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Article

Comprehensive Risk Assessment of Farmer Households in Flood and Earthquake Prone Areas Based on Multidimensional Information Diffusion Model

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Abstract: In recent years, the global practice of regional natural disaster reduction and comprehensive risk prevention has promoted the integration of multiple disciplines, and the theory and technology of comprehensive risk assessment for multiple natural disaster chains urgently need innovation. This article is based on multiple natural disaster chain scenarios and sets secondary indicators for multiple influencing factors based on the first level indicators composed of basic risk factors such as hazard factors, vulnerability of disaster bearing bodies, and disaster prevention and reduction capabilities. By using multidimensional information diffusion technology, multiple hazard factor hazard combination factors, vulnerability combination factors of disaster bearing bodies, and comprehensive disaster prevention and reduction capability combination factors reflecting various natural disaster scenarios are constructed, A household comprehensive risk assessment index system for multi-dimensional information diffusion assessment of natural disaster comprehensive risk was designed by quantifying risk factors such as the intensity of comprehensive disaster causing factors, vulnerability of disaster bearing bodies, and comprehensive disaster prevention and reduction capabilities in disaster scenarios. This paper expands the traditional information diffusion comprehensive risk assessment model, makes up for the lack of information on geographical units, establishes a multi impact factor multi dimension natural disaster risk comprehensive assessment model for multi risk factors of complex disaster scenarios with small samples, obtains the theoretical value of multi-dimensional information Diffusion model comprehensive risk assessment for complex disaster scenarios, breaks through the sample size limit of natural disaster risks, and makes up for the lack of information on small samples of small probability events, Improved the reliability and accuracy of comprehensive risk assessment for multiple natural disaster chains. Then, take the disaster scenario formed by the comprehensive risk of earthquake and flood in a place in the upper reaches of the Fujiang River basin as the analysis sample, calculate the comprehensive risk assessment value of flood and earthquake damage in the study area's micro samples (rural households in villages and towns). By comparison, it is found that the comprehensive risk value assessed by the multi-dimensional information Diffusion model has good reliability and high accuracy, which is significantly better than the traditional Kriging interpolation method and geographical weighted regression method. This article provides a comprehensive risk assessment of natural disasters at the micro household level, which can better reflect the diversity and regionality of risks, help clarify the hidden risks of rural natural disasters, and provide scientific basis for government emergency management decision-making.

Keywords: Comprehensive Risk Assessment; Multidimensional Information Diffusion Model; Comprehensive Risk Assessment Indicator System; Multiple Natural Disaster Chains

1. Introduction

China's geological structure and climate types are complex, and various extreme mixed disasters occur frequently and concurrently, causing significant damage, which is rare globally. The extreme meteorological disasters and geological environment Environmental disaster caused by global climate change have the trend of mass occurrence, chain occurrence, frequent occurrence and concurrent occurrence, and the loss of life and property has increased gradually (Swiss Re-Sigma, 2023) [1]. With the promotion of the International Council for Science (ICSU) and the International Social Science Union (ISSC) "Comprehensive Research Plan on Disaster Risk (IRDR)" and "Human Factors Plan on Global Environmental Change (IHDP)" (1996), as well as the gradual implementation of China's Opinions on Promoting the Reform of the System and Mechanism of Disaster Prevention, Reduction and Relief (2016), and the Notice on Conducting the First National Comprehensive Risk Survey of Natural Disasters (2020). In addition, The United Nations Office for Disaster Risk Reduction (UNDRR) Global Assessment Report on Disaster Risk Reduction (GAR2023) was released. Governments and international institutions around the world attach great importance to regional disaster reduction and comprehensive risk prevention of natural disasters. The results of regional disaster reduction and comprehensive risk prevention of natural disasters are significant, and the "single natural disaster risk assessment" is gradually shifting towards the "comprehensive risk assessment of multiple natural disaster chains", It has promoted the interdisciplinary integration and innovation of the theory and technology of comprehensive risk analysis for disasters (Moscatelli et al., 2020 [2]; Huang, 2023 [3]).

