Research on Chongqing Mountain Flood Disaster Risk Assessment System Based on AHP-GIS

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Abstract: The risk of mountain flood disasters is the fundamental factor restricting the occurrence of disasters. The analysis and assessment of disaster risks is the basis for disaster risk management. Through the investigation of mountain flood disasters from 2013 to 2015, the basic information such as hydrometeorology, topography, socio-economic and mountain flood disaster prevention and control situation in mountain flood disaster prevention and control areas were found out. Taking the city of mountains-Chongqing as an example, this paper considered the results of mountain flood disaster investigation and evaluation in recent years, and divided the risk evaluation indicators into two types of first-level indicators: rainfall and underlying surface, and the secondary indicators were subdivided into comprehensive rainstorm indicators, critical rainfall, topographic relief, land use convergence capacity, soil texture and river network density. Using AHP to set the weight coefficient of each level indicators, those showed that heavy rain conditions, critical rainfall and topographic relief were important factors impacting the mountain flood disasters, and the land use convergence capacity had the minimum weight coefficient. Through GIS superposition analysis, the risk index of mountain flood disasters in the region were obtained. The western, southeastern and northeastern Chongqing were high risk areas for mountain flood disasters, which provided decision-making basis for mountain flood disaster risk management.

1. Introduction
For a long time, mountain flood disasters were serious natural disasters that restrict China's social and economic development. Among them, the area of mountain flood disaster prevention and control was 463 km², accounting for 48% of China's land area [1]. Since 1949, the number of deaths caused by mountain torrents accounted for 70% of the deaths due to floods in China [2]. With the economic development and population growth in the hilly area, the risk and loss of mountain flood disasters
increased significantly. Mountain floods were characterized by sudden, devastating and defensive difficulties [5]. Disaster risk analysis and assessment was the basis for disaster risk management. The risk assessment of mountain flood disasters usually considered the risk and fragility of regional disasters. Among them, the risk of mountain flood disasters was the fundamental factor restricting the occurrence of disasters. Therefore, the risk assessment of mountain flood disasters was an important part of the risk assessment of mountain flood disasters. Considering only the natural attributes of mountain flood disasters, the disaster formation process involved many factors such as precipitation, flood generation and confluence. Rainfall conditions were the direct factors inducing disasters [4]. Topographical and geomorphological conditions were the key factors restricting disaster development [5]. China's investigation of mountain torrents had experienced the “census stage” from 2010 to 2012 and the “detailed stage” from 2013 to 2015. Therefore, in the process of building a mountain flood disaster risk system, the application of the latest results data of mountain flood disaster investigation and evaluation in recent years would undoubtedly improve the accuracy and rationality of risk assessment, and the results would be more instructive for the prevention and control of mountain flood disasters.

In view of the fact that AHP could realize the decision analysis of the combination of qualitative and quantitative multi-objective schemes, GIS software had strong geospatial information processing capability and was widely used in the construction of mountain flood hazard index system. The research scale covered small watershed flash floods [6] [7], large rivers [8] [9] [10] and urban areas [11] [12] [13]. Taking the city of mountainous-Chongqing as an example, this paper combined the results of mountain flood disaster investigation in Chongqing from 2013 to 2015, and used AHP-GIS technology to assess the risk of mountain flood disasters in the region and further guided the prevention and control of mountain flood disasters in Chongqing.

2. Overview of the studied area

Chongqing is located in the southwestern region of China, and the problem of mountain torrents is serious. According to the “National Mountain Flood Disaster Prevention and Control Plan”, the 82,400 km² jurisdiction area in Chongqing belongs to the mountain flood disaster prevention and control area, and the proportion of key prevention and control areas is as high as 40% [1]. In the past 15 years, there have been 364 heavy rains and floods in this area, resulting in 763 deaths and disappearances. The direct economic loss was 53.745 billion yuan, of which 348 were missing due to mountain flood disasters, accounting for more than 45.6%. At the same time, due to the extreme weather in recent years, the number of rainstorms in the territory has increased, the scope of the disaster has expanded, and economic losses have increased.

3. Material and Methods

3.1. Data source and acquisition method

(1) The comprehensive rainstorm index and critical rainfall data were derived from the 2013~2015 mountain flood disaster survey and evaluation data. Land use and soil texture data were the base map for investigation and evaluation. Obtaining Chongqing elevation data (30m×30m) from the National Geographic Data Center platform, the terrain relief layer was produced through Arcgis10.0 Spatial Analysis. In ArcGis10.0, the hydrological analysis module was used to calculate the DEM data of Chongqing, and the water system map of Chongqing was acquired.

