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Research article

How to improve smart emergency preparedness for natural disasters? ---- Evidence from the experience of ten pilot provinces in China for smart emergency

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A R T I C L E I N F O

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A B S T R A C T

The natural disasters faced by modern urban systems are complex, with multiple disaster-causing factors coexisting and secondary disasters occurring concurrently. With emergency management moving towards smart, natural disaster response has shifted from emergency-centered response to pre-disaster prevention. How to improve the government's natural disaster emergency preparedness has become an important issue that needs to be addressed. Based on the TOE (Technology-Organization-Environment) framework, the fsQCA method was used to explore the improvement path of emergency preparedness capacity of 10 pilot units in China to deal with natural disasters in 2020. Analyze the group effects and interrelationships of technology level, simultaneous supporting facilities, organizational construction, financial investment, external pressure, and social repercussions. The results show that: there exist four conditional groupings of high emergency preparedness in two modes. Two modes are organization-environment dual-drive and technology-organization-environment triple-drive, which have multiple concurrencies and follow the principle of consistent results. There are substitution effects in the conditional groupings of high emergency preparedness. There are causal asymmetries in the conditional groupings of high emergency preparedness and non-high emergency preparedness. This study aims to explore the smart emergency preparedness of ten pilot and to provide ideas for the overall development of "smart emergency response" and the improvement of emergency preparedness for natural disasters.

1. Introduction

Under the wave of social, economic, information, and technological integration, natural disasters are frequent, and the damage caused by them is increasing, How to effectively control the catastrophic effects of natural disasters has aroused global concern [1]. China is one of the most severe countries in the world regarding natural disaster occurrence [2], with frequent disasters, rich disaster types, extensive disaster coverage, and heavy disaster extent. In the face of the severe challenges of natural disasters, China attaches great importance to the emergency management system and capacity building. In 2025, China will fully realize scientific emergency response and smart emergency response, forming a new pattern of emergency management for common construction, governance, and sharing [3]. "Smart emergency" refers to the use of information technology to provide scientific, professional, and refined solutions for

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emergency response. "Smart emergency" is an essential feature of the modernization of China's emergency management [4] and a major strategic initiative to promote China's emergency prevention capabilities for natural disasters. China is vigorously promoting the in-depth application of intelligent technology in emergency management. Emergency management work presents a good trend of informatization-intelligence-smart multi-layer burst [5]. Since September 2020, 10 provinces (municipalities directly under the Central Government) have been carrying out the pilot construction of "smart emergency". The pilot construction goal was completed by the end of 2021. Based on the provincial digital government platform, each pilot unit has built a highly integrated emergency management big data resource pool. They have realized data sharing across departments, regions, and levels in the whole business domain. And they have formed a "digital service chain for emergency" with its characteristics. This provides a good model for promoting the development of "Smart emergency" construction nationwide.

The focus of China's emergency management business has shifted from post-emergency reconstruction and relief work to pre-emergency warning and preparation work. But the detection of risk points in the field of natural disasters in most regions is relatively small. Information coverage still needs to be comprehensive, and there is also a lack of support platforms for monitoring and warning, risk control, emergency command, and other information integration. What paths exist to promote a high level of emergency preparedness in a "different way"? How to improve the government's emergency preparedness for natural disasters under the trend of smart emergency? To this end, this paper constructs an analytical framework for government emergency preparedness based on TOE (Technology-Organization-Environment) theory. We uses 10 pilot provinces for "smart emergency" in China to explore the paths of improving government emergency preparedness for natural disasters using fuzzy set qualitative comparative analysis (fsQCA).

The innovations and contributions of this paper are as follows:

1. From the perspective of configuration, this paper explores the impact of multi-factor coordination and integration on the government's emergency preparedness ability under the scenario of natural disasters. Expand the research based on the "net effect" of a single variable to the research on the comprehensive effect of multiple factors based on the configuration perspective, which is helpful to deepen the theoretical perspective of smart emergency response.
2. This paper introduces the TOE framework to explore the influencing factors of the government's emergency preparedness capability from three aspects: technology, organization and environment. This study is not only a further expansion of the TOE framework in the field of smart emergency response, but also a further deepening of the theory of emergency management in China.
3. Through configuration analysis, this paper explores the antecedent configuration of high/low level emergency preparedness capabilities in ten smart emergency pilot provinces, reveals their core influencing factors and substitution effects between different paths, and proves that there is not only one model of smart emergency response (Eisenack and Roggero, 2022). This provides managers with a variety of strategic options. It is helpful for managers to simplify the complexity of problems and flexibly choose the governance mode in the increasingly complex social environment.

