Article

Study on the identification of key impact factors of comprehensive natural disaster risk

- Empirical Evidence from 31 Provinces in China

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Abstract: This paper explores and discusses the key impact factors of comprehensive natural disaster risk. It introduced the basic concept of comprehensive risk of natural hazards and applied the improved TOE framework. Relevant data on natural hazards in 2022 were collected for a sample of 31 provinces in mainland China. Using a qualitative comparative analysis method, the key factors and combinations affecting the combined risk of natural hazards are identified through fsQCA. Finally, some recommendations that can reduce the comprehensive risk of natural disasters are proposed.

Keywords: Natural disaster risk; QCA; Disaster Reduction

1. Introduction

Natural disasters have complex causes and various types, including drought, flood, geological disaster, lightning, high temperature, tropical cyclone, low temperature freezing, snow disaster, hail, wind disaster, sandstorm, etc. The threat of natural disasters to regional functions, building facilities and residents' life and property safety is also increasing [1]. Some scholars pointed out that in addition to the general characteristics of disasters such as danger, accident, urgency, regionality, and delay, urban meteorological disasters also have characteristics such as seasonality, chaining, density, diffusion, and sociality [2]. Since 21st century, major natural disasters such as hurricanes, droughts and floods have occurred frequently around the world, bringing huge disasters to the world [3] In 2022, the global natural disaster situation is complex, with many extreme disaster events, and the losses caused by extreme weather and climate events are particularly prominent. The coupling of natural disasters with other social system disasters also brings new challenges to natural disasters [4]. A series of major natural disasters are a warning to human beings: we are entering a high-risk society. Natural disasters not only cause huge loss of life and property, but also inevitably cause disasters to the development of human society. Strengthening the study of natural disaster risk is a realistic demand of the times.

At the same time, the research on the comprehensive risk of natural disasters has also formed rich literatures. Scholars discussed the comprehensive risk assessment of natural disasters, mainly focusing on natural disaster risk assessment and governance. First, scholars conducted discussions from different disciplinary perspectives according to different types of natural disasters. From the perspective of comprehensive flood risk management, Kim Sangdan [5] et al. used the “stress-state-response” model to assess and partition flood disasters in a certain area. Tonini F et al. [6] mainly discussed from the perspective of regional drought disaster risk assessment. Besides, there are also rich results in the selection of evaluation indicators. Relevant institutions around the world have continuously formulated various plans for the assessment of natural disaster risks, and the index system of risk assessment has also changed with the continuous revision of various plans [7] Scholars all over the world have spared no effort to supplement and improve the index system of natural disaster assessment, intending to make the assessment results more appropriate. Adikari Y et al. [8] established an index system for evaluating flood disasters from the perspectives of flood governance, economic impact, and physical response; in addition, there were also a lot of discussions on the selection of evaluation methods. Evaluation methods such as regional NDVI index [9], normal distribution risk probability [10], GIS [11], entropy AHP [12] have been widely applied and innovated. Of course, due to the wide range of natural disasters, the research on the coupling of natural disasters and other disasters is also very extensive. (Pressure-State-Response) to study the relationship between ecology and economy [13]; Cannon [14] analyzed the close relationship between economy, ecology, and disasters from the perspectives of industry, environment, and society.

Although a wealth of results has been formed, there is still a research gap left. At present, most of the researches are carried out around the topic of evaluation, but there are still a few studies considering the influencing factors of socio-economic conditions. And most of them use qualitative methods to carry out research, while the QCA method can combine the advantages of quantitative research with qualitative research, and provide a combination that is more in line with the actual situation. In both practical and theoretical contexts, this study aims to answer the following questions: What factors affect the comprehensive natural disaster risk level in a region? Therefore, we selected the relevant data of 31 provinces in mainland China, and with the help of qualitative comparative analysis method, selected indicators from the TOE framework to identify the key factors.

The paper is structured as follows. Section 2 introduced the basic concept pf comprehensive natural disasters risk and TOE framework. Section 3 presents our methodology, including sample, data sources and calibration. Section 4 describes the results of our analysis: The two parsimonious solutions and the resulting five configurations that lead to the comprehensive natural disasters risk are concluded, while presenting the results of different combinations of the number of elements of TOE framework. Theoretical and practical implications are also discussed.

