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Quantitative Assessment of Natural Disaster Coping Capacity: An Application for Typhoons

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Received: 17 June 2020; Accepted: 20 July 2020; Published: 23 July 2020

Abstract: At present, natural disaster coping capabilities are quantitatively represented as high, moderate, or low. These classifications, which are described as the results of relative grades, have failed to reveal the specific grades of disaster coping capacity. Therefore, an assessment method of natural disaster coping capacity, which is attempted to quantify the natural disaster coping capacity as disaster grades, was proposed in this study. First, an indicator system consisting of disaster reduction ability index, disaster resilience ability index, and disaster relief ability index was established. The index values were defined as disaster grades according to the historical disaster-related data and information on the equipment and infrastructure for disaster prevention. Second, the weights assigned to these indicators were assessed by using the analytic hierarchy process (AHP). Then, the back propagation (BP) neural network was used to examine the indicator weights. Finally, the disaster coping capacity was estimated by using the fuzzy comprehensive evaluation model. The assessment result was characterized as disaster grade. Cangnan county was chosen as a case study for the assessment of typhoon coping capacity by the proposed method. The results showed that the coping capacity of the county was prepared to deal with 12–13 intensity grades of typhoon. The assessment carried out using the proposed method accurately reflected the typhoon coping capacity of Cangnan. Moreover, the index values of disaster reduction ability, disaster resilience, and disaster relief ability revealed the advantages and limitations of typhoon coping capacity. This suggests that natural disaster coping capacity can be quantitatively assessed by the proposed method.

Keywords: natural disaster; coping capacity; AHP-BP neural network; fuzzy comprehensive evaluation; quantitative estimation

1. Introduction

Natural disasters pose daunting challenges for humans. The scale and frequency of natural disasters have exhibited a rising trend in the 21st century due to the impact of climate change [1–5]. They usually induce great loss of life and property worldwide. From 1998 to 2017, natural disasters induced 1.3 million population deaths and caused 2908 billion dollars of loss [6]. China was widely affected by various types of natural disasters [7,8]. In 2019, a total of 130 million people were affected and 909 people died from natural disasters in China. In addition, more than 40 billion dollars were lost [9]. The loss caused by natural disasters was usually associated with the disaster grade. The natural disaster coping capacity also played an important role in the loss from disaster [10,11]. Therefore, the mitigation of disaster risk obtained increasing attention [12]. Natural disaster coping capacity has

emerged as an area of intensive research in recent years [2,13–15]. Since 2016, the Chinese government has also begun focusing on improving the country's natural disaster coping capacity.

Natural disaster coping capacity reflects the ability of people, organizations, and systems, using available skills and resources, to manage adverse conditions, risk, or disasters, where capacity includes infrastructure, institutions, human knowledge and skills, and collective attributes such as social relationships, leadership, and management [16]. Disaster coping capacity was rarely a concern of international organizations or countries until the Guidelines for Natural Disaster Prevention, Preparedness, and Mitigation were released in 1994 [17]. The guidelines induced wide and long-term impacts on natural disaster coping capacity assessment [18]. In 1997, the United States originally issued the State and Local Government Capability Assessment for Readiness (CAR) [19]. Furthermore, every state of the USA has proposed criteria for the assessment of disaster coping capacity. The assessment index system includes communication, disaster warning, training, financial management, etc. [20]. In 2001, Australia assessed natural disaster management capacity based on policy, preparedness measures, disaster reduction measures, and post-disaster assessment [21]. Japan estimated natural disaster coping capacity according to emergency response, post-disaster reconstruction, training, etc. [20]. In China, studies about the assessment of natural disaster coping capacity have been conducted since 2000 [22,23].