The Global Disaster Risk Indicator Program (DRI) uses population mortality as a risk indicator to evaluate the risks of floods, earthquakes, tropical cyclones, and droughts in various countries. The risk values of each disaster type are simply added to obtain a comprehensive risk of multiple disasters (Pelling, 2004) [4]. The Regional Scale Disaster Risk Hotspot Research Program (Hotspots) uses population mortality and economic loss values as risk indicators to weight and sum the risk values of six natural disasters such as floods and earthquakes to obtain the expected population mortality or economic loss values for comprehensive risk assessment (Schmidt-Thom, 2006 [5]; Eslamian et al., 2021 [6]). The national scale multi hazard risk assessment software package HAZUS-MH provides a simple overlay of earthquake, hurricane, and flood risks within various administrative regions of the United States as a comprehensive risk assessment (FEMA, 2004 [7]; Garcia-Delgado et al., 2022 [8]). Chinese scholars use weighted summation to assess the comprehensive risk level of multi hazard types of county-level administrative units and map them (Gao, 2005) [9], and superimpose the risks of different types of disasters in time and space to obtain the relative level of risk loss of multi hazard types of disasters. The temporal and spatial distribution characteristics of casualties of geological disasters in China (Huang et al., 2022) [10].

The European Comprehensive Risk Assessment (ESPON) weighted the risk of 11 natural disaster factors and 4 human induced disaster factors, as well as the vulnerability of the disaster bearing body, to obtain the overall regional comprehensive risk of disaster causing factors and the vulnerability level of the disaster bearing body (Greiving, 2010) [11]. The South Carolina risk assessment adds the probabilities of multiple disaster factors and vulnerability indices to obtain the comprehensive risk values for each study area (Scemdoag, 2006) [12]. Weighted superposition of risk Degree distribution maps of various single disaster causing factors can obtain the comprehensive risk Degree distribution map of multiple disasters (Gai et al., 2011) [13]. Construct a comprehensive risk matrix using the hazard level of the disaster causing factor and the vulnerability level of the disaster bearing body to evaluate the comprehensive risk of the research area (Wang et al., 2018) [14]. The comprehensive risk assessment index is constructed with the risk of disaster causing factors and the vulnerability of disaster bearing bodies, and the comprehensive risk assessment model of meteorological disasters is established with the weighted comprehensive method to assess the comprehensive risk level of various vegetation areas (Zhou et al., 2020) [15].

To sum up, this paper expands the existing information Diffusion model and establishes a multi-dimensional information Diffusion model, aiming at the complex disaster scenario of multi factor multi factor multi factor combination of hazard combination factors, multi hazard bearing body vulnerability combination factors, and disaster prevention and mitigation capacity combination factors in the disaster system, Establish a sequential chain structure comprehensive evaluation index system of catastrophe risk of "risk environment - Risk factor - risk object - risk event - risk loss - risk subject", establish a universal multi hazard comprehensive risk assessment method, overcome the defect of traditional direct addition or simple weighting to obtain the relative value of comprehensive risk assessment, and obtain the absolute value of comprehensive risk assessment that can reflect the multi hazard complex disaster scenarios, I hope to solve the problem of comprehensive risk assessment for independent and multi disaster superposition, and improve the accuracy of comprehensive risk assessment for multi disaster natural disaster chains.

