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FLOOD FRONTIERS: GIS APPROACHES TO UNRAVELING RISK IN XIANTAO'S HYDROLOGICAL LANDSCAPE

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Abstract: Flood disasters, driven by monsoon climate patterns, recurrently afflict China, leading to significant economic and societal ramifications. Cities, as hubs of development, are particularly vulnerable to the repercussions of these disasters. Hence, conducting meticulous flood risk assessments has become an imperative undertaking. Building upon the extensive research in this domain, including notable work by scholars like Pan Yipeng who have developed models for cities like Zhengzhou and Changzhou, this study endeavors to establish a comprehensive indicator framework for evaluating flood risk across four critical dimensions. This endeavor is poised to furnish invaluable insights for enhancing flood risk assessments.

Keywords: Flood disasters, Risk assessment, Indicator system, Monsoon climate, Urban resilience; Moran's index

Introduction

Flood disasters are frequent natural disasters with short return periods and severe consequences. Influenced by monsoon climate, China is one of the countries most frequently affected by flood disasters. Flood disasters have caused enormous economic losses to society and pose a great threat to the stable development of cities. Therefore, it is increasingly important to conduct flood risk assessments for cities. Many scholars at home and abroad have conducted extensive research on flood disasters. Scholars such as Pan Yipeng have constructed indicator systems and established flood risk models to assess risks in cities such as Zhengzhou and Changzhou. Based on this, this study aims to construct a comprehensive indicator system for flood risk assessment from four aspects, in order to provide reference for flood risk assessment.

In recent years, the causation theory of disaster systems has made significant contributions to regional risk assessment work. Additionally, numerous research experiences have been summarized, resulting in a substantial body of literature. This study is based on three research cases in recent years [1]. In the assessment of flood risk, different researchers employ various techniques and data timeliness for different regions, resulting in differences in the composition of the system elements and expressions of flood risk [2].

In this study, based on the actual situation in Xiantao City, the formation mechanism of flood disasters is considered, and the geographical environment of Xiantao City is taken into account [3]. The hazard of causative factors, vulnerability of the affected bodies, and stability of the disaster-prone environment are selected as the main components of the flood risk assessment indicator system. Additionally, urban resilience is introduced as an indicator to measure the city's emergency management capabilities and analyze its ability to withstand flood disasters. Furthermore, this study combines the Analytic Hierarchy Process with GIS technology to develop a flood risk zoning map for Xiantao City, Hubei Province, and proposes corresponding flood risk prevention and control suggestions. The research model is illustrated in Figure 1.

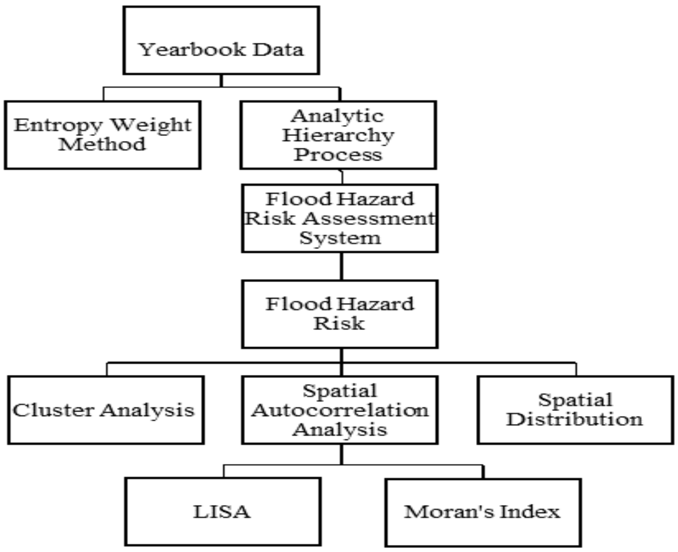

Figure 1: Is based on the spatial pattern analysis model using SPSS and ArcGIS.

