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Risk Assessment of Flood Disaster in Sichuan Province Based on GIS

Jin Guo[1a#], Jian Wang[2b*], Xiaochen Zhao[3c#]

[1]China University of Geosciences Beijing Beijing,China
[2]Chengdu University of Technology Chengdu, China
[3]Southwest JiaoTong University Chengdu, China

Abstract—In the context of global climate change, flood disaster has become one of the significant disasters endangering human life. Sichuan Province has more annual precipitation and complex landforms, which suffer from yearly floods. To reveal the spatial distribution and spatiotemporal dynamic change characteristics, we developed a risk assessment model based on geographic information systems and natural disaster risk assessment theory. Considering both natural and human factors, precipitation, terrain, climate type, population, and GDP are selected as evaluation indexes. We Used the expert score-AHP method to obtain the annual flood disaster risk regionalization from 2017 to 2021. In the end, the results were compared with the entropy weight method in the objective weighting method. The results showed that the comprehensive flood disaster risk in Sichuan Province is higher in the east and lower in the west. The flood disaster risk in the eastern hill area, Panxi area, and northeast Sichuan Basin is generally higher. In contrast, that in the west Sichuan Plateau is lower. Based on the evaluation results, it is found that the risk assessment of flood disasters based on expert scoring-AHP method is more in line with the actual situation.

1. INTRODUCTION

The current global climate change situation is becoming more and more severe, and flooding has become one of the major disasters of global concern. With global warming, frequent occurrence of extreme weather events, and rapid socio-economic development, heavy rainfall, high intensity, and heavy losses have become the development trends of flooding [1, 2].

In recent years, the frequency of floods in China has increased significantly, causing massive human, material, and property losses. Recurrent floods throughout the year threaten some regions. According to statistics, the average annual flood losses in China reached 19.2 billion USD in the past 30 years, accounting for 54% of the total direct economic losses caused by weather disasters in China [3]. According to the information from China National Disaster Reduction Network, from 2004 to 2019, Sichuan torrential rainfall and floods have been listed in the annual “Top Ten National Natural Disaster Events” 15 times [4].

It has great significance for ensuring regional population safety and socio-economic development [5]. The current methods for flood risk assessment can be summarized into three major categories: index system method, historical hazard method, and simulation assessment method [6].The theoretical basis of the index system method is that flooding is generally considered a comprehensive function of disaster-causing factors, disaster-pregnant environment, and disaster-bearing bodies, which can reflect the regional risk status at a macro level. M.Zhang et al. established a flood risk evaluation index system including nine indicators from four aspects: disaster-causing factors, disaster-inducing environment, disaster-bearing body, and regional disaster response capacity and built a cloud model.[7] The historical disaster method is to investigate the historical data of flooding through investigation and analysis. In the statistical method of historical disaster data, Yang Chuanguo et al. [8] collected multi-source data information such as historical survey flood data and measured rainfall data in the Huaihe River basin for the past 500 years, and used mathematical methods to analyze the characteristics of flood and drought changes in the basin during different time cycles. Li Biqi et al. [9] established a coupled model based on the SWMM model and two-dimensional hydrodynamic model. In this paper, we selected the index system method to analyze.

2. STUDY AREA AND DATA

2.1 Overview of the study area

Sichuan province is located in the upper reaches of the Yangtze River. It has an area of 486,000 square kilometers, measuring more than 1,075 kilometers from east to west and more than 900 kilometers from north to south. In the past 60 years, the average temperature in Sichuan province has increased at an overall rate of 0.17°C/decade. Total

e-mail: [a]15611606571@163.com,e-mail:[b] a2966433530@163.com,e-mail: [c]2020114035@my.swjtu.edu.cn

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precipitation has decreased at a rate of 9.03 mm/decade, resulting in a warmer and drier climate overall. This change is more evident in regional variations, with temperatures increasing and precipitation slightly rising from east to west Sichuan [10] .Sichuan Province is full of water systems and has many river tributaries. Abundant hydraulic resources provide a favorable guarantee for water for engineering, agricultural production, and domestic use [11]. Precipitation data in Sichuan Province are collected by various meteorological stations, and their distribution is shown in Fig. 1.