3.2. Research method

The AHP (Analytic Hierarchy Process) was proposed by American operations researcher Saty in the 1970s, and the AHP weighting coefficient was determined by pairwise comparison. According to this scale, the positive and negative (or positive reciprocal) matrices of the relative importance of each layer were established, and the weights of each layer were sorted. After the consistency test, the weights were used to process the factors and obtain the coefficient. The risk evaluation index system
included two major categories of rainfall and underlying surface elements.

4. Results

4.1. Rainfall condition analysis

The rainfall factor was the direct inducing factor of mountain flood disaster. Considering the intensity of storm and critical rainfall threshold were the important factor restricting the occurrence of mountain flood disaster, the comprehensive storm index and critical rainfall index were selected as the secondary indicators of rainfall conditions.

4.1.1. Comprehensive rainstorm indicator \((CH_1)\)

In the 2013~2015 mountain flood disaster investigation, referring to the “Sichuan Province Small and Medium Watershed Storm Flood Calculation Manual”, 3545 disaster prevention objects were designed to calculate heavy rain. The frequency of rainstorm was divided into 5 years, 10 years, 20 years, 50 years and 100 years. The storm duration includes 4 standard hours of 10 minutes, 1 hour, 6 hours and 24 hours. Based on the above-mentioned design rainstorm analysis results, the kriging space interpolation method was used to interpolate the design rainstorm in Arcgis10.0, and the rainstorm classification map was drawn to obtain the design rainstorm distribution under different frequency and time conditions (Figure 1).

Considering that there were many similarities in different frequencies and different time periods, in order to avoid repeated considerations in the overlay analysis, it was necessary to reduce the dimension of the above-mentioned rainfall standard duration to obtain a comprehensive index reflecting the overall characteristics. The greater the value of the comprehensive rainstorm index \((CH_1)\), the greater the annual extreme value of the torrential rain, which was more conducive to the occurrence of flash floods.

![Figure 1. The normal distribution map of design rainstorm under 10min, 1h, 6h and 24h](image)

4.1.2. Critical rainfall \((CH_2)\)

Critical rainfall referred to the minimum magnitude and intensity of rainfall that reached or exceed when a mountain stream floods in a river basin or region may cause disasters. Total rainfall, rain intensity, soil water content and underlying surface characteristics were key factors in critical rainfall analysis. From 2013 to 2015, the investigation of mountain flood disasters in Chongqing was based on the prevention and control objects. Three different soil water conditions (0.2w means dry, 0.5w means normal and 0.8w means wet) were considered to calculate the critical rainfall. The main component
was superimposed to obtain the index of the critical rainfall in the reaction area, and the indicator was normalized to obtain the index for the risk assessment of mountain flood disaster. The smaller the value of the critical rainfall indicator, the greater the possibility of a mountain flood disaster caused by heavy rain in the area.

4.2. Analysis of underlying surface conditions

In the process of mountain flood disasters, the underlying surface was an important factor restricting the occurrence of mountain flood disasters. The terrain relief, land use, river network density and soil texture were the secondary indicators of the underlying surface conditions.

4.2.1. Terrain relief (CH₁)

The terrain relief was also called the terrain fluctuation, the relative terrain or the relative height. It was the height difference between the highest point and the lowest point in a certain area. It could reflect the surface relief characteristics of the macro area, and was an important indicator for quantitatively describing the landform and dividing the landform type. The terrain relief index reflected the fluctuations of the surface morphology. The larger the value, the larger the regional height difference was.

4.2.2. Land use capacity (CH₄)

The land use pattern directly affected the characteristics of surface sediment yield, and based on this, the impact of different land use patterns on rainfall production and confluence were scored and finally mapped. The rainfall infiltration rate of different land use types showed that there were forest land > shrub land > other forest land > high coverage grassland > sparse forest > plain cultivated land > medium cover grassland > hilly cultivated land > low cover grassland > mountain cultivated land > slope cultivated land > water area with the scores 1~9. The lower the score and the higher the catchment capacity of the basin, the more were flash floods prone to.

4.2.3. Soil texture (CH₅)

According to the soil investigated data, the soils in Chongqing were classified. According to the difference of rainfall infiltration, the soil texture types were assigned. The higher the score, the easier it was to produce confluence. The above scores were normalized and the plot of rainfall soil runoff capacity was drawn.

