have a higher proportion of primary industry to GDP. Moreover, since the impact of natural disasters on the primary industry is more significant than that on the secondary and tertiary industries, the social vulnerability to natural disasters in both cities increases. The cities of Shaoxing and Huzhou have a high percentage of the population over 60 years old. When facing natural disasters, the elderly are more vulnerable because of their weak awareness of disaster prevention and mitigation and their lack of self-protection ability, thereby leading to higher social vulnerability to natural disasters in these two cities than in the others. Jiaxing has the highest unemployment rate, and the unemployed have poor personal financial and livelihood security. Hence, they are more vulnerable to natural disasters, increasing the social vulnerability to natural disasters in Jiaxing.



(**a**) 2011 (**b**) 2012
(**c**) 2013 (**d**) 2014
(**e**) 2015 (**f**) 2016

Figure 1. *Cont.*

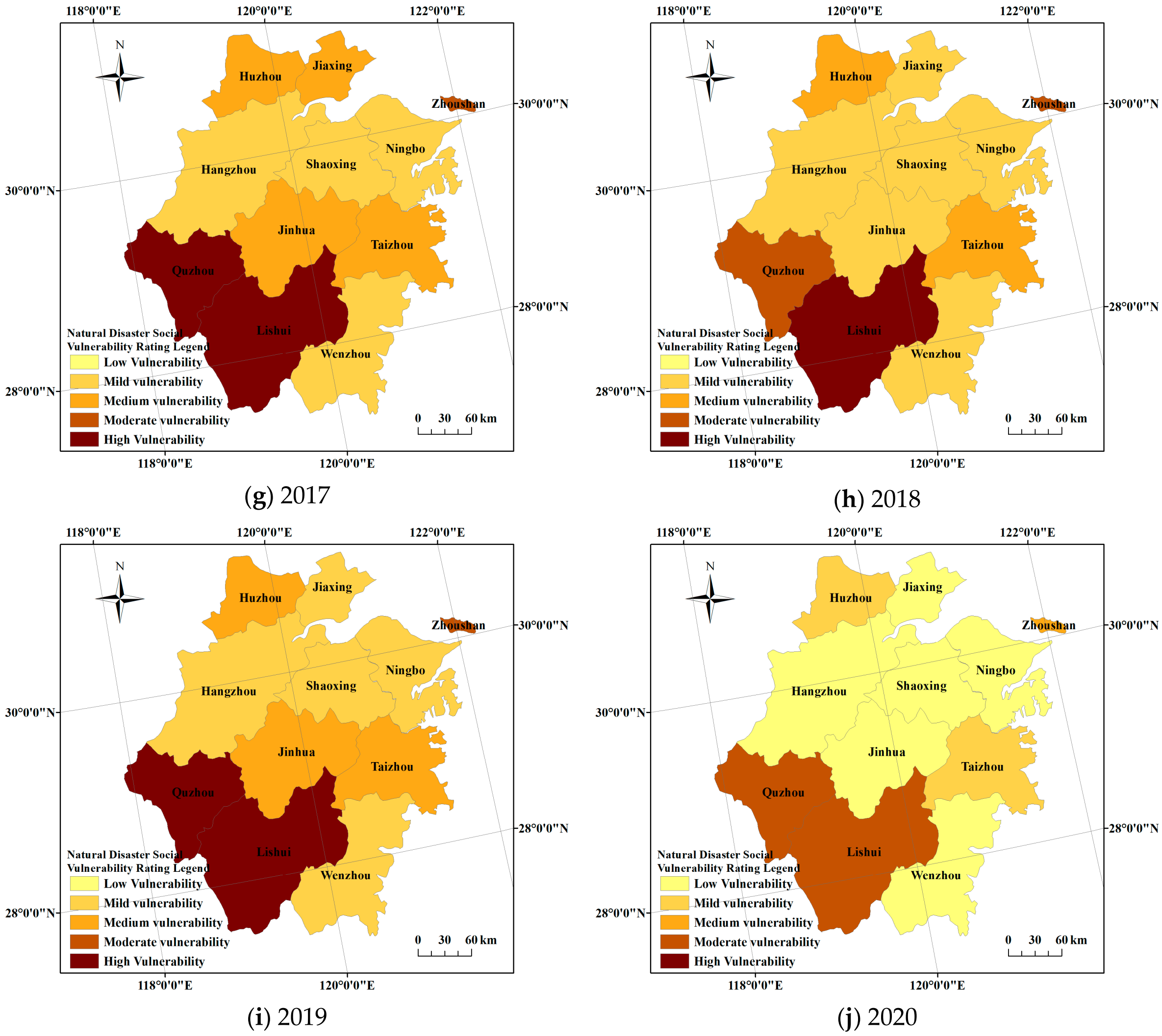


Figure 1. The evolution of the spatiotemporal distribution of social vulnerability to natural disasters in all cities of Zhejiang Province from 2011 to 2020.