2. Materials and Methods

2.1. Study Site Description

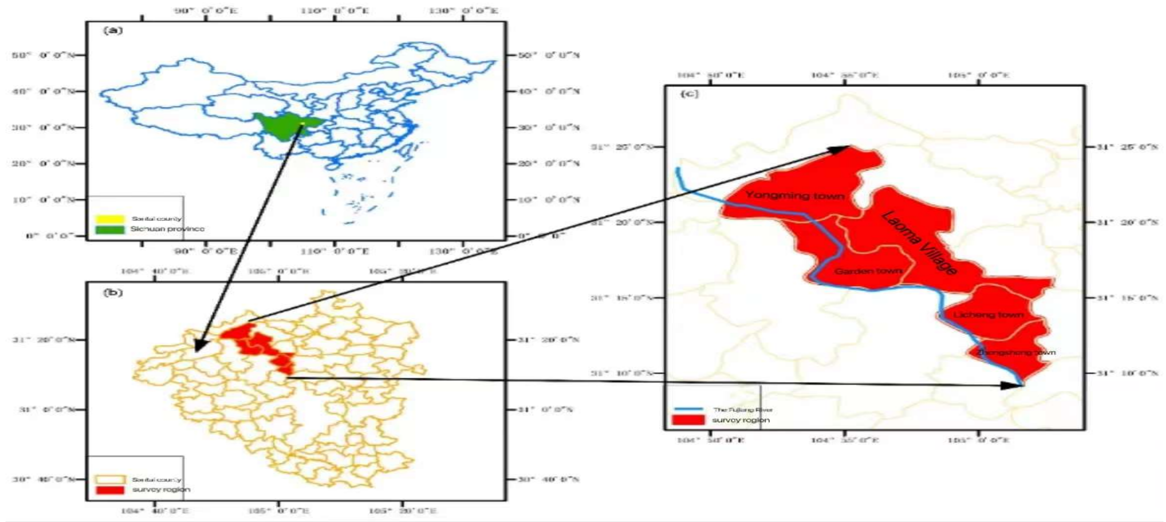

Figure 1. Geographical Location of the Study Area.

Santai County is in the central and northern part of Sichuan Basin, latitude 30º42 '34" ~ 31º26' 35" N, longitude 104º43 '04" ~ 105º18' 13" E, with a total area of 2659.38 square kilometers, 46 rivers and streams, all of which belong to the Jialing River system, a tributary of the Yangtze River. Among them, the Fujiang River flows through Yongming, Garden, Lao Ma, Mileage, Shengsheng five towns, the county's flow length is 70.65 kilometers, the watershed area is 2660.58 square kilometers, the maximum flow is 18,320 cubic meters/second, the minimum flow is 66 cubic meters/second. This paper takes the rural households of the townships and villages in the study area as samples, which are located in five townships on both sides of the Fujiang River in Santai County in the southeast of the Sichuan Basin in southwest China (FIG. 1a) under the jurisdiction of Mianyang City (FIG. 1b) (FIG. 1c). The research area is an area in the northern part of the county which is close to the Neilongmenshan earthquake fault zone and has been repeatedly invaded by natural disasters such as flood, earthquake and flood earthquake in history. In particular, the characteristics of the five townships in the study area (FIG. 1c) are more distinctive, with higher night rainfall and night rain rate, obvious extreme climate, fragile ecological environment, severe impact of human activities on the surface environment, and repeated damage by natural disasters such as floods and earthquakes.

2.2. Study Design and Sampling

Survey questionnaire design: Following the principles of scientific, objectivity, and data availability, design the survey questionnaire. The research focuses on the households of rural households in the research area. From June to July for three consecutive years, we conducted household questionnaire surveys on farmers' families in five townships in the study area, namely, Garden, Yongming, Mileage, Laoma and Zhengsheng. We also conducted surveys and interviews with relevant departments and professional technicians in each township. The survey focused on the repeated natural disasters such as floods, earthquakes, floods and earthquakes suffered by farmers' families in the survey area over the years.

Selection of data indicators: Select flood inundation depth, inundation time, distance from the river channel, earthquake intensity and frequency as the influencing factors of the intensity of flood and earthquake induced disaster factors, and select crop loss, family property loss, and personal injury data as the influencing factors of the vulnerability of the disaster bearing body; The total family income, non-farm income, per capita education years, the ratio of Young adult to young adults, insurance purchase, risk attitude, housing structure quality, and housing construction time are the influencing factors of family disaster prevention and mitigation ability.

Data collection method: With the help of intelligent Internet technology, we designed and developed an intelligent networking platform that integrates small wisdom into big wisdom: an intelligent networking system for risk communication between towns and villages along the Fujiang River in Santai County, Sichuan Province. Using a bottom-up approach to collect data, direct online surveys and data collection of villagers are conducted. The household survey database is composed of basic data from household questionnaire surveys and case interviews.

2.3. Build A Multidimensional Information Diffusion Evaluation Model for Comprehensive Disaster Risk

According to the basic idea of information Diffusion model and evaluation technology, it diffuses the information of each sample point into a fuzzy set, and the diffusion estimate obtained is closer to the truth than the non-diffusion estimate (Huang, 1997) [16]. Therefore, let the sample be $X = \{x_1, x_2, ...x_n\}$, and its domain be $U = \{u_1, u_2, ...u_J\}$.

