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Distribution Characteristics and Disaster Risks of Ancient Opera Stages in Hunan Province

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KEYWORDS

Ancestral Halls;
Revival;
China;
Eastern Hubei;
Rural Areas

ABSTRACT

Focusing on 219 existing ancient opera stages in Hunan Province, this study integrates GIS spatial analysis with the AHP-entropy model to examine their spatial distribution and disaster risk characteristics. The findings reveal a generally discrete distribution pattern (R=1.86), with high-density clusters in southern and western Hunan. Spatial evolution follows a temporal sequence, shifting from a southern concentration during the Ming and Qing dynasties to multi-directional expansion in the late Qing and Republic periods. A total of 72 stages are located in key geologic hazard zones, and 169 are threatened by floods, particularly in mountainous and low-lying areas. Based on disaster risk zoning, a hierarchical protection strategy is proposed—emphasizing structural reinforcement and digital monitoring in high-risk areas, and drainage improvements with community participation in secondary zones. The study establishes a "distribution–risk–response" framework, providing a scientific basis for the preventive conservation of traditional opera heritage under climate change.

1. Introduction

The traditional Chinese opera art and its material carrier, the ancient stage, coexist and co- prosperity, forming a unique cultural system of "performance space". Ancient stage is not only a physical place for opera performance, but also an important social space carrier for clan rituals, trade exchanges and folk activities[1]. Its architectural form since the Song and Yuan hook rail tile house to the Ming and Qing ancestral hall playhouse gradually stereotypes, showing a blend of north and south of the regional characteristics[2]. Hunan Province, as the "ancient sound of Jingchu, the source of the southern opera" cultural town, the number of existing ancient stage among the forefront of the country, Xiang Opera, Qiqu Opera, Yang Opera and other local theater and Dong Nuo opera and other ethnic minorities intertwined here, giving birth to the footstool type, wind and rain bridges, and other very characteristic of the regional architectural types of the stage. However, under the double pressure of accelerated urbanization and frequent occurrence of extreme weather, the ancient stage in Hunan is facing multiple threats such as flooding, termite infestation, improper repair, etc., and its protection has become imminent.

Currently, domestic scholars on the study of the ancient theater mostly focus on the architectural form and cultural functions. For example, Zhou Hua bin[3] systematically sorted out the logic of the spatial evolution of theater buildings, and Chen Zhihua[4] revealed the interaction between Huizhou theater and clan society through field research. At the level of regional studies, Xiao Min[5] conducted a typological analysis of the construction techniques of ancient stage in southern Hunan, while Wu Weiguang[6] paid attention to the cultural symbolism of minority stage in western Hunan. While foreign countries pay relatively less attention to folk architecture such as ancient stage, with the globalization trend of cultural heritage protection and disaster risk management, foreign scholars have made some progress

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in the protection of traditional architecture, disaster risk assessment and application of spatial information technology, etc. Smith and Brown[7] emphasized the vulnerability of traditional architecture and disaster risk through case studies of traditional architecture in Asia and suggested spatial analysis and risk assessment through GIS technology. Lee and Kim[8] systematically analyzed the spatial distribution characteristics of traditional theaters in East Asia. Johnson and Thompson[9] proposed to realize the dynamic monitoring of disaster risk of traditional buildings through the combination of 3D modeling and GIS, while Chen and Liu[10] evaluated the disaster vulnerability of traditional timber-framed buildings, and Rossi and Bianchi[11] evaluated the disaster vulnerability of traditional wooden buildings. Rossi and Bianchi proposed an integrated assessment method for flood and earthquake disaster risk of cultural heritage, combining historical data with geographic information system (GIS) for disaster vulnerability analysis. it is worth noting that there is a gap in the existing results in the study of the use of spatial information technology to analyze the distribution pattern of the playhouse, and most of the studies are confined to the protection of single building, and lack of a systematic assessment of disaster risk perspective. GIS technology has shown significant advantages in the field of cultural heritage protection in recent years. In recent years, GIS technology has demonstrated significant advantages in the field of cultural heritage protection, such as Zhang Ying [12] revealing the fire risk pattern of ancient buildings in Shanxi through spatial superposition analysis, which is an important reference value for the comprehensive risk assessment of ancient stage.

Hunan Province, the spatial and temporal distribution of the ancient theater profoundly reflects the "by the mountains, along the water, along the stage" of the wisdom of the camp. The Qing Dynasty "Hunan Tongzhi"[13] in "where the town wharf, there must be a theater to gather popularity", Yueyang Zhang Guying village "sunny not exposed to the sun, the rain does not wet shoes" of the gable-type stage, the passage of the Dong village "to sing instead of fighting" drum tower stage, all reflecting the environmental adaptation. The drum tower stage of Dong Village, where songs are sung instead of fighting, reflects the deep integration of environmental adaptability and ethnic culture. However, previous studies have mostly used case descriptions or qualitative generalizations, and have not yet established a quantitative analysis framework based on geographic big data, and even less interdisciplinary exploration of the association between spatial distribution characteristics and disaster vulnerability. In this study, we propose to reveal the spatial clustering pattern of ancient opera houses and their disaster risk classification through GIS spatial analysis and AHP-entropy combination model, aiming to provide a scientific basis for the construction of a "preventive protection" system, which is of double practical significance for the continuation of the cultural genes of Hunan opera houses and meeting the new challenges of cultural heritage protection in the face of climate change. This is of double significance for the continuation of the cultural gene of Hunan opera and the new challenges of cultural heritage protection under climate change.

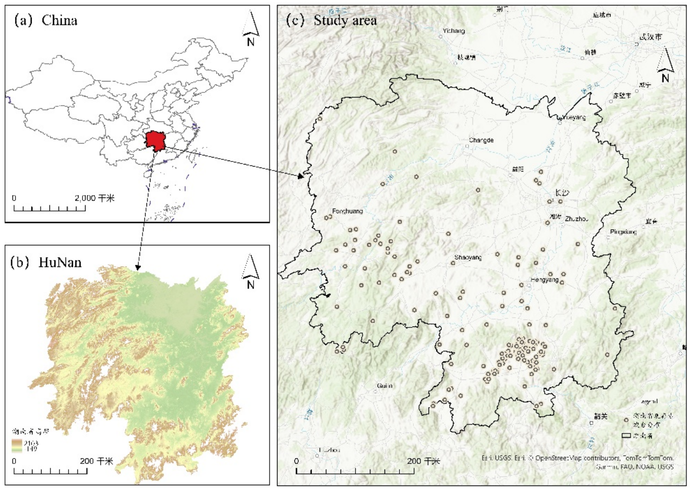


Figure 1 | Overview of the study area

2. Study Area and Data Sources

2.1. Study Area

Hunan Province is located in south-central China, on the south bank of the middle reaches of the Yangtze River, with geographic coordinates between 108°47′ and 114°15′ east longitude and 24°38′ and 30°08′ north latitude, and a total area of 211,800 square kilometers. The province has 13 prefecture-level cities and one autonomous prefecture, with a resident population of about 66 million (2020). Hunan Province is one of the important birthplaces of Chinese opera culture, Xiang Opera, Qi Opera, Yang Opera and other local operas and Dong Nuo Opera, Miao Drum Dance and other ethnic minority operas mingled here, forming a unique "Hunan Opera Cultural Circle"; ancient opera stage as the material carrier of opera performance, widely distributed throughout the province. Meanwhile, Hunan Province has a variety of landforms, with mountains, hills and plains accounting for 51.2%, 29.3% and 13.1% of the total area respectively. Western Hunan and southern Hunan are mainly mountainous and steep, which is the area where the ancient theaters are concentrated; the hills in central Hunan are undulating, and the ancient theaters are mostly built in the center of villages or ancestral halls; the plains of Dong ting Lake in northern Hunan are low and flat, with well-developed water systems, and the ancient theaters are often distributed along the rivers, but they also face a high risk of flooding. The climate is subtropical monsoon climate, with an average annual precipitation of 1200-1700 millimeters, uneven spatial and temporal distribution of precipitation, and heavy rainfall in summer, which is easy to cause flash floods, mudslides and other disasters.

2.2. Data Sources

The data sources mainly contain two parts: the data of ancient theater in Hunan Province and the geographic base data of geology and flooding in Hunan Province. The ancient theater data in this study mainly comes from cultural heritage list, local literature and field research data. The cultural heritage list is derived from the information on ancient theaters in national and provincial cultural protection units in Hunan Province provided by the National Bureau of Cultural Heritage's "List of National Key Cultural Relics Protection Units" (2021) and the Hunan Provincial Department of Culture and Tourism's "List of Provincial

Cultural Relics Protection Units in Hunan Province" (2020), while the local records and related literature are mainly from the "Journal of Hunan Theatre and Opera"[14], Hunan Traditional Architecture Journal, as well as Xue Linping's[15] Study of Traditional Theater Architecture in Hunan, and Hong Xuemei's[16] Study of Existing Ancient Theater Stages in Hunan South; the team conducted field surveys in some areas of Hunan Province in 2022, and supplemented some of the information on ancient theater stages through GPS positioning, photographs taking, and interview records. By the end of 2022, after removing duplicates, there were a total of 219 extant ancient stage in Hunan Province, including 151 ancestral halls, 20 guild halls, 15 temples, and 33 houses and pueblos.

The basic geographic data mainly include topography and geomorphology, hydrology and climate, and disaster risk information. Among them, the DEM digital elevation model of Hunan Province (30-meter resolution) comes from the Geospatial Data Cloud Platform (http://www.gscloud.cn); the geological map of Hunan Province (1:500,000 scale) is provided by the China Geological Survey (http://www.cgs.gov.cn), which covers the geological structure and lithological distribution information of Hunan Province; the River system data (1:250,000 scale) from the National Center for Basic Geographic Information (http://www.ngcc.cn); and Hunan Province precipitation and extreme weather data (1981-2020) from the China Meteorological Data Network (http://data.cma.cn).