1. Overview of the Research Area

Xiantao City, Hubei Province, is located in the Jianghan Plain, with rivers crisscrossing and lakes scattered throughout the area, forming a complex river network. Historically, the city has been plagued by frequent floods, which severely hindered the local socioeconomic development. This study also examines the history and causes of flood disasters in Xiantao City, Hubei Province, and explores the impact of floods on human life. It has practical significance for strengthening the coordination of human-water relationships and ecological environment protection.

Natural Geography Overview of the Research Area Xiantao City belongs to the subtropical monsoon climate zone, with a mild climate throughout the year, abundant rainfall, sufficient sunshine, distinct four seasons, and a long frost-free period. The annual average sunshine hours are 2002.6 hours, with a sunshine rate of about 46%. The annual average temperature is 16.3°C, and the frost-free period is generally 256 days.

The four seasons are divided based on the average temperature, with temperatures below 10°C considered as winter, above 22°C as summer, and between 10-22°C as spring and autumn. The approximate duration of each season is as follows: spring lasts from mid-March to mid-May (about 70 days), summer lasts from late May to mid-September (about 120 days), autumn lasts from late September to mid-November (about 65 days), and winter lasts from late November to early March of the next year (about 110 days). It has the characteristic of longer winter and summer seasons and shorter spring and autumn seasons.Research Methodology From the perspective of regional disaster system causation theory, the formation conditions of flood disasters can be identified as follows: causative factors, disaster-prone environment, and vulnerable elements. Based on the above analysis, the main influencing factors of flood disaster risk are divided into four parts: the hazardousness of causative factors, the vulnerability of vulnerable elements, the stability of disaster-prone environment, and urban resilience. By quantifying each indicator and determining the weights through the Analytic Hierarchy Process (AHP), a flood disaster assessment function can be constructed and mathematically expressed as follows (Equation 1):

(1)In the equation above, D represents the severity of flood disaster, E stands for the stability of disaster-prone environment, H denotes the hazardousness of causative factors, and S represents the vulnerability of vulnerable elements. The function f(x) represents the interaction of these three categories of elements resulting in the severity of flood disaster.

At the same time, urban resilience, which refers to a city's ability to withstand and recover from disasters, also plays a crucial role in flood disasters. Therefore, combining the previous equation, a flood disaster risk assessment model specific to Xiantao City, Hubei Province, can be constructed using the Analytic Hierarchy Process (AHP) again, and mathematically expressed as follows (Equation 2):

(2)In the equation above, R stands for flood disaster risk, D represents the severity of the disaster, and V represents urban resilience. The function f(x) now represents the interaction of these two categories of elements leading to flood disaster risk.

1.1. ***Construction of Indicator System***

In the process of flood risk assessment, a multitude of indicators are involved, and the varying impacts of these indicators on flood risk are not entirely proportional. Drawing from the research experience of scholars [4], this paper focuses on the fundamental situation of flood disasters in Xiantao City, Hubei Province. Based on the four criteria levels, different indicators are further selected to collectively establish a flood risk assessment indicator system for Xiantao City, Hubei Province. Simultaneously, this paper introduces urban resilience as a standard for measuring the city's disaster prevention and reduction capabilities, jointly constructing the flood risk assessment indicator system.

1.2. ***Hazard of Disaster-causing Factors***

When analyzing the degree of influence of precipitation on the hazard of flood disaster-causing factors, it is inappropriate to consider the total amount of annual precipitation in different regions. Instead, the frequency of historical occurrences of flood disasters in each region should be considered. Xiantao City, Hubei Province, is located within a typical subtropical monsoon zone, characterized by a prominent monsoon climate. Rainfall is concentrated mainly in the summer months, with heavy rainfall occurring primarily from May to September. As heavy rainfall is a major cause of flooding in Xiantao City, areas experiencing more frequent disasters also sustain greater losses. Consequently, the greater the frequency of disaster occurrence in a region, the higher the corresponding risk of future flood disasters [5]. Therefore, this paper selects indicators such as frequency of heavy rain, frequency of heavy rainfall, and frequency of extremely heavy rainfall to measure the hazard of disaster-causing factors.