Then, the information carried by the sample points is spread to all monitoring points in the universe according to equation (1).

$$f(u_j)=\frac{1}{h\sqrt{2\pi}}\sum_{i=1}^{n}\exp\left(-\frac{\left(x_i-u_j\right)^2}{2h^2}\right) \tag{1}$$

$$\text{Order}\quad C_i=\sum_{j=1}^{J}f_i(u_j) \tag{2}$$

Normalize the sample point information to obtain the membership function of the corresponding fuzzy subset.

$$\mu(x_i,u_j)=\frac{f_i(u_j)}{C_i} \tag{3}$$

The probability of the event occurring again is:

$$p(u_j)=\frac{1}{n}\sum_{i=1}^{n}\mu(x_i,u_j) \tag{4}$$

Obviously, this one-dimensional information diffusion evaluation method for the probability of event risk occurrence is limited to evaluating a single risk element, such as the hazard of the disaster causing factor, the vulnerability of the single disaster bearing body, and the ability to prevent and reduce disasters. However, it cannot evaluate the composite risk of their combination, let alone the more complex comprehensive risk of their combination. Therefore, it is necessary to extend the traditional one-dimensional information Diffusion model to the multidimensional model.

If there are n sample values and *m-1* independent variables, the sample is represented as:

$$A=\left\{y_1,x_{11},x_{12},\dots x_{m-1};y_2,x_{21},x_{22},\dots x_{2(m-1)};\dots;y_n,x_{n1},x_{n2},\dots x_{n(m-1)}\right\}$$

The theoretical domains of each indicator are denoted as follows: $\left\{\mu_j,v_k,\dots w_l\right\}$, when each dimension is independent of each other, the sample points are subjected to multi-dimensional information diffusion in the m-dimensional space, and the multi-dimensional normal information diffusion expression is:

$$\mu(y,x_1,\cdots,x_n)(u_j,v_k,\cdots w_l)=\frac{1}{\left(\sqrt{2\pi}\right)^m h_u h_v\cdots h_w}\exp\left(-\frac{1}{2}\left(\frac{(y-\mu_j)^2}{h_u^2}+\frac{(x_1-v_k)^2}{h_v^2}+\cdots+\frac{(x_n-w_l)^2}{h_w^2}\right)\right) \tag{5}$$

Using the multidimensional normal information diffusion formula (5), allocate the information carried by each sample point to each monitoring point in the multidimensional space, and sum the amount of information allocated to each observation point:

$$Q_{jk\cdots l}=\sum_{i=1}^{n}u_j v_k\cdots w_l(y_i x_{1i}\cdots x_{(m-1)i}) \tag{6}$$

The fuzzy relationship matrix between various indicators of multidimensional information diffusion is:

$$H_j=\max_{\substack{1\le l\le L\\ \cdots\\ 1\le k\le K}}\left\{Q_{jk\cdots l}\right\} \tag{7}$$

$$r_{jk\cdots l}=Q_{jk\cdots l}/H_j \tag{8}$$

Among them, the multidimensional information diffusion matrix Q :

$$Q = \left\{ \begin{array}{ccccc} & & & \begin{array}{cccc} v_1 & v_2 & \cdots & v_K \end{array} \\ w_1 & \cdots & \begin{array}{c} u_1 \\ u_2 \\ \vdots \\ u_J \end{array} & \begin{bmatrix} Q_{11\cdots 1} & Q_{12\cdots 1} & \cdots & Q_{1K\cdots 1} \\ Q_{21\cdots 1} & Q_{22\cdots 1} & \cdots & Q_{2K\cdots 1} \\ \vdots & \vdots & \vdots & \vdots \\ Q_{J1\cdots 1} & Q_{J2\cdots 1} & \cdots & Q_{JK\cdots 1} \end{bmatrix} \\ w_2 & \cdots & \begin{array}{c} u_1 \\ u_2 \\ \vdots \\ u_J \end{array} & \begin{bmatrix} Q_{11\cdots 2} & Q_{12\cdots 2} & \cdots & Q_{1K\cdots 2} \\ Q_{21\cdots 2} & Q_{22\cdots 2} & \cdots & Q_{2K\cdots 2} \\ \vdots & \vdots & \vdots & \vdots \\ Q_{J1\cdots 2} & Q_{J2\cdots 2} & \cdots & Q_{JK\cdots 2} \end{bmatrix} \\ \vdots & \vdots & \vdots & \vdots \\ w_L & \cdots & \begin{array}{c} u_1 \\ u_2 \\ \vdots \\ u_J \end{array} & \begin{bmatrix} Q_{11\cdots L} & Q_{12\cdots L} & \cdots & Q_{1K\cdots L} \\ Q_{21\cdots L} & Q_{22\cdots L} & \cdots & Q_{2K\cdots L} \\ \vdots & \vdots & \vdots & \vdots \\ Q_{J1\cdots L} & Q_{J2\cdots L} & \cdots & Q_{JK\cdots L} \end{bmatrix} \end{array} \right\} \tag{9}$$

