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Evaluation of Comprehensive Emergency Capacity to Urban Flood Disaster: An Example from Zhengzhou City in Henan Province, China

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Abstract: In the context of climate change and urbanization, increasing flood disasters leads to severe losses and impacts on urban inhabitants. In order to enhance urban capacity to cope with floods and reduce losses, the comprehensive emergency-response capacity to flood disaster (CERCF) was studied in Zhengzhou City, which is seriously affected by floods. Firstly, the evaluation index system of flood emergency capacity was constructed from three aspects, including pre-disaster prevention capacity, during-disaster disposal capacity and post-disaster recovery capacity. Secondly, the weight of each index was calculated by the combination of the entropy weight method and the coefficient of variation method, and the evaluation model was established by the comprehensive index method. Thirdly, the CERCF of Zhengzhou City was classified into three grades by the Jenks natural-breakpoint classification method. Finally, the contribution model was used to reveal the contribution factors of flood emergency capacity in Zhengzhou city. The following beneficial conclusions were drawn: (1) The overall CERCF of Zhengzhou City was on a low level. The proportions of the study area at low, medium and high levels were 58.33%, 33.33% and 8.34%, respectively. Spatially, the CERCF was high in central regions and low in in the west and east parts of Zhengzhou City. (2) It was found that PDPC and PDRC made the greatest contribution, while DDDC has a relatively low contribution degree.

Keywords: flood disasters; coefficient of variation; contribution analysis; disaster prevention and mitigation

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1. Introduction

Flooding is one of the most frequent and destructive natural disasters in the world. Frequent urban flood disasters seriously threaten people's lives and the urban economy against the backdrop of surging population, continuously accelerated urbanization and intensifying global climate change. Recent years have seen frequent extreme rainstorms in cities of China, which influenced a large area and caused great property losses. In particular, Zhengzhou City has undergone heavy rains and torrential rains, and the average precipitation has exceeded the recorded extreme value many times since July 2021. According to the statistics of the People's Government of Henan Province, this disaster caused 302 deaths and 50 missing people, resulting in direct economic losses of 114.269 billion CNY. Among them, Zhengzhou City suffered 292 deaths, 47 missing people and direct economic losses of 53.2 billion CNY. These climatic disasters have made the flood emergency capacity one of the hotspots and focuses of natural disaster research.

The evaluation index system of urban flood disasters in foreign countries has been developed relatively maturely, and research on the evaluation index system of urban flood disasters is mainly carried out from the aspects of risk assessment, loss assessment and management assessment [1,2]. (1) Risk assessment. Risk assessment models are the basis and core of flood disaster risk management and emergency response, in which hazard, exposure

and vulnerability are the focus factors of risk assessment, such as the hazard-vulnerability model [3], hazard-exposure-vulnerability model [4] and hazard-exposure-vulnerability-recovery model [5]. (2) Damage assessment. The flood loss model is the basis of optimizing the investment in flood risk management, and some scholars separately evaluate the loss of a specific object such as the losses of residential buildings and content [6,7]. Some scholars construct a comprehensive loss model to conduct a comprehensive loss assessment for both tangible and intangible losses [8]. (3) Management evaluation. Comprehensive risk-management assessment is the focus of flood disaster management research, and many countries and regions have formulated corresponding management frameworks, such as the EU's "Flood Directive" [9], the French "National Flood Risk Management Strategy" [10], and the United States' "Flood Risk Map" [11], etc. Otherwise, the relationship between legislation, policy and development is the focus of flood risk management and spatial planning [12]. There are also many scholars who conduct management evaluation on certain aspects, such as transportation infrastructure management [13–15], household management [16], insurance pricing [17] and so on. The evaluation methods of urban flood disaster generally fall into four types, i.e., those based on historical disaster data [18], those based on remote sensing [19] and GIS technology [20], those based on index systems [21] and those based on scenario simulations [22].

At present, for the purpose of analyzing and evaluating the possibility of urban flood disasters and minimizing the damage, research on the response capacity evaluation and area classification of urban flood disasters is increasingly attracting the attention of scholars and government departments. The social sciences believe that flood management is inherently flawed by only focusing on structural mitigation measures, such as floods exceeding the discharge capacity of dams or flood walls, which can lead to catastrophic consequences. In addition, the building systems and underground pipe networks of many cities have been formed with the development of the city, and it is difficult to carry out larger-scale debugging and construction according to the existing environmental changes. Under such a management background, social non-structural measures have entered managers' fields of vision as a supplement to structural measures, providing new management tool options for flood disaster management. Therefore, the scientific evaluation of urban flood emergency-response capability and the discovery of outstanding problems can effectively improve the level of urban disaster emergency management.

In the early 1990s, the United States developed the first emergency preparedness evaluation system, focusing on evaluating 13 functions in emergency management [23]. Wang established an indicator system consisting of disaster-reduction ability index, disaster-resilience ability index, and disaster-relief ability index to assess natural disaster coping capacity [24]. Chen et al. studied the social vulnerability and resilience of flood disasters in urban communities in China by analyzing the social vulnerability characteristics of flood disasters in other countries and gaining experience from relevant research results [25]. With the disaster-prone Henan Province regarded as the research area, Liu et al. established an index system of social vulnerability to disaster based on socio-economic data and geographic information data, and evaluated the social vulnerability of Henan Province to natural disasters by selecting 11 indexes out of 62 indexes through anecdotal correlation analysis and the PCA method [26]. In a word, most scholars explored urban disasters from the aspects of disaster-inducing mechanisms, influence factors and relevant social attributes. These existing studies have achieved certain research results, while there are few research studies directly aimed at the evaluation of urban flood disaster emergency-response capacity, and few evaluated the comprehensive emergency-response capacity to floods of cities considering the whole process of the disaster, from the perspectives of social response improvement and disaster prevention and mitigation capacity.

Based on the theory of disaster life cycle, this study established an evaluation index system of the CERCF of Zhengzhou City from three aspects: pre-disaster prevention capacity (PDPC), during-disaster disposal capacity (DDDC) and post-disaster recovery capacity (PDRC). Moreover, it classified the capacity grades and analyzed the distribution

characteristics according to the evaluation results. The research results provide a scientific foundation for a flood-controlling and disaster-reducing plan and sustainable development in Zhengzhou City.

