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Resilience Assessment of Flood Disasters in Zhengzhou Metropolitan Area Based on the PSR Model

Shubo Cheng [1,2] and Haoying Li [1,*]

1 Safety and Emergency Management Research Center, Henan Polytechnic University, Jiaozuo 454000, China; shubohpu@163.com
2 Emergency Management Laboratory, Henan Polytechnic University, Jiaozuo 454000, China
* Correspondence: haoying1li@163.com

Abstract: Flood disasters occur frequently and cause great losses. Improving the resilience of urban flood disasters is of great significance to improving disaster prevention and mitigation in the region. The metropolitan area is the center of regional economic development and the key to strengthening the construction of local resilience. However, there is little research on resilience in the metropolitan area. Taking nine cities in the Zhengzhou metropolitan area as the research object, this paper uses the pressure state response (PSR) model to build the evaluation system of the Zhengzhou metropolitan area's flood disaster resilience and comprehensively uses the entropy weight method, analytic hierarchy process, kernel density estimation method, and factor contribution model to measure the temporal and spatial evolution characteristics of Zhengzhou metropolitan area's flood disaster resilience from 2010 to 2022, excavating the development trend of the level of flood disaster resilience of members in the Zhengzhou metropolitan area, and explore the driving factors affecting the resilience of the Zhengzhou metropolitan area's flood disaster. The results show that (1) from 2010 to 2022, the development trend of flood disaster resilience among the Zhengzhou metropolitan area members has obvious differences, the change of pressure resilience is stable, and the state resilience and response resilience increase as a whole; (2) the results show that the resilience of flood disaster in the Zhengzhou metropolitan area has obvious change characteristics in time and space, and the overall trend is to take Zhengzhou as the core to drive the surrounding members' upward development; (3) in the driving factor analysis, the number of ordinary colleges and universities and the proportion of public security expenditure in fiscal expenditure are the main influencing factors in the resilience evaluation index. The Zhengzhou metropolitan area is the key area of economic development in Henan Province. The research results provide a reference for improving the resilience level of the Zhengzhou metropolitan area and strengthening the prevention and control of flood disasters.

Keywords: Zhengzhou metropolitan area; flood disaster; resilience assessment; disaster prevention and mitigation; PSR model; enhancement strategy

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1. Introduction

The issue of climate change has been accentuated by the increase in greenhouse gas emissions as a result of human activities, a change that has exacerbated the phenomenon of extreme weather-induced heavy rainfall and flooding [1]. The annual International Top 10 Natural Disaster Events released by the Global Platform for Disaster Data shows that storm-induced disasters alone accounted for six of the top 10 disasters in 2022 (https://www.gddat.cn/newGlobalWeb/#/riskAssessment, accessed on 13 November 2024). China is a country with a large population and economy, and it is also one of the countries suffering from flood disasters. In recent years, the acceleration of urbanization has increased the risk of flood disasters [2]. According to the 2022 China Flood and

Drought Disaster Prevention Bulletin, from 1950 to 2022, the affected area of floods and droughts in China was 684.5825 million hectares, resulting in 284,195 deaths, 122.999 million collapsed houses, and a direct economic loss of CNY 52.10202 billion [3]. According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, the global temperature rise will exceed 1.5 °C in 2021–2040, and sustained warming will lead to multiple concurrent disasters with irreversible impacts on the ecosystem [4]. The United Nations Office for Disaster Risk Reduction pointed out that disaster risk is affecting global development, and countries must take action to establish and improve disaster risk management systems to withstand more severe, complex, and frequent disasters in the future [5].

The word "resilience" is derived from the Latin word "resilio", which originally means "to return to the original state". In 1973, resilience theory was first applied by Canadian ecologist Holling from physics to systems ecology, and he began using the concept of resilience to study system problems [6,7]. In the 1980s, the application of resilience theory extended to the field of disaster management, shifting the focus of academia from vulnerability to resilience [8]. After entering the 21st century, research on resilient cities has attracted much attention. In 2010, the United Nations International Strategy for Disaster Reduction proposed that resilience is a measure of urban resilience, and the construction of resilient cities has become a common goal for the sustainable development of cities around the world. The Resilience Alliance emphasized that resilience has three characteristics: self-organization, self-control, and adaptability [9]. Berkes believes that resilience is an ability to cope with disasters, and resilience research provides prospective references to cope with uncertain future changes [10]. Cutter et al. believe that resilience is the ability of a social system to respond to disasters and recover from disasters, including the internal conditions that enable the system to absorb impacts and popular science events and the post-adaptation process that promotes the ability of the social system to reorganize, change and learn in response to threats [11]. Teng et al. pointed out that the current mainstream idea in academia is to integrate economic and social impacts into the concept of resilience. They believed that "resilient city" refers to the ability to take flexible measures under external interference, maintain development vitality, attract resource agglomeration, avoid potential losses, and cope with challenges and changes through self-organized learning of social systems [12].

Against the backdrop of increasingly frequent natural disasters, resilience research has gradually become an important aspect of disaster risk management in countries around the world. The research on disaster resilience focuses on three aspects: capability, process, and subject. Capability theory holds that resilience is the ability to measure a region's level of risk resistance. Summarizing and exploring the spatial heterogeneity of disaster resistance capabilities in different regions provides governments with differentiated management strategies for different regions [13–15]. Process theory emphasizes the dynamism and complexity of resilience, and by exploring the evolution laws of disaster resilience in time and space, it grasps the entire process of regional resilience development under disaster scenarios [16,17]. Subjectivity theory focuses more on the relationships between subjects, evaluating the resilience performance of cities in disasters from multiple dimensions and usually proposing specific suggestions that are conducive to resilience development from the perspective of subjects [18,19]. The analysis of influencing factors can help scholars identify the more important key factors in the model and, based on the numerical increase and decrease patterns of key elements, provide more accurate policy recommendations in research. The current research on influencing factors and resilience is becoming increasingly close. Scholars mainly use methods such as systematic literature review, systematic evaluation, Delphi method, principal component analysis, geographic detector, and factor contribution model to identify the key driving factors of urban resilience, analyze the relationships and interactions between various influencing factors, and provide suggestions for cities to better improve their resilience level and promote sustainable development in the region [20–24].

In recent years, more and more researchers have combined multidisciplinary methods such as mathematical models, remote sensing, and GIS with resilience research. The mainstream evaluation methods include the index system method, scenario simulation method, data-driven method, etc. In the study of the index system method, there are studies on the scale characteristics of the study area. For example, Zhang et al. used the entropy weight method, Moran index, and hot spot analysis method to explore the spatiotemporal dynamic evolution of urban resilience in 31 provinces and cities in China and reduced the differences in the level of resilience between provinces by identifying the factors affecting urban resilience in the study area [25]. There are index systems constructed from the aspects of nature, economy, society, and infrastructure. For example, Cao et al. proposed the evaluation index system of urban flood control and disaster resilience based on nature, economy, society, and infrastructure and evaluated the urban flood control capacity and spatiotemporal variation trend in Zhejiang Province [26]. In the research of the scenario simulation method, some research has been carried out by using a machine learning algorithm. For example, Chen et al. used the existing flood data as the model training sample, used radial basis function neural network (RBF) to predict the flood risk level of the Three Gorges Reservoir area, and verified the effectiveness of the research results with actual data [27]. Some research has been carried out using numerical models, such as Xu et al., who proposed a quantitative method for urban flood disaster resilience, simulated urban floods by coupling urban rainfall and flood models, and used the simulation results to calculate index weights and evaluate the spatial distribution of urban flood disaster resilience in the study area [28]. Research on the data-driven method by Pei et al. determined the weight value of the urban safety resilience evaluation index based on the Delphi method and cloud model, providing a reference for the determination of complex index weight and the application of the evaluation model [29]. Jiang et al. combined the BP neural network algorithm and entropy weight method, constructed the evaluation index system of healthy city resilience, and studied the key factors affecting healthy city resilience [30].

A megalopolis is a high-level spatial organization form of urban development, a highly integrated and coordinated development area composed of multiple cities, and an area with the greatest potential for regional economic growth, which plays a leading role in the construction of a modern urban area [31]. In 2012, the concept of the "Zhengzhou metropolitan area" was put forward for the first time, and the spatial scope is limited to the urban area of Zhengzhou. In December 2016, the Central Plains urban agglomeration development plan was officially released, which defined the spatial pattern of "1 + 4" (Zhengzhou, Kaifeng, Xinxiang, Jiaozuo, Xuchang) for the first time at the national level. In August 2019, the general office of the Henan Provincial Party committee and the general office of the Henan Provincial Government jointly initiated the spatial planning of the Zhengzhou metropolitan area (2018–2035), proposing to build a spatial pattern of "one core, four axes, three belts, and multiple points", gradually bringing the counties under the jurisdiction of the existing metropolitan area members and the counties directly under the jurisdiction of the province into the scope of the Zhengzhou metropolitan area, and the Zhengzhou metropolitan area has begun to take shape. In October 2021, Henan Province proposed to accelerate the integrated development of Xuchang, Xinxiang, Jiaozuo, Pingdingshan, Luohe, and Zhengzhou. In December of the same year, the Zhengzhou metropolitan area was officially expanded, adding Pingdingshan, Luoyang, Luohe, and Jiyuan to the original five cities. So far, the Zhengzhou metropolitan area has formed a "1 + 8" development layout.