According to formula (7), the maximum value of each column in the multi-dimensional information matrix is calculated, and the fuzzy relation matrix formula (8) is derived. To unify the following symbols, the fuzzy relation matrix is recorded as $\mu_R(u_j, v_k \cdots \mathrm{w}_l)$, and the Fuzzy set on the universe $U, V, \cdots$ is taken as the input $\mu_A(u), \mu_B(v)\cdots$, as $\mu_R(u_j, v_k \cdots \mathrm{w}_l)$ the causal relationship, and is substituted into formula (10) to obtain the Fuzzy set W on the output universe $\mu_l(w)$.

$$\mu_L(w) = \underset{\mu_j, v_k, \cdots}{\vee} [\mu_A(u) \wedge \mu_B(v) \wedge \cdots \wedge \mu_R(u, v, \cdots, \mathrm{w})] \tag{10}$$

The membership degree L of the loss Fuzzy set $U, V, \cdots,$ with respect to any element $u_j, v_k, \cdots,$ in the universe is obtained $\mu_L(w)$, and the comprehensive risk (loss value) is obtained L by fuzzifying it with the barycenter method u of formula (11).

$$u = (\sum_{j=1}^{J} \mu_L(w_l) w_l) / (\sum_{j=1}^{J} \mu_L(w_l)) \tag{11}$$

According to equation (12), the probability $v_k, \cdots, w_l$ of loss for different disaster factors can be calculated.

$$p_{jk\cdots l} = \frac{Q_{jk\cdots l}}{\sum_{j=1}^{J} \sum_{k=1}^{K} \cdots \sum_{l=1}^{L} Q_{jk\cdots l}} \tag{12}$$

3. Results

The weight vectors of each influencing factor are calculated using the cosine method of vector angle, and then based on the values of each influencing factor and the corresponding weight values, the comprehensive disaster factor intensity of household floods and earthquakes is obtained by weighted summation. Using the same method, calculate the comprehensive vulnerability and disaster prevention and mitigation capabilities of flood and earthquake disasters in each household. Then, the obtained multi hazard factor hazard, multi disaster bearing body vulnerability, and comprehensive disaster prevention and reduction capability index values are substituted into the multidimensional information diffusion formulas (3) - (11) to calculate the flood and earthquake comprehensive risk values under different disaster causing factor intensities and disaster prevention and reduction capability levels (Table 1).Then Kriging interpolation method and geographically weighted Law of Return method are used to evaluate the comprehensive risk value of township flood respectively, and the comprehensive risk value evaluated by the three methods is compared with the original risk value.

Table 1. Comprehensive Risk of Household Floods and Earthquakes with Different Disaster Intensity and Disaster Reduction Attributes.

Risk value		Disaster prevention and reduction capability level					
		0.45	**0.51**	**0.57**	**0.63**	**0.69**	**0.75**
Causing disasters factor strength grade	**0.24**	20955.32	16782.10	14546.54	13825.21	12672.82	11441.02
	0.32	24781.12	20864.05	17459.03	15996.44	17676.10	17503.38
	0.40	41776.47	24387.46	20397.56	18415.33	19632.75	22439.51
	0.48	53454.53	39996.64	30841.13	27553.75	24022.66	24072.04
	0.56	52390.83	39500.26	39553.50	41031.14	39845.06	40871.08
	0.64	44586.51	38068.01	42830.13	46609.56	46015.25	46857.61

For ease of comparison, the evaluation results of the three methods and the original risk values were presented using software graphics. According to the size of all four risk values, they were divided into three levels, and the risk values of different levels were represented in different colors (Figure 2). Among them, blue represents the low-risk area, yellow represents the medium risk area, and red represents the high-risk area. It can be seen from the comparison of the total value of household flood and earthquake losses with the comprehensive risks plotted by the three methods (Figure 2).