2. Overview of the Research Area

Zhengzhou City, located in north-central Henan Province, China, borders Kaifeng City in the east, Luoyang City in the west, the Yellow River in the north, and Xuchang City and Pingdingshan City in the south (Figure 1). It is of a high terrain in the southwest and a low terrain in the northeast; the altitude is about 80–120 m, making it a typical plain area [27]. At present, Zhengzhou has six districts and six county-level cities; it has a total area of 7446.2 km^2, accounting for about 4.5% of the total area of Henan Province. According to the data of the seventh population census, as of November 2020, Zhengzhou had a permanent resident population of 12.6 million, with an urban population of 9.879 million and an urbanization rate of 78.4%, and its per-capita GDP accounted for 21.8% of the province. Zhengzhou, the capital of Henan Province and a core city of the central plain urban agglomeration, is also an important comprehensive transportation hub for China. It boasts a dense population and active economic interactions. Its geographical location is so important that its urban flood control emergency-response capacity will face great challenges once a flood disaster occurs. Zhengzhou was repeatedly hit by heavy rains and a major flood disaster that occurred in July 2021, which resulted in large economic losses and social impact. According to the survey report, 398 people died or went missing in Henan Province, including 380 in Zhengzhou. A total of 14.786 million people were affected and it caused 120.06 billion yuan of damage, with Zhengzhou suffering 40.9 billion yuan of damage. This study took Zhengzhou City as the research area, established an expression for the CERCF of Zhengzhou from three aspects, i.e., PDPC, DDDC and PDRC, and evaluated its CERCF by analyzing the relevant data in economy, society, population and infrastructure construction in different districts. This study aimed to improve disaster prevention and reduction capacity.

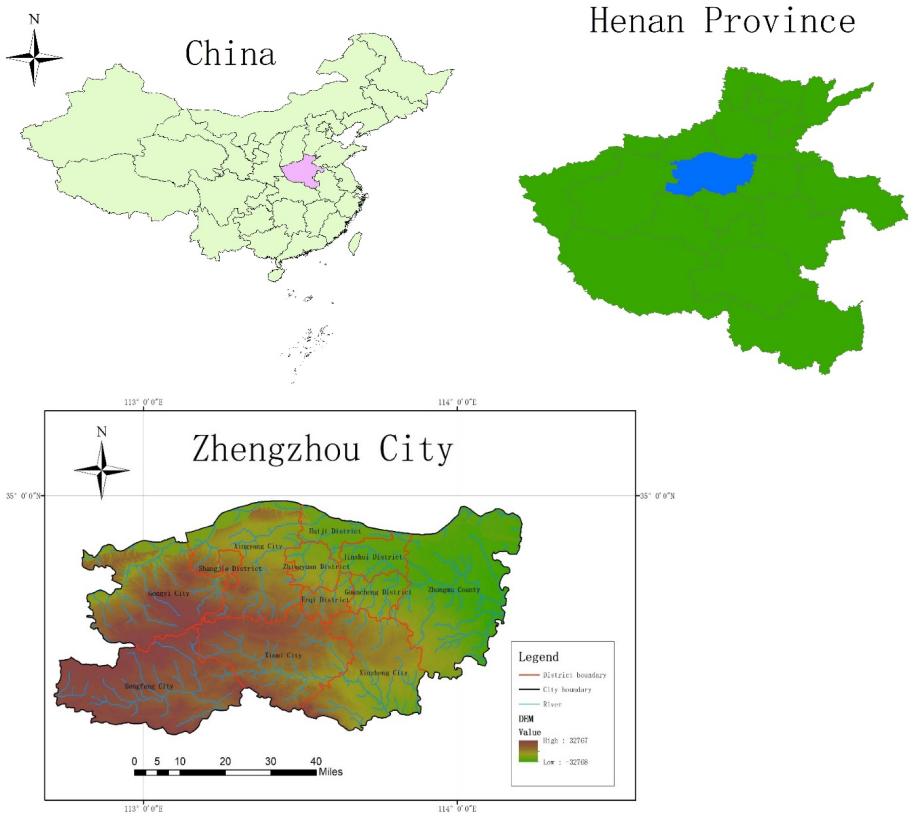


Figure 1. Study area.

3. Research Methods and Case Analysis

3.1. Research Methods

3.1.1. Establishment of a Data Index System

The CERCF of a city is mainly demonstrated by the bearing capacity and response level of social groups, organizations or the country in actual and potential urban flood events. The evaluation of the CERCF of a city involves multiple social systems such as the people, the government, and urban management, and all factors should be considered comprehensively. Therefore, according to the actual situation of Zhengzhou, on the basis of a literature review, expert consultation and reference to previous research results [28–32], five indexes were selected from three aspects (PDPC, DDDC and PDRC) in the process of flood disasters, respectively following the principles of scientificity, effectiveness, systematization and operability. That is, a total of 15 indexes were determined to establish an evaluation system for the CERCF of Zhengzhou City (Table 1).

1. PDPC mainly refers to the preparation made by social groups and government departments in financial support, material supply and emergency awareness education to eliminate or reduce the losses before the occurrence of floods. Therefore, five secondary indexes were selected for the PDPC: the proportions of government financial investment in public security, disaster prevention and emergency management, health, urban and rural community construction and education.
2. DDDC means the response made by the government and society to reduce personnel and property losses when a disaster occurs. A quicker response means a stronger management capacity. It is mainly reflected in the mobilization of rescue materials, medical assistance, supply of life necessities, self-assistance and the mutual assistance capacity of people and social and economic development. Therefore, five secondary indexes were determined for the DDDC: the number of community health service centers, the total retail sales of social consumer goods, the age structure of the population, the urbanization rate and the proportion of the output value of the tertiary industry.
3. PDRC refers to the efforts made by the government and the people to restore normal production and life soon after the disaster. Stronger PDRC is conducive to a fast recovery to a normal state. It is mainly reflected in government finance, people's living conditions and social employment security. Hence, five secondary indexes were set for the PDRC: per-capita GDP, government fiscal revenue, per-capita disposable income, proportion of labor force population and the total government expenditure on social security and employment.