2.3. Research Methodology

For the spatial distribution characteristics of the existing ancient opera stages in Hunan Province, this study adopts GIS technology and spatial analysis methods, combined with ArcGIS software, using the spatial statistical methods of kernel density analysis, nearest-neighbor analysis, and standard deviation ellipse analysis (see Table 1), to quantitatively analyze the spatial distribution characteristics and evolutionary trends from the perspective of spatial distribution characteristics and evolutionary trends. Among them, kernel density analysis can intuitively and quantitatively analyze the spatial trend of statistical points, and objectively and accurately express the spatial distribution status of ancient theaters by strengthening the pattern of displaying spatial distribution[17]; standard deviation ellipse analysis can observe geometric parameters such as ellipse's area, long and short semiaxes, and oblateness to intuitively reflect spatial features such as the scope of distribution of the performance venues, directionality, and the degree of discrete; Mean nearest-neighbor analysis can be used to evaluate the degree of agglomeration of elements, and the nearest-neighbor index can be used to determine whether the global distribution pattern of ancient performance venues in Hunan Province is agglomerated, discrete, or stochastic[18].

On the other hand, in the study of disaster risk in Hunan Province, the informativeness method, the weighted comprehensive evaluation method and the geohazard risk index have been used to assess the risk of different types of disasters (see Table 1). The informativeness method is used to study the susceptibility of geohazards, and its basic principle is to measure the potential risk of geohazards in different regions by calculating the ratio of the number of units known to occur geohazards to the total number of units in the region. For the study of flood hazard susceptibility, the weighted comprehensive evaluation method was used, and the corresponding risk model was constructed by evaluating the factors affecting flood hazard susceptibility. The geohazard risk index model is used to comprehensively assess the risk of geohazards by combining the susceptibility and risk coefficients, and this method further refines the assessment of disaster risk through the calculation of the risk index. The flood hazard risk index is used to assess the comprehensive risk of flood hazards and provide a scientific basis for regional disaster risk zoning. Finally, based on the results of the calculation of the susceptibility and danger of geology and flooding, three risk zones were divided into high, medium and low, respectively.

3. Distributional Characterization

3.1. Types of Spatial Distribution

By comparing the average distance of the actual observation with the theoretically expected average distance, the nearest neighbor index R can be calculated to infer the distribution pattern of spatial points. When the index value is small, it means that the spatial point distribution presents a more irregular or discontinuous state. In order to assess the statistical significance of this distribution pattern, the nearest-neighbor index and P-value can be applied to calculate and draw conclusions. When the index of the calculation result is less than 1, it indicates that the point elements present an agglomeration pattern, i.e., there is an obvious aggregation effect; if it is greater than 1, it indicates that the point elements present a dispersed tendency, which is not in line with the characteristics of aggregation. When the index is close to 1, it indicates that the distribution of point elements is close to the random distribution mode.

Previous studies have found that the distribution of ancient theaters in certain areas can be of different types such as aggregated, uniform or random. The nearest neighbor index, as a geographic indicator, is often used to describe the relative proximity between point elements and is widely used in the analysis of spatial distribution characteristics. In the study of ancient theaters, due to the influence of geographic and cultural factors, their distribution usually shows strong clustering characteristics. Using ArcGIS spatial analysis tools, the distribution of existing ancient opera stages in Hunan Province was measured, and the spatial distribution types of ancient opera stages in Hunan Province at different scales were finally identified by calculating the theoretical closest proximity distance and the closest point index R. The spatial distribution of ancient opera stages at different scales in Hunan Province is shown in the following table.

The distribution of the existing ancient stage in Hunan Province is analyzed, and the results are shown in Table 2. The actual nearest point distance of ancient stage in Hunan Province is much larger than the theoretical distance of the average neighboring point, and the actual nearest point distance is 9093 m. The nearest point index is $1.8 > 1$, and the z-value is 24.50, and the significance level p-value < 0.01, which indicates that the ancient stage in Hunan Province has a strong discrete characteristic. Among the 14 cities in Hunan Province, the actual nearest neighbor distance of the urban areas with a larger number of ancient theaters does not reach the theoretical nearest neighbor distance, indicating that the spatial distribution of ancient theaters in these areas shows aggregation characteristics; on the contrary, in the urban areas with a smaller

Table 1 | Statistical analysis model and implications [19]

Exponents	Mould	Model Implications
nuclear density index (NDI)	$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - xi}{h}\right)$	k is the kernel density function; h is the bandwidth; n is the number of points in the threshold range; $x - xi$ denotes the distance from the valuation point x to the event at xi
nearest neighbor index (NMI)	$R = \frac{\bar{r}_i}{r_e}$ $r_e = \frac{1}{2\sqrt{\frac{m}{A}}} = \frac{1}{2\sqrt{D}}$	$\bar{r}_i$ represents the average of the distances between each point and its nearest neighbor; r_e is the theoretical nearest neighbor distance when point elements are randomly distributed; m represents the number of point elements; A represents the study area and Drepresents the number of point elements per unit area.
standard deviation elliptic index (SDEI)	$\mathrm{SDE_x} = \sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{p}_x\right)^2}{n}}$ $\mathrm{SDE_y} = \sqrt{\frac{\sum_{i=1}^{n}\left(y_i - \bar{p}_y\right)^2}{n}}$	x_i and y_i are the coordinates of the spatial position of each element; $\bar{p}_x$ and $\bar{p}_y$ are the arithmetic mean centers; and the variation of the ellipse calculated by $\mathrm{SDE_x}$ and $\mathrm{SDE_y}$.
information quantity method	$I_{A_{j \to B}} = ln\frac{N_j/N}{S_j/S}$	N is the total number of units in the study area where geologic hazards are known to occur, and S is the total number of units in the survey area.
Weighted Comprehensive Evaluation Method (WCEM)	$K_{cz} = \sum_{i=1}^{n} M_{czi}Q_i$	$\mathrm{K_{cz}}$ denotes the total value of susceptibility; n is the number of evaluation indicators; $\mathrm{M_{czi}}$ is the normalized value of the i indicator of factor z; $\mathrm{Q_i}$ denotes the weight of the ith indicator.
Geologic Hazard Risk Index (GHRI)	$H_i = S_i \times e_{h_i}$	$\mathrm{H_i}$ denotes the hazard index of the grid cell; $\mathrm{S_i}$ is the normalized susceptibility index of the grid cell, and e_{h_i} is the hazard coefficient
Flood hazard index	$L = \sum H_i D_i$	L is the hazard index, H_i and D_i correspond to the number of occurrences of each evaluation factor and their corresponding weights.
riskiness index	$V = U \times Y$	V represents the result of the risk evaluation of the disaster; U represents the result of the hazard evaluation of the disaster; and Y is the result of the vulnerability evaluation of the disaster.

number of ancient theaters, such as Changde City, Yiyang City, Loudi City, etc., the spatial distribution of ancient theaters tends to be randomly distributed or discrete distribution.

From a comprehensive point of view, the distribution of the existing ancient stage in Hunan Province has significant regional differences. In southern Hunan and western Hunan, the distribution of ancient theaters shows an obvious aggregation, especially in Xiangxi Tujia and Miao Autonomous Prefecture and Chenzhou City, where the distribution of ancient theaters is dense, reflecting strong cultural inheritance characteristics. The distribution of ancient stage in central and northern Hunan is relatively decentralized, with central Hunan showing a random spatial distribution pattern. Overall, the spatial distribution of ancient opera stages in Hunan Province is discrete, showing local aggregation, but most areas still show discrete or random distribution.

3.2. Degree of Spatial Aggregation

The density of spatial point elements can be estimated using the kernel density analysis method. The method evaluates the spatial density around each point by weighting and summing the spatial point elements, thereby revealing the distribution characteristics of the point elements. Specifically, kernel density analysis obtains the density value of each point by setting a window, calculating the influence of each point within that window and sum-

Table 2 | Spatial distribution types of ancient theater in Hunan Province cities

Shore	City	Number of Ancient Theaters	Theoretical distance	Actual distance	Nearest neighbor index	z-value	Distribution type
South Hunan	Yongzhou	41	9502	5548	0.58	-10.00	Aggregate Distribution
	Chenzhou	103					
	Hengyang	14					
Western Hunan	Huaihua	27	19382	14470	0.75	-2.86	Aggregate Distribution
	Xiangxi Autonomous Prefecture	8					
	Zhangjiajie	——					
North Hunan	Changde	——	75295	98963	1.31	0.85	Discrete Distribution
	yueyang	1					
	Yiyang	1					
Central Hunan	Xiangtan	4	24367	26170	1.07	0.69	Randomized Distribution
	Loudi	2					
	Shaoyang	12					
	Changsha	4					
	Zhuzhou	2					
Hunan Province		219	4878	9093	1.86	24.50	Discrete Distribution

ming it up. Compared with the traditional assumption of uniform distribution, kernel density analysis can more accurately reflect the clustering or dispersion trend of point elements in space.

Through the kernel density analysis, we are able to identify the spatial aggregation area of the ancient theaters more clearly. The spatial distribution density of the ancient theaters in Hunan Province is analyzed in detail by using the spatial analysis tool in the ArcGIS-Pro software, and its distribution pattern is revealed. As shown in Fig. 2, the ancient opera houses in Hunan Province are mainly concentrated in western Hunan and southern Hunan, which show the strongest spatial aggregation. The distribution of ancient opera houses in the eastern and northern Hunan regions is relatively sparse, and the overall distribution shows a pattern of "one center and many belts", specifically, the western part of Chenzhou and the eastern part of Yongzhou serve as the core area for the distribution of traditional ancient opera houses, while the central part of Huaihua City and the central parts of Hengyang and Changsha form a number of important belts for the distribution of ancient opera houses.

Among them, the core of distribution in southern Hunan is located in the western Chenzhou and eastern Yongzhou areas, especially in the western Chenzhou area, where the kernel density value is significantly higher, with 12 to 20 ancient theaters per 100 square kilometers, concentrated in Guiyang County. This is closely followed by the eastern parts of Xintian and Ningyuan counties, which have a kernel density of 8 to 12 per 100 square kilometers. The distribution in other areas is sparser, and the distribution of ancient theaters in southern Hunan is characterized by obvious spatial heterogeneity. Western Hunan also shows a more concentrated distribution of ancient opera tages, especially in Huaihua City, along the belt of the Xuefeng Mountain Range. The geographical conditions of western Hunan provide a favorable natural and cultural environment for the formation of ancient stage, and the lofty mountains, abundant water resources, and unique geographic location make this area an important concentration of ancient stage.