It can be seen from the calculation and analysis results that: The sample size of data used for disaster risk analysis is small, and the information is often incomplete and insufficient, making it difficult to construct valuable theoretical distributions. The theoretical foundation of classical statistics is the theorem of large numbers, which requires a sufficient sample size. The evaluation of small samples has a large bias and loses the effectiveness and accuracy of the evaluation. It is urgent to establish a comprehensive evaluation model for natural disaster risks based on small samples and a comprehensive evaluation technology system for multiple disaster risks based on small samples. In view of the lack of information on risk assessment of natural disasters such as fire, earthquake, flood, drought and meteorology, the information Diffusion model and assessment technology diffuse the information of each sample point into a fuzzy set, and the diffusion estimate is closer to the truth than the non-diffusion estimate (Huang and Wang, 1995) [17], which improves the risk assessment results and prediction accuracy (Huang, 1997) [16]. Therefore, the information Diffusion model and evaluation technology have been widely used.

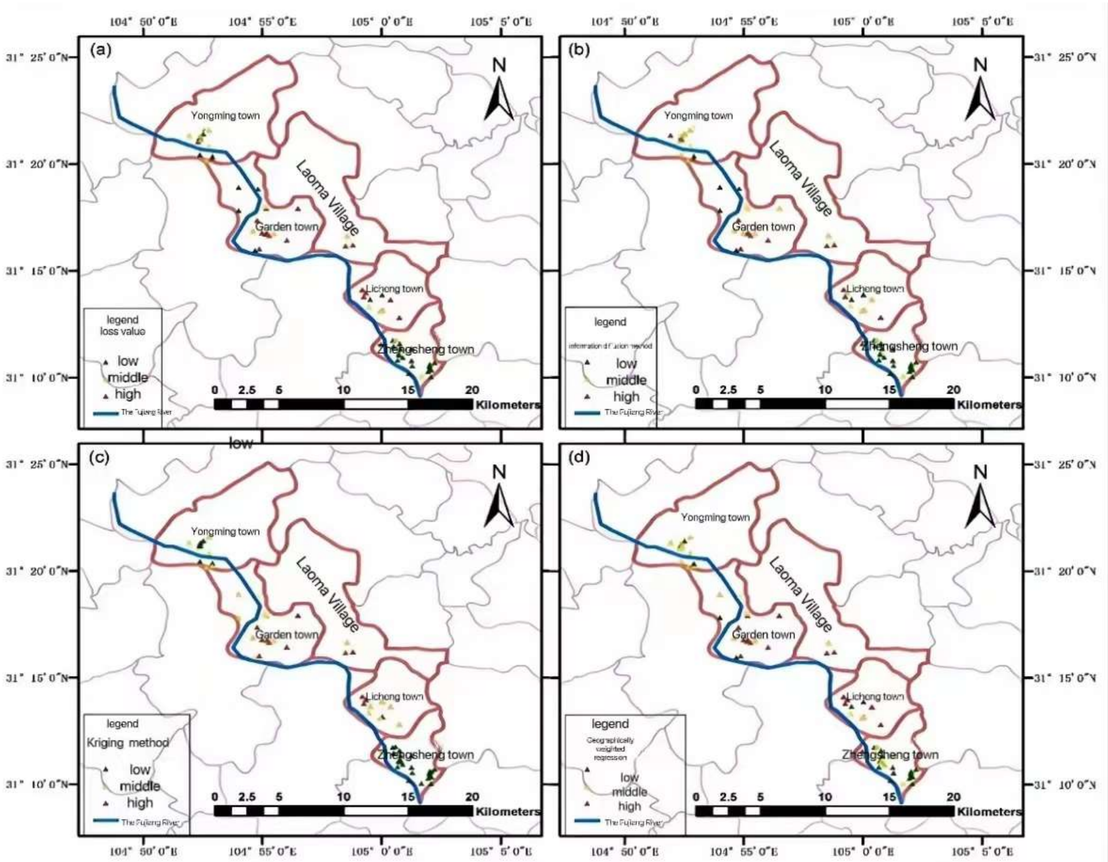

Figure 2. Compares the total value of household flood and earthquake losses with the comprehensive risk maps drawn using three methods. Risk maps corresponding to research data (a), analysis charts for information diffusion evaluation (b), Risk map evaluated using Kriging interpolation method (c), risk map evaluated using geographic weighting method (d).