3.1.2. Determination of Index Weights

Entropy belongs to the physical concept in the field of thermodynamics, and Shannon created the information theory with his outstanding article, describing information disorder with information entropy. The entropy weight method is based on index information entropy and determines the weight of the degree of individual index change on the system. However, the entropy weight method only adjusts the information transmission variation among the index columns, which defects the equalization of weight distribution results [33]. The coefficient of variation method assigns the degree of variation of the value of the index in the evaluation system, focusing on reflecting the gap between the evaluation objects, which can avoid the inherent defects of the entropy weight method to some extent [34]. Based on this, this paper uses a combination of the entropy weight method and the coefficient of variation method to determine the index weight, so as to reduce the subjective randomness of the index construction and the uncertainty of a single assignment. Supposing there are m evaluation indicators and n evaluation objects, the original data matrix $R = (r_{ij})_{m \times n}$ is formed. The specific steps are as follows:

Table 1. Evaluation index system and weights of the CERCF of Zhengzhou City.

Target	Criterion	Weight	Index	Meaning	Weight
CERCF of Zhengzhou	PDPC	0.30923	Proportion of public security financial investment/% r_{11}	Government financial investment in social public security	0.05396
			Proportion of financial input in disaster prevention and emergency management/% r_{12}	Government financial investment in disaster prevention and emergency management	0.06328
			Proportion of health financial investment/% r_{13}	Government financial investment in health	0.08415
			Proportion of financial investment in urban and rural communities/% r_{14}	Government financial investment in urban and rural community construction	0.06024
			Proportion of financial investment in education/% r_{15}	Government financial investment in education	0.04760
	DDDC	0.37721	Number of community health service centers r_{21}	Social medical rescue capacity	0.08533
			Total retail sales of social consumer goods/10^8 CNY r_{22}	Retail sales of consumer goods	0.07543
			Proportion of population aged 15–59/% r_{23}	Population aged 15–59 as a percentage of the total population, it represents people's self-help and mutual rescue ability to a certain extent	0.05455
			Urbanization rate/% r_{24}	The ratio of urban population to total population, it represents the development level of urban	0.08876
			Proportion of output value of tertiary industry/% r_{25}	The GDP of the tertiary industry accounts for the proportion of the total GDP. It represents regional industrial structure and economic development level	0.07314
	PDRC	0.31356	Per capita GDP (CNY/person) r_{31}	Per capita economic development level	0.05559
			Government revenue/10^8 CNY r_{32}	Financial support capacity for disaster recovery	0.05777
			Per capita disposable income of residents/CNY r_{33}	Household income	0.07808
			Proportion of labor force population/% r_{34}	Labor force as a percentage of the total population. It represents the urban population structure and human resource level	0.05548
			Total social security and employment expenditure/10^4 CNY r_{35}	It reflects the basic investment of government agencies in urban disaster management.	0.06665

(1) Standardization of the original data matrix. The data of different indicators are quite different, and there are positive indicators and reverse indicators. In this study, the index data were standardized by the range normalization method. The calculation formula is follows:

$$\text{Positive Indicators}: \ R_{ij} = \frac{r_{ij} - r_{\min}}{r_{\max} - r_{\min}} \tag{1}$$

$$\text{Reverse Indicators}: \ R_{ij} = \frac{r_{\max} - r_{ij}}{r_{\max} - r_{\min}} \tag{2}$$

R_{ij} is the standard value of the j-th evaluation object on the i-th evaluation indicator; r_{ij} is the original value of the j-th index datum of each evaluation unit; $r_{\max}$ and $r_{\min}$ are the maximum and minimum values in the original data of each evaluation unit respectively.

(2) The coefficient of variation calculated according to the mean value and the standard deviation of each measure index, and the calculation formula is:

$$\partial_j = \frac{\sqrt{\sum_{j=1}^{n} (R_{ij} - \overline{R_j})^2}}{n} \tag{3}$$

$$V_j = \frac{\partial_j}{\overline{R_j}} \tag{4}$$

$$\overline{R_j} = \frac{1}{n} \sum_{j=1}^{n} R_{ij} \tag{5}$$

$$W_{j1} = \frac{V_j}{\sum_{j=1}^{n} V_j} \tag{6}$$

where $\overline{R_j}$ is the average of the R_{ij} indicators, ∂_j is the standard deviation of the R_{ij} indicators, V_j is the coefficient of variation for the indicators, and W_{j1} is the weight of the R_{ij} indicators.

(3) The information entropy of the j-th index was calculated using the normalized index value R_{ij}. Then, we calculated the weight W_{j2} of each measure indicator value R_{ij}. The calculation formula is:

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^{m} \frac{R_{ij}}{\sum_{i=1}^{m} R_{ij}} \ln \frac{R_{ij}}{\sum_{i=1}^{m} R_{ij}} \tag{7}$$

$$W_{j2} = \frac{1 - E_j}{\sum_{j=1}^{n} (1 - E_j)} \tag{8}$$

(4) The weight is determined by using the combination assignment. Referring to Li's study [35], the combined assignment preference coefficient is set at $\alpha = 0.5$, and the calculation formula is:

$$W_j = \alpha \times W_{j1} + (1 - \alpha) \times W_{j2} \tag{9}$$

3.1.3. Establishment of an Evaluation Model for the CERCF of Zhengzhou City

This study mainly evaluates the CERCF of Zhengzhou City from three aspects: PDPC, DDDC and PDRC. Therefore, the scores of the three indexes were calculated by using the standardized index data according to the determined weights for the data. The equations are as follows:

$$P = \sum_{j=1}^{5} W_j \times R_{ij} \tag{10}$$

$$D = \sum_{j=6}^{10} W_j \times R_{ij} \tag{11}$$

$$R = \sum_{j=11}^{15} W_j \times R_{ij} \tag{12}$$

where P, D and R are the PDPC, DDDC and PDRC indexes, respectively, and greater values of P, D and R mean stronger PDPC, DDDC and PDRC, respectively; R_{ij} is the standardized datum value of the j-th index in each evaluation unit; W_j is the weight of the j-th index in each evaluation unit.