In contrast, the distribution of ancient theaters is sparse in the central and northern Hunan regions because of the relatively flat topography and convenient transportation, and the rapid urbanization process that these regions have experienced. The number of ancient opera houses in central and northern Hunan is significantly lower than that in western and southern Hunan. In conclusion, the distribution of ancient opera houses in Hunan Province shows obvious regional differences, with western Hunan and southern Hunan being the main gathering areas, especially in the western part of Chenzhou and the Xuefeng Mountain Range, while central Hunan and northern Hunan have a relatively small number of existing ancient opera houses due to the rapid modernization process and the relatively flat terrain.

3.3. Trends in Spatial Distribution

In spatial statistical analysis, Standard Deviation Ellipse (SDE) is a commonly used method to analyze the spatial distribution trend of point elements. This method is able to measure the spatial characteristics of geographic ele-

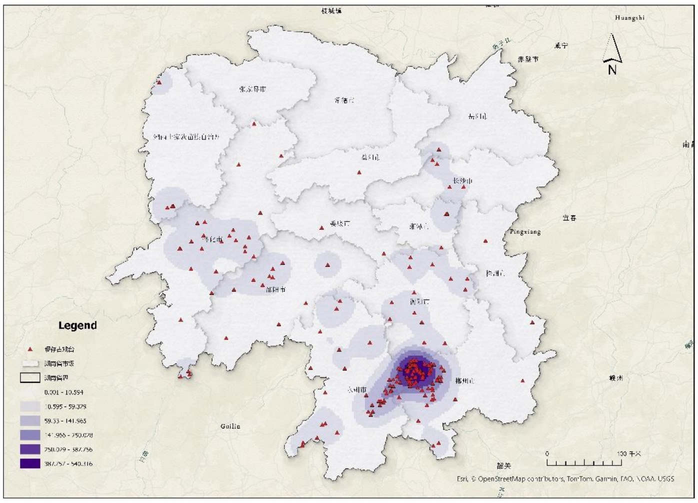


Figure 2 | Kernel density analysis of ancient theaters in Hunan Province

ments, specifically including the center trend, distribution dispersion and directional trend. In the SDE method, the mean center represents the concentrated area of the distribution of geographic elements; while the dominant direction of the distribution can be reflected by rotating the azimuth angle; and the offset is used to measure the change of geographic lements within the region. In addition, the direction and extent of the distribution of geographic elements can be described by the standard distances of the long and short axes. Applying this method to analyze the spatial distribution of the extant ancient theaters in Hunan Province can effectively assess their changes in different time periods.

By utilizing the standard deviation ellipse tool in ArcGIS Pro, the spatial analysis of the existing ancient theaters of different construction periods in Hunan Province was carried out, and their evolution patterns in various historical stages were studied. Taking the earliest construction time mentioned in the traditional documentary records as the benchmark, the 141 ancient stages of the known period are divided into three periods: the early Ming and Qing dynasties (1507-1735), the mid-Qing dynasty (1736-1850), and the late Qing and Republic of China (1851-1949). Through this division, the geospatial development trend of the existing ancient stage in Hunan Province is explored from a temporal perspective (see Figure 3).

According to the standard deviation ellipse analysis in GISPro, the spatial distribution of the ancient stage built from the Ming and Qing Dynasties to the Republic of China (1507~1949) in Hunan Province shows obvious regional characteristics. The results obtained from the standard deviation ellipse analysis show that the distribution of ancient stage has a strong spatial concentration trend, and the distribution trend is mainly concentrated in the south-central part of Hunan Province and part of western Hunan Province. From the results of the analysis in the figure, the ancient stage built in the early period (1507-1735) was mainly concentrated in the south of Hunan, and the distribution showed a long-axis trend in the north-south direction; and into the middle of the Qing Dynasty and the Republic of China (1736-1949), the distribution of the ancient stage was gradually extended to the central and western Hunan areas. Especially in the late Qing and Republican period, the distribution of the ancient theater appeared to have a wider expansion trend, and the western and central Hunan regions became the emerging distribution areas. The results of standard deviation ellipse analysis also reveal the aggregation of distribution. The analysis shows that, although the number of ancient stages gradually increased in all periods, the dense areas of distribution were still concentrated in the southern and western Hunan regions, and this trend persisted throughout the time span. Overall, the distribution trend of ancient stage in Hunan Province from the Ming and Qing Dynasties to the Republic of China is characterized by a gradual expansion from southern Hunan to central and western Hunan. With the advance of time, the construction of ancient theaters was not only concentrated in the traditional southern Hunan area, but also gradually expanded to other regions, especially the number of ancient theaters in the western and central Hunan areas increased, which shows the gradual expansion and development of the spatial distribution of ancient theaters in this period.

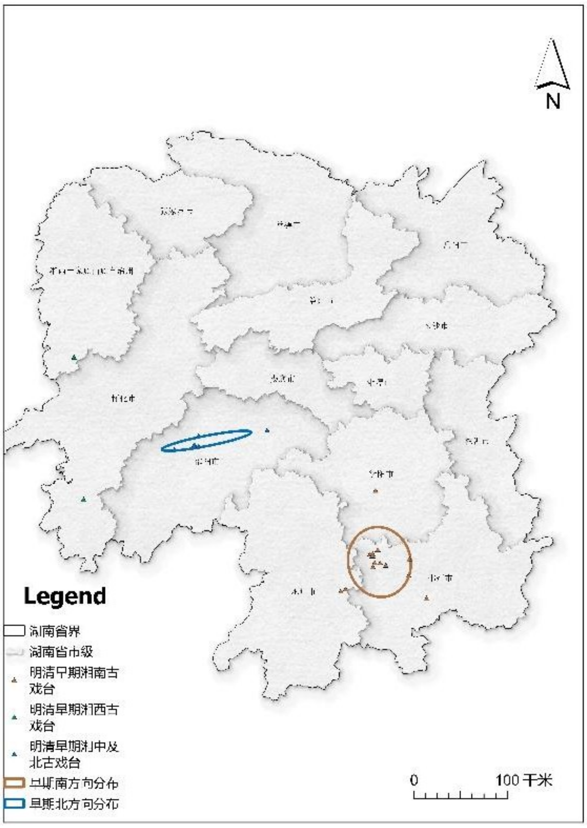
3.4. Continuous Regional Distribution

According to the statistical analysis, the county average distribution density of the existing ancient stage in Hunan Province is 1.14 per thousand square kilometers. Through the use of ArcGIS Pro software to screen out the counties where the distribution density of ancient stage is higher than the average value of the province, a total of 23 counties have a distribution density of ancient stage exceeding the average level of the province. Among them, the top three counties with the highest density of ancient stage are Guiyang County, Shuangqing District and Xintian County, while three of the top five counties belong to the southern Hunan region (see Table 3).

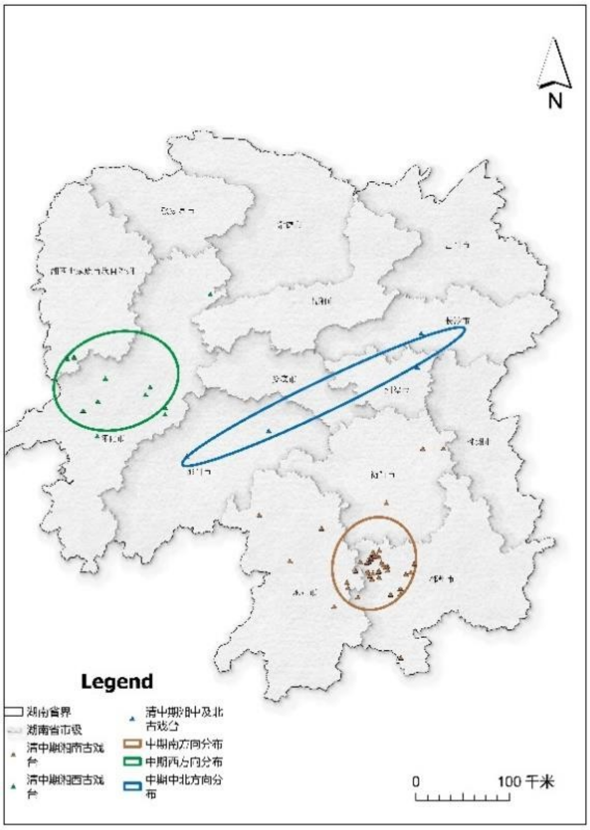
From a spatial distribution point of view (see Figure 4), among the counties with a high density of ancient theaters, there are 11 counties in the southern Hunan region, 6 counties in the central and western Hunan respectively,

Table 3 | Top five contiguous areas at the county level in Hunan Province

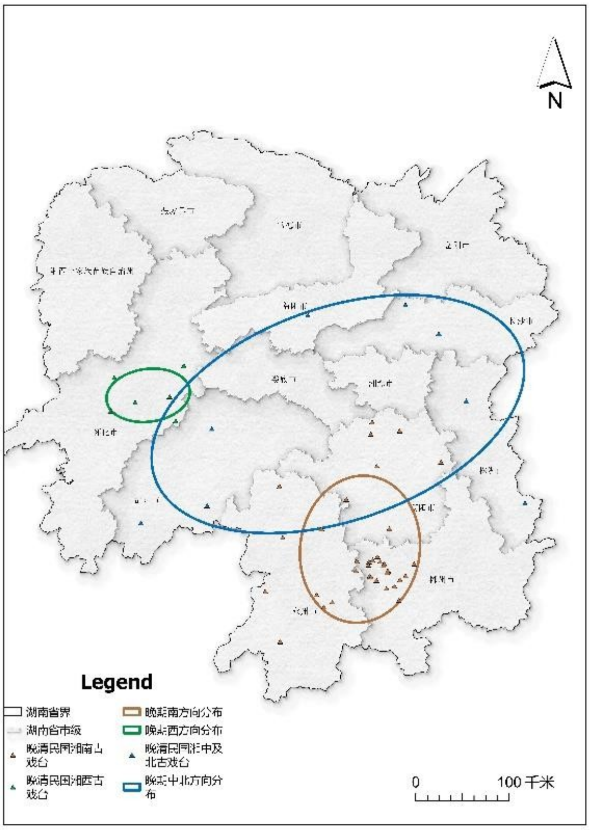
County	Number of Ancient Opera Stages	Area	Area (square kilometers)	Density (pcs/thousand square kilometers)
Guiyang county	95	South Hunan	2958.17	32.11
Shuangqing District	2	Central Hunan	135.87	14.71
Xintian County	12	South Hunan	999.58	12.00
Steamboat District	1	South Hunan	110.99	9.00
Yuhu District	3	Central Hunan	450.44	6.66