In recent years, urbanization has developed rapidly, and due to extreme weather disasters, floods have become the main disaster risk faced by various regions in China. In July 2020, due to heavy rainfall, severe floods and waterlogging occurred in the Yangtze River and Huaihe River basins, causing 34.173 million people in 11 provinces (cities) to be affected. From 17 to 23 July 2021, Henan Province encountered a rare extremely heavy rainstorm, which led to serious floods. In particular, Zhengzhou suffered heavy casualties and property losses on July 20. The disaster caused a total direct economic loss of CNY 120.06 billion, of which CNY 40.9 billion was in Zhengzhou City, accounting for 34.1% of the province's total; 398 people have died or gone missing due to disasters in the province, of which CNY 40.9 billion was in Zhengzhou, accounting for 95.5% of the total. The "July 20" extremely heavy rainstorm event in Zhengzhou has received great attention from the state. The deployment of flood prevention and disaster relief, disaster investigation, etc., was made for the first time, and 89 relevant responsible persons were seriously investigated and held accountable, which has aroused widespread concern in the academic community.

The Zhengzhou metropolitan area is the core of economic development in Henan Province. Studying the resilience of flood disasters in the Zhengzhou metropolitan area is of great significance for enriching the research content of urban resilience and formulating a comprehensive evaluation of regional resilience levels. At present, there are abundant research results on disaster resilience, most of which involve identifying influencing factors, constructing evaluation systems, analyzing spatiotemporal distribution characteristics, simulating disaster scenarios, etc., laying a solid foundation for further research. However, the existing research content still needs to be improved. First of all, the existing research on the resilience of rainstorms and flood disasters is still in the exploratory stage, and the construction of the resilience index system lacks the support of a theoretical model. Secondly, the existing resilience assessment does not pay enough attention to the research on regional coordinated development, and the research on the resilience of rainstorm and flood disasters involving urban agglomeration is less.

Therefore, this article takes nine cities in the Zhengzhou metropolitan area as the research area, selects the pressure-state-response (PSR) model to evaluate the resilience of flood disasters in the Zhengzhou metropolitan area, and combines ArcGIS, kernel density estimation, and factor contribution models to comprehensively grasp the distribution law of resilience and urban differences, identify the influencing factors of flood disaster resilience, and propose countermeasures to enhance the resilience to flood disasters, providing a decision-making reference for the overall improvement of disaster prevention and reduction capabilities in the Zhengzhou metropolitan area and further promoting the sustainable and healthy development of the Zhengzhou metropolitan area economy.

2. Study Area and Data Source

The Zhengzhou metropolitan area includes nine cities: Zhengzhou, Luoyang, Kaifeng, Pingdingshan, Jiaozuo, Xuchang, Xinxiang, Luohe, and Jiyuan (Figure 1). It is located at the confluence of the Yellow River, Huaihe River, and Haihe River and has the typical characteristics of "one core, one belt, and many points", which is the core level of promoting the rise of the central region and is also a typical representative of the structural significance of the central and western metropolitan area. The cities under the jurisdiction of the Zhengzhou metropolitan area all have a humid–semi-humid monsoon climate, with a transition from the plains to the hills and mountains from east to west, with cold and dry winters, high temperatures, and rainy summers, and a distribution of average annual temperatures that is higher in the south than in the north, and higher in the east than in the west.

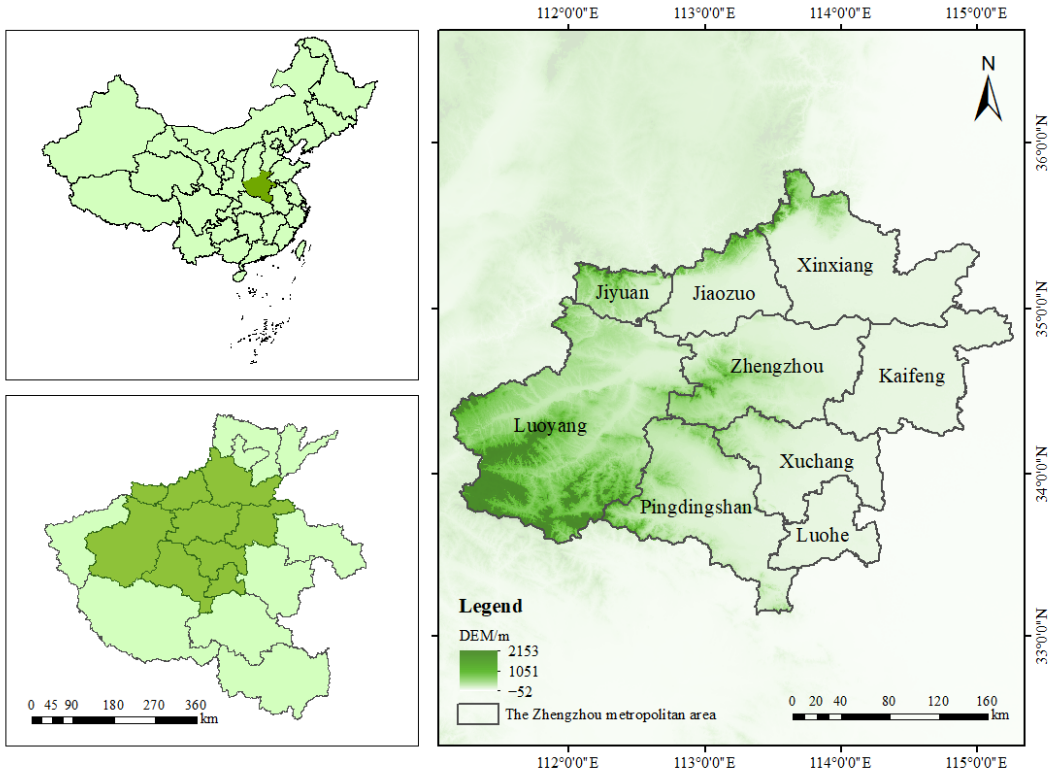

Figure 1. Location of Zhengzhou metropolitan area.

This study takes nine cities in the Zhengzhou metropolitan area as the research objects, combined with the actual situation of the study area, and follows the principles of data accessibility, independence, and completeness to select evaluation indicators. Among them, the elevation data come from the geospatial data cloud (https://www.gscloud.cn/, accessed on 26 October 2024) and the precipitation data from the China Meteorological Data Network (https://data.cma.cn/, accessed on 26 October 2024). The river network density data are extracted based on ArcGIS, and other index data are from the Henan Statistical Yearbook, China Urban Statistical Yearbook, and Urban Construction Statistical Yearbook. The indicator data are calculated using Microsoft Office Excel 2016. Annual data have comparability and stability. Through the analysis of annual data, it is beneficial to identify the long-term trends and changing patterns of regional indicators, providing a scientific basis for the continuous improvement of policies. Due to the fact that the statistical yearbook data released by the National Bureau of Statistics are from the year before publication, and the Zhengzhou metropolitan area was first mentioned in 2012, in order to make the research content more timely and targeted, the research interval has been determined from 2010 to 2022.

3. Model Settings

“Pressure-State-Response” (PSR) is a framework proposed by the United Nations Organization for Economic Cooperation and Development in the 1980s [32], which divides the criterion layer of the evaluation index system into three subsystems of pressure-state-response, each of which contains the corresponding evaluation indexes. The PSR model is widely used in research fields such as ecosystem health evaluation [33], land use [34], ecological safety [35], and sustainable development [36], and with the global emphasis on urban safety and disaster management in recent years, the application of the PSR model is gradually reflected in research fields such as urban risk assessment [37–39]. For urban systems, flood resilience refers to the ability of a city to use its existing resource conditions to withstand disasters, minimize the economic losses caused by disasters, and rapidly recover its original state and functions after a disaster during the whole process of heavy rainfall and flooding. To assess the flood resilience of the Zhengzhou metropolitan area, this paper constructs a flood resilience assessment index system by selecting 15 indicators using PSR as the assessment framework (Table 1). The indicator composition, definition, and model calculation method of each dimension are as follows:

(1) Pressure refers to the threatening force that heavy rainfall and flooding may pose to urban systems. Elevation can reflect the drainage capacity of a city, thereby determining potential flood risk areas, while data such as precipitation and river network distribution can directly reflect the impact of flood disasters on the city. Therefore, elevation, annual average precipitation, and river network density were selected as indicators of pressure resilience;

(2) State refers to the state of the urban system and its ability to withstand pressure when hit by heavy rainfall and flooding. The state of the urban system is reflected from three perspectives, namely economic, social, and ecological; indicators of economic factors include regional GDP, the proportion of secondary and tertiary industries, and per capita disposable income of the residents; indicators of social factors include road density, population density, and the proportion of old and young people; and indicators of ecological factors include the greening coverage rate of the built-up area, sewage treatment rate, and per capita green area of parks;

(3) Response refers to a city's ability to quickly adapt and restore system function after the stress has subsided. In the aftermath of a disaster, education, healthcare, and fiscal expenditures best reflect a city's disaster management capacity. Therefore, the number of general higher education schools, the proportion of public safety expenditure to fiscal expenditure, and the number of beds per 1000 people in healthcare institutions are chosen to represent the response resilience capacity of the urban system.

Table 1. The index system for flood disasters in the Zhengzhou metropolitan area.