According to the correlation between indexes and urban floods, an evaluation model for the CERCF of Zhengzhou City was established using the linear weighted synthesis method, specifically:

$$A = \sum_{j=1}^{n} W_j \times R_{ij} \tag{13}$$

where A is the CERCF index of the city; R_{ij} is the standardized datum value of the j-th index in each evaluation unit; W_j is the weight of the j-th index in each evaluation unit.

3.1.4. Establishment of a Contribution Model

The improvement of the CERCF of cities is an important premise to ensure the safety of people's lives and property to the greatest extent. In this study, with the aid of the contribution degree model, the main contribution factors and their contribution degrees were analyzed to improve the CERCF of cities. On the basis of analyzing single factors, the contribution degrees of three criteria (PDPC, DDDC and PDRC) to the CERCF of cities were further explored.

$$S_j = \frac{W_j \times R_{ij}}{\sum_{j=1}^{n} W_j \times R_{ij}} \times 100\% \tag{14}$$

where S_j is the contribution degree of the j-th index to the CERCF of cities; R_{ij} is the standardized datum value of the j-th index in each evaluation unit; W_j is the weight of the j-th index in each evaluation unit. The larger the S_j value is, the greater the contribution is.

3.2. Case Analysis

3.2.1. Determination of Evaluation Unit

With the CERCF of Zhengzhou as the research object, 12 regions (including six districts and six county-level cities) under the jurisdiction of Zhengzhou City, Henan Province, China, serve as the evaluation units.

3.2.2. Data Source and Processing

Data concerning the total retail sales of consumer goods, the urbanization rate, the proportion of the output value of the tertiary industry, the per-capita GDP and the per-capita disposable income of residents in this study were from the Statistical Yearbook of Henan Province (2020). Data concerning community health service institutions were sorted according to the information released by Henan Provincial Health Commission. The proportion of the population aged 15–59 mainly came from the 7th National Census Bulletin of Zhengzhou City. The proportions of financial investment in public security, disaster prevention and emergency management, urban and rural communities, education, social security and employment were from relevant data releashed by local governments and civil affairs departments. The index data were normalized according to Equations (1) and (2).

4. Results and Analysis

Standardized values (Table 2) for each evaluation unit were calculated using Equations (1) and (2). In addition, the Jenks natural-breakpoint classification method is

used to divide the comprehensive emergency-response capacity of each assessment unit into three grades: low, medium and high, which are represented by I, II and III, respectively. Their specific value ranges are given in Table 3. The evaluation results and grades of PDPC, DDDC, PDRC and CERCF of each region can be obtained according to the Equations (6)–(8) and Table 3 (Tables 4–7). Moreover, based on such a classification, the spatial pattern distribution map of Zhengzhou's CERCF is obtained using the spatial visualization function of GIS (Figure 2).

Table 2. Standardized results of evaluation indexes of the CERCF of Zhengzhou City.

Evaluation Unit	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{21}	R_{22}	R_{23}	R_{24}	R_{25}	R_{31}	R_{32}	R_{33}	R_{34}	R_{35}
Zhongyuan District	0.23	0.00	0.16	0.76	0.59	0.65	0.30	0.60	0.98	0.40	0.37	0.24	0.72	0.25	0.31
Erqi District	0.00	0.25	0.27	0.98	0.37	0.70	0.35	0.83	0.97	0.79	0.21	0.27	0.78	0.00	0.43
Jinshui District	0.33	0.63	0.00	1.00	0.78	1.00	1.00	0.84	1.00	1.00	0.65	0.78	1.00	0.63	0.39
Guancheng District	0.27	0.38	0.67	0.58	0.68	0.40	0.79	0.94	0.88	0.24	1.00	0.22	0.67	0.72	0.20
Huiji District	0.10	0.38	0.30	0.27	1.00	0.25	0.14	1.00	0.58	0.54	0.22	0.12	0.35	0.85	0.01
Shangjie District	1.00	0.00	0.03	0.75	0.18	0.00	0.00	0.54	1.00	0.29	0.32	0.00	0.92	0.06	0.00
Zhongmu County	0.48	0.13	0.00	0.35	0.62	0.05	0.23	0.20	0.00	0.13	0.31	0.65	0.00	0.99	0.16
Xinzheng City	0.54	1.00	0.18	0.68	0.36	0.15	0.24	0.86	0.17	0.14	0.50	1.00	0.17	1.00	0.93
Xinmi City	0.48	0.50	0.93	0.22	0.63	0.15	0.11	0.33	0.16	0.11	0.17	0.34	0.13	0.69	0.61
Xingyang City	0.81	0.75	0.49	0.11	0.70	0.05	0.09	0.41	0.08	0.13	0.15	0.54	0.12	0.76	0.46
Dengfeng City	0.63	0.38	0.78	0.00	0.90	0.10	0.09	0.00	0.07	0.11	0.00	0.22	0.05	0.60	0.37
Gongyi City	0.35	0.38	1.00	0.35	0.00	0.10	0.18	0.27	0.11	0.00	0.25	0.51	0.20	0.70	1.00

Table 3. Criteria for classifying the grades of different indexes of CERCF of Zhengzhou City.

Index Grade	PDPC	DDDC	PDRC	CERCF
Low (I)	[0.0847–0.1187)	[0.0296–0.0614)	[0.0746–0.0944)	[0.2471–0.3904)
Medium (II)	[0.1187–0.1551)	[0.0614–0.1775)	[0.0944–0.1254)	[0.3904–0.5769)
High (III)	[0.1551–0.1790)	[0.1775–0.3685)	[0.1254–0.2202)	[0.5769–0.7437)

Table 4. Evaluation results and grades of PDPC of Zhengzhou City.