4.2.4. River network density (CH₆)

River network density referred to the total length of river water system per unit area, which was a comprehensive reflection of rainfall and underlying surface conditions in the region, indirectly reflecting the sensitivity of the mountain flood disaster environment. In ArcGIS, the DEM data was processed and the water system map was obtained through several major steps, such as filling the ground, calculating the flow direction, calculating the water flow, and converting the vector of the river network. The total length of the river system was 6.8×10⁴ km, the river network density ranged from 0~4.7 km/km², with the average density 0.84 km/km². The density of river network was the key factor that restricting the occurrence of mountain flood disasters in the region. The higher the density of river networks, the higher the densities of mountain flood disasters were. The river network density was normalized to obtain the river network density index within the range of 0~1.
4.3. Risk calculation

Through AHP analytic hierarchy process, based on the conditions of rainfall and underlying surface, the weight coefficients of heavy rainfall index, critical rainfall conversion index, topographic relief, land use convergence capacity, soil texture and river network density were calculated respectively (Table 1). The results showed that heavy rain conditions, critical rainfall and topographic relief were important factors controlling the development of mountain flood disasters, and the land use convergence capacity was the lowest.

Table 1. The weight coefficient of the secondary risk evaluation indicators

| First-level indicators | Weight coefficient | The secondary indicators | Weight coefficient |
|------------------------|--------------------|--------------------------|--------------------|
| Rainfall condition (R) | 0.5                | CH1 0.5                  |                    |
|                       |                    | CH2 0.5                  |                    |
|                       |                    | CH3 0.5                  |                    |
| underlying surface conditions (D) | 0.5 | CH4 0.1 | |
|                       |                    | CH5 0.2                  |                    |
|                       |                    | CH6 0.2                  |                    |
Loading the above layers in Arcgis10.0, the first-level evaluation index of rainfall conditions and underlying surface conditions were obtained in consideration of the index weight assignment and risk calculation formula of the risk system. According to the above-mentioned first-level evaluation index, the above operation steps were repeated to obtain a risk distribution map. The superposition results showed that the high risk in the territory was mainly distributed in the western, southeastern, northeastern Chongqing.

5.Discussion
In the construction process of the risk index evaluation system, there was a certain difference in the regional mountain flood disaster risk due to the different indicators, Tang Yuxue et al. [14] used principal component analysis to establish a model of mountain flood disaster zoning in Chongqing. In the GIS software, the inverse distance weight method was used to interpolate the various impact factors. It was found that the northeastern part of Chongqing was the high-incidence area and the western part was low-incidence area. Zhao Wei et al. [15] had shown that the western Chongqing belonged to high-risk areas and the most the northeastern region was in lower risk. Mei Yong et al. [16] believed that the high-hazard and sub-high-hazard areas were mainly distributed in the north western. Based on the results of the mountain flood disaster investigation and evaluation, this paper integrated AHP-GIS technology to construct a flood disasters risk system for Chongqing. The flood-prone areas were mainly distributed in the northeastern, western and southeastern, which was basically consistent with the three major rainstorm areas in Chongqing and consistent with the results of Zhao Zhijun et al. [17]

At present, there were relatively few researches on mountain flood risk zoning in Chongqing due to the scarce of data. For example, Tang Yuxue et al. [14] collected the data of mountain flood disasters in 34 districts of Chongqing before 2008, and used the principal component analysis method to establish a model of mountain flood disaster zoning in Chongqing. In the process of mountain flood disaster risk assessment, the vulnerability and resilience were not considered. Zhao Wei et al. [15] take no consideration of several key factors restricting the occurrence of mountain torrents, such as critical rainfall, land use patterns and soil texture, during the flood risk assessment process in Chongqing. Although Mei Yong et al. [16] conducted the risk zoning study of the Chongqing storm and flood disasters considering the risk, vulnerability and resilience, but the critical rainfall, land use and soil texture factors in the risk indicator system, regional GDP were not included. In the process of constructing the mountain flood risk assessment system, this paper comprehensively considered the indicators selected by previous scholars and some key indicators that restrict mountain flood were used, and meanwhile, the latest results of investigation and evaluation were introduced, which further improved the accuracy of mountain flood risk.

6.Conclusion
The risk of mountain flood was the fundamental factor restricting the occurrence of disasters. The analysis and assessment of disaster risks was the basis for disaster risk management. Through the investigation of mountain flood disasters from 2013 to 2015, basic information such as hydrometeorology, topography, socio-economic and mountain flood disaster prevention and control status were basically found out. Taking the city of mountains-Chongqing as an example, this paper combined the results of mountain flood disaster investigation and evaluation in recent years, and divided the risk evaluation indicators into two types of first-level indicators: rainfall and underlying surface. The secondary indicators were subdivided into comprehensive rainstorm indicators, critical rainfall and topographic relief, land use convergence capacity, soil texture and river network density. The AHP was used to set the weight coefficient of each level of indicators, and then the GIS overlay analysis was used to obtain the risk indexes of mountain flood disasters in the region, which provided decision-making basis for mountain flood disaster risk management.
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