Rules	Domains	Indicators	Index Properties
Pressure resilience	Topography	Elevation (P1) [40,41]	+
	Precipitation	Annual average precipitation (P2) [37,41]	−
	Hydrology	Drainage density (P3) [37]	−
State resilience	Economy	Regional GDP (S1) [42]	+
		Secondary and tertiary industry ratios (S2) [42]	+
		Per capita disposable income (S3) [43,44]	+
	Society	Road density (S4) [37,41,45]	+
		Population density (S5) [41,43,45]	−
		Proportion of elderly and young (S6) [39,42]	−
	Ecology	Green coverage rate of built-up areas (S7) [44]	+
		Sewage treatment rate (S8) [42]	+
		Per capita park green space area (S9) [46]	+
Response resilience	Prevention	Number of universities (R1) [46]	+
		Public security spending ratio (R2) [39,44]	+
	Disposal	Hospital beds per 1000 people (R3) [39,43,44]	+

3.1. Data Standardization

In the flood resilience assessment, considering the different units of the collected indicator data, the original data were standardized using the extreme value method in order to eliminate the bias generated by the difference in the magnitude between the indicator data and to ensure the accuracy and reasonableness of the final calculation results [47].

The processing formula for positive indicators is as follows:

$$y_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \tag{1}$$

The processing formula for negative indicators is as follows:

$$y_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max\ (x_{ij}) - \min\ (x_{ij})} \tag{2}$$

where y_{ij} is the standardized result of the jth indicator of the ith assessment object; x_{ij} is the raw data of the jth indicator (i = 1, …, m; j = 1, …, n).

3.2. Index Weight Calculation

The entropy is used to measure the amount of information, and when the entropy is larger, it indicates that the system is more chaotic and thus carries less information [48]. The entropy weighting method is based on the principle of information entropy, which usually only considers the amount of information in the indicator itself and is not affected by the decision maker's subjective preference, and is able to objectively assess the weight of the indicator [49]. The hierarchical analysis method (AHP), on the other hand, can synthesize the knowledge and experience of experts to analyze and compare the indicators in a hierarchical way, which is helpful for practical decision-making [50]. For this reason, this paper adopts the combination of hierarchical analysis and the entropy weight method to determine the indicator weights; the main steps are as follows:

(1) Calculate the weight P_{ij} of the jth indicator for the ith object on the basis of data normalization:

$$P_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{3}$$

(2) Calculate the information entropy e_j for the jth indicator factor:

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} P_{ij} \ln\ (P_{ij}) \tag{4}$$

(3) Determine the indicator weights W_1 for the entropy weighting method:

$$W_1 = \frac{1 - e_j}{\sum_{\mathrm{j}=1}^{\mathrm{n}} (1 - e_j)} \tag{5}$$

(4) Using the analytic hierarchy process to calculate subjective weights, it is necessary to first establish a hierarchical structure model based on the evaluation index system, and construct a judgment matrix A between two indicators according to the hierarchy:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & 1 & \cdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \tag{6}$$

Among them, the importance level of the judgment scale is represented by increasing numbers from 1 to 9. a_{ij} represents the relative importance of indicator i relative to indicator j, and $a_{ij} = 1$, $a_{ij} = 1/a_{ji}$, $a_{ij} = a_{ik}/a_{jk}$, (1, j, k = 1,2, …, n).

(5) Based on the constructed judgment matrix, the maximum eigenvalue of matrix A and its corresponding eigenvector are found, and the weight vector is the weight value of each index. To ensure the reasonableness of the weights, the consistency index test CR is performed on the judgment matrix A. The formula is as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{7}$$

$$CR = \frac{CI}{RI} \tag{8}$$

where CI is the consistency index; λ_{max} is the maximum eigenvalue; RI is the average random consistency index. When CR is less than 0.1, the judgment matrix meets the consistency requirements, otherwise the judgment matrix needs to be modified. After passing the consistency test, the maximum eigenvalue vector of λ_{max} is obtained, and the weight W_2 of the analytic hierarchy process index is obtained through normalization.

(6) According to the above steps, the weight W_1 of the entropy weight method and the weight W_2 of the analytic hierarchy process can be distributed and calculated:

$$W_1 = [w_1 \quad w_2 \quad \cdots \quad w_n] \tag{9}$$

$$W_2 = [w_1 \quad w_2 \quad \cdots \quad w_n] \tag{10}$$

The result of combining weighting u is:

$$u = \beta W_1 + (1 - \beta) W_2 \tag{11}$$

where β is the resolution factor, usually defined as 0.5 [51].

3.3. Comprehensive Evaluation Model

The Zhengzhou metropolitan area flood disaster resilience evaluation index Y_i under the three dimensions of pressure-state-response is measured by establishing a comprehensive evaluation model with the following formula:

$$Y_i = \sum_{j=1}^{n} u_{ij} y_{ij} \tag{12}$$

where u_{ij} denotes the weight of the jth indicator of the ith indicator layer; y_{ij} denotes the normalized value of the jth indicator of the ith indicator layer. Factor weights for flood resilience assessment in the Zhengzhou metropolitan area were finally obtained (Table 2). The calculated overall resilience, pressure resilience, state resilience, and response resilience indices of flooding in the Zhengzhou metropolitan area were classified into five levels using the natural breakpoint method, and the resilience assessment results were visualized and displayed.

Table 2. Weights of resilience factors for flood disasters in the Zhengzhou metropolitan area.

Rules	Indicators	Weight		
		Entropy Method	**AHP Method**	**Combined Method**
Pressure resilience	P1	0.1242	0.0654	0.0948
	P2	0.0154	0.2158	0.1156
	P3	0.0554	0.1188	0.0871
State resilience	S1	0.1141	0.0113	0.0627
	S2	0.0152	0.0123	0.0138
	S3	0.0609	0.0261	0.0435
	S4	0.1087	0.0227	0.0657
	S5	0.0145	0.0331	0.0238
	S6	0.0175	0.0381	0.0278

	S7	0.0202	0.0294	0.0248
	S8	0.0089	0.0084	0.0086
	S9	0.0306	0.0187	0.0246
Response resilience	R1	0.2470	0.0783	0.1626
	R2	0.1182	0.1243	0.1212
	R3	0.0492	0.1974	0.1233

3.4. Kernel Density Estimation

Kernel density estimation is a statistical nonparametric density large estimation method that can use a continuous curve to describe the distribution characteristics and evolution law of the research elements, which is only based on the sample data characteristics of the analysis, avoiding the drawbacks of the subjective setting of the function. This section is based on StataMP 18 software to draw kernel density curves, demonstrating the distribution characteristics and evolution laws of overall resilience, pressure resilience, state resilience, and response resilience of flood disasters in the Zhengzhou metropolitan area. This is part of the content as follows:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{y_i - \bar{y}}{h}\right) \tag{13}$$

where n is the number of study subjects; y_i is the composite resilience (stress resilience, state resilience, and response resilience); y is the average of all urban resiliencies for the year in which it is located; and K and h denote the core functionality and bandwidth of the StataMP 18 [52].

3.5. Factor Contribution Model

The factor contribution model is a widely used statistical model for influencing factor identification [53]. The factor contribution model can help us identify the key factors that have an impact on the results and adjust and optimize the decision-making in a more targeted way. In order to explore the key factors affecting the resilience of flooding in the Zhengzhou metropolitan area, the analysis is based on the factor contribution model, and the calculation formula is as follows:

$$I_j = 1 - y_j \tag{14}$$

$$O_j = \frac{I_j \times w_j}{\sum_{j=1}^{15}\left(w_j \times I_j\right)} \times 100\% \tag{15}$$

where O_j is the contribution of the jth indicator to resilience; I_j is the indicator deviation; y_j is the normalization result of the indicator; and w_j is the weight of each indicator.

4. Results

4.1. General Variation Law of Flood Disaster Resilience Level

Flood and waterlogging disasters are important disasters in the Zhengzhou metropolitan area. In recent years, the severity of flood and waterlogging disasters in the Zhengzhou metropolitan area has been increasing year by year due to the impact of climate change. Therefore, conducting resilience awareness and evaluation of flood and waterlogging disasters in the metropolitan area is a prerequisite and important means to improve regional disaster prevention and reduction capabilities. The main purpose of this chapter is to apply the data collected in the early stages to measure the resilience level of flood disasters in the Zhengzhou metropolitan area, providing data that can be used to improve urban resilience.

According to Formulas (1)–(12), calculate the overall resilience, pressure resilience, state resilience, and response resilience of the Zhengzhou metropolitan area. Analyze the evolution law of the overall resilience of the Zhengzhou metropolitan area from the perspectives of time and space, respectively. The positive and negative values on the vertical axis represent the positional relationship between urban resilience and the average level. From a time scale perspective, the overall resilience of the Zhengzhou metropolitan area showed an upward trend from 2010 to 2022, but there was a significant decline in 2018, 2020, and 2021, respectively (Figure 2). The possible reasons are as follows: firstly, with the improvement of urbanization layout and form and the strengthening of urbanization management requirements at the beginning of the 12th Five Year Plan, urban development has gradually entered the stage of connotation and quality improvement from scale expansion, so the level of urban resilience has steadily increased since 2011. In 2018, the "August 18" rainstorm and flood event in Henan Province caused serious disasters in many places, so the overall resilience level of the Zhengzhou metropolitan area declined in 2018. The impacts of COVID-19 in 2020 and the "July 20" extremely heavy rainstorm in Zhengzhou in 2021 on the industrial economy and healthcare have led to a continuous decline in the resilience index of the metropolitan area.