Evaluation Unit	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	PDPC Index	Grade
Xinmi City	0.0259	0.0316	0.0783	0.0133	0.0300	0.1791	III
Xingyang City	0.0437	0.0475	0.0412	0.0066	0.0333	0.1723	III
Dengfeng City	0.0340	0.0240	0.0656	0.0000	0.0428	0.1664	III
Xinzheng City	0.0291	0.0633	0.0151	0.0410	0.0171	0.1656	III
Guancheng District	0.0146	0.0240	0.0564	0.0349	0.0324	0.1623	III
Jinshui District	0.0178	0.0399	0.0000	0.0602	0.0371	0.155	II
Gongyi City	0.0189	0.0240	0.0842	0.0211	0.0000	0.1482	II
Huiji District	0.0054	0.0240	0.0252	0.0163	0.0476	0.1185	I
Erqi District	0.0000	0.0158	0.0227	0.0590	0.0176	0.1151	I
Shangjie District	0.0540	0.0000	0.0025	0.0452	0.0086	0.1103	I
Zhongyuan District	0.0124	0.0000	0.0135	0.0458	0.0281	0.0998	I
Zhongmu County	0.0259	0.0082	0.0000	0.0211	0.0295	0.0847	I

4.1. PDPC

PDPC demonstrates the importance a region attaches to disasters. The region with stronger PDPC is more capable of containing the occurrence of disasters in time and minimizing the losses. According to Table 4, Xinmi City, Xingyang City, Dengfeng City, Xinzheng City and Guancheng District, whose indexes range from 0.1623 to 0.1791, are of high PDPCs. Zhongmu County, Zhongyuan District, Erqi District, Huiji District and Shangjie District, with indexes of merely 0.0847 to 0.1185, are of low PDPCs. The rest of the regions correspond to medium PDPCs. According to Figure 2a, the regions with high PDPCs are generally in central Zhengzhou City, while those with low PDPCs are generally in the central and eastern parts. An analysis on indexes reveals that the government's

awareness to disasters, namely financial investment, is the key to the PDPC. Xinmi City boasts the highest score in the whole PDPC index. The main reason is that the government has invested heavily in pre-disaster prevention, and the key index of health financial investment accounts for 11.9% in the government budget expenditure, which fully reflects the government's awareness. In contrast, Zhongmu County has the lowest score in the PDPC index, merely 0.0847, and government finance invests the least in the key index of health financial investment, merely 5.7%.

Table 5. Evaluation results and grades of DDDC of Zhengzhou City.

Evaluation Unit	R_{21}	R_{22}	R_{23}	R_{24}	R_{25}	DDDC Index	Grade
Jinshui District	0.0853	0.0754	0.0458	0.0888	0.0731	0.3684	III
Erqi District	0.0597	0.0264	0.0453	0.0861	0.0578	0.2753	III
Guancheng District	0.0341	0.0596	0.0513	0.0781	0.0176	0.2407	III
Zhongyuan District	0.0555	0.0226	0.0327	0.0870	0.0293	0.2271	III
Huiji District	0.0213	0.0106	0.0545	0.0515	0.0395	0.1774	II
Shangjie District	0.0000	0.0000	0.0295	0.0888	0.0212	0.1395	II
Xinzheng City	0.0128	0.0181	0.0469	0.0151	0.0102	0.1031	II
Xinmi City	0.0128	0.0083	0.0180	0.0142	0.0080	0.0613	II
Xingyang City	0.0043	0.0068	0.0224	0.0071	0.0095	0.0501	I
Gongyi City	0.0085	0.0136	0.0147	0.0098	0.0000	0.0466	I
Zhongmu County	0.0043	0.0173	0.0109	0.0000	0.0095	0.0420	I
Dengfeng City	0.0085	0.0068	0.0000	0.0062	0.0080	0.0295	I

Table 6. Evaluation results and grades of PDRC of Zhengzhou City.

Evaluation Unit	R_{31}	R_{32}	R_{33}	R_{34}	R_{35}	PDRC Index	Grade
Jinshui Distric	0.0361	0.0451	0.0781	0.0350	0.0260	0.2203	III
Xinzheng City	0.0278	0.0578	0.0133	0.0555	0.0620	0.2164	III
Guancheng District	0.0556	0.0127	0.0523	0.0399	0.0133	0.1738	III
Gongyi City	0.0139	0.0295	0.0156	0.0388	0.0666	0.1644	III
Zhongyuan District	0.0206	0.0139	0.0562	0.0139	0.0207	0.1253	II
Xingyang City	0.0083	0.0312	0.0094	0.0422	0.0307	0.1218	II
Zhongmu County	0.0172	0.0376	0.0000	0.0549	0.0107	0.1204	II
Xinmi City	0.0094	0.0196	0.0101	0.0383	0.0407	0.1181	II
Erqi District	0.0117	0.0156	0.0609	0.0000	0.0287	0.1169	II
Huiji District	0.0122	0.0069	0.0273	0.0472	0.0007	0.0943	I
Shangjie District	0.0178	0.0000	0.0718	0.0033	0.0000	0.0929	I
Dengfeng City	0.0000	0.0127	0.0039	0.0333	0.0247	0.0746	I

Table 7. Evaluation results and grades of CERCF of Zhengzhou City.

Evaluation Unit	PDPC	DDDC	PDRC	CERCF	Grade
Jinshui District	0.1550	0.3685	0.2202	0.7437	III
Guancheng District	0.1623	0.2407	0.1739	0.5768	II
Erqi District	0.1152	0.2753	0.1168	0.5073	II
Xinzheng City	0.1657	0.1031	0.2163	0.4851	II
Zhongyuan District	0.0997	0.2271	0.1252	0.4520	II
Huiji District	0.1186	0.1774	0.0943	0.3903	I
Gongyi City	0.1482	0.0466	0.1645	0.3592	I
Xinmi City	0.1790	0.0613	0.1182	0.3586	I
Xingyang City	0.1723	0.0500	0.1217	0.3441	I
Shangjie District	0.1102	0.1394	0.0929	0.3426	I
Dengfeng City	0.1665	0.0296	0.0746	0.2707	I
Zhongmu County	0.0847	0.0420	0.1204	0.2471	I