2. Research framework

2.1. Comprehensive natural disaster risk

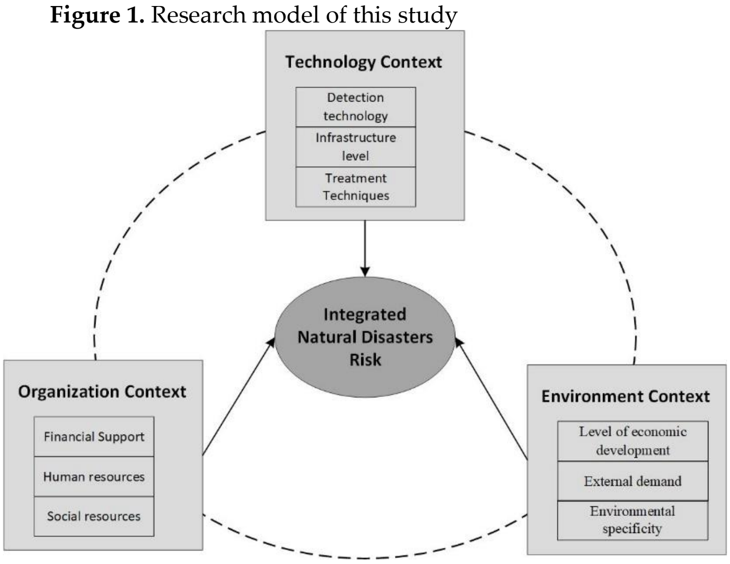
The United Nations defines natural disaster risk as the expected loss of people's lives, property and economic activities caused by specific natural disasters in a certain area and within a given period of time [15]. According to Cardona [16], disaster risk exposure comes from the interaction between a natural hazard (the external risk factor) and vulnerability (the internal risk factor). Therefore, the disaster risk index defined in this study reflects the comprehensive risk of disasters in a region to a certain extent, which is affected by many factors. Such as the risk of hazards, the exposure of disaster-affected bodies, the sensitivity to risks, and the ability to deal with them. According to the evaluation structure of the World Risk Index, the comprehensive risk of disasters can be divided into two aspects: the risk of natural disasters and the vulnerability of disaster-affected bodies. The risk of natural disasters refers to the degree of natural variation that causes disasters, which is mainly determined by the scale (intensity) and frequency (probability) of catastrophic activities. Generally, the greater the disaster intensity and the higher the frequency, the more serious the damage and loss caused by the disaster, and the greater the risk of the disaster. The vulnerability or vulnerability of the disaster-affected body refers to the degree of injury or loss of any property existing in a given dangerous area due to potential risk factors, which comprehensively reflects the degree of loss of natural disasters. Generally, the lower the vulnerability or vulnerability of the disaster-affected body, the smaller the disaster loss and the smaller the disaster risk, and vice versa. In this study, the China Natural Disaster Comprehensive Risk Report released by the International Society for Crisis and Emergency Management in 2023 is mainly used as a reference, which is also the outcome variable of this study.

2.2. Research framework: TOE

The TOE framework (Technology-Organization-Environment) was first proposed by Tornatizky and Fleischer [17]. The two scholars discussed the conditions affecting the application of technology under the three levels of Technology, Organization and Environment. Besides, the Interdisciplinary Research Center for Earthquake Engineering in the United States proposed "TOSE" framework [18] when studying community resilience, which means that resilience indicators can be identified from four aspects: technical, organization, social, and economic. Based on the research results of the above scholars, combined with the research content and specific data sources, this paper forms a TOE framework for studying the comprehensive risk of natural disasters, and makes different definitions on the content. The comprehensive risk level of natural disasters is based on the TOE sub-framework, combined with existing research and the institutional scenarios of the Chinese government, to construct a theoretical model framework that affects the comprehensive risk level of natural disasters (Figure 1).