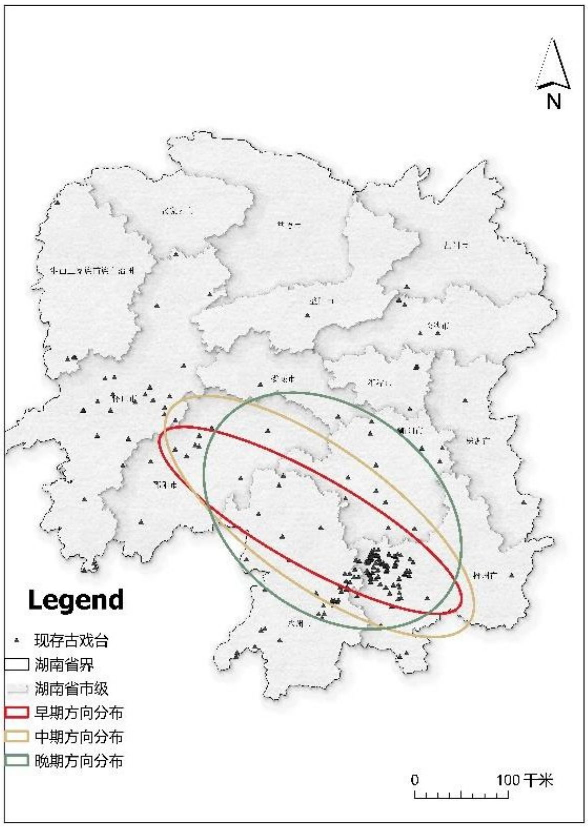
a. Trends in the Distribution of Ancient Opera Stages Built in the Early Ming and Qing Dynasties (1507-1735)



b. Trends in the Distribution of Ancient Opera Stages Built in the Mid-Qing Period (1736-1850)



c. Trends in the Distribution of Old Opera Stages Built in the Late Qing and Republic of China (1851-1949)



d. Trends in the distribution of ancient theaters built in the Ming and Qing Dynasties-Republic of China (1507-1949)

Figure 3 I Distribution of the direction of ancient theaters in each period (1507-1949)

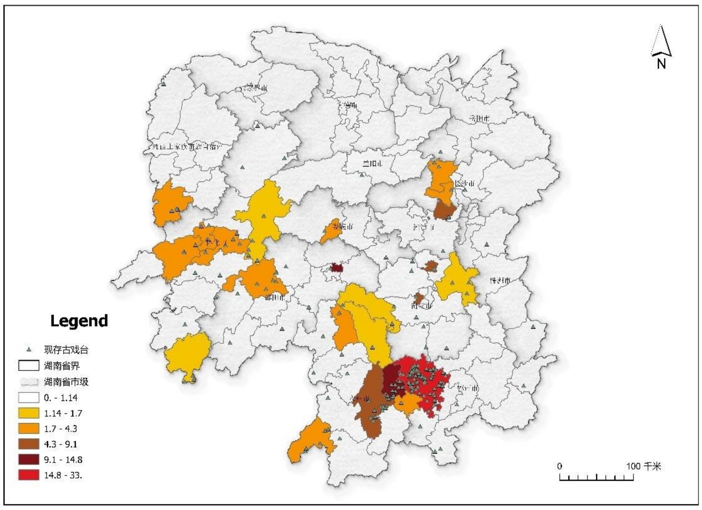


Figure 4 I County-level centralized area of existing ancient theatres

while the northern Hunan region fails to find any counties with a density exceeding the provincial average. According to the statistics, Nanyue District of Hengyang City, Ningyuan County and Jiangyong County of Yongzhou City, Jiahe County of Chenzhou City, Fenghuang County of Xiangxi Autonomous Prefecture, and Zhongfang County of Huaihua City, together with the five contiguous areas in the table below, the distribution densities of the ancient theaters in a total of 11 districts and counties are all higher than 3 per 1,000 km2, which are areas of high potential for centralized and contiguous conservation and utilization.

4. Geologic Hazard Risk Zoning

4.1. Evaluation of Susceptibility

Geological disaster susceptibility refers to the possibility of geological disasters occurring in a specific area due to geological conditions. When carrying out the vulnerability assessment, it mainly analyzes the occurrence of existing geohazards in the area and predicts the trend of possible disasters in the future, which lays the foundation for further hazard and risk assessment. In this paper, the information quantity method is used to assess the susceptibility to geological hazards, and the information quantity model measures the degree of influence of various disaster-causing factors on geological hazards with the help of probabilistic statistical methods.

According to the relevant requirements for the evaluation of the susceptibility of geologic disasters in Hunan Province, this study carried out a comprehensive assessment of the susceptibility of geologic disasters by combin-

Table 4 I Geologic Hazard Vulnerability Evaluation Factor Table

Evaluation factors	Weights	Indicator Grading	Indicator weights
Slope/(。)	0.20	<20	0.25
		[20, 45)	0.35
		[45, 60)	0.25
		≥60	0.15
Land use type	0.25	Agricultural Land	0.30
		Forests, grasslands and unutilized land	0.20
		Urban, rural, industrial, mining and residential land	0.30
		Water area	0.10
		Transportation Land	0.10
Vegetation cover	0.15	[-1, 0]	0.20
		(0, 0.2]	0.30
		(0.2, 0.4]	0.30
		>0.4	0.20
Slope type	0.10	Concave	0.40
		Linear	0.35
		Convex	0.25
Degree of terrain undulation/m	0.15	≤10	0.30
		(10, 20]	0.30
		(20, 30]	0.25
		>30	0.15

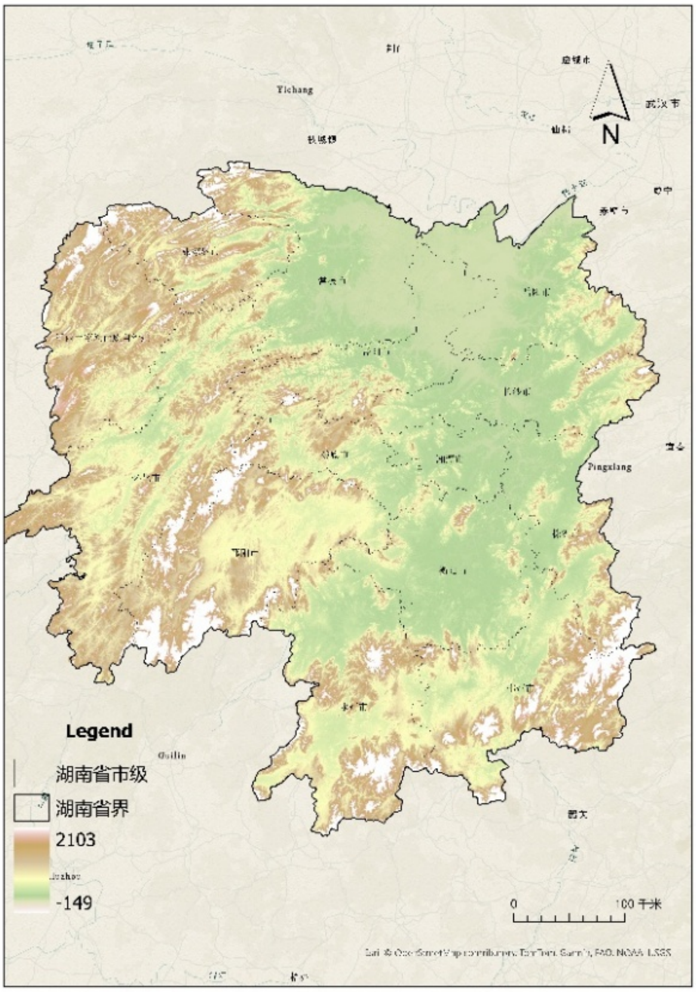


Figure 5 l Topography of Hunan Province

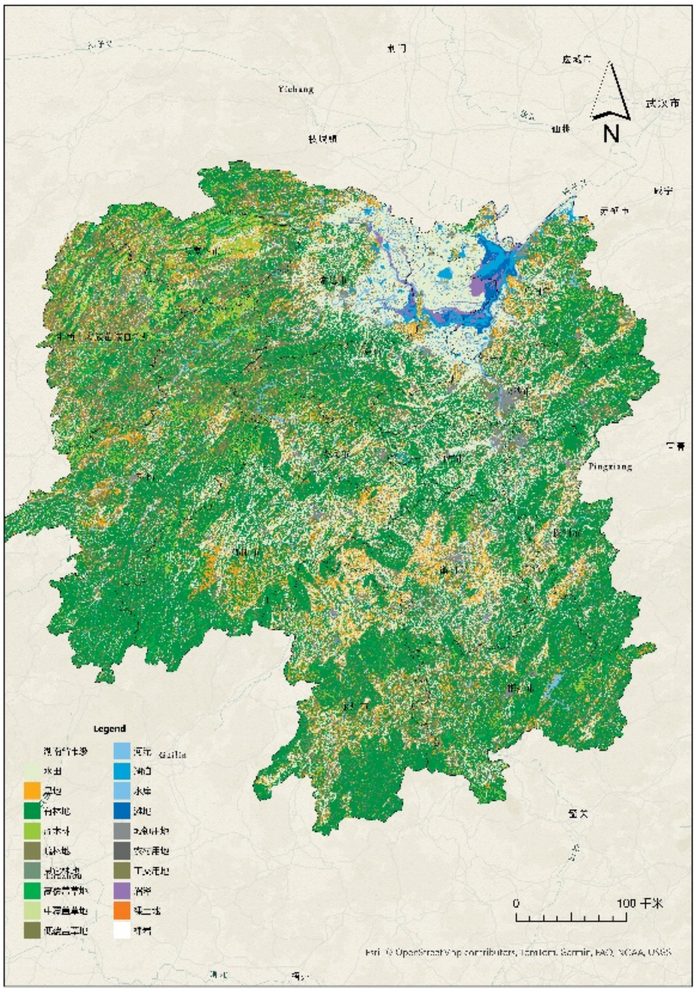


Figure 6 l Land use map of Hunan Province

ing the characteristics of the geologic environment and the types of disasters in Hunan Province. Firstly, according to the development pattern and geological conditions of geological disasters in Hunan Province, through the investigation and analysis of various factors affecting the occurrence of geological disasters, a number of influencing factors were selected as indicators of susceptibility assessment (see Table 4).