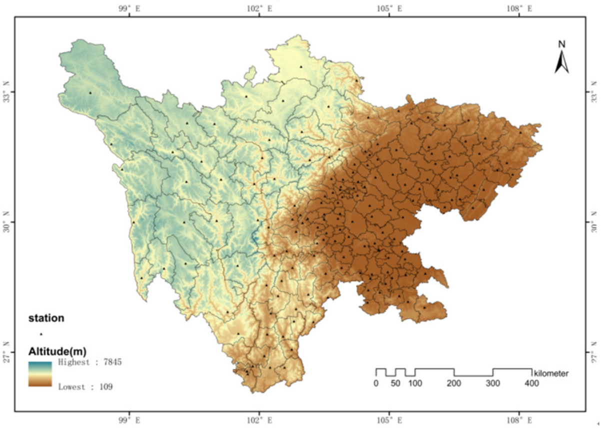

Fig. 1. Distribution map of meteorological stations in Sichuan Province

2.2 Sources of data

Taking into account the natural and social environmental characteristics of flooding in Sichuan Province, the data used for the comprehensive flood risk assessment in Sichuan Province mainly include:

2.2.1 Basic geographic information data

The source is from National Center for Basic Geographic Information (http://www.ngcc.cn/ngcc/) and the Geospatial Data Cloud (https://www.gscloud.cn). For example, the elevation data were obtained from ASTER GDEM 30M resolution digital elevation data.

2.2.2 Meteorological data

We collected meteorological data from 2017 to 2021 on an annual basis from the National Tibetan Plateau Scientific Data Center (http://data.tpdc.ac.cn). The precipitation data were collected regularly from 156 meteorological stations in Sichuan Province.

2.2.3 Socio-economic data

This paper's population and county GDP data are obtained from the Sichuan Provincial Statistical Yearbook for 2017 to 2021.

3. Method of Research

This paper mainly uses the expert scoring-AHP method to classify the flood risk area in Sichuan Province. We selected comprehensive risk assessment indicators, calculated the weight of indicators, established a comprehensive risk assessment model, and used ArcGIS software to set thresholds. Finally, we compared the results with those obtained by the entropy weight method. The specific process is as follows.

3.1 Selection of indicators

Based on the geographical environment characteristics and data availability in Sichuan Province, this paper selected eight comprehensive risk evaluation indicators of flood disasters from the hazard of causal factors, the sensitivity of the disaster-forming environment, and the vulnerability of the hazard-bearing body are shown in TABLE 1 .

Table 1 Evaluation index

Criterion Layer	Index
Hazard of causal Factors	Average annual precipitation
Sensibility of Disaster-forming Environment	Standard deviation of elevation
	Slope
	River density
	Climate belt
	Bare land
Vulnerability of Hazard-bearing Body	Density of population
	GDP

3.2 Standardization of indicators

In the index system, qualitative indicators and quantitative indicators are included. As the original data cannot be directly processed due to the different units of each indicator, all evaluation indicators need to be normalized, that is, transformed into data with a unified dimension and scale. In this paper, the qualitative and quantitative indexes were treated as follows:

3.2.1 Text-type indicators

In this paper, climate belts belong to text indicators. We normalized them into numerical values to participate in the comprehensive risk assessment of flood disasters. The TABLE 2 shows the transformation of text-type indicators.

Table 2 Transformation of text-type indicators

Climate belt type	Normalized value
Subtropical humid climate	0.75
Plateau monsoon climate	0.25

3.2.2 Numerical index

Based on the characteristics of the index data, we normalized all data into numbers between 0 and 1.

In the numerical indicators, some indicators' characteristic is: the greater the value, the higher the risk represented. We refer to this class of indicators as positive indicators. For the positive indicator, we normalized it with the following formula:

$$a = \frac{\log I - \log I_{min}}{\log I_{max} - \log I_{min}} \quad (1)$$

Vice versa, other indicators' characteristics are: the greater the value, the lower the risk represented. We call them negative indicators. For the negative indicators, we did the following normalization:

$$a = \frac{\log I_{max} - \log I}{\log I_{max} - \log I_{min}} \quad (2)$$

Where a is the normalized data, which value domain range between 0 and 1. I represents the raw data, while $I_{max}$and I_{min}represent the maximum and minimum values of the raw data, respectively.