The estimation of natural disaster coping capacity is the basis for formulating plans and improvement. It is an important area of research in the geographical sciences [10,24–28]. The indicators used in current index systems to estimate natural disaster coping capacity in China usually include casualties, economic losses, restoration, disaster prevention, and disaster preparedness [29–34]. Some researchers suggested that natural disaster coping capacity included disaster prevention, disaster relief, and disaster recovery [20,35]. Several studies used casualties, economic losses, and recovery time to estimate disaster coping capacity [23]. However, these index systems vary significantly in terms of the content and indicators, and no systematic and uniform indicator system is available to estimate natural disaster coping capacity [36–39]. The assessment methods of disaster coping capacity mainly include coping index, fuzzy comprehensive evaluation, and the back propagation (BP) neural network [40–43]. However, the estimation results using these methods are mainly characterized as scores or relative rank values. The disaster coping capacity is classified as high, moderate, or low. These classifications have failed to reveal whether a region's available natural disaster coping capacity is adequate to deal with a specific natural disaster grade. In addition, it is difficult to identify the factors limiting the coping capacity.

Therefore, it is important to establish a quantitative method that can determine disaster coping capacity for different disaster grades. The assessment results can be used to identify the advantages and disadvantages of disaster coping capacity, and can provide planning and decision support for disaster management. Therefore, this study developed an index system, including disaster reduction ability index, disaster resilience ability index, and disaster relief ability index, for the assessment of natural disaster coping capacity based on historical disaster-related data and information on the available equipment and infrastructure for disaster reduction. The analytic hierarchy process (AHP) and the back propagation (BP) neural network were used to estimate and verify the weights of indicators. A fuzzy comprehensive evaluation model was applied to assess natural disaster coping capacity, which was expressed according to the corresponding disaster grade. A case study was conducted to verify the feasibility of the proposed method and the reliability of the estimation results. The work here can provide a scientific basis for assessing natural disaster coping capacity at the regional scale.

2. Materials and Methods

2.1. Conceptualization of Assessment Framework

The concept of the quantitative assessment of natural disaster coping capacity is depicted in Figure 1.

Figure 1. Conceptual approach to quantitative assessment of natural disaster coping capacity.

First, an index system of natural disaster coping capacity, which includes disaster reduction ability index, disaster resilience ability index, and disaster relief ability index, was established. Second, data for the indices were collected and preprocessed. To quantify the index data as disaster grade, the indices were divided into qualitative and quantitative indices. The qualitative indices included equipment for disaster monitoring and disaster warning. We used descriptive words such as “Yes” and “No.” “Yes” describes “the highest disaster grade given the disaster monitor equipment in a given region, whereas “No” signifies the lowest disaster grade where the requisite equipment is lacking. The quantitative indices included the disaster-fighting grade of a house and other facilities. The data were calculated by using historical data and infrastructure-related information. For instance, the refuge coping grade was determined through the relationship between refuge capacity and the number of people who required emergency transfer associated with the historical disaster grade. Third, in order to ensure full comparability among different indices, all the index data of natural disaster coping capacity were standardized. Fourth, the AHP-BP neural network was used to determine the weight of each index. Finally, the index values of disaster reduction ability, disaster resilience ability, and disaster relief ability were estimated by an index-weighted assessment according to the data. The fuzzy comprehensive evaluation model was then used to assess natural disaster coping capacity. The fuzzy comprehensive evaluation model is considered a multi-factor system with fuzzy characteristics. The fuzzy set can be used to describe the disaster coping capacity in case of many factors.

2.2. Index System

Natural disaster coping capacity assessment included monitoring, forecasting, early warning, insurance, and other measures. At present, most of the index systems for evaluation of natural disaster coping capacity had some deficiencies. The time series of natural disasters (pre-disaster, in-disaster, and post-disaster), the literature [34,44] and the principle of index selection, variety factors of disaster coping capacity, and opinions of various experts were considered for the index system in this paper. Therefore, the index system for typhoon coping capacity is described as a function of three dimensions, namely reduction ability, resilience ability, relief ability. The index system contained 21 secondary indices (Table 1).

Table 1. Index system for typhoon coping capacity.