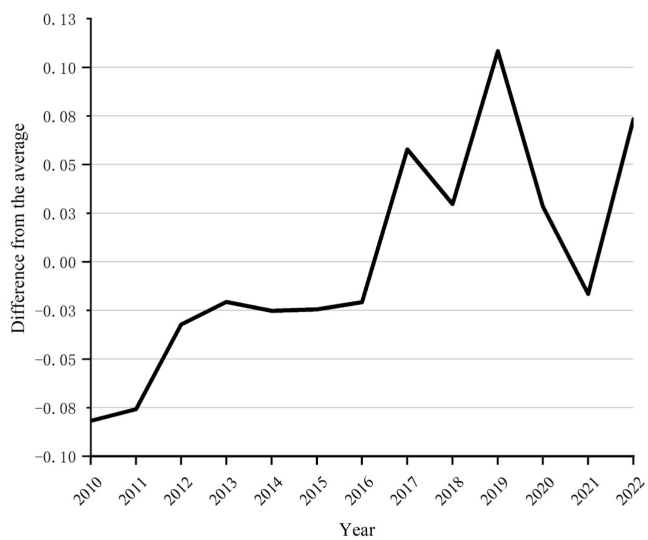

Figure 2. General temporal evolution of flood disaster resilience in Zhengzhou metropolitan area from 2010 to 2022.

On a spatial scale, the resilience level of cities in the Zhengzhou metropolitan area diverges significantly, with only four out of nine cities having resilience levels above the average (Figure 3). The possible reasons for this are the following: first, Zhengzhou, Luoyang, Jiyuan, and Jiaozuo are in a faster process of urbanization, with obvious advantages in economic empowerment, green development, etc., and a higher degree of transformation of the results of resilience development; second, the first time that China put forward the construction of "Resilient Cities" from a national level was in 2017, and the time of policy implementation is located in the time of the study area. The development of resilient cities in some cities is still in its early stages, so the resilience level is relatively weak.

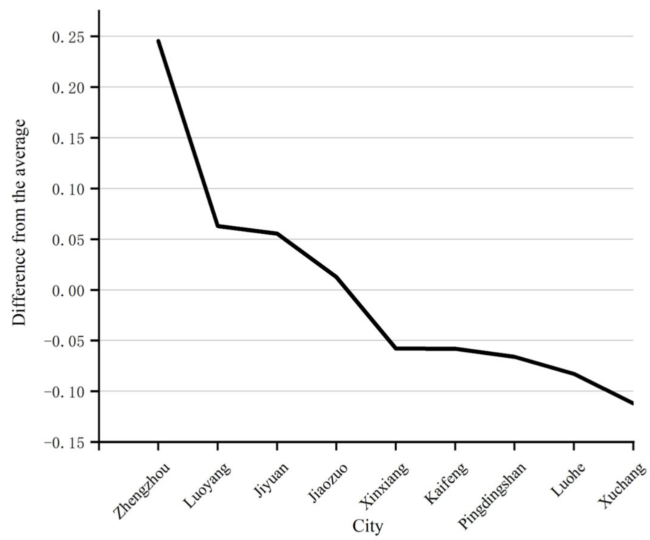

Figure 3. General spatial evolution law of flood disaster resilience in Zhengzhou metropolitan area.

4.2. Analysis of the Development Trend of Flood Disaster Resilience

Based on the overall resilience, pressure resilience, state resilience, and response resilience data of the metropolitan area obtained from the above measurements, the distribution law of the overall resilience, pressure resilience, state resilience, and response resilience of the flooding disaster in Zhengzhou metropolitan area is analyzed by using the method of nonparametric kernel density estimation. Due to space limitation, the cross-section data of 2010, 2016, and 2022 are selected to analyze the changing law of flood resilience level in the Zhengzhou metropolitan area with the help of the location, shape, number of crests, and ductility of the kernel density curve (Figure 4).

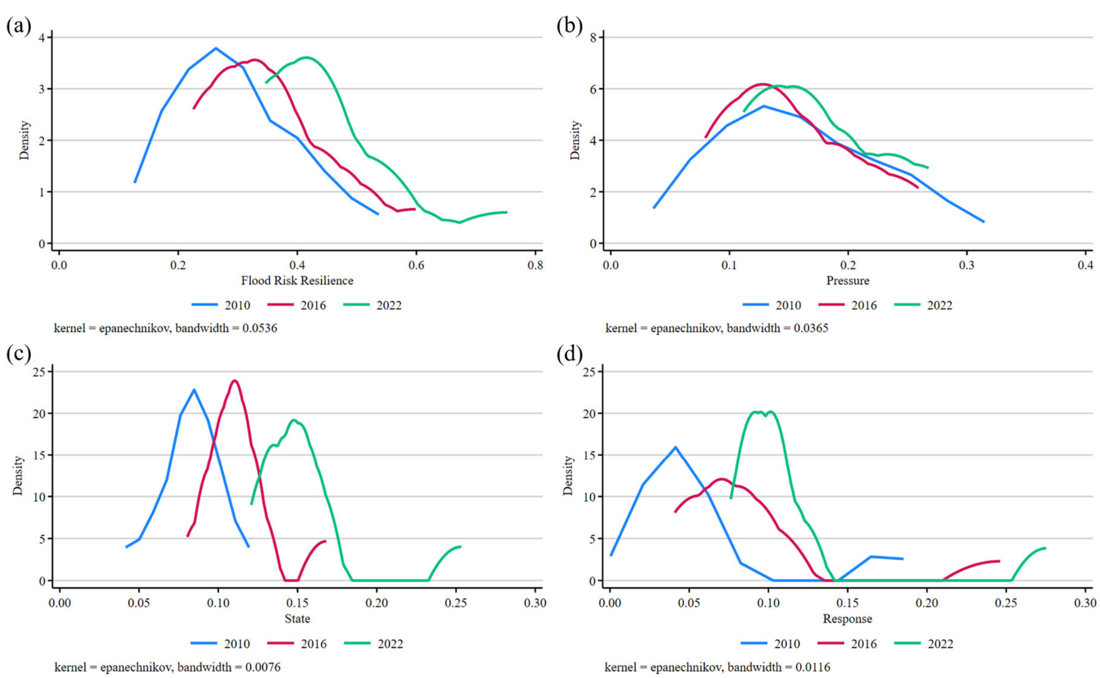

Figure 4. Kernel density curves for flood resilience levels in the Zhengzhou metropolitan area: (**a**) overall resilience; (**b**) pressure resilience; (**c**) state resilience; (**d**) response resilience.

Figure 4a depicts the kernel density curve of the overall resilience level of flood hazards in the Zhengzhou metropolitan area. In terms of location, the kernel density curves for 2010, 2016, and 2022 shifted to the right as a whole, which indicates that the overall resilience level of flood hazards in the Zhengzhou metropolitan area shows an upward trend. From the viewpoint of morphology change, the curve tends to be smooth from 2010 to 2016 from sharp, which indicates that there is a trend of uniform distribution of the overall resilience level values in the Zhengzhou metropolitan area. From the viewpoint of peak height change, the peak value of the wave declined slightly from 2010 to 2016 and increased slightly in 2022, which indicates that the resilience level of some cities in the Zhengzhou metropolitan area is higher. From the viewpoint of ductility, the right trailing feature of the kernel density curve in 2022 is obvious, and the distribution ductility of the kernel density curve in the observation period shows a trend of gradual widening, indicating that the gap of the overall resilience index of the cities in Zhengzhou metropolitan area is gradually widening.

Figure 4b–d depict the kernel density curves of pressure resilience, state resilience, and response resilience of the Zhengzhou metropolitan area flood disaster during the observation period, respectively. As can be seen in Figure 4b, the kernel density curves converge to the center as a whole, and the change in the position of the wave peak is not significant, which indicates that the level of pressure resilience of flood disasters in the Zhengzhou metropolitan area is relatively stable. Specifically, compared with 2010, the curve shifted upward, and the right tail narrowed in 2016, indicating an increase in pressure resilience; compared with 2016, the curve shifted to the right, and the right tail further narrowed in 2022, and the width of the peak of the curve narrowed, indicating that the distribution of pressure resilience level in Zhengzhou metropolitan area tends to be centralized and the value is stable and tends to converge. As can be seen in Figure 4c, the kernel density curve shifts to the right on the whole, which indicates that the resilience level of the Zhengzhou metropolitan area flooding condition shows an elevated trend. Specifically, compared with 2010, the curve shifted to the right in 2016, the peak value elevated, and the curve changed from sharp to smooth, which indicates that the state resilience is elevated as a whole; compared with 2016, the curve shifted to the right, and the peak value declined in 2022, the right trailing feature was obvious, and the curve became wider, which indicates that the state resilience index increased in general, and the value was distributed in a wide range. As can be seen in Figure 4d, the kernel density curve shifts to the right on the whole, and the right trailing trend is obvious, which indicates that the level of flood disaster response resilience in the Zhengzhou metropolitan area shows an upward trend. Specifically, compared with 2010, the curve shifted to the right, and the peak declined in 2016 and the width of the crest became wider, and the curve at the peak was smooth, indicating that the response resilience tended to improve, and the distribution of values was more decentralized; compared with 2016, the curve shifted to the right and the peak lifted sharply in 2022, and the right trailing tail became longer, indicating that the response resilience index increased in general, and the response resilience index of some cities was higher, and the inter-city data are more widely distributed.