Using the information quantity method and GIS spatial analysis tools, the spatial analysis and information quantity calculation of each evaluation factor were carried out, and finally the evaluation layer of geohazard susceptibility in Hunan Province was generated. According to this evaluation layer, combined with the proportion and frequency of various types of geohazards, the geohazard susceptibility was divided into three levels: high, medium and low susceptibility areas. After filtering and denoising, the susceptibility evaluation map was further optimized and finally formed the geohazard susceptibility zoning map of Hunan Province (see Figure 7).

4.2. Hazard Evaluation

Geological disaster risk mainly reflects the probability of occurrence of a specific type and scale of geological disaster in a certain area within a certain time frame under the effect of specific triggering factors. According to the research and analysis, most of the geohazards in Hunan Province occur during the rainy season, and precipitation is the main triggering factor for the occurrence of geohazards. Based on the foundation of geohazard susceptibility evaluation, combined with the monthly average precipitation data, the risk coefficient is introduced to carry out the geohazard risk assessment.

On the basis of the susceptibility evaluation, the hazard coefficient was introduced in combination with the monthly mean precipitation distribution (see Fig. 8) to carry out the

Table 5 l Hazard secondary evaluation factor weights

	Vulnerability results	Average monthly precipitation	Wi
Vulnerability results	1	2	0.6667
Measured quantity of rain	1/2	1	0.3333

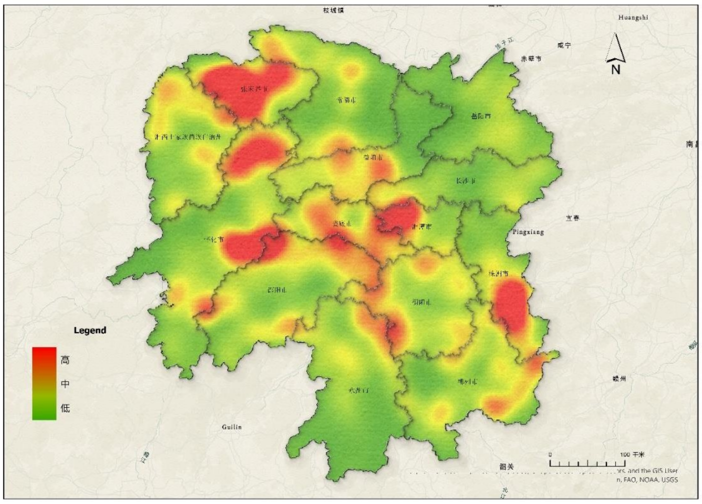


Figure 7 | Geological hazard susceptibility zoning map of Hunan Province

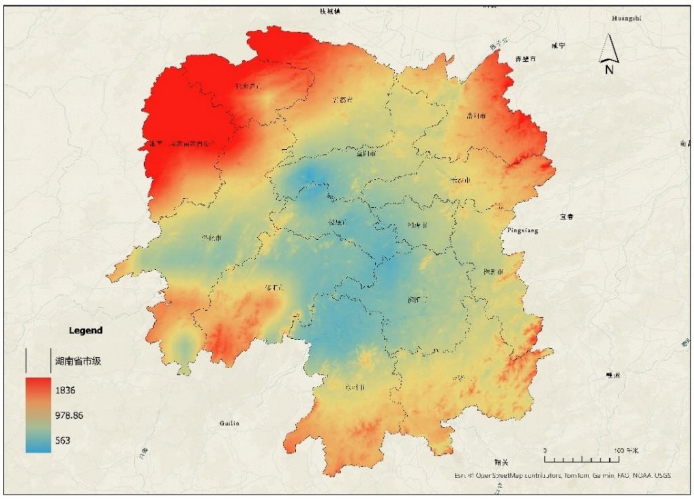


Figure 8 | July mean precipitation in Hunan Province (2022)

hazard assessment of geologic hazards in . A hierarchical analysis model of geologic hazards was constructed using Matlab software, and the judgment matrix of the susceptibility evaluation results and monthly mean precipitation in the hazard evaluation was set on this basis (see Table 5). The weighting factors of the susceptibility evaluation results and average monthly precipitation were calculated as (0.6667, 0.3333), respectively.

Through the hierarchical analysis method and combined with the evaluation standard of geologic hazards, the weights of the average monthly precipitation and the evaluation result of susceptibility were determined, and the precipitation and susceptibility evaluation results of Hunan Province were superimposed and analyzed to derive the geologic hazard risk evaluation map of Hunan Province.

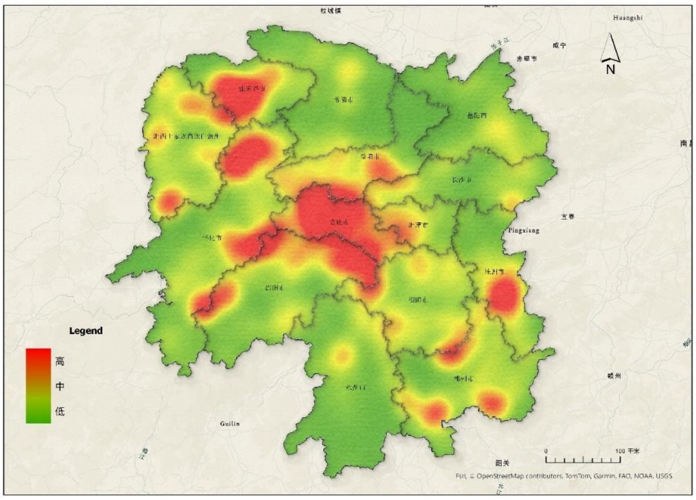


Figure 9 | Geologic Hazard Risk Evaluation Map

Using the natural discontinuity method in ArcGIS software, the results of the hazard evaluation were categorized into three types, namely, low-hazard zone, medium-hazard zone, and high-hazard zone, and the geohazard hazard zoning map of Hunan Province was drawn (see Fig. 9).

4.3. Geologic Hazard Risk Areas

Geological disaster risk reflects the possibility of losses caused by geological disasters to different types of disaster-bearing bodies in a specific region and period of time. The final geohazard risk evaluation results are obtained by combining the results of the evaluation of the danger and the susceptibility of geohazards, and by classifying the risk level based on the matrix judgment method, and integrating the data by using focal statistical tools. The risk evaluation of geohazards can be expressed by the product of hazard evaluation and susceptibility evaluation, risk = hazard⊠susceptibility.

Matrix analysis method is used for specific evaluation. The results of the evaluation of the risk of geologic hazards in the study area are superimposed on the results of the evaluation of the susceptibility to geologic hazards to obtain a table of the classification of the risk of geologic hazards in the study area (see Table 6), and the calculation and analysis is carried out by using the formula of the risk to obtain the results of the evaluation of the risk of geologic hazards in the study area, and the results of the evaluation are classified into three levels of intervals, and the evaluation map of the risk of geologic hazards in the study area is obtained (see Fig. 10)

The percentage of each risk zone is derived by statistically analyzing the results of hazard risk evaluation in Hunan Province. Low-risk zone, medium-risk zone and high-risk zone account for 58.25%, 30.45% and 11.3% of the total area respectively. High-risk zones are mainly concen-

Table 6 | Geologic hazard risk classification table

Vulnerability/hazard	high Hazard	Medium Hazard	low Hazard
Low susceptibility	medium risk	high risk	high risk
Medium Vulnerability	high risk	medium risk	high risk
High Vulnerability	high risk	high risk	medium risk

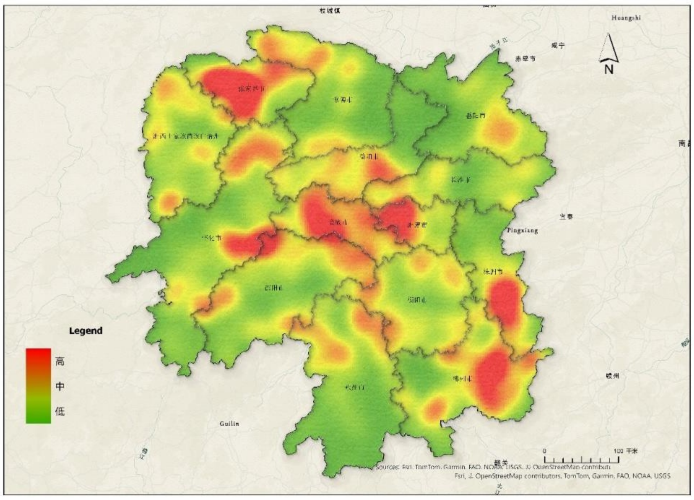


Figure 10 | Geologic hazard risk zoning map

trated in central Hunan, northwestern Hunan and southern Hunan mountainous areas, especially in the central area of Loudi City, the northern area of Zhangjiajie City, and the western mountainous area of Chenzhou City, with an area of about 23,900km². Medium-risk zones are mainly distributed in the central and southern low-hill areas of Hunan Province, covering an area of about 64,500km². The low-risk zone is mainly concentrated in the plains and river alluvial areas in the province, with the largest area of about 123,400km². Overall, the distribution of low-risk areas in Hunan Province is wide, and mainly concentrated in the central and southern plains; the area of very high-risk areas is the smallest, and mainly distributed in mountainous areas with complicated terrain. In terms of the distribution of geohazard risk, the mountainous areas in the east-central part of Hunan Province have higher geohazard risk, the central and western parts are medium-risk zones, and the plains in the south and east are low-risk zones.

5. Flood Risk Zoning

5.1. Evaluation of Susceptibility

Disaster-causing factor is the external condition that triggers flood disaster, and it is the key factor indispensable to the occurrence of disaster, and the disaster-causing factor and the environment that breeds disaster work together to constitute the conditions for the occurrence of flood disaster. By determining the disaster-causing factors, the weighted comprehensive evaluation method is used to analyze the influence of each factor on the overall disaster, and the influence degree of each specific index is summarized, so that the strengths and weaknesses of the overall evaluation object are reflected centrally through the quantitative indexes. In this study, the weighted comprehensive evaluation method is used to construct a risk assessment model for heavy rainfall and flooding in Hunan Province.