3.3 Determination of the index weight

Weight measures the effect of each unit's mark value on the population. It is an essential measure of an index item in the index system. It represents the influence of this index item's change on the result when other index items are unchanged. These methods can be divided into three categories according to the different sources of the original data when calculating the weight. They are the subjective empowerment method, objective empowerment method, and combined empowerment method [12]. In this paper, we combine the hierarchical analysis method in the personal empowerment method with the expert scoring method. We also use the entropy weight method in the objective empowerment method to set the weight of the eight indicators. We compare the risk zoning results obtained by the two methods to those obtained by actual flood disaster situations in five years. The technical roadmap for determining the weight is shown in Fig. 2.

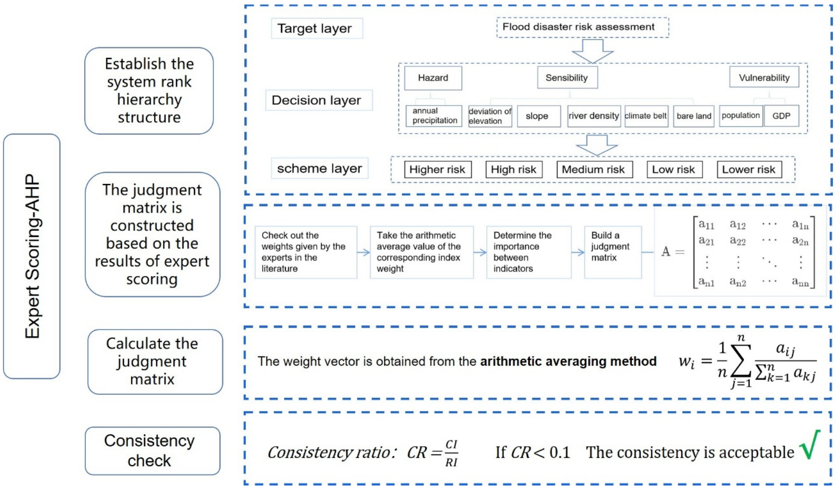

Fig. 2. Technical roadmap for determining the weight

3.4 Evaluation model of flood disaster risk

We apply the natural disaster risk assessment theory proposed by Maskrey to establish the flood risk assessment model [13]. It can be expressed as follows：

$$R = f(H、E、V) \quad (3)$$

$$H = \sum_{i=1}^{p} H_i w_{H_i} \quad (4)$$

$$E = \sum_{i=1}^{p} E_i w_{E_i} \quad (5)$$

$$V = \sum_{i=1}^{p} V_i w_{V_i} \quad (6)$$

Where R is the comprehensive risk of flood disaster, H is the risk index of hazard factor, E is the environmental sensitivity index of disaster-forming, V is the vulnerability index of hazard-bearing body, $w_{H_i}$is the sub-index weight of causal factor risk, w_{E_i} is the sensibility index weight of disaster-forming environment, and w_{V_i} is the sub-index weight of vulnerability of the hazard-bearing body.

For the final comprehensive risk value of flood disasters, we set the threshold and used the spatial analysis of ArcGIS to divide the results into five grades: the lower-risk area, the low-risk area, the medium-risk area, the high-risk area, and the higher-risk area.

4. RESULTS AND ANALYSIS

4.1 Risk zoning based on expert scoring-AHP method

AHP is a method for multi-criteria decision analysis, which requires building a hierarchical model and using a pairwise comparison method to calculate weights. This paper referred to Feng Lingtong [14], Ma Rongyong, Zhang Donglong [15], Zhou Yanlian [16], Li Lintao [17], and other authoritative experts on flood disaster evaluation. It used the weighted average for the selection results of each expert. The calculation formula is as follows:

$$\bar{x} = \frac{\sum x_i f_i}{\sum f_i} \quad (7)$$

Where $\bar{x}$ is the weight coefficient of an indicator or factor; $x_i$is the weight coefficient taken by each expert; f_i is the weight of each expert. TABLE 3 shows the weight values of each indicator obtained by the expert scoring-AHP method.