4.3. Analysis of Spatiotemporal Distribution of Flood Disaster Resilience

4.3.1. Analysis of Temporal and Spatial Variation of Overall Resilience

The results of the flood resilience assessment and the spatial distribution of the resilience index levels in the Zhengzhou metropolitan area in 2010, 2016, and 2022 are shown in Figure 5. As can be seen in Figure 5a, the overall resilience of floods in the cities of the Zhengzhou metropolitan area has shown an upward trend throughout the study, with Zhengzhou, Luoyang, and Jiyuan ranking among the top three cities in terms of overall resilience levels. As the capital and economic center of Henan Province, Zhengzhou has a stable and strong momentum of resilience development. The increase in the overall resilience level of Zhengzhou metropolitan area cities in 2016 compared to 2010 is attributed to the 12th Five-Year Plan of Henan Province, which emphasizes the development of the economy and the strengthening of emergency response capacity building. In addition to Zhengzhou, Kaifeng, Xinxiang, Jiaozuo, Xuchang, Luohe, and Jiyuan have shown significant growth in overall resilience because the concept of the Zhengzhou metropolitan area was proposed during the 13th Five-Year Plan period, and Henan Province has emphasized the importance of enhancing the radiation-driven capacity of the leading cities to lead regional development and promoting the development of neighboring cities in the same region. This is because during the 13th Five-Year Plan period, the concept of "Zhengzhou Metropolitan Area" was put forward, and Henan Province emphasized the enhancement of its ability to lead the regional development in terms of radiation and promote the group development of neighboring cities with Zhengzhou in terms of transportation and industrial layout.

From Figure 5b–d, it can be seen that from 2010 to 2022, the areas with a moderate to low level of resilience to flood disasters in the Zhengzhou metropolitan area are mainly distributed in the southeast of the Zhengzhou metropolitan area. The overall trend of resilience level changes in urban areas is stable, and the number of cities with medium to low resilience levels has decreased. From 2010 to 2016, the Zhengzhou metropolitan area's resilience level was lower than that of the cities of Kaifeng and Luohe, with the lowest resilience level being the city of Xuchang. The 2022 Kaifeng flood resilience level changed from a lower level to a medium level. The city with a low resilience level is Xuchang. In 2022, Kaifeng's flood resilience level was raised from a low grade to a medium level. In recent years, Zhengzhou Municipality has accelerated the construction of Kaifeng as a sub-center city and the creation of an integrated and coordinated development pattern in Zhengbian, which promotes the development of Kaifeng in the fields of economic production, infrastructure, and healthcare, which in turn increases the resilience level of Kaifeng to flooding. In addition, Xuchang is relatively lagging in the development of public services, education and culture, and medical care, which, to some extent, limits the improvement of the city's resilience level.

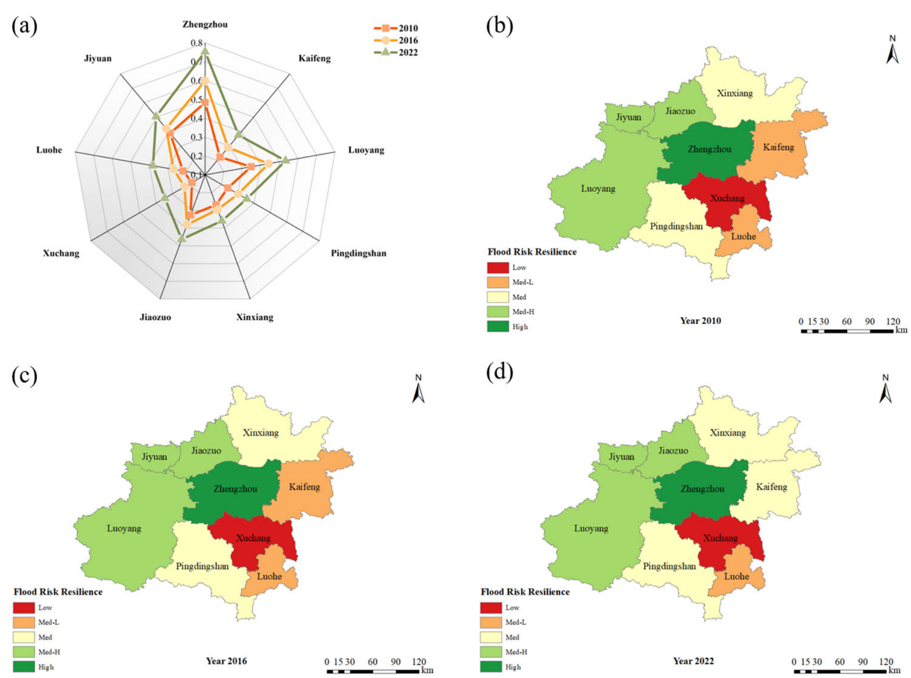

Figure 5. Overall resilience assessment results and spatial distribution characteristics of flood disasters in the Zhengzhou metropolitan area from 2010 to 2022: (**a**) represents the Rada map; (**b**) represents 2010; (**c**) represents 2016; (**d**) represents 2022.

4.3.2. Analysis of Temporal and Spatial Variation of Pressure Resilience

The spatial distribution of flood stress resilience assessment results and stress resilience index rank for the Zhengzhou metropolitan area in 2010, 2016, and 2022 are shown in Figure 6. As can be seen from Figure 6a, the change in flood stress resilience in the Zhengzhou metropolitan area has steadily increased throughout the study, and the small fluctuations in stress resilience that have been observed in some of the cities have been affected by fluctuations in the average annual precipitation amount. Among them, Jiyuan, Luoyang, Zhengzhou, and Jiaozuo are subject to the direct pressure brought about by high precipitation from uplifted terrain and the indirect pressure brought about by industrialization, urbanization of human activities and rapid population growth, and thus the degree of pressure resilience is higher in these cities.

From Figure 6b–d, it can be seen that the degree of flood stress resilience in Zhengzhou metropolitan area generally decreases from west to east from 2010 to 2022, in which the stress resilience level of Pingdingshan shows an upward trend, and the stress resilience level of Xinxiang and Jiaozuo shows a small fluctuation. Pingdingshan is a resource-based industrial city. According to the urban statistical yearbook data, before 2010, the city's tertiary industrial structure was severely imbalanced, and the proportion of industry remained high [54]. Since the promotion of the economic restructuring policy in late 2010, the imbalance in the proportion of industrial structure has been gradually improved, and the development of urbanization and the yearly increase in population density have aggravated the urban heat island effect, which has raised the stress resilience rating of Pingdingshan from low to medium. In addition, with the urbanization development of other members of the metropolitan area, Xinxiang and Jiaozuo do not excel in the overall improvement of the stress resilience index and thus experience fluctuations in rank.

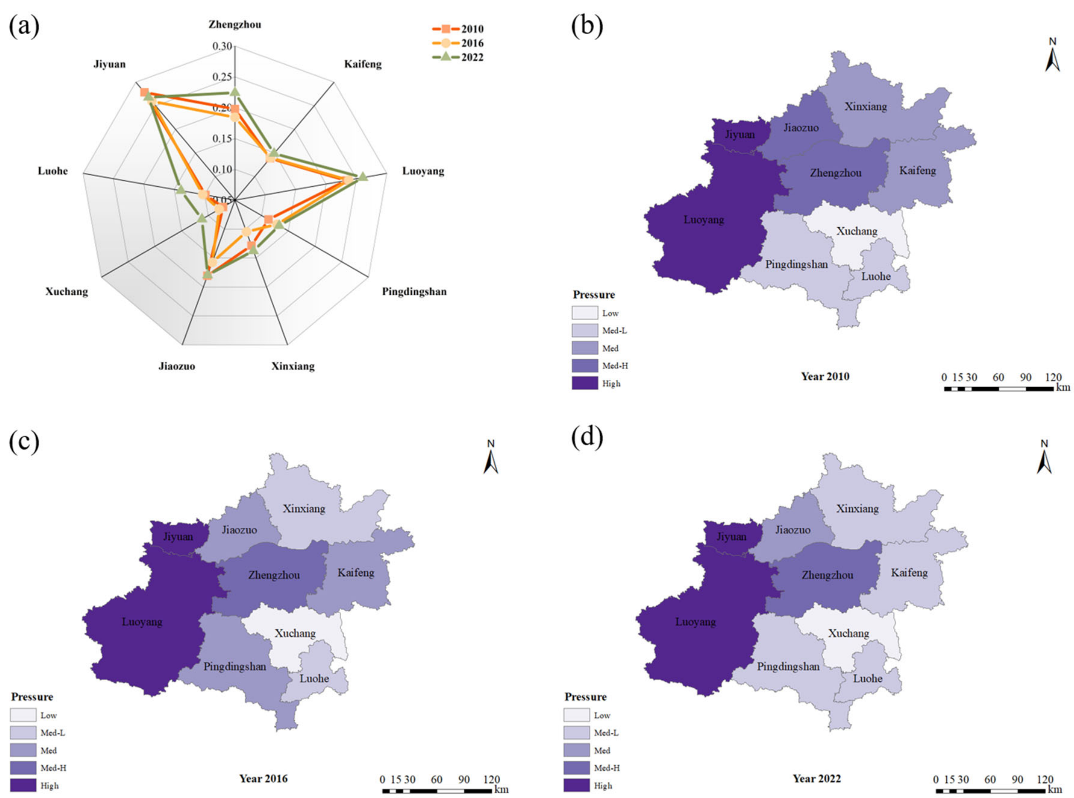

Figure 6. Results and spatial distribution characteristics of pressure resilience assessment of flood disasters in the Zhengzhou metropolitan area from 2010 to 2022: (**a**) represents the Redmap; (**b**) represents 2010; (**c**) represents 2016; (**d**) represents 2022.