1.3. Vulnerability of Disaster-Affected Elements

Research over the long term has found that, under similar disaster contexts, regions with higher population densities experience more severe impacts when disasters occur. GDP density is an essential indicator reflecting the level of socio-economic development. When a region has a higher GDP density, the economic losses resulting from a disaster are also more severe. Therefore, this paper selects GDP density and population density as measures of the vulnerability of disaster-affected elements.

1.4. Disaster-Prone Environment Stability

The disaster-prone environment primarily refers to various factors related to disasters, including ecological conditions. The stability of the disaster-prone environment reflects the sensitivity of the study area to flood disasters. Under the same disaster context, regions with lower stability in their disaster-prone environment experience more significant impacts from disasters. Many studies on flood disasters indicate that ground elevation plays a crucial role in their formation. Different altitudes lead to varied flood risk in urban areas. Lower ground elevations result in a less stable disaster-prone environment. Additionally, the terrain has an important redistributive effect on floods, where lower slopes indicate higher stability in the disaster-prone environment. The formation of flood disasters mainly depends on the distribution of river networks in the region. Under the same flood intensity, areas closer to lakes and rivers have a more stable disaster-prone environment. Moreover, different land types have varying effects on rainfall. Higher degrees of land utilization lead to lower stability in the disaster-prone environment. This paper selects four indicators—ground elevation, slope, river network density, and land type—to evaluate the stability of the disaster-prone environment for Xiantao City, Hubei Province.

1.4.1. Urban Resilience

Urban resilience refers to a city's ability to mitigate or withstand external disasters or impacts while maintaining its main features and functions unaffected, and its capacity to recover rapidly after a disaster occurs. It can effectively reduce the losses caused by flood disasters in the region, thereby lowering the risk of flood disasters in the area. Per capita GDP serves as an objective representation of urban resilience [5]. Under equally severe disasters, the more developed the economy, the more prominent the capacity for disaster prevention, reduction, and response. In this study, per capita GDP is used as a positive indicator to measure urban resilience.

The formulation and practice of flood control and emergency response plans are the core elements of preparation during the early stage of flood disaster emergency rescue and an important basis for carrying out emergency management and rescue work [6]. Emergency rescue material reserves provide critical material support during emergency response operations, primarily consisting of sandbags, equipment, and devices. The evaluation of drainage and flood discharge capacity mainly depends on the setting of drainage networks and the standards of drainage pipelines in various streets of Xiantao City, Hubei Province. Shorter drainage network setups and lower drainage pipeline standards have a greater impact on drainage and flood discharge capacity, leading to lower urban resilience. Therefore, this study selects per capita GDP, the level of completeness of flood control and emergency response plans, flood control material reserves, and drainage pipeline density as measures of urban resilience (Figure 2).

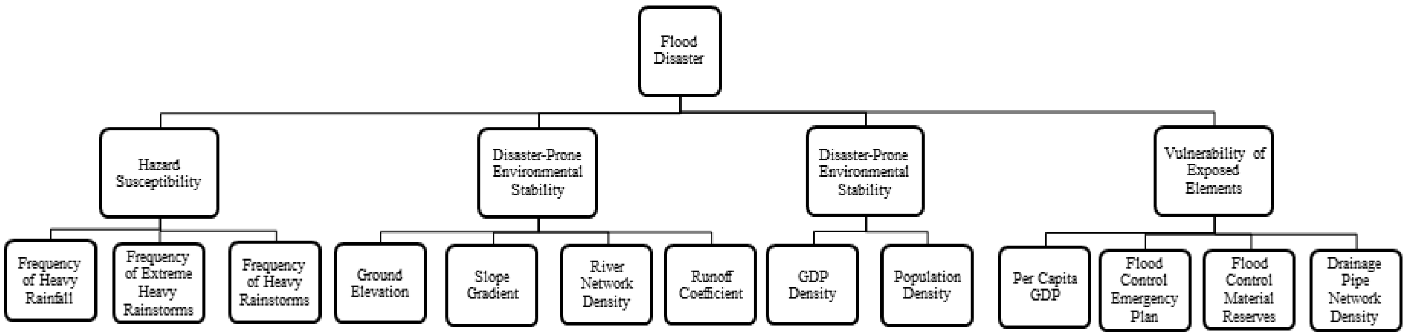

Figure 2: Diagram of Flood Disaster Risk Assessment Indicator System.