Target Layer	First-Grade Index	Second-Grade Index	Description
Typhoon reduction ability		Monitoring time resolution	The monitoring equipment operates in real time (Yes/No)
		Monitoring stations	Number of disaster monitoring stations ≥ 1 (Yes/No)
		Warning systems	Number of disaster warning systems ≥ 1 (Yes/No)
		Warning time resolution	The warning system issues early warning information in real time (Yes/No)
		Typhoon coping grade of housing insurance	The ratio of purchasing natural disaster farm house insurance is higher than that of farm house collapse caused by the specific typhoon grade (grade)
		Typhoon coping grade of public awareness	The highest typhoon grade encountered by the public (grade)
		Typhoon coping grade of hospital	The number of hospital beds is sufficient to deal with people injured by a typhoon of a specific grade (grade)
		Disaster research institute	Number of disaster scientific research institutes ≥ 1 (Yes/No)
		Flood control grade of flood control projects	Flood control standard of flood control projects (grade)
		Flood control grade of traffic facilities	Flood control standard of traffic facilities (grade)
Typhoon coping capacity		Flood control grade of communication facilities	Flood control standard of communication facilities (grade)
		Flood control grade of power facilities	Flood control standard of power facilities (grade)
		Anti-wind grade of house	Anti-wind standard of house (grade)
		Anti-wind grade of traffic facilities	Anti-wind standard of traffic facilities (grade)
		Anti-wind grade of communication facilities	Anti-wind standard of communication facilities (grade)
		Anti-wind grade of power facilities	Anti-wind standard of power facilities (grade)
		Typhoon emergency response plan	The number of government emergency plans for typhoon > 3 (Yes/No)
		Typhoon coping grade of relief materials	Relief materials are sufficient to cope with the typhoon grade (grade)
		Typhoon coping grade of refuges	Refuges can cope with emergency transfer due to the typhoon of the given grade (grade)
		Typhoon coping grade of fire-fighting equipment	The fire equipment is adequate to deal with the typhoon grade (grade)
Typhoon relief ability		Typhoon coping grade of emergency equipment	Emergency equipment can deal with the typhoon grade at hazardous sites (grade)

(1) The index for typhoon reduction ability included the monitoring time resolution, monitoring stations, warning systems, warning time resolution, typhoon coping grade of housing insurance, grade of public awareness, typhoon coping grade of the hospital, and the disaster research institute. The monitoring ability was the basis for the capabilities of natural disaster prevention and rescue operations, and played an important role in early warning. The warning platform for natural disasters was an important pathway for the public to learn about natural disasters. The popularization of education related to disaster prevention and mitigation can reduce the loss of life and property. Public awareness, disaster science and technology, insurance, medicine, and others also played an important role in disaster prevention. (2) The index for typhoon resilience ability consisted of the flood control grade or anti-wind grade of power facilities, communications facilities, traffic facilities, anti-wind grade of house, and the flood control grade of flood control projects. The anti-wind grade of house, which directly affected the safety of the residents, was the most immediate anti-wind infrastructure available to the public. The anti-wind or flood control grade of public facilities, such as transportation, communication, and power infrastructures, reflected the development level of disaster coping capacity. (3) The index for typhoon relief ability referred to the supply of relief materials, equipment, and the availability of a typhoon emergency response plan.

According to the quantitative characteristics of the data, the indices were divided into qualitative and quantitative indices. The qualitative index included the disaster monitoring station and monitoring

time resolution, warning time resolution, and typhoon emergency response plan, etc. The quantitative index covered the typhoon coping grade of hospital and anti-wind grade of house, etc.

2.3. Preprocessing Index Data

The assessment of typhoon coping capacity was chosen to illustrate the preprocessing of the index data, including data cleaning and conversion. Data cleaning was mainly to delete the typhoon events data which slightly influenced the study area, also to correct the mistake or biased disaster data. Data conversion involved converting equipment- and infrastructure-related information into disaster grades by using historical disaster-related data.