Disaster susceptibility refers to the environment and conditions affecting the occurrence of disasters, which can, to a certain extent, exacerbate or weaken the occurrence of disasters and their consequences. In Hunan Province, the terrain is complex and hilly, and water in low-lying areas is difficult to discharge, making it easy to form waterlogging. At the same time, there are many rivers running from northeast to southwest in Hunan Province, and continuous precipitation can easily lead to a rapid rise in water level, which in turn triggers flooding. Therefore, the average annual precipitation, topographic relief and river network density were mainly selected as indicators to measure the susceptibility to pregnant disasters, and the corresponding weight values were assigned to combine the degree of influence of each factor on flooding.

Table 7 | Flood vulnerability evaluation factor table

Evaluation factors	Weights	Indicator Grading	Indicator weights
DEM/m	0.25	> 1200	0.05
		(500, 800]	0.15
		(200, 500]	0.25
		(50, 200]	0.35
		≤50	0.20
Density of river network/（m / m²）	0.25	(0.03, 0.05]	0.40
		(0.01, 0.03]	0.35
		≤0.01	0.25
Average annual precipitation（mm）	0.35	(400, 800]	0.25
		(800, 1200]	0.40
		> 1200	0.35
Slope/(。)	0.15	<20	0.25
		[20, 45)	0.35
		[45, 60)	0.25
		≥60	0.15

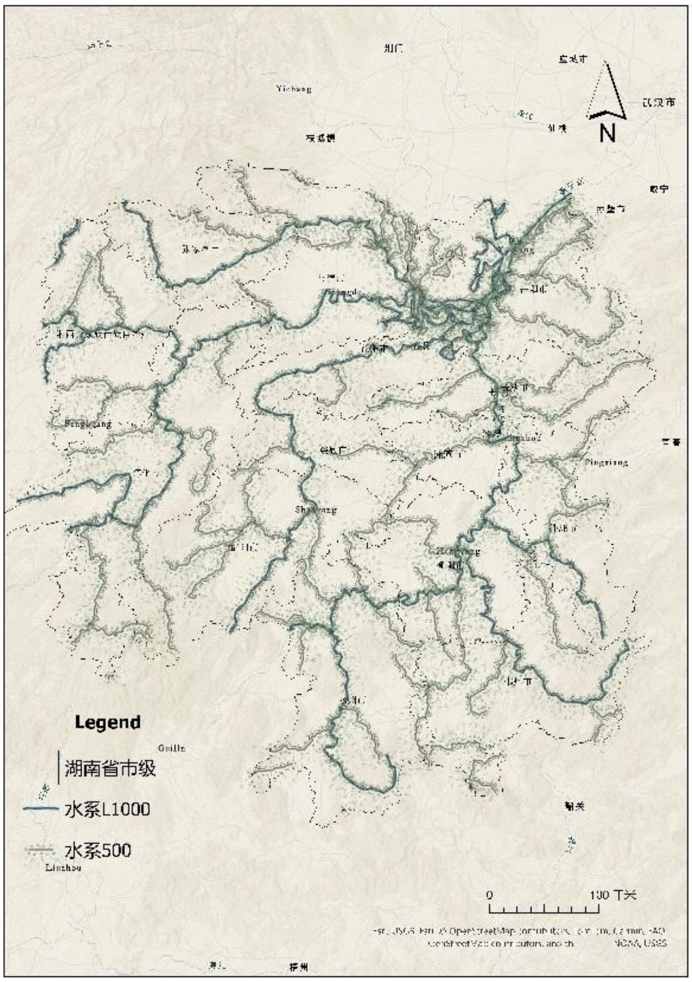


Figure 11 I Density map of water systems in Hunan Province

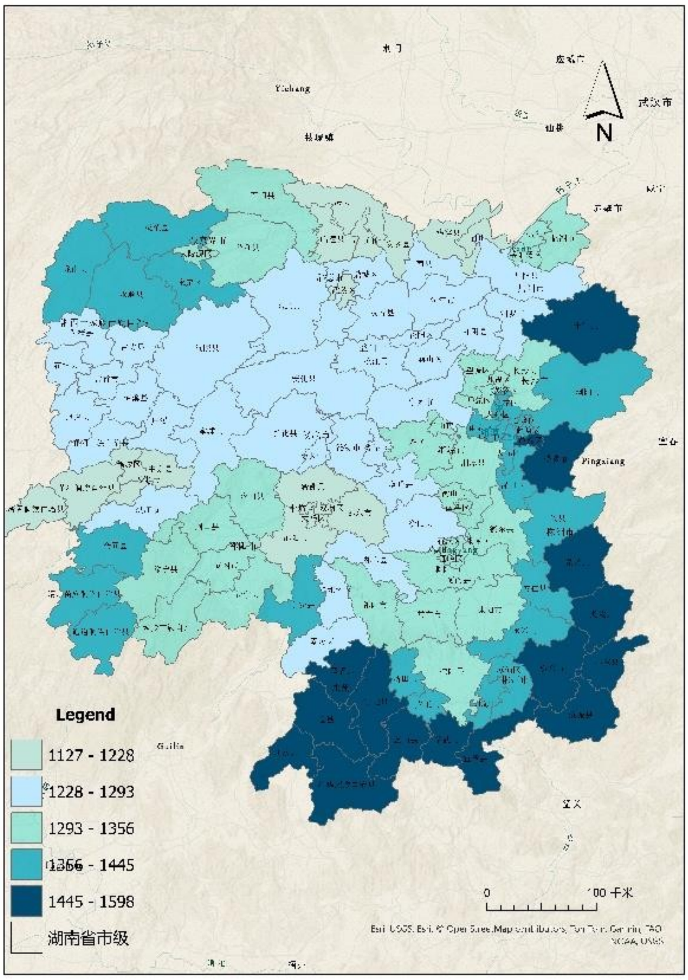


Figure 12 I Average annual precipitation statistics for Hunan Province

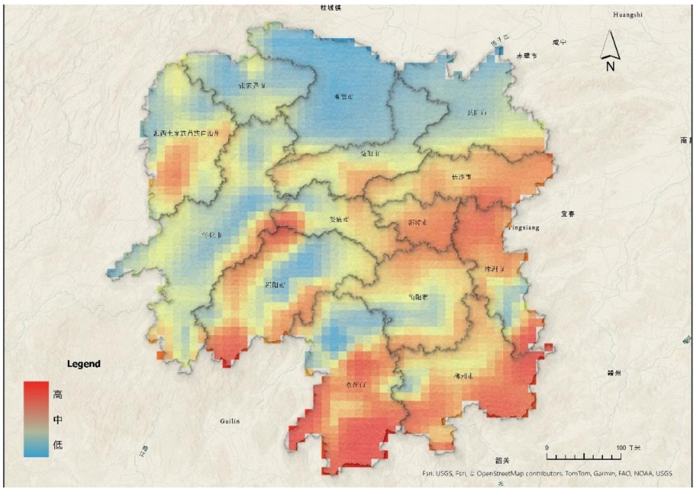


Figure 13 I Flood vulnerability zoning map of Hunan Province

In ArcGIS, the raster data of flood disaster susceptibility in Hunan Province were obtained by assigning different amounts of information to the influencing factors in each interval and spatially overlaying them using a raster calculator. The natural discontinuity method can effectively reflect the spatial distribution status of each influence factor when flooding occurs. Therefore, the natural discontinuity method is used in the ArcGIS reclassification tool to divide the total value of information into three grade intervals, which are low susceptibility zone, medium susceptibility zone, and high susceptibility zone (see Figure 13). Based on this, the distribution map of flood disaster susceptibility assessment in Hunan Province was obtained.

5.2. Hazard Evaluation

Hunan Province is located in the monsoon climate zone, and precipitation characteristics show long duration, high intensity and obvious seasonality. Especially in the summer, heavy rainstorms are frequent, and precipitation is concentrated and of significant intensity. In order to study the risk of flooding in Hunan Province, the heavy rain days in Hunan are defined as daily precipitation ≥ 50 mm, which is used as one of the evaluation factors of flooding risk. The intensity and frequency of heavy rainfall are closely related to the occurrence of floods, so evaluating the risk of heavy rainfall is of great significance for predicting and preventing floods.

In order to quantify the risk of flooding, two key factors, the daily maximum rainfall and the annual average number of days of heavy rainfall, were selected. The daily maximum rainfall reflects the extreme intensity of precipitation on a single day, which is an important factor in the degree of flood hazard. Based on the collected meteorological data for Hunan Province in 2022, the daily maximum rainfall was categorized into four classes: (86.20, 122.06]mm,

Table 8 I Flood Hazard Evaluation Factor Table

Evaluation factors	Weights	Indicator Grading	Indicator weights
Maximum daily rainfall/mm	0.48	(86.20, 122.06]	0.35
		(62.99, 86.20]	0.30
		(38.90, 62.99]	0.20
		(0, 38.90]	0.15
Average annual number of days of heavy rainfall/(d)	0.52	(5, 8]	0.40
		(3, 5]	0.35
		(1, 3]	0.20
		(0, 1]	0.05

(62.99, 86.20]mm, (38.90, 62.99]mm, and (0, 38.90]mm, which were assigned a weight of 0.35, 0.30, 0.20, and 0.15, respectively, and the annual average number of days of rainstorms reflects the frequency of heavy rainfall in Hunan Province, and this factor is important for the prediction of flooding.

Statistically, the annual average number of days of heavy rainfall was categorized into four intervals: (5, 8] days, (3, 5] days, (1, 3] days, and (0, 1] days, which were assigned weights of 0.40, 0.35, 0.20, and 0.05, respectively. Higher frequency of heavy rainfall days implies a more severe risk of flooding occurrence, and thus higher weights are given to high frequency heavy rainfall areas. By combining the evaluation weights of the two factors of daily maximum rainfall and annual average number of days of heavy rainfall, the risk of flooding in Hunan Province can be described more comprehensively.

Based on the statistical data of the number of days of heavy rainfall and the maximum rainfall in each county of Hunan Province in 2022, the spatial analysis and informativeness calculation of each evaluation factor were carried out by the informativeness method and the GIS spatial analysis tool. Through the calculation of these data, the results of the evaluation of the risk of flooding in each region of Hunan Province were obtained. According to the calculation results, the regions were divided into high, medium and low danger zones from high to low (see Figure 16).