Table 3 The weight obtained by expert scoring-AHP method

Indicator	Weight
GDP	0.0270
Bare land	0.1424
Density of population	0.0449
Average annual precipitation	0.3685

Standard deviation of elevation	0.1286
River density	0.0589
Slope	0.0589
Climate belt	0.1707

After calculating the comprehensive risk value, ArcGIS software was used to visualize the flood situation of each county and city in Sichuan Province from 2017 to 2021. The final risk zoning map based on the expert scoring-AHP method was obtained, as shown in Fig. 3.

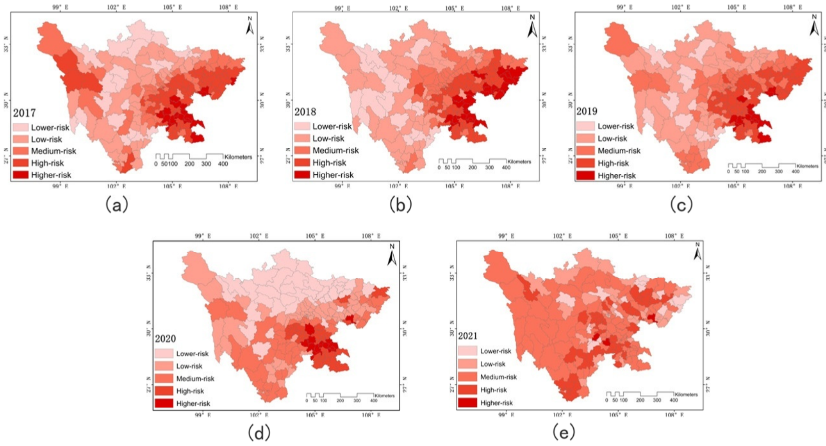

Fig. 3. Risk zoning map based on expert scoring-AHP method

Fig. 3 shows that the overall flood risk in Sichuan Province presents a high-east-low-west pattern. Among them, the flood risk in Sichuan Basin was the highest, and the flood risk in eastern Sichuan was relatively high due to gentle slopes, low elevations, and slow flood drainage. The western plateau has a plateau mountain climate with dry and cold characteristics, less precipitation, and high altitude, so the flood risk is the lowest. In addition, there were also medium-high flood risks in southern Sichuan, such as Panzhihua and Xichang.

From a temporal perspective, there were more high-risk areas in 2018, The total coverage of the high-risk areas in 2018 reached 41.2 thousand square kilometers, accounting for about 8.56% of the province's total area. According to related news reports, the average annual precipitation in 2021 was large, and when the expert scoring-AHP method confirmed that the weight coefficient of rainfall was relatively large. Therefore, Sichuan Province was at a medium-high risk level in 2021. From a spatial perspective, high-risk areas were mainly concentrated in southeast and northeast regions such as Yibin City, Zigong City, Ziyang City, and Dazhou City.

4.2 Risk zoning based on entropy weight method

In the study of flood disaster risk, to determine the importance of each index in the evaluation more objectively through the obtained data, this paper selects the weight method and scientifically uses the tool of information entropy to determine the weight. According to the entropy weight method, the weights of the eight indicators are shown in TABLE 4.