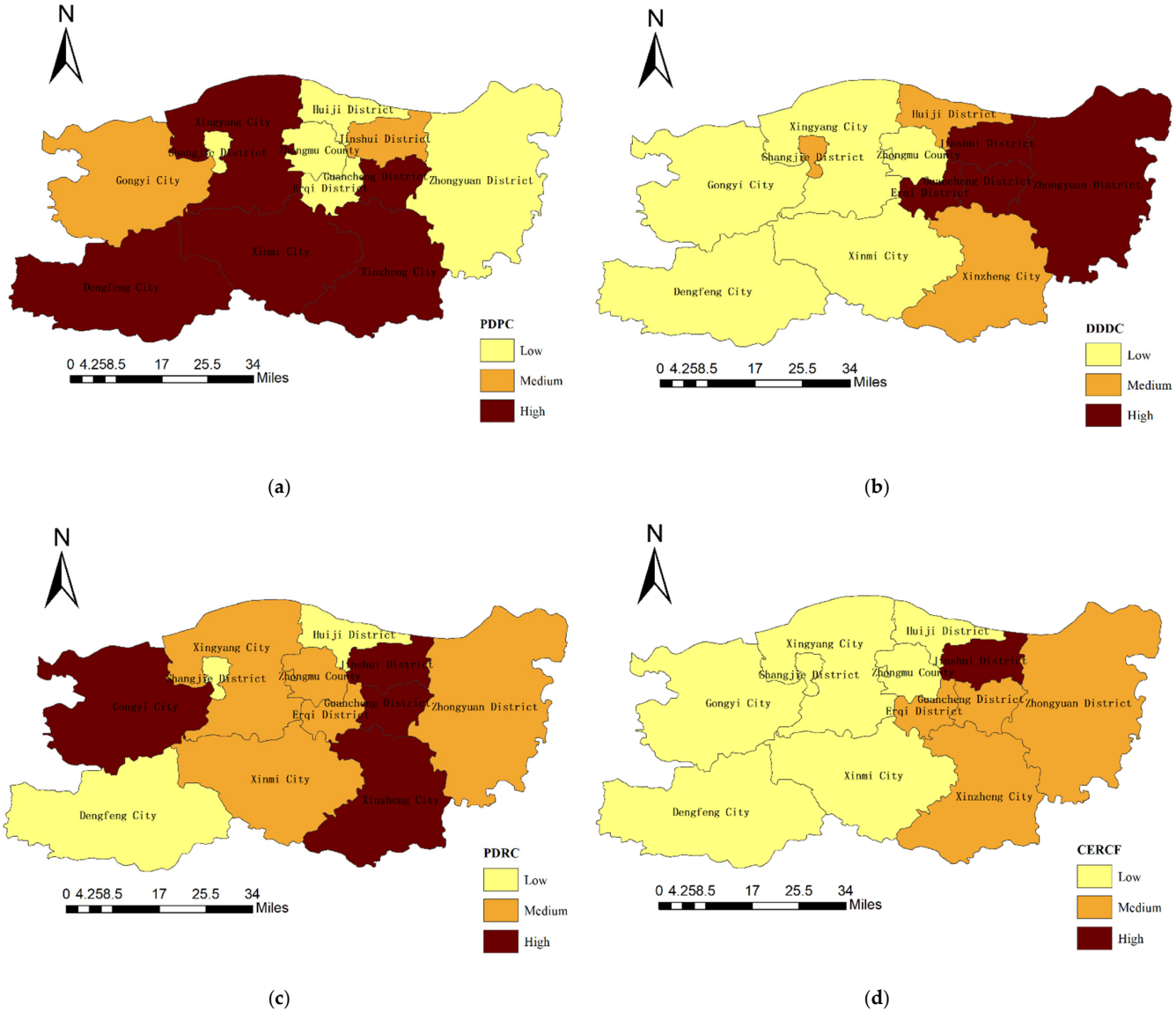


Figure 2. Spatial distributions of PDPC, DDDC, PDRC and CERCF of Zhengzhou City. (**a**) PDPC. (**b**) DDDC. (**c**) PDRC. (**d**) CERCF.

4.2. DDDC

DDDC reflects the emergency-response level in a region. The region with stronger DDDC can control a disaster sooner and reduce the losses to the greatest extent. According to Table 5, Jinshui District, Erqi District, Guancheng District and Zhongyuan District boast strong DDDCs, with their index scores ranging from 0.2271 to 0.3684. In contrast, Dengfeng City, Zhongmu County, Gongyi City and Xingyang City have weak DDDCs, with their index scores lying in the range of 0.0295 to 0.0501. The remaining four regions correspond to medium DDDCs. As can be seen from Figure 2b, overall, the DDDC is strong in the central part yet weak in the eastern and western parts. Jinshui District gains the highest score in the DDDC index. It is found that the number of community health service centers, the total retail sales of social consumer goods, the proportion of the output value of the tertiary industry and the urbanization rate are all the highest among the 12 regions. Dengfeng City, Zhongmu County, Gongyi City and Xingyang City correspond to relatively weak DDDCs, mainly because of their low scores in some key indexes. For example, the population age structure affects the DDDC and reaction speed of people during disasters to a certain extent. The higher the proportion of young and middle-aged people is, the stronger the DDDC is. Accordingly, Dengfeng City, Zhongmu County, Gongyi City and Xingyang City, with

the lowest scores, correspond to only 58.01%, 60.08%, 61.75% and 63.56%, respectively, for the population aged 15–59, while Jinshui District, Erqi District, Guancheng District and Zhongyuan District, with the highest DDDCs, correspond to 69.48% 69.34%, 70.81% and 66.23%, respectively.

4.3. PDRC

The PDRC reflects the capacity of a region to cope with disasters and conduct post-disaster reconstruction in the most efficient way. The region with stronger PDRC can restore normal production and the lives of the society faster. According to Table 6, Jinshui District, Xinzheng City, Guancheng District and Gongyi City boast the best PDRCs, and their index scores exceed 0.16. In contrast, Dengfeng City, Shangjie District and Huiji District, whose index scores range from 0.0746 to 0.0943 have the worst PDRCs, and the remaining five regions have moderate PDRCs. It can be seen from Figure 2c that the PDRC is generally high in most regions yet low in southwestern parts. Jinshui District has the highest score in the whole PDRC evaluation, and its PDRC score is up to 0.2203. With respect to the key index of a high score in per-capita disposable income, Jinshui District ranks first among all counties and districts in Zhengzhou City. As can be seen from Table 1, this index occupies the highest weight in the five indexes for PDRC. In addition, Xinzheng District also scored higher in government revenue, labor force proportion and other indicators, and its PDRC index reaches 0.2164, closely following Jinshui District. Shangjie District and Dengfeng City have relatively low scores in many indexes, especially in the government financial revenue, per-capita GDP, social security and employment, resulting in their weak PDRCs.