4.3.3. Analysis of Temporal and Spatial Variation of State Resilience

The spatial distribution of flood state resilience assessment results and state resilience index rank of the Zhengzhou metropolitan area in 2010, 2016, and 2022 are shown in Figure 7. From Figure 7a, it can be seen that the flood state resilience of the cities in Zhengzhou metropolitan area showed an upward trend during the study period, in which Zhengzhou, Luoyang, Luohe, Xuchang, and Kaifeng showed obvious state resilience growth performance, which indicates that the regional industry and economy, infrastructure, public service benefits, and the quality of life of urban residents continue to improve while reflecting the core city of Zhengzhou to the radiation effect of the surrounding cities to drive the effectiveness of synergistic development.

From Figure 7b–d, it can be seen that the resilience to flood disasters in the Zhengzhou metropolitan area has significantly increased from 2010 to 2022, with Zhengzhou leading the resilience development of urban areas. In 2010, cities with higher levels of resilience were Zhengzhou, Jiaozuo, Jiyuan, and Luohe. In 2016, the state resilience level of Luohe dropped to a medium level, and the city of Luoyang improved from the original low to medium level to a medium level; due to the rapid economic development process, Luohe built-up area greening coverage is relatively weak, while Luoyang in 2014 after the promulgation of the Luoyang greening regulations [55], the quality of urban greening construction and management aspects of the city significantly improved. In 2022, cities with a higher level of resilience will develop into Zhengzhou, Jiaozuo, Luoyang, and Xuchang, reflecting the effectiveness of the integrated development of the Zhengzhou metropolitan area after the release of the Zhengzhou Metropolitan Spatial Plan (2018–2035) by Henan Province in 2019.

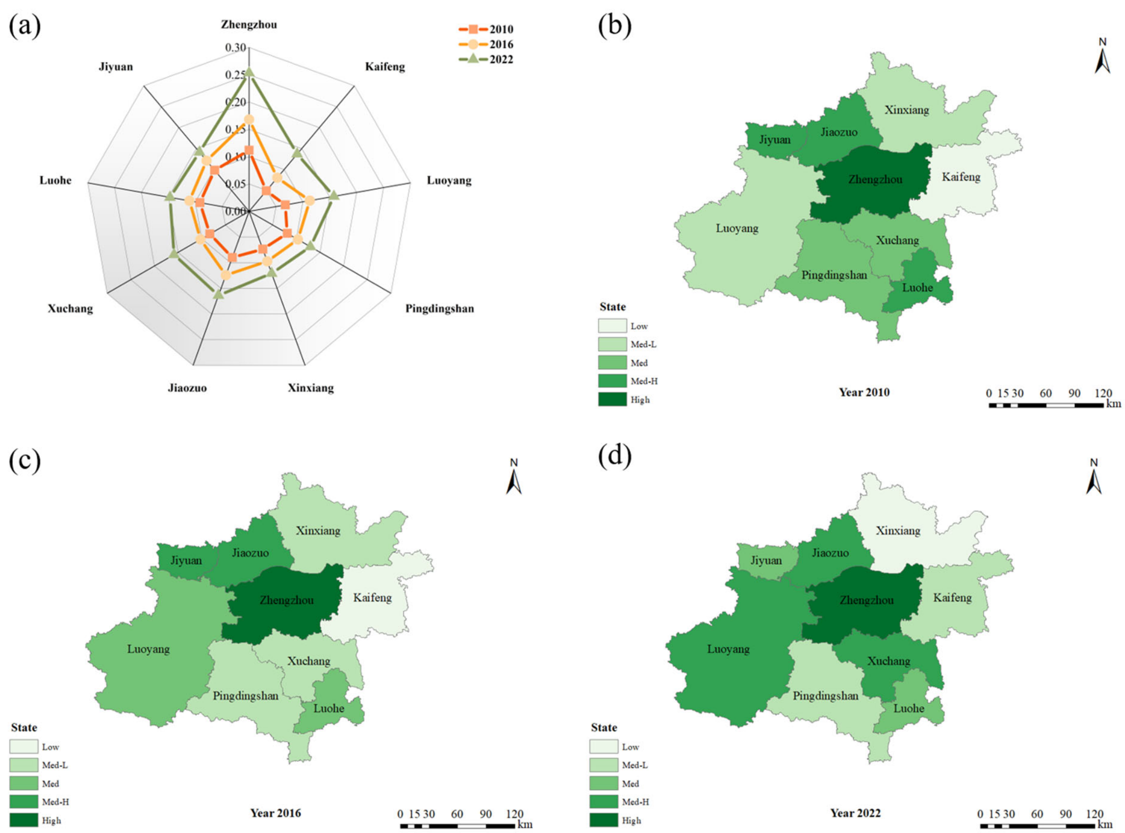

Figure 7. Results and spatial distribution characteristics of pressure resilience assessment of flood disasters in the Zhengzhou metropolitan area from 2010 to 2022: (**a**) represents the Redmap; (**b**) represents 2010; (**c**) represents 2016; (**d**) represents 2022.

4.3.4. Analysis of Temporal and Spatial Variation of Response Resilience

The results of the flood response resilience assessment and the spatial distribution of the response resilience index levels in the Zhengzhou metropolitan area in 2010, 2016, and 2022 are shown in Figure 8. In Figure 8a, the flood response resilience of the cities in the Zhengzhou metropolitan area maintains a steady increase over the period of the study, with Zhengzhou's response resilience index increasing from 0.174 in 2010 to 0.275 in 2022, which is the highest level among the nine cities in the Zhengzhou The nine cities in the metropolitan circle are always at the highest level, which indicates that Zhengzhou has a prominent core position in the metropolitan circle, and its radiation role of leading the members of the metropolitan circle to jointly realize the growth of the resilience level.

From Figure 8b–d, it can be seen that in 2022, the cities in the Zhengzhou metropolitan area with higher resilience levels to flood disasters include Zhengzhou, Xinxiang, Jiaozuo, and Luoyang. Among them, the resilience levels of Jiaozuo and Luoyang increased to a higher level in 2016. Except for cities with a higher level of response resilience, the response resilience levels of Luohe City and Jiyuan City will be raised to a moderate level in 2022. In addition, the response resilience level of Xuchang City was at the lowest level from 2016 to 2022, which is consistent with the actual situation of Xuchang City's relatively weak financial expenditure on education, medical and health, and public safety.

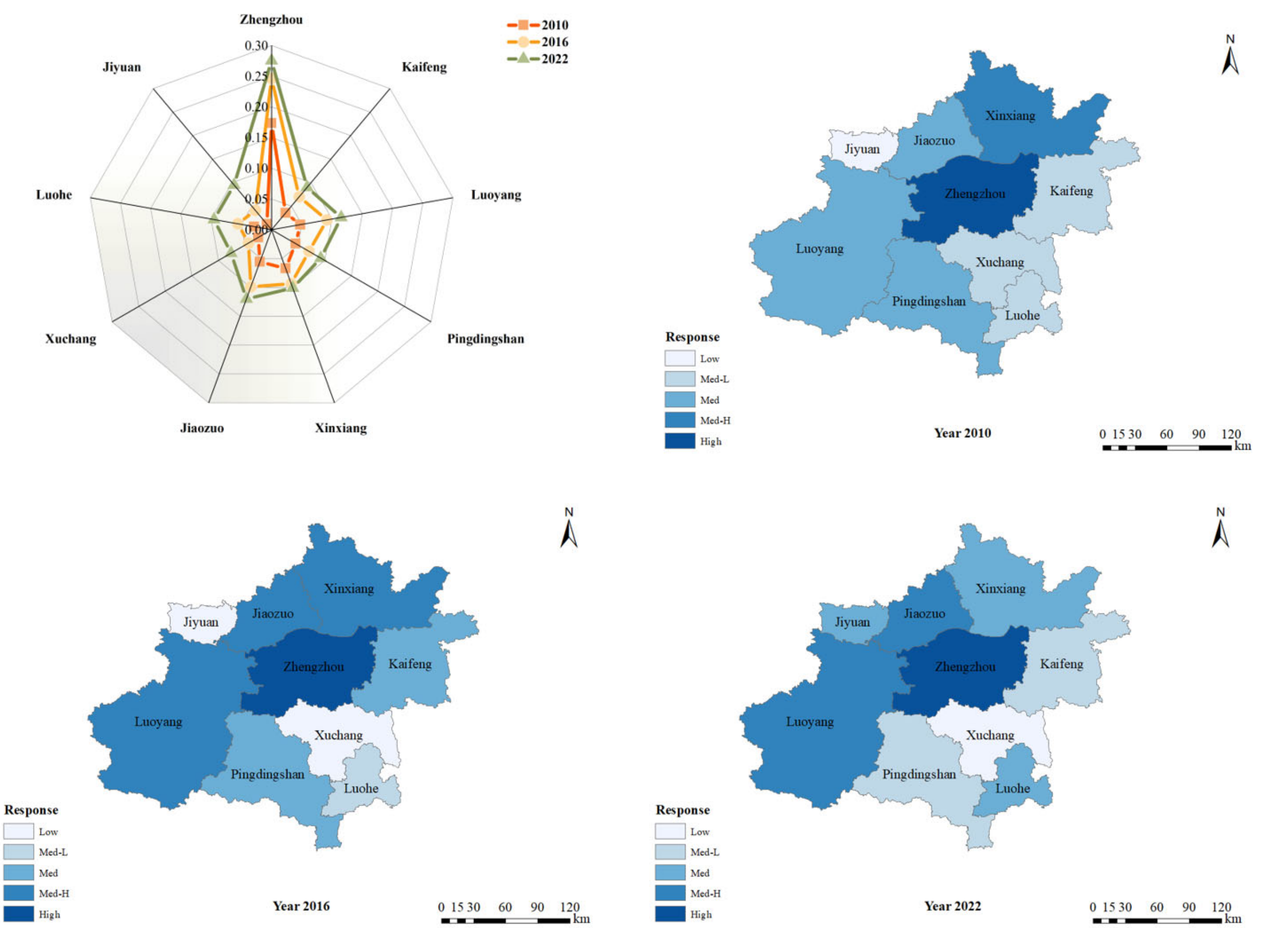

Figure 8. Results and spatial distribution characteristics of pressure resilience assessment of flood disasters in the Zhengzhou metropolitan area from 2010 to 2022: (**a**) represents the Redmap; (**b**) represents 2010; (**c**) represents 2016; (**d**) represents 2022.