Table 4 Weight obtained by entropy weight method

Indicator	Weight
GDP	0.0846
Bare land	0.0616
Density of population	0.1311
Average annual precipitation	0.0621
Standard deviation of elevation	0.3401
River density	0.0165
Slope	0.1342
Climate belt	0.1698

We used ArcGIS software to draw the flood situation from 2017 to 2021 and obtained the flood disaster risk zoning map based on the entropy weight method shown in Fig. 4

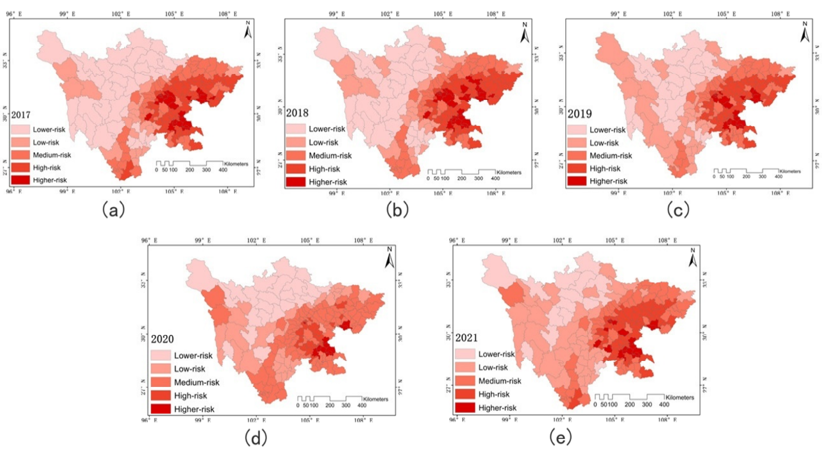

Fig. 4. Risk zoning map based on entropy weight method

Fig. 4 shows that the overall flood risk in Sichuan Province presented a characteristic of being high in the east and low in the west. The high-risk areas are still concentrated in the eastern hilly area and the Sichuan Basin area, followed by those in the Panxi area, while the western plateau is generally low.

From a temporal perspective, the high-risk areas covered a large range in 2018 and 2020, covering more than 30 counties and cities, with a total area of 27.3 thousand square kilometers and 30.9 thousand square kilometers, respectively. In the comprehensive risk assessment based on the entropy weight method, Chengdu's main urban districts - Qingyang, Jinjiang, Jinniu, Wuhou, Chenghua, and some surrounding areas were repeatedly classified as high-risk. It was analyzed that this was because when determining weights by entropy weight method, it was considered that socio-economic indicators in the vulnerability of carriers had a greater influence. Chengdu is the provincial capital of Sichuan Province, with prosperous economic development and high population density. Therefore, flood risk in various districts of Chengdu is generally high. Spatially, the northeastern region had more medium-risk and high-risk areas concentrated in Guangyuan, Bazhong, Dazhou, Mianyang. Low-risk areas were mainly found in the western part, especially the northwest. In addition, due to terrain rainfall, Baoxing County, Emeishan City, Mianyang City, and Beichuan County had higher flood risks which were consistent with the actual situation according to previous years' flood data.

5. Conclusion

Based on the natural disaster risk assessment theory, this paper conducted a yearly flood disaster risk assessment for Sichuan Province from 2017 to 2021 based on the expert scoring-AHP method.We draw some conclusions: On a spatial scale, there were more high-risk areas in the eastern Sichuan Province and lower-risk areas in the western Sichuan Province. Among them, the high-risk areas were mainly distributed in the eastern Sichuan hills, Sichuan Basin, and the Panxi area. In terms of hazard factors, rainfall is higher in the east; in terms of disaster-forming environment sensitivity, these areas have more hills and mountains, lower average elevation, and gentler slopes, which is not conducive to timely drainage of floods; in terms of disaster-bearing body vulnerability, economic conditions are more developed and population density is higher in the east, showing higher vulnerability. The risk of flood disaster is more negligible in the western Sichuan Plateau area, benefiting from high altitude and dry climate conditions as well as a less developed economy and low population resulting in the lower vulnerability of the disaster-bearing body. On a temporal scale, based on the analysis of annual data from 2017 to 2021, we found that high-risk areas gradually decreased while medium-risk and low-risk areas showed an increasing trend, but they still fluctuated, so each county should strengthen the prevention and control of flood disasters.

This study still has shortcomings: Flood disaster risk assessment is highly complex. Sichuan's natural geography and socio-economic conditions are complex. Our paper still has some incompleteness in indicator selection. Future research would provide more powerful guidance for flood control and disaster reduction work if we could improve the evaluation system and indicators.

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