(1) Qualitative index

The qualitative indices were converted as follows:

$$X = \begin{cases} 7, Y < 1, \text{ or "no"} \\ 17, Y \geq 1, \text{ or "yes"} \end{cases} \quad (1)$$

X represents the preprocessed values of the qualitative indicators, Y represents the monitoring stations, warning system, warning time resolution, typhoon emergency response plan, or monitoring time resolution.

(2) Quantitative index

The quantitative indices referred to values characterized by typhoon grade using mathematical operations based on historical typhoon-related data. Table 2 shows methods for quantitative index data conversion.

Table 2. Data conversion of quantitative index for typhoon coping capacity.

Index	Conversion
Typhoon coping grade of housing insurance	The proportion of purchased natural disaster house insurance (Y) corresponding to the typhoon grade (X) determined by the curve between historical typhoon grade (X_k) and house collapse (Y_k).
Typhoon coping grade of public awareness	The highest typhoon grade encountered by the public (grade).
Typhoon coping grade of hospital	The number of hospital beds (Y) corresponding to the typhoon grade (X) determined by the curve between the historical typhoon grade (X_k) and the injured population (Y_k).
Flood control grade of flood control projects	The minimum daily cumulative rainfall (Y) in case of flood corresponding to the typhoon grade (X) determined by the curve between historical typhoon grade (X_k) and daily cumulative rainfall (Y_k).
Flood control grade of traffic facilities	The designed daily cumulative rainfall that transportation facilities can handle (Y) to the corresponding typhoon grade (X) determined by the curve between historical typhoon grade (X_k) and maximum daily cumulative rainfall (Y_k).
Flood control grade of communication facilities	The designed daily cumulative rainfall that communication facilities can handle (Y) to the corresponding typhoon grade (X) determined by the curve between the historical typhoon grade (X_k) and the maximum daily cumulative rainfall (Y_k).
Flood control grade of power facilities	The designed daily cumulative rainfall that power facilities can handle (Y) to the corresponding typhoon grade (X) determined by the curve between the historical typhoon grade (X_k) and the maximum daily cumulative rainfall (Y_k).
Anti-wind grade of house	The anti-wind grade of house as determined by the stress level, structure, and other indices.

Table 2. Cont.

Index	Conversion
Anti-wind grade of power facilities	The maximum wind speed that power facilities can handle (Y) to the corresponding typhoon grade (X) determined by the curve between the typhoon grade (X_k) and the maximum wind speed (Y_k).
Anti-wind grade of communication facilities	The maximum wind speed that communication facilities can handle (Y) to the corresponding typhoon grade (X) determined by the curve between the typhoon grade (X_k) and the maximum wind speed (Y_k).
Typhoon coping grade of relief material	The number of items of equipment (Y) corresponding to the typhoon grade (X) determined by the curve between the typhoon grade (X_k) and demand for the material from victims of disaster (Y_k).
Typhoon coping grade of refuges	The refuge capacity (Y) corresponding to the typhoon grade (X) determined by the curve between the typhoon grade (X_k) and victims of the disaster (Y_k).

2.4. Standardizing Index Data

The magnitudes and units of the index data varied widely. They were standardized by using the min-max standardization method.

In general, the typhoons of 7–17 intensity grades can land in residential areas. We assumed that the corresponding value for a typhoon of intensity grade 17 was 1, and that one of intensity grade 7 was 0. The index data were standardized as follows:

$$Y_i = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}} \quad (2)$$

where Y_i is the standardized value, X_i is the value of the pre-processed typhoon coping index data, $i = 1, 2, 3, 4, \dots, n$, and “min” and “max” are the minimum and maximum values of each index, respectively.