4.4. Analysis of Driving Factors of Flood Disaster Resilience

To explore the variation pattern of the contribution of various indicators of flood disaster resilience in the Zhengzhou metropolitan area over time, the contribution of various indicators of flood disaster resilience in the Zhengzhou metropolitan area from 2010 to 2022 was calculated. The calculation results are shown in Table 3. It can be seen that the key influencing factor of pressure resilience is elevation, and the contribution of elevation factors has been increasing year by year, indicating that natural geographical factors are an important prerequisite for determining urban flood resilience. The key influencing factors of state resilience are regional GDP and road density, reflecting the important role of regional economic development and the improvement of social public service quality in urban flood resistance. The key influencing factors of response resilience are the number of ordinary higher education institutions and the proportion of public security expenditure to fiscal expenditure, both of which are positive indicators and have a positive effect on the recovery and construction of regional resilience. The average contribution of ordinary higher education institutions is 21.77%, and the average contribution of public safety expenditure to fiscal expenditure is 16.83%. Both are not only the main influencing factors of response resilience, but also the main influencing factors of flood disaster resilience in the Zhengzhou metropolitan area. The contribution of indicator resilience has steadily increased from 2010 to 2022. On the whole, the resilience to flood disasters in the Zhengzhou metropolitan area is mainly affected by pressure resilience and response resilience. To improve the resilience to flood disasters in the Zhengzhou metropolitan area, the metropolitan area should attach importance to the construction of ordinary colleges and universities, strengthen higher education cooperation and resource sharing within the metropolitan area, and also attach importance to public security financial investment to improve the city's risk perception level and response ability to rainstorm and flood disasters.

Table 3. Contribution of various indicator factors to the resilience of flood disasters in the Zhengzhou metropolitan area from 2010 to 2022.

Target Layer	Resilience Contribution/%												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Elevation	8.64	8.78	9.33	9.61	9.57	9.50	9.57	11.09	10.71	12.35	10.69	9.77	11.73
Annual average precipitation	5.22	5.50	1.31	1.46	3.94	4.75	6.82	5.21	4.80	3.11	6.50	16.20	3.43
Drainage density	5.07	5.14	5.44	5.51	5.47	5.47	5.47	6.21	5.99	6.84	5.92	5.54	6.38
Regional GDP	8.20	8.03	8.44	8.46	8.24	8.13	7.97	8.76	7.88	8.75	7.49	6.77	7.68
Secondary and tertiary industry ratios	0.77	0.74	0.77	0.78	0.72	0.67	0.62	0.60	0.52	0.59	0.57	0.51	0.58
Per capita disposable income	5.88	5.67	5.73	5.52	5.14	4.37	4.15	4.75	3.31	3.56	2.84	2.19	2.16
Road density	8.40	8.31	8.79	8.83	8.68	8.69	8.29	8.93	8.18	9.26	7.70	6.73	7.60
Population density	1.33	1.38	1.55	1.58	1.64	1.54	1.47	1.48	1.44	1.52	1.41	1.26	1.61
Proportion of elderly and young	0.80	0.91	1.12	1.22	1.32	1.52	1.67	2.20	2.49	3.18	3.12	2.53	2.95
Green coverage rate of built-up areas	2.25	2.24	2.19	2.02	1.79	2.04	2.13	2.07	1.76	1.84	1.39	0.98	1.14
Sewage treatment rate	0.39	0.39	0.34	0.32	0.23	0.22	0.13	0.12	0.10	0.10	0.06	0.03	0.02
Per capita park green space area	2.60	2.55	2.67	2.65	2.50	2.49	2.27	2.21	1.92	1.98	1.40	1.13	1.31
Number of universities	20.24	20.04	21.31	20.89	20.50	21.13	21.29	24.04	22.39	25.80	21.87	20.19	23.33
Public security spending ratio	14.76	15.50	16.50	17.44	17.47	17.59	17.28	11.07	18.73	10.49	19.49	19.15	23.29
Hospital beds per 1000 people	15.45	14.83	14.50	13.72	12.80	11.88	10.88	11.27	9.78	10.63	9.56	7.00	6.80

In order to further explore the factors affecting the resilience of flood disasters within the scope of cities in the Zhengzhou metropolitan area and improve the resilience level of rainstorm and flood disasters of cities in the Zhengzhou metropolitan area, the factor contribution degree model was used to calculate the influencing factors of the resilience of flood disasters of cities in the Zhengzhou metropolitan area, and the first two factors of each criterion layer are selected to highlight the contribution degree of indicator factors (Table 4).

The main factors influencing flood stress resilience in the Zhengzhou metropolitan area are elevation and river network density, among which Luoyang and Jiyuan cities' stress resilience influencing factors, in addition to elevation, are average annual precipitation. Natural geographic factors are closely linked to urban flood resilience, so strengthening urban flood control infrastructure construction according to local conditions, improving flood monitoring and early warning and emergency response planning, and enhancing public emergency response capacity are the keys to optimizing flood resilience in the Zhengzhou metropolitan area.

The main factors influencing the state's resilience to flood disasters in the Zhengzhou metropolitan area are regional GDP and road density, and only the state's resilience in Zhengzhou is influenced by population density and green space coverage of the built-up area. As a megacity, Zhengzhou's future development focus should be on population density regulation and urban green space transformation. Through policy and economic means, population density allocation should be optimized while protecting existing green spaces and strengthening green engineering construction such as sponge cities. Core members of the metropolitan area other than Zhengzhou should enhance the economic vitality of the city and improve urban road transportation so as to better cope with the pressures brought by population, resources, and the environment, and thus improve the resilience of the city to floods.

The main factors influencing the response resilience to floods in the Zhengzhou metropolitan area are the number of general higher education institutions and the proportion of public safety expenditures to fiscal expenditures, of which the response resilience of Zhengzhou is influenced by the number of beds per 1000 people in healthcare institutions, in addition to the proportion of public safety expenditures to fiscal expenditures. Cities in the Zhengzhou metropolitan area should pay attention to the investment in public safety affairs, rationalize the fiscal budget, gradually increase the proportion of public safety expenditure, and at the same time, pay attention to the construction of higher education for urban residents and the sharing of educational resources in the metropolitan area, so as to improve the emergency response capacity of all people in the metropolitan area. In addition, Zhengzhou should strengthen the construction and investment of medical and health institutions, optimize and integrate the allocation of medical resources within the city, and break down the barriers to medical resources flow between cities with policy support so as to narrow the gap of medical services with the cities in the metropolitan area.

Table 4. Contribution of main index factors of flood resilience in various cities of the Zhengzhou metropolitan area in 2022.

City	Project	Pressure Resilience		State Resilience		Response Resilience	
		1	2	1	2	1	2
Zhengzhou	Contribution factors	P1	P3	S5	S7	R2	R3
	level of contribution	23.9203	3.7765	6.0081	4.9859	46.9257	6.4384
Kaifeng	Contribution factors	P1	P3	S1	S4	R1	R2
	level of contribution	13.6127	5.4819	8.2004	7.4718	24.1125	19.4188
Luoyang	Contribution factors	P1	P2	S4	S1	R1	R2

	level of contribution	5.5435	2.3375	11.8153	7.7504	31.2229	24.9776
Pingdingshan	Contribution factors	P1	P3	S4	S1	R1	R2
	level of contribution	10.1186	9.1631	8.6548	7.7950	22.9577	18.3990
Xinxiang	Contribution factors	P1	P3	S4	S1	R1	R2
	level of contribution	14.8024	7.2842	9.8179	7.3633	21.6010	18.4476
Jiaozuo	Contribution factors	P1	P3	S1	S4	R1	R2
	level of contribution	9.8623	8.1112	9.9252	7.1070	28.0321	20.0290
Xuchang	Contribution factors	P3	P1	S1	S4	R1	R2
	level of contribution	13.3263	13.1888	7.0011	6.7032	23.7707	18.1657
Luohe	Contribution factors	P1	P3	S1	S4	R1	R2
	level of contribution	14.5162s	9.0417	8.9444	6.8464	25.4799	19.5782
Jiyuan	Contribution factors	P2	P3	S1	S4	R1	R2
	level of contribution	4.7410	1.2542	12.1774	9.9720	32.7891	23.6406

5. Discussion and Suggestions

5.1. Discussion

Urban resilience assessment is an important part of flood disaster prevention and control, which provides a scientific basis for flood disaster prevention and response. Zhengzhou metropolitan area is the 10th metropolitan area planning in China to receive a reply, which has strong development vitality and deep development potential. Improving the overall resilience level of flood disasters in the Zhengzhou metropolitan area plays an important role in enhancing the coordinated development among the members of the metropolitan area and flood disaster risk prevention. As can be seen in Sections 4.1 and 4.3 above, the resilience to flood disasters in the Zhengzhou metropolitan area is on the rise as a whole, which reflects the role of economic and social development in new urban organizations [56]. In the trend analysis part of 4.2, the nuclear density curve reflects the distribution of overall resilience, pressure resilience, state resilience, and response resilience in the Zhengzhou metropolitan area. On the whole, in 2022, in addition to the curve contraction of pressure resilience, the curves of overall resilience, state resilience, and response resilience are significantly expanded. This indicates that the data are more widely distributed, further reflecting the existence of a gap in resilient development among members of the Zhengzhou metropolitan area. In emerging urban groups, there are differences in resources, environment, policies, and other aspects between different cities, so this unbalanced development phenomenon is common [57]. In order to narrow the gap of resilient development between cities, the government should improve the radiation linkage of high-level resilient cities, give full play to the resilience advantages of the members of the metropolitan area, and improve the overall resilience, cohesion, and development vitality of the metropolitan area [58].