1.5. Determination of Indicator Weights

Using the Analytic Hierarchy Process (AHP), we compared and scored the judgment matrices for each indicator to obtain their subjective weights. Additionally, the Entropy Weight Method was employed to process the data itself and calculate the objective weights for each indicator. By combining the subjective and objective weights, we assessed the level of influence of each indicator on flood disaster risk. The results of these calculations are presented in Table 1 below.

Table 1: Flood Disaster Risk Assessment Indicator System and Weights.

1	2	AHP	EWM	CM
Hazard Susceptibility	Frequency of Heavy Rainfall	0.085	0.118	0.119
	Frequency of Heavy Rainstorms	0.155	0.148	0.270
	Frequency of Extreme Heavy Rainstorms	0.143	0.116	0.196
Disaster-Prone Environmental Stability	Ground Elevation	0.172	0.034	0.069
	Slope Gradient	0.101	0.152	0.182
	River Network Density	0.033	0.074	0.029
	Runoff Coefficient	0.014	0.109	0.018
Vulnerability of Exposed Elements	GDP Density	0.053	0.014	0.009
	Population Density	0.107	0.024	0.030
Urban Resilience	Per Capita GDP	0.073	0.059	0.051
	Flood Control Emergency Plan	0.037	0.014	0.006
	Flood Control Material Reserves	0.016	0.032	0.006
	Drainage Pipe Network Density	0.012	0.106	0.014

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2. Flood Disaster Risk Assessment

2.1. Flood Disaster Risk Assessment

Due to variations in units, scales, and impact levels of different indicators on flood disasters, to avoid unnecessary errors, the data has been subjected to standardization in this study[7]. By employing this method, the indicator values have been normalized within a range of 0 to 1, facilitating scientific data processing and analysis. The standardization process is represented as follows: represents the data value of the indicator, represents the maximum value in the indicator data, and represents the minimum value in the indicator data.

For positively correlated indicators, the formula is given by Equation (3): (Insert Equation (3) here)

For negatively correlated indicators, the formula is given by Equation (4): (Insert Equation (4) here)

By utilizing the weighted comprehensive evaluation method, the data from various specific indicators are quantified and represented in a unified manner. The formula for this process is given by Equation (5): (Insert Equation (5) here)

Where represents the vulnerability to flood disasters, represents the weights of each indicator, and represents the indicator data after normalization. Using Equation (10), the assessment results of flood disaster risk were calculated for the 18 streets (townships) in Xiantao City, Hubei Province, China. Table 2 presents the vulnerability assessment results for each county (city, district) in Xiantao City.

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Table 2: Vulnerability Assessment of Various Streets (Townships) in Xiantao City

Name	Value	Name	Value
Shahu Town	0.244	Xiliuhe Town	0.222
Chenchang Town	0.195	Miancheng Town	0.135
Zhengchang Town	0.178	Guohe Town	0.206
Sanfutan Town	0.238	Huchang Town	0.221
Pengchang Town	0.586	Changtangkou Town	0.192
Yanglinwei Town	0.105	Tonghaikou Town	0.192
Louhe Town	0.148	Zhanggou Town	0.304
Maozui Town	0.311	Shazui Town	0.505
Ganhe Town	0.562	Longhuashan Town	0.557

Utilizing ArcGIS software, a preliminary visual exploration of the vulnerability of each street (township) in Xiantao City was conducted, leading to the distribution map depicted in Figure 3 below.