2.5. Index Weight Determination

The analytic hierarchy process (AHP), as a multi-objective decision-making method, obtained the quantitative analysis of indices according to the subjective judgment of experts. The method included hierarchical framework establishing, judgment matrixes constructing, index weight calculating, and consistency testing. The BP neural network, composed of the input layer, hidden layer, and output layer, was a multi-network training with index weights by nonlinear differential function. It was widely used to reduce the influence of human subjective factors. Therefore, the index weight for typhoon coping capacity was calculated and verified by the AHP-BP neural network. Firstly, the index weight was calculated by AHP. Secondly, the index values of disaster reduction ability, disaster resilience ability, and disaster relief ability were calculated according to the index weight and the index values. Finally, the index values of 17 towns obtained in the previous step were randomly selected for training the BP neural network model. The index values for the other 2 towns were verified by the values from the BP neural network. The error values must be lower than 0.1.

2.6. Quantitative Assessment Model

The disaster coping capacity is represented by a fuzzy system that considered the society, economy, population, and the environment. All these factors can significantly affect the estimation results of disaster coping capacity. Fuzzy comprehensive evaluation is usually applied to deal with fuzzy systems [28,32]. Typhoon coping capacity was assessed by using the fuzzy comprehensive evaluation method.

(1) Coping capacity factor set $U = [U_1, U_2, U_3]$. They were calculated as follows:

$$U_1 = W_{P1} \times Y_{P1} + W_{P2} \times Y_{P2} + \cdots + W_{P7} \times Y_{P7} \quad (3)$$

$$U_2 = W_{R1} \times Y_{R1} + W_{R2} \times Y_{R2} + \cdots + W_{R7} \times Y_{R7} \quad (4)$$

$$U_3 = W_{M1} \times Y_{M1} + W_{M2} \times Y_{M2} + W_{M3} \times Y_{M3} \quad (5)$$

where U_1 is the reduction ability factor set, U_2 is the resilience ability factor set, and U_3 is the relief ability factor set. Y_P , Y_R and Y_M represent the normalized values of the indices for reduction ability, resilience ability, and relief ability. W_P , W_R , and W_M refer to the index weights reduction ability, resilience ability, and relief ability, respectively.

(2) Evaluation set (V). Index values of the disaster coping capacity were divided into 10 intensity grades according to the typhoon grade $V = [V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_9, V_{10}]$, where $V_1, V_2, \dots, V_{10}$ indicated the typhoon grade corresponding to "8", "9", "10", "...", and "17".

(3) Evaluation matrix (R). The evaluation matrix is corresponding to the membership degrees of indices in the evaluation set. This degree is determined by a membership degree function (U_{ij}). The triangle membership function is used to determine the membership degree. Namely, the membership degree of any normalized index value at the corresponding disaster grade was determined by a combination of the membership functions of the large and small triangles [32].

The formula for V_i is listed as follows:

$$U_{ij} = \begin{cases} 1, x = D_j \\ \frac{x-D_j}{D_{j+1}-D_j}, D_j < x < \frac{D_j+D_{j+1}}{2} \end{cases} \quad (6)$$

where U_{ij} is the membership degree of index i in grade j ($i = 1, 2, 3; j = 1, 2, 3, \dots, 10$), and x represents the normalized index data.

The formula for $V_{(i+1)}$ is as follows:

$$U_{ij+1} = \begin{cases} \frac{D_{j+1}-x}{D_{j+1}-D_j}, \frac{D_j+D_{j+1}}{2} \leq x < D_{j+1} \\ 1, x = D_{j+1} \end{cases} \quad (7)$$

where U_{ij} and $U_{(ij+1)}$ indicate the membership degrees of the capabilities for typhoon reduction, typhoon resilience, or typhoon relief. D_j and $D_{(j+1)}$ indicate grades of typhoon coping capacity corresponding to the index value. The relationship between the grade of typhoon coping capacity and the index value is listed in Table 3.

Table 3. The relationship between the grade of typhoon coping capacity and the index value.