Technology mainly focuses on whether the technology matches the comprehensive risk prevention and control of natural disasters, and whether it can provide technical support and external guarantee for the detection of natural disasters, including natural disaster detection technology [19] infrastructure construction level [20], and medical and health resources. Organization includes organizational scale, communication mechanism, and organizational resources. In the comprehensive risk-oriented natural disaster, it involves the organization's economic resources, human resources, and social resources that can be mobilized; the environment here includes both the natural environment and the regional placement of natural disasters. External pressures on comprehensive risks, such as the level of economic development, frequency of natural disasters, population density, etc.

Figure 1. Research model of this study



3 Methodology

3.1 Qualitative comparative analysis

Qualitative Comparative Analysis (QCA) is a set method, which integrates the advantages of both qualitative and quantitative research. Different from traditional linear regression analysis, QCA assumes that the influence of independent variables on the results is not necessarily symmetrical, and it is dedicated to examining the complex causal relationships between several independent variables and the outcome, describing the combinations of conditions that lead to a specific result. After years of exploration and research, the QCA method now can be categorized into four specific methods, including crisp set QCA (csQCA), multi-value QCA (mvQCA), fuzzy-set QCA (fsQCA) and MSDO/MDSO (system program matching cases and conditions) (Rihoux and Ragin 2018). Particularly, fsQCA combines categories and degrees of set membership, with more precise and exacting set-theoretic consistency assessment (both sufficiency and necessity) during analysis, a wider range of evaluations, and less influence of limited diversity. Therefore, we have chosen to use the method fsQCA. Its strengths and necessity are demonstrated as follows: on the one hand, the factors affecting individuals' technological risks perceptions are complex and influenced by different risk amplification stations, and it is difficult for a single influencing factor to fully explain the reasons for the high or low level of individual risk perceptions; on the other hand, the nine factors affecting individual risk perceptions mentioned in this study are difficult to divide in a simple way by a binary method, which satisfies the requirements of fsQCA for continuous variables.

In recent years, QCA has been widely used in different fields: business economics [21-22], public administration [23-24] and so on to identify the conditional combinations of different factors that affect the results, which is consistent with the question that our study wanted to address. Thus, this method is chosen to analyze our problem in this paper.

3.2 Sample and data sources

Based on the sample of 31 provinces in mainland China, our study analyzed the key factors and combinations affecting the regional comprehensive risk of natural disasters with nine indicators selected from three dimensions: technology, organization, and environment (Table 1). The comprehensive natural disaster risk index, which is derived from the results of the comprehensive evaluation of natural disasters in China published by the International Society for Crisis and Emergency Management in 2023, was used as the outcome variable of the study.

The indicator data for this study are mainly from the 2022 Statistical Yearbook published by the China National Bureau of Statistics, and the relevant disaster data are from the data published by the China Earthquake Networks Center (CENC) and the official website of the China Meteorological Administration, et al.

Table 1. Variable descriptions

Primary dimension	Secondary indicator	Description	Sources
Technology	Detection technology	Number of relevant natural disaster detection equipment	2022 Statistical Yearbook
	Infrastructure level	Investment in infrastructure construction	2022 Statistical Yearbook
	Treatment Techniques	Number of medical and health institutions	2022 Statistical Yearbook
Organization	Financial Support	Budget for disaster-related expenditures	2022 Statistical Yearbook
	Human resources	Number of firefighting recruits	China's national comprehensive fire rescue team

	Social resources	Number of social organization institutions	2022 firefighter recruitment plan China NPO Services Platform
Environment	Level of economic development	Average GDP	2022 Statistical Yearbook
	External demand	Frequency of natural disasters	2022 Statistical Yearbook
	Environmental specificity	Population density	2022 Statistical Yearbook
Outcome	Regional comprehensive risk level	Index of comprehensive risk	Comprehensive Evaluation of Natural Disasters in China

3.3 Data calibration

After getting the data, the direct calibration method was applied to convert the acquired data into fuzzy membership scores that between 1 and 0. The key to this part of analysis is the identification of three qualitative anchor points: the threshold value of full membership, the crossing point and the threshold value of complete non- membership.