4.4. CERCF

According to the evaluation results of the PDPC, DDDC and PDRC indexes, a CERCF model was established for calculating the CERCF for different regions of Zhengzhou City (Equation (9)) (Table 7).

The index scores of the CERCF of Zhengzhou City were obtained by evaluating the flood disaster of Zhengzhou City from three aspects (before, during and after the disaster). According to the scores, the grades and areas were classified. As can be seen from Table 7, the CERCFs of Jinshui District is in Grade III, its index scores exceeding 0.7. Those of Guancheng District, Erqi District, Xinzheng City and Zhongyuan District are in Grade II, with their index scores lying in the range of 0.4520–0.5768. Those of Huiji District, Gongyi City, Xinmi City, Xingyang City, Shangjie District, Dengfeng City and Zhongmu County are in Grade I, with their index scores all being below 0.25. As illustrated in Figure 2d, spatially, the CERCF of Zhengzhou City is generally strong in the central part yet weak in the west and east parts. Jinshui District ranks first in the evaluation of CERCF with a score of 0.7437, mainly because it gains high scores in PDPC, DDDC and PDRC. In particular, it obtains the highest score of 0.3685 in the key index DDDC. Zhongmu County and Dengfeng City rank relatively behind, and they have lower index scores than other regions, explaining their weak CERCFs.

4.5. Analysis on the Contribution Degree of CERCF of Zhengzhou City

With the aid of the above contribution degree model (Equation (10)), the contribution degrees and contribution factors of CERCF of Zhengzhou City were analyzed at the criterion level and the index level, respectively. In addition, to better identify factors with a high contribution degree, this study sorted the top three factors with the highest contribution degrees.

(1) At the criterion level, the contribution degrees of PDPCs, DDDCs and PDRCs of regions were obtained by calculating the contribution degrees of all factors (Table 8). The leading factors that affect the CERCF of the city were determined by the standard that the sum of the contribution degree of a single subsystem and the contribution degrees of the other two subsystems equals 80% [36]. Meanwhile, the CERCF was classified into seven types, namely, the PDPC-dominating type, the DDDC-dominating type, the

PDRC-dominating type, the PDPC- and DDDC-dominating type, the PDPC- and PDRC-dominating type, the DDDC- and PDRC-dominating type and the balanced type. According to the calculated contribution degrees, the CERCF of Zhengzhou City mainly involves two types (the PDPC- and PDRC-dominating type and the balanced type). It can be seen from Table 8 that the contribution degrees of the six municipal districts and Xinzheng City were relatively balanced in the three stages (PDPC, DDDC and PDRC), indicating their relatively complete CERCFs. Among the six county-level cities under the jurisdiction of Zhengzhou City, the leading factors affecting the CERCF are mainly concentrated in the PDPC and PDRC stages, and the contribution of the DDDC stage is relatively low, which requires further improvement.

Table 8. Contribution degrees and types of CERCF of Zhengzhou City.

Evaluation Unit	PDPC	DDDC	PDRC	Type
Jinshui District	20.85%	49.55%	29.61%	Balanced type
Guancheng District	28.14%	41.72%	30.14%	Balanced type
Erqi District	22.71%	54.26%	23.03%	Balanced type
Xinzheng City	34.15%	21.26%	44.59%	Balanced type
Zhongyuan District	22.07%	50.24%	27.69%	Balanced type
Huiji District	30.38%	45.46%	24.16%	Balanced type
Gongyi City	41.25%	12.97%	45.78%	PDPC- and PDRC-dominating type
Xinmi City	49.93%	17.11%	32.96%	PDPC- and PDRC-dominating type
Xingyang City	50.09%	14.54%	35.37%	PDPC- and PDRC-dominating type
Shangjie District	32.18%	40.70%	27.13%	Balanced type
Dengfeng City	61.52%	10.93%	27.55%	PDPC- and PDRC-dominating type
Zhongmu County	34.28%	17.01%	48.71%	PDPC- and PDRC-dominating type

(2) At the index level, the contribution degrees of the top three key indexes with the highest contribution degrees in improving the CERCF of Zhengzhou City were obtained by calculating the contribution degrees of all factors (Table 9). The average cumulative contribution degree exceeds 44%, suggesting that the contribution factors at the index level can fully reflect the contribution degrees of indexes. Specifically, Shangjie District and Gongyi City have the highest cumulative contribution degrees: 62.63% and 52.79%, respectively. A further analysis on the contribution factors and contribution degrees discloses that among the contribution factors of CERCF in different regions, those with a contribution degree over 20% mainly include the following: r_{34} (proportion of labor force population), r_{13} (proportion of health financial investment), r_{24} (urbanization rate) and r_{33} (per-capita disposable income of residents). It is found that the top three factors with the highest cumulative contribution degrees are mainly concentrated in the PDPC and PDRC stages. However, factors correspond to relatively low contribution degrees in the stage of DDDC. Hence, it is necessary to further enhance investment in the DDDC while maintaining the PDPC and the PDRC.

Table 9. Main contribution factors and contribution degrees of the CERCF of Zhengzhou.