Indicators	Grade									
	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}
	8	9	10	11	12	13	14	15	16	17
Typhoon reduction ability	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Typhoon resilience ability	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Typhoon relief ability	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

The evaluation matrix (R) was represented as:

$$R = \begin{bmatrix} u_{1,1} & u_{1,2} & \cdots & u_{1,10} \\ u_{2,1} & u_{2,2} & \cdots & u_{2,10} \\ u_{3,1} & u_{3,2} & \cdots & u_{3,10} \end{bmatrix}$$

(4) The evaluation results of typhoon coping capacity by the fuzzy comprehensive were calculated as:

$$B = A \times R \quad (8)$$

where B represents the fuzzy comprehensive evaluation results of typhoon coping capacity, A represents the matrix of index weights, and R represented the evaluation matrix, the value in the matrixes (A , B , or R) is between 0 and 1.

(5) The grade of the typhoon coping capacity P was calculated as follow:

$$P = BV^T \quad (9)$$

where T refers to the matrix transposition, $V = [8 \ 9 \ 10 \ 11 \ 12 \ 13 \ 14 \ 15 \ 16 \ 17]$. The value of P represents the grade of typhoon coping capacity ($7 < P \leq 17$).

3. Evaluation Case

3.1. Area for Case Study

Cangnan County is located in the coastal area of Zhejiang Province. It covers an area of 1261 km² with a 155-km-long coastline. It includes 19 towns (Figure 2) and has a population of 1.184 million. Cangnan County has a mid-subtropical monsoon climate, with significant alternation between winter and summer, distinct seasons, and a mild climate. Typhoons accompanied by heavy rain occurred frequently. In 2000–2016, a total of 25 to 35 times a typhoon occurred in Cangnan county, including Saomai, Sepat, Fitow, Soudelor, etc. According to the historical data, the rainfall of typhoons in this region was characterized by high intensity and concentrated, especially during powerful typhoons. This usually induced heavy flooding, serious damage to infrastructure, agriculture, forestry, and fisheries losses. The Saomai Typhoon in 2006 caused 73,000 houses to collapse and induced a loss of 9.1 billion RMB.

Figure 2. Location of area for the case study.

3.2. Data Source

The socioeconomic data used to assess typhoon coping capacity were obtained from the Wenzhou Statistical Yearbook (2001–2016). Such basic data as those pertaining to the water systems and anti-wind grades of houses were provided by the emergency department of Cangnan County, Zhejiang Province. Climate data were obtained from the China Meteorological Administration, and administrative division data were taken from the Geospatial Data Cloud database and the National Catalogue Service for geographic information systems.

3.3. Results

3.3.1. Index Weight

An index system for the typhoon coping capacity of Cangnan was established according to the index system of typhoon coping capacity in Table 1. Based on the availability of data for the index system, 17 indices were obtained for the assessment of typhoon coping capacity in Cangnan. The obtained indices covered the three domains of typhoon reduction ability, typhoon resilience ability, and typhoon relief ability (Table 4). Therefore, the 17 indices were reliable for the assessment of typhoon coping capacity. The AHP was then applied to calculate the weights of the 17 indices.

Table 4. Index weights for typhoon coping capacity in Cangnan County.

Figure	Weight	Second-Grade Index	Weight
Typhoon reduction ability	0.4429	Monitoring time resolution	0.0479
		Monitoring stations	0.0479
		Warning systems	0.0857
		Warning time resolution	0.0857
		Typhoon coping grade of housing insurance	0.0445
		Typhoon coping grade of public awareness	0.0774
		Typhoon coping grade of hospital	0.0538
Typhoon resilience ability	0.3873	Flood control grade of flood control projects	0.1321
		Flood control grade of traffic facilities	0.0283
		Flood control grade of communication facilities	0.0133
		Flood control grade of power facilities	0.0199
		Anti-wind grade of house	0.1291
		Anti-wind grade of power facilities	0.0323
		Anti-wind grade of communication facilities	0.0323
Typhoon relief ability	0.1688	Typhoon emergency response plan	0.053
		Typhoon coping grade of relief materials	0.0336
		Typhoon coping grade of refugees	0.0832

Finally, the BP neural network was used to verify the accuracy of the results. The results of index weights are shown in Table 5.