5.3. Flood Risk Areas

The risk of flooding reflects the likelihood of flood damage suffered by different types of bearers in a given area and time period. By combining the results of flood hazard and susceptibility evaluation, and using the matrix judgment method to classify the risk level of (see Table 6), and integrating the data with the Focus Statistical Tool, the risk assessment results of flood hazard are finally derived. Based on the flood disaster risk evaluation model of Hunan Province, combined with the evaluation results of danger and susceptibility obtained from the above calculation, the risk formula was used to calculate and substitute the corresponding evaluation index weights, i.e., risk = Dangerousness× Susceptibility.

The specific evaluation also adopts the matrix analysis method. The results of the evaluation of flood hazard risk in the study area are superimposed on the results of the evaluation of flood hazard susceptibility to obtain the classification of flood hazard risk in the study area, which is calculated and analyzed by using Equation 4-3 to obtain the results of the evaluation of flood hazard risk in the study area, which is divided into three grade intervals to obtain the evaluation map of flood hazard risk in the study area (see Fig. 17).

According to the results of the flood risk assessment in Hunan Province, the flood risk in Hunan Province shows obvious spatial distribution differences and is mainly divided into three risk zones: low, medium and high. The high-risk zones are usually located in the low-lying areas around South Hunan, West Hunan and Dongting Lake, especially in Yueyang, Changde, Zhangjiajie and Chenzhou. These areas have low topography, well-developed water systems, frequent and intense rainstorms, and are prone to waterlogging, so the risk of flooding is high, and severe flooding often occurs during heavy rains. Medium-risk areas are mainly located in hilly and low-mountain areas in central and southern Hunan Province, in cities like Changsha, Hengyang, and Loudi. These areas have moderate precipitation and moderate frequency of heavy rainfall, and although they do not have the dense water systems of the high-risk zones, they are also at risk of poor flood drainage due to the relatively gentle topography. The low-risk areas are concentrated in the mountainous and higher terrain areas of Hunan Province, including parts of northern and eastern Hunan. These areas have relatively low precipitation and steep topography, which makes water flow faster and floodwaters easier to discharge, so they are at lower risk of flooding. The natural drainage capacity of these regions is high, which avoids the occurrence of floods. Overall, flood riskiness in Hunan Province shows different levels from south to north and from low-lying to upland areas, with high- risk areas mainly concentrated in the south and

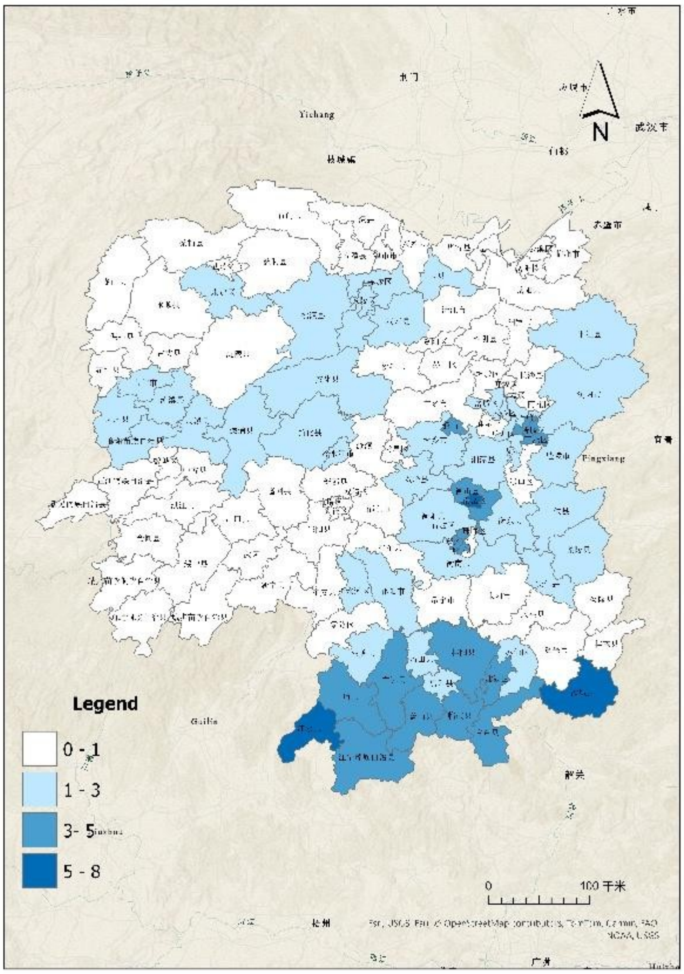


Figure 14 | County-level storm days statistics

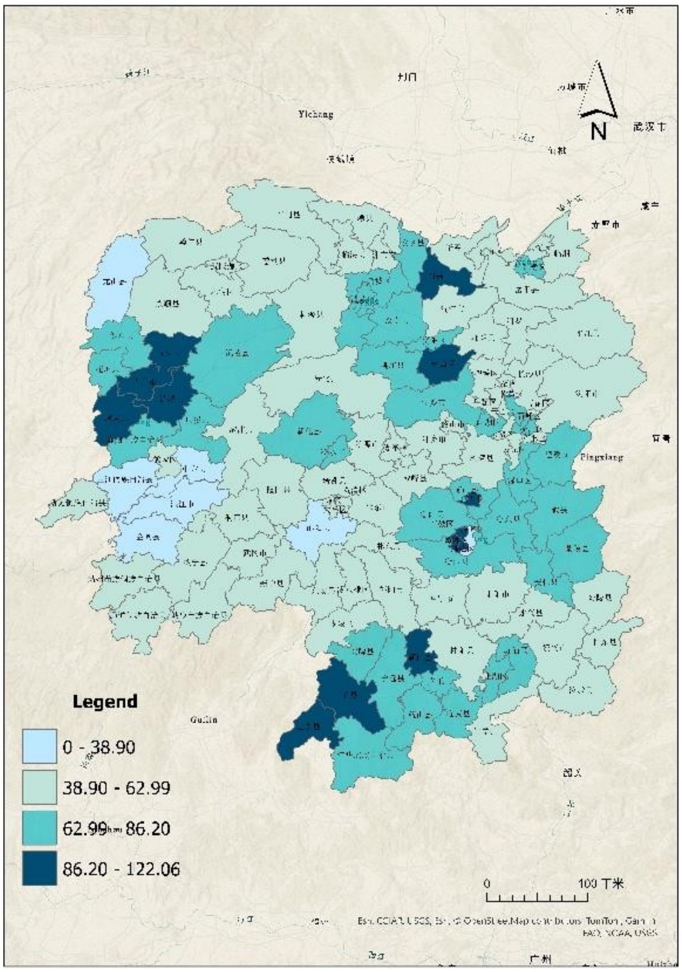


Figure 15 | County-level maximum rainfall statistics

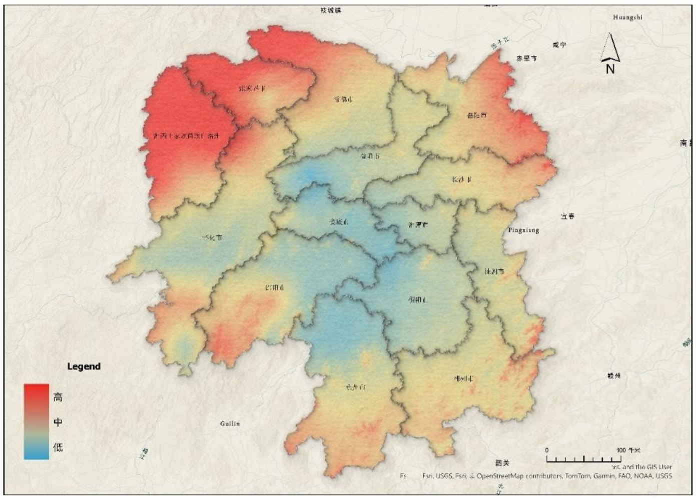


Figure 16 | Flood Hazard Evaluation Map

lowlands, while low-risk areas are distributed in mountainous areas and upland zones.

6. Control Zoning and Countermeasures

6.1. Disaster Prevention and Control Zoning

According to the results of the flood risk assessment of the ancient stage in Hunan Province, combined with the natural environment of the region, the distribution characteristics of geological hazards and the need for protection of cultural heritage, based on the distribution of the 72 ancient stages in the medium- and high-risk areas, and through the optimization of cold hot spot analysis of GIS-Pro, the 72 ancient stages in the risk area are divided into three levels of key prevention and control areas, sub-priority prevention and control areas, and general prevention and control areas, to form the Geological disaster prevention and control zoning map of Hunan Province.

The map of geohazard prevention and control zones is shown in Figure 18, and the key prevention and control areas are mainly located in places with frequent geologic activities, such as high mountainous areas and low hilly areas. The area is about 10,640,000 square kilometers, accounting for 4.99% of the province's area. Most of the ancient theaters in Hunan Province are located in these key prevention and control areas, and the probability of disasters is high. Protective measures should be focused on strengthening. The sub-priority prevention and control areas are mainly located in the valleys or fringes of Hunan Province, covering an area of 61,400 square kilometers, accounting for 28.89% of the province's area. The risk of geologic hazards in these areas is relatively low, but there

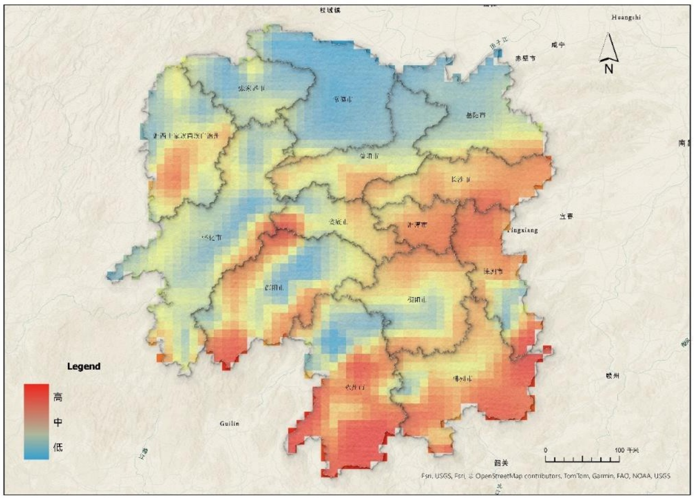


Figure 17 I Flood risk zoning map of Hunan Province

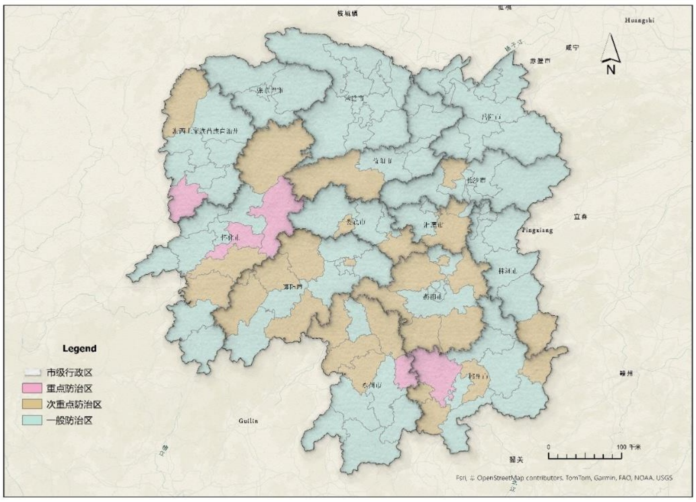


Figure 18 I Geologic Hazard Prevention and Control Zone Map

are still potential disaster threats, which may also cause a large impact in case of occurrence. Therefore, ancient theaters in the sub-priority prevention and control zones should develop moderate protection strategies and conduct routine safety inspections and maintenance.