City	1		2		3		Cumulative Contribution Degree
	Contribution Factor	Contribution Degree	Contribution Factor	Contribution Degree	Contribution Factor	Contribution Degree	
Jinshui District	r_{24}	11.93%	r_{21}	11.47%	r_{22}	10.14%	33.54%
Guancheng District	r_{24}	13.54%	r_{22}	10.33%	r_{13}	9.77%	33.64%
Erqi District	r_{24}	16.97%	r_{33}	12.00%	r_{21}	11.77%	40.74%
Xinzheng City	r_{12}	13.04%	r_{35}	12.78%	r_{22}	11.91%	37.73%

Table 9. *Cont.*

City	1		2		3		Cumulative Contribution Degree
	Contribution Factor	Contribution Degree	Contribution Factor	Contribution Degree	Contribution Factor	Contribution Degree	
Zhongyuan District	r_{24}	19.25%	r_{33}	12.44%	r_{21}	12.27%	43.96%
Huiji District	r_{23}	13.98%	r_{24}	13.19%	r_{15}	12.20%	39.37%
Gongyi City	r_{13}	23.43%	r_{35}	18.55%	r_{34}	10.81%	52.79%
Xinmi City	r_{13}	21.83%	r_{35}	11.34%	r_{34}	10.68%	43.85%
Xingyang City	r_{12}	13.79%	r_{11}	12.70%	r_{34}	12.25%	38.74%
Shangjie District	r_{24}	25.91%	r_{33}	20.97%	r_{11}	15.75%	62.63%
Dengfeng City	r_{13}	24.25%	r_{15}	15.83%	r_{11}	12.56%	52.64%
Zhongmu County	r_{34}	22.22%	r_{32}	15.19%	r_{15}	11.94%	49.35%

Note: The specific meanings of the index letters are given in Table 1.

5. Discussion and Conclusions

5.1. Discussion

From the perspective of social management, this study evaluated the CERCF of Zhengzhou City from the PDPC, DDDC and PDRC stages. The findings highlight the differences across the region. At the same time, by analyzing and comparing with the official data released by the government, the research results are basically consistent with the actual situation. Specifically, at the county (district) level, 64 people were killed in Gongyi City, 58 in Xingyang City, 46 in Xinmi City, 12 in Dengfeng City, 2 in Xinzheng City, 2 in Shangjie district and 0 in Zhongmou County, with a total of 184 people killed. The areas with serious casualties belong to Grade I. According to the analysis of the contribution degree, per-capita disposable income is an important indicator for measuring the economic development of a region. It can also reflect the capacity of urban residents after the flood disaster. This result was similar to the findings of Lv et al. [28]. Additionally, we also found that proportion of health financial investment has a great impact on the emergency-response capacity as it represents how much importance a city attaches to health care and its resources reserve level. This result was similar to the findings in some previous studies. For example, Zhu et al. chose medical capacity and health access to assess the coping capacity because they can indicate the medical rescue capacity that can be provided during the flood [37]. For the proportion of the labor force population, studies showed that it had significant impact on the CERCF index. This result is supported by previous studies, which found that the more people work and live outside the household, the higher the dependents ratio and the lower emergency evacuation capability [38].

The limitations of the study should also be taken into consideration. Affected by many factors, the evaluation results may be subject to the selected evaluation indexes and the determined index weights. Firstly, although many influencing factors exist, they are not included in the indicator system due to difficulties in obtaining or quantifying. Secondly, some influencing factors are dynamic and sometimes change from key influencing factors to indirect influencing factors with the passage of time. Hence, attention should be paid to the time evolution characteristics and variation laws, such as population density and natural population growth rate. Therefore, the establishment of an accurate, reasonable and effective index system requires further research [38]. In addition, due to the different regional backgrounds of each city, the type and intensity of disasters vary significantly. Therefore, each city needs to adjust the index system according to the characteristics of its own disasters established in the current study or other relevant research institutes to establish a more targeted index system.

5.2. Conclusions

With the rapid development of the economy and urbanization in China, the economic loss and social influence caused by urban disasters presented an increasing trend. The premise was enhancing emergency management to evaluate urban disaster emergency capability accurately. Based on the emergency management process, the CERCF index

system was established from three phases, called preparation, disposal and recovery. Then, by using a combination of the entropy weight method and the coefficient of variation method, an evaluation model was constructed to assess the CERCF of Zhengzhou City. The preliminary conclusions are as follows: (1) From the perspective of CERCF grade, Jinshui District is classified as Grade III, belonging to regions with strong CERCFs. Huiji District, Gongyi City, Xinmi City, Xingyang City, Shangjie District, Dengfeng City and Zhongmu County are rated as Grade I, belonging to regions with weak CERCFs. The rest regions are classified as Grade II, belonging to regions with medium CERCFs. (2) As for the areas of regions with different CERCF grades, the regions with weak, medium and strong CERCFs account for 35.9%, 55.26% and 8.84% of the total area, respectively. (3) Spatially, the regions with strong CERCFs are mainly distributed in central Zhengzhou City, while those with low CERCFs are primarily distributed in the west and east parts. (4) With respect to contribution factors and contribution degrees, at the criterion level, PDPC and PDRC contribute a lot to the CERCF of Zhengzhou City, while DDDC contributes little. At the index level, the average cumulative contribution of the top three contribution factors exceeds 44%, and most of them are concentrated in the indexes of the PDPC and PDRC stages. (5) According to the comprehensive evaluation results, the CERCF of Zhengzhou City is in the medium and low grade overall. Further analysis of relevant data and evaluation results discloses that the CERCF of cities is closely correlated with regional economic development and investment in flood control and disaster reduction construction.

It is of great significance to improve the scientificity and pertinence of the emergency-response capability improvement strategy and to improve the level of emergency management. Based on the above research conclusions, we propose the following policy recommendations. Firstly, it can be seen from the assessment results that the emergency-response capacity of each district in Zhengzhou is quite different, so the government departments can take different measures to improve the weak points of each region in accordance with the principles of adapting measures to local conditions, promoting classified development and differentiated development. At the same time, we should give full play to the radiation-driving role of areas with high emergency-response capacity, to narrow the gap between cities from point to area. Secondly, the government should reduce barriers to exchanges between regions, promote the circulation efficiency of elements in various regions, and promote the coordinated and sound development of cities in the region. Thirdly, the level of the CERCF is closely correlated with regional economic development and investment in flood control and disaster reduction construction, found through further analysis of relevant data. Therefore, it is necessary to enhance the CERCF of cities through the financial support of the government, reasonable municipal planning, and the training of emergency awareness of personnel, so as to minimize the losses.

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