Table 5. Results of comparison between the analytic hierarchy process (AHP) method and the back propagation (BP) neural network model.

Index	Town	The Evaluation Value from a Different Way		Error
		Result of the AHP	Result of the BP Neural Network	
Typhoon reduction ability	Mazhan	0.8705	0.8437	0.0308
	Longgang	0.8110	0.8122	0.0014
Typhoon resilience ability	Lingxi	0.4243	0.4243	0
	Nansong	0.3802	0.3803	-0.0001
Typhoon relief ability	Zaoxi	0.5279	0.5278	0.0001
	Qianku	0.3853	0.3852	0.0001

3.3.2. Typhoon Coping Capacity

(1) Typhoon reduction ability index

Index values of the typhoon reduction ability for each town in the county are shown in Figure 3a. The highest value (0.88) was recorded for Lingxi. The index values varied slightly among the towns. This might be attributed to equal values of the second-grade index, except for those of housing insurance (Figure 4a).

Figure 3. Cont.

Figure 3. Spatial distribution of index values of typhoon reduction ability (a), resilience ability (b), and relief ability (c).

Figure 4. Cont.

Figure 4. Values of second-grade indices for typhoon reduction ability (a), resilience ability (b), and relief ability (c).

(2) Typhoon resilience ability index

Figure 3b shows that the index values of the typhoon resilience ability for all towns were lower than 0.5. The index values varied significantly due to the differences in the indices of anti-wind grade of house and flood control grade of the facilities (Figure 4b). The highest index values (0.42) of typhoon resilience ability were observed in Lingxi and Longgang, while the lowest (0.31) were found in Wangli and Dayu.

(3) Typhoon relief ability index

The spatial distribution about the index values of typhoon relief ability is displayed in Figure 3c. The lowest value was 0.16 for Wangli, Yanpu, and Nansong, while the highest value was 0.57 for Zaoxi. The variations in index values of typhoon relief ability were mainly caused by differences in typhoon emergency response plans and typhoon coping grade of refuges among towns (Figure 4c).

(4) Typhoon coping capacity grade

The results of the fuzzy comprehensive evaluation model are illustrated in Figure 5. The figure shows that the typhoon coping capacities of the towns were at 12–13 intensity grades. The differences in coping capacity among the towns were influenced by housing insurance, anti-wind grade of the house, flood control grade of the power facilities, and typhoon emergency response plans. Towns with higher economic development levels usually had higher typhoon coping capacities.

Figure 5. Spatial distribution of typhoon coping capacity in Cangnan County.

4. Discussion

Few studies have represented the natural disaster coping capacities as disaster grade based on historical disaster-related data. To understand the earthquake coping capacity in cities, Ferreira et al. (2016) proposed an adaptive earthquake assessment index for cities in Portugal by using a disruption index (DI) [40]. Estember and Abiog (2018) applied the adaptive index to assess the coping capabilities of typhoons, floods, and landslides in the Pangasinan region of Philippines [34]. Tian et al. (2019) identified the spatial distribution of the relative disaster coping capacity for multiple disasters (landslides, rockfall, and debris flow) in the Anning River Basin from the southwest of China [38]. In addition, Kim-Anh et al. (2019) estimated the spatial distribution of typhoon coping capacity in Vietnam by using GIS and other methods [37]. Chen et al. (2020) calculated the value of disaster risk reduction by using expert opinions, questionnaires, and analytic hierarchy process methods [20]. Zhang and Chen (2019) evaluated the value of typhoon and flood disaster coping capacity by analytical hierarchy process and multi-factor analysis through geographic information system (GIS) and the comprehensive weighted evaluation [45]. The assessment results reflected the spatial distribution of natural disaster coping capacity, while they were hardly compared among different regions. Consequently, the results were difficult to use to determine and plan for regional natural disaster coping capacity. In addition, the indices used for the assessment of disaster coping capacity varied widely among the methods. It is necessary to adopt some mathematical methods based on historical data in order to evaluate disaster coping capacity more objectively and accurately.