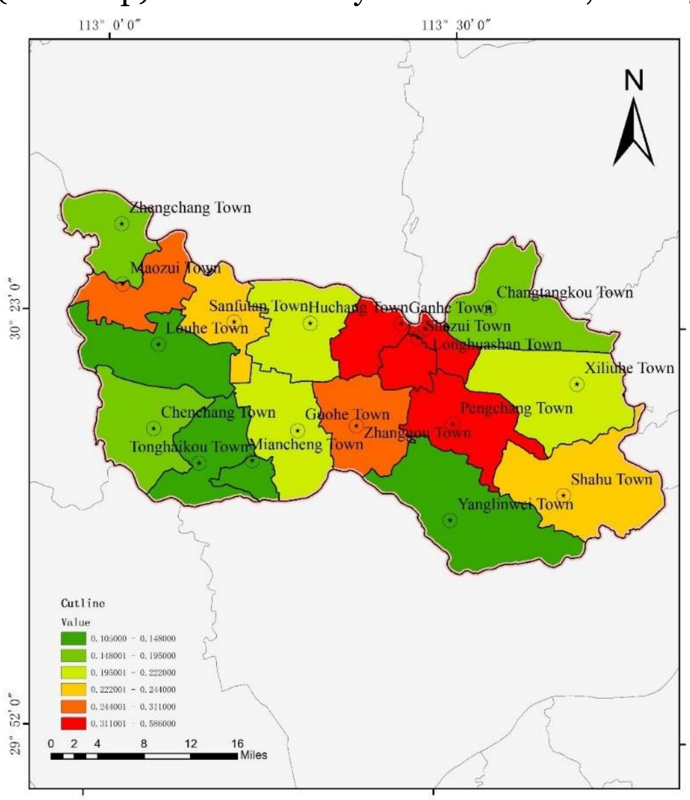

Figure 3: Vulnerability Map of Flooding Hazards in Various Townships of Xiantao City.

2.2. *Spatial Autocorrelation Analysis of Flooding Hazards*

Foreign scholar Tobler [8] explained the concept of spatial autocorrelation in the first law of geography, stating that geographical entities and their semantics exhibit correlation in space, with closer geographical entities having stronger associations compared to distant ones [9]. Spatial autocorrelation analysis is a method used to explore the distribution of spatial data, which can detect three types of spatial data patterns: clustering, dispersion, and randomness. Spatial autocorrelation can be categorized into two indicators, namely global and local autocorrelation [10]. Global autocorrelation examines the correlation of a particular attribute within the study area, while local autocorrelation investigates the spatial correlation of a specific unit with its neighboring units concerning a certain attribute.

2.2.1. *Global Spatial Autocorrelation Analysis*

In order to uncover spatial correlations among multiple variables, scholar Anselin extended the concept of spatial autocorrelation to propose bivariate spatial autocorrelation, which reveals the relationships between a specific attribute value of a spatial unit and the remaining attribute values of its neighboring spaces. Global spatial autocorrelation is highly applicable and effective in describing spatial associations and dependencies between two geographic elements, represented by the global Moran's I index. As shown in Figure 4, Moran's I is 0.69, indicating an overall spatial correlation of flooding hazard risks among the various streets (townships) in Xiantao City.