Similarly, based on the flood risk assessment results of the ancient theaters in Hunan Province, combined with the geographic environment, historical disaster data and potential threat of flooding in each region, and also based on the distribution of 169 ancient theaters in the medium- and high-risk areas, the 169 ancient theaters in the risk area are divided into three levels: key prevention and control area, sub-priority prevention and control area, and general prevention and control area, through the optimization of the cold hotspot area analysis by ArcGIS Pro. The 169 ancient theaters in the risk area were divided into three levels: priority control area, sub-priority control area and general control area through ArcGIS Pro optimized cold-hot spot area analysis.

The flood hazard control zoning map is shown in Figure 19, and the key control zones are mainly concentrated in the localized low hills and river valleys in southern Hunan Province, covering an area of about 0.64 million square kilometers, or 3.01% of the province's area. These areas have a higher degree of vulnerability to flooding and are low-lying and densely populated, and therefore have a higher risk. The sub-priority prevention and control areas are mainly located in the southern and western low mountainous areas in the north and the low mountainous areas in the center of Hunan Province, with an area of 98,900 square kilometers, accounting for 46.73% of the total area of the province. These areas are moderately prone to flooding, with a relatively low disaster density and a relatively decentralized population. Although such areas face a certain degree of flood risk, the frequency and impact of disasters is relatively limited because of the moderate importance of the disaster-bearing body, and prevention and control efforts should focus on strengthening flood management and infrastructure development in order to mitigate the risks that may be posed.

6.2. Recommendations for Prevention Strategies

6.2.1. Strengthening Disaster Risk Assessment and Zoning Management

The ancient theaters in Hunan Province are located in a number of areas with high incidenceof geologic hazards; therefore, it is necessary to first conduct a disaster risk assessment and divide different risk prevention and control zones based on the potential impacts of geologic hazards and flooding. The results of the risk assessment for each zone will provide the basis for the development of targeted prevention and control measures, ensuring that the safety management of each ancient theater is accurately assessed.

6.2.2. Improvement of Disaster Early Warning and Emergency Response Mechanisms

The establishment of a sound disaster warning and emergency response mechanism is crucial in the disaster risk control of the ancient theater. Through the Meteorological Bureau, the Geological Hazard Monitoring Center and other institutions, disaster warning information is issued on a regular basis to warn of possible disasters in advance and ensure that the Government and relevant management departments can respond quickly.

6.2.3. Promoting Digital Preservation and Monitoring of Cultural Heritage

With the development of modern science and technology, digital technology has been widely used in cultural heritage protection. The implementation of digital protection is an indispensable part of the disaster risk control of ancient opera stages in Hunan Province. Intelligent monitoring equipment, such as geological sensors and meteorological monitoring systems, are installed in conjunction with the Internet of Things technology to monitor the structural condition of the ancient theater in real time and discover potential risks in a timely manner.

6.2.4. Enhancement of Public and Local Government Awareness of Disaster Prevention and Management

Disaster risk management in ancient theaters does not only depend on the efforts of the government and profes-

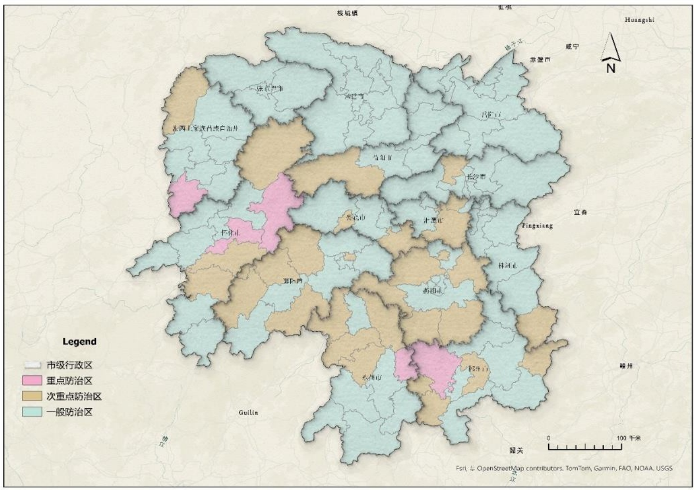


Figure 19 | Flood control zoning map

sional organizations, but also requires the active participation of local communities and the public. By raising the awareness of local residents on disaster control, the risk in case of disaster can be effectively reduced.

6.2.5. Enhancement of Financial Support and Policy Guarantees

Disaster risk control requires strong financial support and policy guarantee. Hunan Province should ensure the smooth progress of disaster prevention and control of the ancient theater through diversified funding channels such as government investment, social financial support, and international assistance. In terms of policy, local governments can introduce relevant regulations to provide legal protection for disaster prevention and control.

7. Conclusion

In this study, the spatial distribution characteristics of ancient stage and its disaster risk pattern in Hunan Province are systematically investigated by combining the GIS spatial analysis technology and disaster risk assessment model with the ancient stage in Hunan Province. The results show that the distribution of ancient stage in Hunan Province has significant regional differences, and its disaster risk pattern is closely related to the natural geographic environment, climate conditions and human activities.

The distribution of ancient stage in Hunan Province presents a spatial pattern of "built along the water and built on the mountain", with obvious local aggregation characteristics. Through kernel density analysis, nearest-neighbor index and standard deviation ellipse analysis, it is found that in terms of spatial distribution type, the overall distribution of ancient opera houses in Hunan Province shows a discrete distribution (nearest-neighbor index R=1.86), but in the south and west of Hunan Province, there is a significant agglomeration, especially in the western part of Chenzhou and the central part of Huaihua, where the kernel density value is higher, and the number of ancient theaters reaches 12-20 per 100 square kilometers. In the spatial distribution trend from the Ming and Qing Dynasties to the Republic of China, the distribution range of ancient opera houses gradually expanded from southern Hunan to central and western Hunan, showing a diffusion trend of "from south to north, from the center to the periphery". The southern Hunan region is always the core area of the distribution of ancient stage, while the western and central Hunan regions became new distribution areas in the late Qing and Republic of China periods. In terms of the distribution of continuous areas, the high-density continuous area of ancient stage in Hunan Province is mainly concentrated in the south of Hunan, such as Guiyang County, Xintian County, etc. The distribution density of ancient stage in these areas is significantly higher than the average level of the whole province (1.14/thousand km²), which is of high centralized and continuous conservation value.

The disaster risks faced by ancient theaters in Hunan Province mainly include geological disasters (landslides, mudslides) and floods. Through the information quantity method, weighted comprehensive evaluation method and GIS spatial analysis, the study concludes that the high-risk areas of geologic hazards in Hunan Province are mainly concentrated in the mountainous areas of central Hunan, northwest Hunan and south Hunan, accounting for 11.3% of the province's area. These areas have complex topography and concentrated precipitation, and the ancient theater faces high threats of landslides and mudslides. The medium-risk area accounts for 30.45%, mainly located in the low hills of central and southern Hunan; the low-risk area accounts for 58.25%, mainly located in the plains of northern Hunan and the highlands of eastern Hunan. The high-risk areas of flooding in Hunan Province are mainly located in the low-lying areas around Hunan South, Xiangxi and Dongting Lake, accounting for 3.01% of the province's area. These areas have well-developed water systems and frequent heavy rainfall, and the ancient theater is vulnerable to flooding. The medium- risk area accounts for 46.73%, mainly located in the low mountainous areas of central and southern Hunan; the low-risk area accounts for 50.26%, mainly located in the highlands of northern and eastern Hunan.

Based on the results of disaster risk assessment, the study divides the ancient stage in Hunan Province into key prevention and control areas, sub-priority prevention and control areas and general prevention and control areas, of which the key prevention and control areas are mainly located in the high-risk areas of geologic hazards and floods, such as Guiyang County, south Hunan Province, Huaihua City, west Hunan Province, and other places. It is recommended to strengthen the construction of the disaster early warning system, implement the structural reinforcement project of the ancient theater, and establish a digital monitoring platform. The sub-priority prevention and control zones are mainly located in medium-risk zones, such as Loudi City in central Hunan and Yongzhou City in southern Hunan. It is recommended to improve the drainage facilities, carry out regular safety inspections of the ancient stage, and promote community participation in the protection work. General prevention and control zones are mainly located in low-risk areas, such as Yueyang City in northern Hunan and Changsha City in eastern Hunan. It is recommended to strengthen daily maintenance, raise public awareness of disaster prevention and control, and develop emergency plans.

This study combines GIS spatial analysis and disaster risk assessment model for the first time,

and systematically reveals the spatial distribution pattern of ancient stage and its disaster risk pattern in Hunan Province, which provides a scientific basis for "preventive protection" of cultural heritage. This study is mainly based on the existing data, and in the future, the field research data can be further supplemented to refine the architectural characteristics and disaster vulnerability assessment of the ancient stage. In addition, the impact of climate change on the disaster risk of the ancient stage has not yet been deeply explored, and subsequent studies can be combined with climate modeling to predict the trend of future risk changes.

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