The fsQCA method requires the calibration of the original data into fuzzy membership scores [0,1] by specifying three anchors [25]:one for full non-membership (value = 0.00), one for the crossover point (value = 0.50), and one for full membership (value = 1.00) [26]. For variables built from multi-item measures, indices (computed as average scores of the items) are used. To proceed with the analysis, the authors calibrated the data to transform variables into fuzzy sets [27] in the Statistical Package for the Social Sciences (SPSS) software using relative anchors, that is, percentiles of data [28], representing groups of values with varying degrees of membership in a specific category or condition. Sets do not represent variables in a typical sense, but rather are groups of values that reflect the degree of membership in a particular category or the degree of membership in a specific condition [29]. Consequently, set membership scores represent the result of calibrating original variable scores into fuzzy set scores, which are not probabilities but rather transformations of ordinal or interval scales into degrees of membership in the given set [30]. We referred to the studies of Du & Kim [31], Fainshmidt et al [32], we finally applied the direct calibration method and chose the 75%(full-membership), 50% (Intersection), and 25%(non-membership) percentiles as the anchor points and calibrated the data through SPSS (Table 2).

Table 2 Data calibration

Data	**Name**	**Fuzzy set calibrations**		
		Full in	**Crossover**	**Full out**
Number of relevant natural disaster detection equipment	Equip NumFZ	2619	1885	950
Investment in infrastructure construction	InvestFZ	3322602	1521118	1049848
Number of medical and health institutions	Medi NumFZ	36764	29291	16970
Budget for disaster-related expenditures	Disaster BugFZ	58.92	42.39	31.32
Number of firefighting recruits	People NumFZ	540	390	300
Number of social organization institutions	NGO NumFZ	151	55	31
Average GDP	Ave GDPFZ	86879	65026	56831
Frequency of natural disasters	FreFZ	277	96	21
Population density	DensFZ	3819	3099	2238
Index of comprehensive natural disaster risk	RIFZ	0.23	0.15	0.08

4 Result and analysis

4.1 Necessity analysis

To test whether a single condition (including its non-set) is necessary for comprehensive natural disaster risk based on whether the consistency level is greater than 0.9 [33]. Table 3 shows the results of the analysis of the necessity test of individual risk perceptions analyzed by the fsQCA 3.0 software, where the level of consistency for all conditions is less than 0.9. Therefore, there are no necessary conditions that lead to comprehensive natural disasters risk, which means that we could use all the independent variables in the research design for further analysis.

Table 3. Analysis of necessary conditions

Variable	RIFZ		~RIFZ	
	Consistency	Coverage	Consistency	Coverage
Equip NumFZ	0.695013	0.681078	0.480469	0.462406
~ Equip NumFZ	0.451407	0.469415	0.66862	0.682846
InvestFZ	0.634911	0.659801	0.41862	0.427242
~ InvestFZ	0.448849	0.440125	0.666667	0.642006
Medi NumFZ	0.686061	0.656671	0.436198	0.410037
~ Medi NumFZ	0.383632	0.409277	0.634766	0.665075
Disaster BugFZ	0.669437	0.651119	0.472656	0.451493
~ Disaster BugFZ	0.436061	0.457105	0.634766	0.653485
People NumFZ	0.638107	0.67115	0.419271	0.433087
~ People NumFZ	0.460997	0.446993	0.681641	0.649101
NGO NumFZ	0.66688	0.672903	0.42513	0.42129
~ NGO NumFZ	0.426471	0.430323	0.669922	0.663871
Ave GDPFZ	0.555627	0.542109	0.582682	0.558328
~ Ave GDPFZ	0.547315	0.57181	0.522135	0.535738
FreFZ	0.68798	0.73297	0.358073	0.374659
~ FreFZ	0.413043	0.395833	0.744792	0.70098
DensFZ	0.638747	0.653368	0.41862	0.420536
~ DensFZ	0.433504	0.431572	0.654948	0.640356

4.2 Analysis of sufficient conditions

The sufficiency analysis takes a set-theoretic perspective to explore the relationship between the set of samples corresponding to combinations composed of different antecedent variables and the outcome set. The consistency is used to measure the sufficiency of the configurations, and in general the level of consistency should not be less than 0.75 [33]. In this study, the consistency threshold was set at 0.8. When selecting conditions, all nine secondary variables of RI were selected as "present or absent", without subjectively deciding on the presence or absence of antecedent variables. Table 4 presents the parsimonious solution for the outcome (P1–P2), and Table 5 shows the configuration results formed by the 9 conditions. In the table, "&" means "AND", "~" means "NOT". For example, the first parsimonious configuration P1 "~AveGDPFZ*FreFZ" means "Non-capital GDP and frequency of natural disasters are the core variables that contribute to natural disaster risk, which increases when the level of per capita GDP is low and the frequency of natural disasters is high."