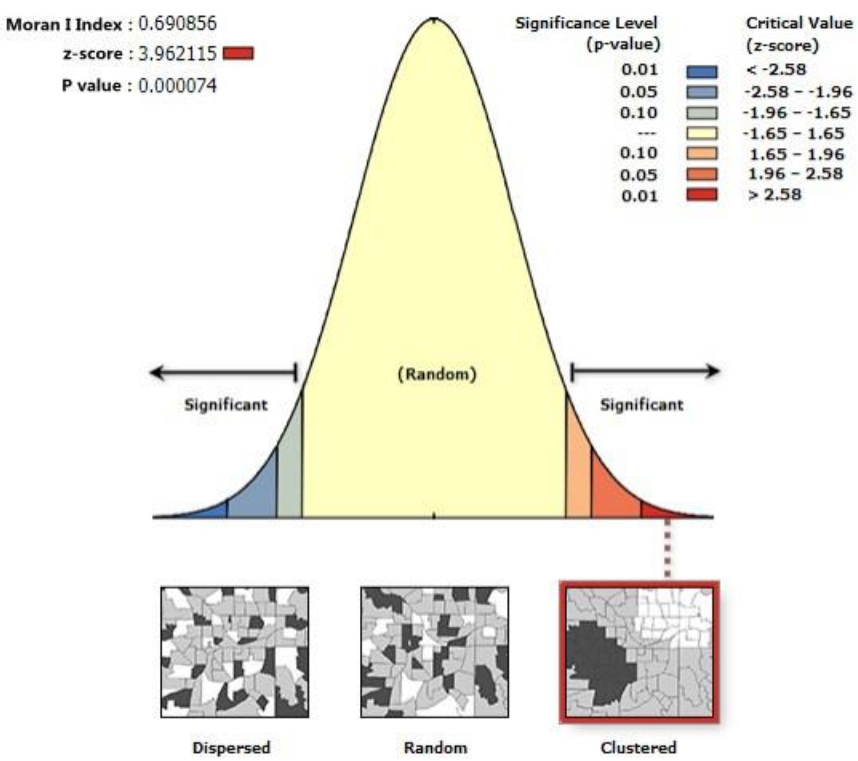

Figure 4: Global Moran's I Index Analysis Result

2.2.2. Local Indicators of Spatial Association (LISA) Clustering Analysis

The analysis of global spatial autocorrelation in this study reveals the overall spatial correlation of vulnerability between cities in Hebei Province through the Global Moran's I map. However, it lacks a descriptive analysis of local spatial correlations. In order to provide a more comprehensive and specific spatial analysis result, this research utilizes SPSS and ArcGIS software to conduct LISA analysis on the local spatial distribution pattern of earthquake disaster vulnerability in Hebei Province. The results are displayed in the form of layers, as shown in Figure 5.

2.2.3. Flooding Hazard Risk Cluster Analysis

The local LISA statistic measures the similarity between the value of variable X in a specific area (designated as A) and the values of the same variable in its neighboring areas. Positive local LISA autocorrelation occurs when the values of the variable X in the neighboring areas are similar to those in area A. Conversely, negative local LISA autocorrelation occurs when there is a significant difference between the values of variable X in the neighboring areas and area A, resulting in differences in directions from the mean value. Therefore, this study further employs local indicator methods to determine whether areas in the research region with values of variable X greater than the mean are clustered or whether areas with values of variable X smaller than the mean are clustered. The results are shown in Figure 6.