Therefore, a quantitative conceptual model for the assessment of disaster coping capacity was proposed in this study. It was used to assess the typhoon coping capacity. Based on historical typhoon-related data, information on the relevant equipment, and typhoon prevention-related information on infrastructures, the index data for the assessment of typhoon coping capacity were defined as specific typhoon grade. Typhoon coping capacity was assessed by a fuzzy mathematic model using the indices of typhoon reduction ability, typhoon resilience ability, and typhoon relief ability. The assessment results were characterized as typhoon grade.

The results of the case study showed that the existing typhoon coping capacities of the towns can deal with 12–13 typhoon intensity grades. The typhoon coping capacity of Mazhan, Longgang, Yanting, Lingxi, and Zaoxi were 13 typhoon intensity grade. The economic development levels of these towns were higher than that of the others. The contributions of reduction ability, resilience ability, and relief ability to typhoon coping capacity significantly varied (Figure 4). Therefore, the indices of resilience ability and relief ability should be improved to enhance the typhoon coping capacity of the towns. The towns with 12 typhoon intensity grade were mainly located in the central, southern, southeastern, and northwestern regions of Cangnan country. These towns have a higher average altitude, complex geographical environment, fragile ecological condition, and less disaster-resistant infrastructure. It is necessary to enhance typhoon coping capacity by increasing the economic investment for disaster reduction. With the development of social economy, the losses from a typhoon might be increased. Residents could increase the level of insurance involvement to reduce adverse consequences of disasters. The results suggested that typhoon coping capacity in the towns from Cangnan can be improved by increasing the investment for insurance, anti-wind grade of house, relief materials, refuges, and emergency response plans.

According to the historic data about typhoon occurrence and the losses in Cangnan, the assessment results were accurate and objective. The index values of typhoon reduction ability, typhoon resilience ability, and typhoon relief ability reflected the advantages and disadvantages of typhoon coping capacity of the towns in Cangnan. The final values successfully reveal the disaster coping capacity dealing with a specific disaster grade. The results of this study indicated that the proposed method was feasible for the quantitative assessment of natural disaster coping capacity.

This study had two main limitations. First, the number of indices used for the assessment of typhoon coping capacity was relatively small due to the unavailability of data. This might induce a bias in the estimation results. The availability of index-related data needs to be improved. However, the relatively limited indices indicated that the method can be applied to quantitatively assess the natural disaster coping capacity. Second, the accuracy of index weights needs to be improved.

5. Conclusions

The results of the case study indicated that the typhoon coping capacities for the towns of Cangnan County were at 12–13 typhoon intensity grades, which meant that the existing typhoon coping capacities could deal with the typhoon grades. Special attention might be required for the regions with higher vulnerability and hazard impacts while with lower typhoon coping capacity. The typhoon coping capacity in the towns from Cangnan can be improved by increasing the investment for insurance, anti-wind grade of house, relief materials, refuges, and emergency response plans.

The data availability was still a major issue for typhoon coping capacity assessments. However, the indices with available data in this study could reveal the typhoon coping capacity. The results also reflected the advantages and disadvantages of the county's typhoon coping capacity. It also suggested that disaster coping capacity can be assessed by the proposed methods, including comprehensive fuzzy evaluation model and the index system based on historical disaster-related data, as well as information on the relevant equipment and infrastructure for disaster prevention.

Author Contributions: Conceptualization, B.W.; data curation, J.G.; investigation, L.Y.; resources, S.W.; writing—original draft, T.W.; writing—review and editing, B.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Program of China (No. 2018YFC1508801).

Acknowledgments: We thank Xu Wei from Beijing Normal University for his valuable advice for this work.

Conflicts of Interest: The authors declare no conflict of interest.

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