Regarding coping ability/resilience, the cities of Hangzhou and Ningbo have the lowest social vulnerability to natural disasters, which may be attributed to the following reasons:

- The GDP of Hangzhou and Ningbo reaches the level of developed countries, implying strong government economic power. The government can devote more financial resources to education, culture, and the management of disaster prevention and mitigation. Consequently, the public can access more educational resources, raising awareness of disaster prevention and mitigation. Their enhanced capacity to cope with natural disasters reduces social vulnerability to natural disasters;
- Both cities have a higher urbanization rate than the others, and buildings in cities are more resilient to natural disasters than those in the countryside. After a disaster, the developed urban economy and transportation lay the foundation for rapid recovery and reconstruction. For example, well-developed transportation enables the transportation of relief supplies to disaster-stricken areas in time, ensuring the smooth implementation of medical treatment, rescue, and emergency response, significantly shortening the recovery time after a disaster and reducing disaster losses.
- Since there are higher-education institutions in both cities and the majority of talents migrate to the developed regions, the percentage of the population with higher education is higher than that in the other cities. Their awareness of disaster prevention and

mitigation and their ability to cope with natural disasters are higher, indicating more robust coping ability and resilience.

4. Discussion

Through the study of social vulnerability to natural disasters in Zhejiang Province, this paper puts forward some views:

For areas with high exposure to disasters, such as the cities of Zhoushan and Wenzhou, suffering from perennial typhoon attacks, typhoon monitoring and early warning should be strengthened, and disaster prevention and mitigation forces and relocation of vulnerable groups should be deployed in advance. Moreover, it is suggested that the emergency and medical rescue teams should be strengthened, and the stockpile of disaster relief should be increased.

For areas with high sensitivity to disasters, such as Lishui and Zhoushan, the structure of the local planting industry can be adjusted by planting disaster-resistant crops and planting in different seasons. The government can also introduce flooding insurance for agriculture to protect the interests of primary industry producers, thus decreasing social vulnerability to natural disasters.

For areas with low coping ability/resilience, the advantages of regional resources should be fully utilized. For example, Zhoushan can use marine resources to develop marine aquaculture, tidal power generation, and wind power generation so as to enhance its economic development. Moreover, it can strengthen infrastructure support, improve public services, and expand social security coverage. Meanwhile, the government can work with relevant research institutions to formulate reasonable disaster prevention and mitigation plans and strengthen the corresponding management. The social vulnerability to natural disasters can be reduced by enhancing coping ability/resilience.

The development experience across Zhejiang Province suggests that economic development has a negative correlation with social vulnerability to natural disasters. The regional economic development in Zhejiang Province is uneven, with the cities of Lishui and Quzhou developing at a slower pace. Consequently, their social vulnerability to natural disasters is higher in these two cities. With the release of the "Opinions of the CPC Central Committee and State Council on Supporting Zhejiang's High-Quality Development and Building a Common Wealth Demonstration Zone", the government supports and encourages Zhejiang to explore high-quality development and establish a benchmark wealth demonstration zone first. The support of policies is expected to lead to a more balanced development of Zhejiang Province, thereby reducing social vulnerability to natural disasters in each city.

Indicators such as the frequency and type of natural disasters and losses caused by them can be included in future studies to further enhance the systematization and completeness of the evaluation indicator system. Limited by data availability, they are not investigated in this study. In future research, it is recommended that the statistics for relevant indicators and their monitoring should be further improved to lay a solid data foundation for evaluating social vulnerability to natural disasters.

5. Conclusions

This paper provides an understanding of social vulnerability to natural disasters: Social vulnerability to natural disasters is when societies exposed to natural disasters are adversely affected or damaged because of their sensitivity and lack of capacity to cope with and recover from natural disasters. Natural disasters are the conditions of social vulnerability, and the intrinsic structural characteristics of a society are the primary determinants of social vulnerability.

This paper has established a method for evaluating social vulnerability to natural disasters in Zhejiang Province, which can be used as a reference for areas with similar conditions to Zhejiang Province, such as coastal areas, areas frequently impacted by typhoons, and areas with mountainous terrains.

Among the current research, the most commonly used method of selecting indicators is to apply an existing indicator system and then add or subtract some of them. Although this method can quickly screen indicators, it has limitations in terms of its integration with the local area. This paper believes that selecting indicators is crucial for the accuracy of evaluation results. The indicators selected in this paper using demand analysis and feasibility analysis are from the Bureau of Statistics. Not only does it conform to the actual situation of Zhejiang Province, but it also considers management costs, making it convenient for managers to apply to a wider range of fields.

This study is the first to conduct a social vulnerability evaluation of natural disasters in Zhejiang Province as a case study. Moreover, the following patterns are found: Zhejiang Province has experienced a slight increase in exposure, a continuous decrease in sensitivity, and a significant rise in coping ability/resilience from 2011 to 2020, implying an overall downward trend of social vulnerability to natural disasters. Social vulnerability to natural disasters displays significant spatial variability, and the areas with the highest vulnerability index are primarily located in the southwest of Zhejiang Province. Economic density, population density, GDP, and the percentage of the population with higher education in cities are the primary factors affecting social vulnerability to natural disasters. Although Hangzhou and Ningbo are more exposed to natural disasters, they are less sensitive and can cope with and recover from natural disasters. Their social vulnerability to natural disasters is the lowest.

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