4. Discussion

This can be seen from the comparison of the total value of household flood and earthquake losses with the combined risks drawn by the three methods:

(1) Multidimensional information diffusion evaluation value: The difference between the comprehensive risk map 2 (b) of household floods and earthquakes evaluated using multidimensional information diffusion method and the original risk map 2 (a) is very small. The comprehensive risk values of each household in Zhengsheng Town, Mileage Town, and Laoma Township are consistent with the original risk values. The risk of each household in Huayuan Town is consistent with the risk of the original data. The risk of each household in Yongming Town is consistent with the risk of the original data.

(2) Evaluating values using the Kriging interpolation method: On the contrary, in Figure 2 (c), the Kriging interpolation method is used to evaluate the comprehensive risk of household floods and earthquakes, which differs significantly from the original risk control in (a). 1 high-risk household in Zhengsheng Town (indicated by a red dot) is evaluated as medium risk (indicated by a yellow dot), and 2 high-risk household (indicated by a yellow dot) is evaluated as low risk (indicated by a green dot). Mileage Town 2 high-risk households (indicated by a red dot) are assessed as medium risk (yellow dot); 2 low-risk households (green dots) were assessed as medium risk (yellow dots). The 2 low risk (green dots) in Huayuan Town are assessed as medium risk (yellow dots). Yongming Town has evaluated 1 high-risk household (indicated by a red dot) as medium risk (indicated by a yellow dot).

(3) Geographical weighted Law of Return assessment value: In addition, the results of geographical weighted Law of Return assessment of household flood and earthquake comprehensive risk in Figure 2 (d) and Figure 2 (a) are quite different. The 3 low-risk households in Zhengsheng Town (indicated by green dots) were assessed as medium risk (yellow dots). The assessment of 1 low risk (green dot) in Huayuan Town is high risk (red dot). Yongming Town has evaluated 1 high-risk household (indicated by a red dot) as medium risk (indicated by a yellow dot).

5. Conclusions

Based on multiple natural disaster chain scenarios, this article sets secondary indicators for multiple influencing factors based on the first level indicators composed of basic risk factors such as hazard factors, vulnerability of disaster bearing bodies, and disaster prevention and reduction capabilities. By using multidimensional information diffusion technology, a combination factor of multiple hazard factors, vulnerability of disaster bearing bodies, and comprehensive disaster prevention and reduction capabilities is constructed to reflect various natural disaster scenarios, A household comprehensive risk assessment index system for multi-dimensional information diffusion assessment of natural disaster comprehensive risk was designed by quantifying risk factors such as the intensity of comprehensive disaster causing factors, vulnerability of disaster bearing bodies, and comprehensive disaster prevention and reduction capabilities in disaster scenarios.

This paper expands the traditional information diffusion comprehensive risk assessment model, makes up for the lack of information on geographical units, establishes a small sample of complex disaster scenarios, multi risk factors, multi impact factors and multi-dimensional natural disaster risk comprehensive assessment model, obtains the theoretical value of multi-dimensional information Diffusion model comprehensive risk assessment of complex disaster scenarios, breaks through the sample size limit of natural disaster risks, and makes up for the lack of information on small samples of small probability events, Improved the accuracy of comprehensive risk assessment for multiple natural disaster chains.

Using the constructed multi-dimensional information diffusion assessment model for comprehensive risk of natural disasters and taking the disaster scenario formed by the comprehensive risk of earthquake and flood in a place in the upper reaches of the Fujiang River basin as the analysis sample, calculate the comprehensive risk assessment value of flood and earthquake damage to the micro samples (rural households in villages and towns) in the study area. By comparison, it is found that the comprehensive risk value assessed by the multi-dimensional information Diffusion model has good reliability and high accuracy, it is significantly superior to traditional Kriging interpolation and geographic weighted regression methods for evaluation.

The research object of this paper focuses on five towns in Santai County, such as Garden and Yongming, which objectively solves the deficiencies in the comprehensive risk assessment of natural hazards: regional differences in disaster-causing factors, strong regional differences in the disaster-bearing body, and increasing complexity in disaster vulnerability areas; regional differences between the five towns of Garden and Yongming in this paper are small, and therefore the conclusions of its research are also more rigorous and accurate.

This article presents a comprehensive risk assessment of natural disasters at the micro household level, which can better reflect the diversity and regionality of risks, help clarify the hidden risks of rural natural disasters, enhance their comprehensive disaster prevention and reduction capabilities, and is consistent with the goal of China's first national comprehensive risk assessment of natural disasters, providing scientific basis for government emergency management decision-making.

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