Table 4. Configurations of comprehensive natural disaster risk (Parsimonious solution)

	Configurations	Raw Coverage	Unique Coverage	Consistency	Total Solution Consistency	Total Solution Coverage
P1	~AveGDPFZ*FreFZ	0.439898	0.123402	0.92973	0.839688	0.619565
P2	FreFz*DensFZ	0.496164	0.179668	0.824655		

Table 5. Configurations of comprehensive natural disaster risk (Intermediate solution)

		I1	I2	I3	I4	I5
Technology	Equip Num	•	•		⊗	⊗
	Invest	•		•	⊗	⊗
	Medi Num	•	•	•	⊗	•
Organization	Disaster Bug	•	•	•	⊗	•
	People Num	•		•	⊗	⊗
	NGO Num	•	•	•	⊗	⊗
Environment	Ave GDP		•	•	⊗	⊗
	Fre	●	●	●	●	●
	Dens	●	●	●	⊗	●
Consistency		0.877598	0.847826	0.905172	0.97351	0.991803
Raw Coverage		0.242967	0.199488	0.201407	0.0939898	0.0773657
Unique coverage		0.0690538	0.0294118	0.0319694	0.0645781	0.0249361
Total consistency		0.889197				
Total coverage		0.510486				

Note: ● represents the configuration of the core conditions exist, ⊗represents the core conditions are absent, •represent edge conditions exist, ⊗represents the edge conditions are absent, blank means configuration of the condition can also can be absent.

According to the truth table and calculation of fsQCA, the sufficiency analysis was carried out to test the conditional combination sufficient for the result to occur in the casual relationship. Two types of measures were used to validate the outcomes: consistency and coverage [34]. Consistency is like the p-value in correlational analysis and shows how a configuration is a sufficient solution for the outcome. In general, the coverage accounts for the empirical relevance and validity of the results generated by the configuration. Raw coverage shows the proportion of each set of data to the output results, which is like the explained variance (R2) in correlational analysis. Unique coverage means that each configuration has a coverage in which there is no overlap with other configurations[35].

Table 4 shows the configuration results formed by the 9 conditions. The consistencies for each solution are in Table 4 as well. Consistencies for each solution are in the ranges of 0.847826 and 0.991803 correspondingly, which are considerably above the acceptable level of .80. With the help of fsQCA, we got 2 parsimonious solutions and 5 intermediate solutions. The consistency level of the 5 configurations presented in the table is higher than the minimum acceptable consistency level of 0.75 for both the single solution and the overall solution. The coverage of the overall solution is 0.51, showing a high coverage in the sample. It means that all 5 configurations can fully explain the existence of the results and can be regarded as a combination of sufficient conditions to influence comprehensive natural disaster risk.

Based on the number of parsimonious solutions, we divided the five groupings into 2 general results.

4.2.1 High frequency of natural disasters coupled with high population density

This category is mainly reflected in the three configurations I1 to I3, and the core solutions of these three configurations are FreFz*DensFZ. These three configurations show that when the two conditions of disaster frequency are high enough and regional population density is large enough exist and couple together, the comprehensive risk of natural disasters is high. Even if technical and organizational resources exist, it still leads to a higher combined risk of natural disasters. Among them, the consistency of I1 is 0.877598, and the original coverage rate is 0.242967, which means that the I1 group can explain 23.3% of the regional samples. In I1, GDP per capita is blank, that is, when the frequency of natural disasters is high and the population density is high, even if the level of economic development is higher, the huge risk of natural disasters cannot be ignored. Compared with I1, I2's investment in infrastructure construction and the number of firefighters recruited are both vacant. The consistency of this configuration is 0.847826 and the original coverage is 0.199488. It shows that in 19.95% of the samples covered by this configuration, the two indicators of infrastructure construction investment and the number of firefighters recruited are not important to the comprehensive risk of natural disasters. In I3, the number of technical equipment such as weather stations and seismic stations is vacant. In addition, there is still a high level of natural disaster risk when other conditions exist. The consistency of this configuration is 0.905172, the original coverage is 0.201407, and 20.14% of the samples can be explained by I3 only.