In the analysis of driving factors, the number of ordinary higher education institutions and the proportion of public safety expenditure to fiscal expenditure are key influencing factors for flood disaster resilience assessment. Canadian scholar Agrawal [59] proposed breaking down policy barriers between local governments, improving regional education levels, and enhancing public perception of flood disasters when studying flood resilience in Ontario. This viewpoint is consistent with the analysis results of the main driving factors and also applies to the resilience enhancement strategy for flood disasters in the Zhengzhou metropolitan area. By formulating the overall emergency plan for flood disasters in the Zhengzhou metropolitan area, improving the emergency management coordination mechanism among members of the metropolitan area, and regularly holding emergency drills for flood disasters, policy support can be provided to improve the overall resilience of flood disasters in the metropolitan area, and the public's awareness and sensitivity to flood prevention can be strengthened. In addition, British scholar Carvalho [60] and German scholar Fekete [61] emphasized the importance of government participation in flood control when researching and developing strategies to enhance flood resilience. They put forward suggestions for disaster prevention and order restoration, calling on government organizations to increase their participation and response efficiency in flood control. The strategy is consistent with the measures proposed in this article to improve the resilience to flood disasters in the Zhengzhou metropolitan area. By increasing the proportion of public safety expenditure to fiscal expenditure, which is a key influencing factor of flood disaster resilience, the resilience of flood disasters in the Zhengzhou metropolitan area can be improved more effectively.

Zhengzhou is the capital and core city of Henan Province. It plays a leading role in the assessment of flood disaster resilience in the Zhengzhou metropolitan area, which is inseparable from Zhengzhou's unique political advantages and resource allocation strength. However, in the previous analysis of the impact factors of resilience, the contribution factors of Zhengzhou and other members of the metropolitan area are different. The difference is that the obstacle factors of state resilience are population density and green space coverage of built-up areas, and the obstacle factor of response resilience is the number of beds in healthcare institutions per thousand people. This result can further show the core position of Zhengzhou in the Zhengzhou metropolitan area. Under the background of the continuous expansion of population scale, Zhengzhou, as a megacity, has increased its construction land year by year, which has correspondingly brought about a shortage of ecological construction land [62]. In order to enhance the resilience of Zhengzhou and promote sustainable development [63], Zhengzhou needs to pay attention to adjusting population density, strengthening green space protection and land resource management in urban built-up areas, reasonably planning the layout of urban construction, and accelerating ecological restoration and sponge city construction [64]. On the other hand, we should also increase the expenditure on medical and health services, build a medical and health service system with perfect functions and efficient services, promote the sharing of medical resources and the flow of talent in Zhengzhou, and do a good job in medical security in response to floods.

5.2. Suggestions

This article constructs a resilience assessment model for flood disasters in the Zhengzhou metropolitan area and analyzes and measures the spatiotemporal distribution, trend analysis, and main influencing factors of flood disaster resilience in the Zhengzhou metropolitan area. To avoid and alleviate the casualties and property losses caused by floods and waterlogging disasters in the Zhengzhou metropolitan area, accelerate the resilience construction speed of the Zhengzhou metropolitan area, and propose countermeasures and suggestions from three aspects: pressure resilience, state resilience, and response resilience to enhance the flood resilience of the Zhengzhou metropolitan area, we propose the following:

For pressure resilience, the government should improve the city's emergency plan for rainstorms and flood disasters, establish a coordinated mechanism for flood control and emergency response in the Zhengzhou metropolitan area, build a natural disaster prevention and early warning information system, and improve the accuracy of disaster monitoring. At the same time, meteorological departments and emergency departments of Zhengzhou metropolitan area members should strengthen information and technology sharing among departments and cities, actively promote the construction of smart emergency response in various cities of the metropolitan area, gradually form an integrated smart emergency management system, and use information and network means to ensure that disaster information can be timely conveyed to society.

For state resilience, the government and relevant public organizations should innovate institutional mechanisms for coordinated development, maintain sustained and healthy growth of the urban economy, strengthen economic interaction among members of the Zhengzhou metropolitan area, enhance top-level design, and optimize industrial structure and resource allocation. In addition, the government needs to further increase financial expenditure on disaster prevention and reduction, strengthen investment in road network maintenance, do a good job in infrastructure maintenance and urban greening protection, ensure that urban hardware can withstand the damage of natural disasters, and provide solid material conditions for public disaster avoidance and post-disaster reconstruction.

For response resilience, on the one hand, the government needs to pay attention to public safety fiscal expenditures, prepare sufficient emergency supplies and rescue facilities, establish closer connections among members of the Zhengzhou metropolitan area, attach importance to organizing joint exercises, and enhance the internal and external linkage capabilities of the Zhengzhou metropolitan area. On the other hand, it is necessary to strengthen the public's awareness of participation and disaster prevention and reduction capabilities. Through popular science propaganda and emergency drills, the risk awareness, self-rescue, and mutual aid abilities of urban residents should be improved. Schools should be encouraged to regularly carry out disaster prevention and reduction education activities, strengthen higher education construction and emergency management professional talent training, build industry education integration training bases with radiation leading roles, stimulate the overall emergency response vitality of society, and minimize urban losses caused by disasters.

6. Conclusions

6.1. Conclusions

Zhengzhou metropolitan area is the 10th national metropolitan area in China, and it is also an important urban group in Henan Province. It carries the important mission of building a modern Henan and reshaping the advantages of regional development. In this paper, the resilience of flood disasters in the Zhengzhou metropolitan area is evaluated using the three dimensions of pressure, state, and response. The entropy weight method and analytic hierarchy process are used to determine the index weight. The kernel density estimation method is used to analyze the change trend of the resilience of flood disasters in the Zhengzhou metropolitan area. The factor contribution model is used to identify the main factors affecting the resilience to flood disasters in the Zhengzhou metropolitan area. Conducting a flood disaster resilience assessment for the Zhengzhou metropolitan area can enhance the disaster prevention capabilities of its members, optimize government policy formulation and resource allocation, and, to some extent, provide a reference for other metropolitan areas to prevent flood disasters and improve resilience, promoting sustainable development of the city.

The main scientific contributions of this paper are as follows: first, this paper attempts to introduce the PSR model into the study of urban flood disaster resilience, which enriches the application scenarios of the PSR theoretical model; second, the paper measures the resilience of flood disasters in the Zhengzhou metropolitan area. The evaluation results are helpful to the development of member cities in the Zhengzhou metropolitan area and provide targeted suggestions for the city to carry out flood control work, which is conducive to the construction and improvement of the overall pattern of disaster prevention and mitigation in the Zhengzhou Metropolitan area. This paper draws the following conclusions: first, there are obvious differences in the development of resilience among the members of the Zhengzhou metropolitan area. The more obvious changes in resilience are state resilience and response resilience. In addition, the overall degree of resilience is low, and only the resilience values of Zhengzhou, Luoyang, Jiyuan, and Jiaozuo are above the average. Second, the overall resilience of spatiotemporal flood disasters in the Zhengzhou metropolitan area takes Zhengzhou as the core with the highest level of resilience, driving the development of other members of the metropolitan area. Among them, Xuchang, Luohe, and Kaifeng are the cities with rapid growth in overall resilience. In the driving factor analysis, the number of ordinary colleges and universities and the proportion of public security expenditure in fiscal expenditure are the main influencing factors in the resilience evaluation index.

6.2. Deficiencies and Prospects

This paper takes nine cities in the Zhengzhou metropolitan area as the research object, uses the entropy weight method and analytic hierarchy process to evaluate the resilience of flood disasters, and makes trend analysis and influencing factor analysis on this basis. In the subsequent assessment of flood disaster resilience, the reserve status of emergency resources and the number of flood disaster risk points in the Zhengzhou metropolitan area can be further considered so as to enrich the assessment content of flood disaster resilience. However, due to the difficulty in obtaining relevant index data, the research results have certain limitations.

In the context of climate change, flood disaster has become one of the most important natural disasters in China. Its strong suddenness, uncertainty, and destructiveness pose a serious threat to the development of cities. Zhengzhou metropolitan area is the core of economic development in Henan Province. Studying the resilience of flood and waterlogging disasters in the Zhengzhou metropolitan area and carrying out resilience measurements is conducive to the sustainable development of the Zhengzhou metropolitan area and puts forward suggestions for improving the resilience of the Zhengzhou metropolitan area. At the same time, it enriches the resilience assessment research in the metropolitan area and provides an application reference for the comprehensive assessment of resilience in other regions.

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