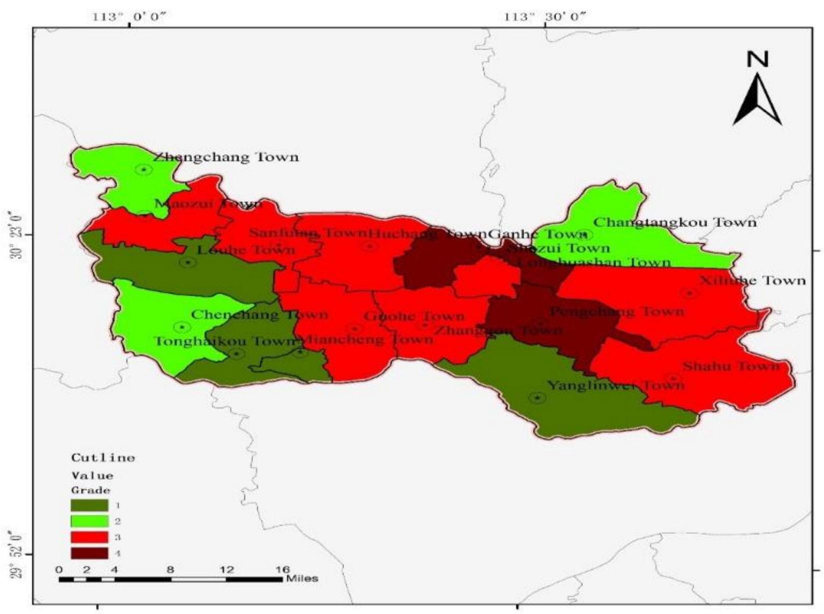

Figure 5: LISA Cluster Map

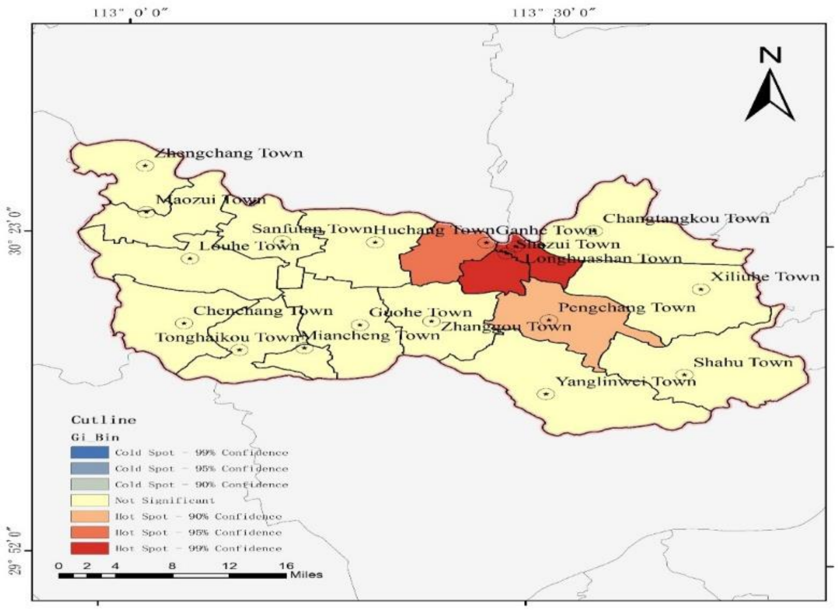

Figure 6: Hotspot and Coldspot Cluster Map

Through Figures 4 to 6, it is observed that among the flood hazard risk assessment indicators, the susceptibility of flood hazards has the greatest impact, while the influence of urban resilience is minimal. Among different regions in Xianta City, Hubei Province, Pengchang Town has the highest flood hazard risk value, while Yanglinwei Town has the lowest flood risk value. Therefore, for the socio-economic development of these areas, we should focus on the influence of the three mentioned indicators. It is essential to continuously improve the emergency response mechanisms in these regions. For areas with lower ground elevation, during urban planning, efforts should be made to avoid these areas as much as possible to prevent significant losses from disasters. For densely populated areas, further strengthening the formulation and rehearsal of emergency plans is necessary to prevent secondary disasters after the occurrence of hazards.

Furthermore, through further analysis, it is evident that the Analytic Hierarchy Process (AHP) constructed indicator weights reveal a strong correlation between heavy rainfall frequency, ground elevation, population density, and flood disasters. Heavy rainfall frequency, as a measure of the danger of triggering factors, ground elevation as a measure of disaster-prone environmental stability, and population density as an indicator of vulnerable elements' transformation, greatly influence the assessment of flood hazard risks.

Moreover, the overall flood hazard risk level in Xianta City, Hubei Province, is considered moderate, with a few areas classified as high-risk zones. The areas with prosperous economic development, such as Ganhe Street, Shaji Street, Longhuashan Office, and Pengchang Town, also face higher flood hazard risks, while areas with relatively less economic development have relatively lower flood risks. To enhance social and economic development, it is imperative to strengthen disaster prevention and mitigation projects and continuously improve emergency management and prevention mechanisms in the region to reduce flood hazard risks.

3. Conclusion

To enhance local emergency management capabilities, several measures can be implemented [11]. Firstly, raise the standards for construction of drainage systems and strengthen urban flood control projects in the city and various townships. For flood control rivers, drainage channels, and rainwater pipelines that have not yet met planning standards, the goal should be to reach a standard of 50-year return period by 2035 and a standard of 100-year return period by 2050, effectively improving Xianta City's flood control and drainage capabilities. Secondly, disseminate disaster prevention knowledge widely [12]. Utilizing community broadcasts, community classes, village meetings, and other methods, professional personnel can explain measures for evacuation, self-help, and mutual assistance, thereby improving disaster awareness and responding to flood hazards more calmly. Additionally, accelerate the urbanization process in villages, transform production methods, and improve the standard of living in rural areas. Lastly, optimize emergency plans [13]. Urban flood emergency plans serve as the backbone and starting point of emergency management. Establish a comprehensive urban flood emergency planning system that covers all levels from top to bottom, including strategic and tactical plans, as well as on-site actions.

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