4.2.2 Low level of economic development coupled with the frequency of natural disasters

This category is mainly for the core solution of ~AveGDPFZ*FreFZ, and there are two configurations. This category shows that when the level of economic development is low and the frequency of natural disasters is high, it also leads to a higher combined risk of natural disasters. The consistency of the I4 configuration is 0.97351, and the original coverage is 0.0939898, which can cover 9.34% of the samples. I4 only has the core solution of ~AveGDPFZ*FreFZ, and the rest of the conditions do not exist. This also reflects that in some areas with backward economic development levels, they are relatively fragile overall, relatively weak in technology and organization, and therefore face a higher level of comprehensive risk in the face of some natural disasters. I5 reflects areas with a high frequency of natural disasters and a low level of economic development. These areas have a large population density. Although they have certain disaster investment budgets and medical and health institutions, they still face serious comprehensive risks of natural disasters. The I5 agreement was 0.991803 and the raw coverage was 0.0773657, indicating that 7.74% could be explained by this pathway.

4.3 Robustness test

To verify the robustness of the results, robustness tests were conducted on the configurations that led to comprehensive natural disasters risk. Increasing the consistency threshold from 0.8 to 0.85, The outcomes were consistent with the results just presented. Therefore, the configurations were ultimately identified as robust.

5 Discussion

5.1 Conclusion

The high risk of natural disasters is the result of a variety of conditions, among which the frequency of natural disasters, population density, and the level of economic development interact with each other will lead to a higher risk index. From the perspective of the TOE framework, the factors affecting the comprehensive risk of natural disasters are mainly concentrated in the dimension of the environment, which includes both the natural environment and the economic environment. Further verified the characteristics of the comprehensive risk of natural disasters: the danger of natural disasters themselves and the characteristics closely related to the economy and society. From the perspective of comprehensive risk assessment of natural disasters, It is determined by the risk of natural disasters and regional vulnerability, which is also in line with our understanding of this point of view. At the same time, our research also provides a reference for the prevention and response to the comprehensive risk of natural disasters.

First of all, it is necessary to improve local technical capabilities to improve the monitoring and response capabilities of natural disasters. With the in-depth development of information technology, the establishment and application of an intelligent research and judgment management platform can greatly improve disaster prediction and disaster prevention and mitigation capabilities. Adopt the "professional and informatized" disaster basic data collection mode, and take the comprehensive risk analysis needs of natural disasters as the starting point, develop and apply the intelligent research and judgment management platform for natural disaster comprehensive risks, and provide technical support for the prevention of natural disasters. Secondly, it is necessary to improve the level of organizational governance to provide human security and social motivation for the response to the comprehensive risk of natural disasters. Interaction between the government and social assistance organizations is needed. For example, the government takes the lead in establishing a coordination training platform for social assistance organizations, and the government allocates funds to provide professional training for volunteers in the organization, form a team with high professional quality, and strengthen emergency rescue forces. At the same time, rationally use disaster-related budgets, effectively mobilize organizational personnel, funds, and technology, and provide organizational guarantees for the governance of natural disaster comprehensive risks.

5.2Limitations and future research

Our study also needs further improvement. The comprehensive risk of natural disasters is not a characteristic of a certain time period, but also varies in different regions, and we can further expand our study and analyze the mechanism of socioeconomic impact on natural disaster risk from a longer time dimension. Second, the indicators selected in our study are mainly based on the TOE framework, but there must be other factors that also have an impact in the actual process, so we need to add more indicators to deepen the scientific and applicability of the study by taking into account the specific situation in the actual natural disaster response.

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