2. Literature review

2.1. The assessment system of emergency preparedness capability

Gu believe that emergency preparedness capability is a capability that can guarantee not only the maximum safety but also the stability and order of the society under the public emergencies [6]. The academic research on emergency preparedness capability mainly focuses on the assessment system and the optimization model. About the assessment system of emergency preparedness capability, Xiaodong Wang constructed an index system for assessing the emergency preparedness capability of hazardous events based on the emergency management process. This index system includes organization, system, personnel, information, material, and logistics [7]. Wang constructed a disaster management control capability assessment model based on the Capability Maturity Model (CMM) [8]. The model evaluates the organization's capabilities from eight aspects, and divides the capability assessment results into four levels. It provided a common assessment guide for different types of emergency management organizations. Adini [9] designed an assessment system to measure the organization's emergency preparedness level, which contains four dimensions: SOPs, training and drills, staff literacy, and infrastructure and equipment. DIAN JIA [10] established an intelligent evaluation system for government emergency management based on an IoT environment. Through practical application, they proved that the system has strong execution capability, outstanding big data computing capability, and can objectively evaluate and analyze government emergency management work. Yuzhen Han [11] constructed a hybrid intelligent model for the evaluation of critical success factors of high-risk emergency response systems. This model contains ten dimensions such as a well-planned emergency relief supply system, appropriate emergency response plans, and disaster prevention education activities. In terms of emergency preparedness optimization models, since 2000, Western countries have gradually focused on government emergency preparedness. The United States has established a specialized agency, FEMA (Federal Emergency Management Agency), to provide knowledge and funding support for state and local government emergency preparedness. Maor, Moshe [12]proposed three models for improving government emergency preparedness: a central/federal-focused model, a locally focused model, and an integrated model. These models have been applied to local government training in countries such as Denmark, England and Wales, Israel, and the U.S. TianXie [13] constructed a DES-PSDF model to optimize emergency preparedness capabilities based on parallel emergency management, Discrete Event System theory(DES) and Project Simulation Decision Framework (PSDF). Their experimental simulation results validate the effectiveness and operability of their proposed DES-PSDF approach.

2.2. Factors influencing emergency preparedness capabilities

Technology is the primary driver for enhancing the government's emergency preparedness capabilities. Natural disaster response is shifting from emergency-focused to pre-disaster prevention and risk reduction. Crisis prediction requires monitoring risk points and crisis sources, but they are increasingly difficult to manage. Using big data to collect, analyze, and process multi-source heterogeneous data can compensate for the lack of emergency management and warning capabilities, and filter out key information clues from massive data. Zhi Xu et al. proposed that if establish a monitoring and warning platform based on multivariate data, it would play a supportive role in the new emergency think tank's early warning and decision-making research. The platform will enhance and highlight its risk early warning capability [14]. Guibin Xiong also proposed that big data can enhance the government's emergency management capability, specifically by paying attention to ex-ante prediction, from causal analysis to big data correlation analysis, and carrying out all-factor emergency management [15]. Mitsova et al. argued that infrastructure security has a significant impact on emergency management disposal. Maintaining good infrastructure is of great help to emergency coordination and post-disaster recovery [16]. RuiChang Li also believes that developing emergency management technologies, such as risk perception technology and risk assessment technology, can improve the effectiveness of urban emergency management [17].

Organizational elements are essential supports to enhance the government's emergency preparedness capabilities. T Mitchell recognizes that well-coordinated organization, orderly planning, and vigilance in response to unavoidable natural disasters can help improve emergency management capabilities [18]. Ta Kurki et al. in analyzing the operational work of emergency organizations, found that the distribution of tasks and role positioning has an essential impact on the emergency capability and puts high demands on emergency commanders [19]. Miehl GF et al. suggests using big data resources to build an integrated platform for disaster emergency management and disaster risk analysis to improve the collaboration of government departments. Also, they think that establishing a disaster risk assurance system will help improve government emergency preparedness [20]. Naim, Kapucu believes that all emergencies are unpredictable, so it is necessary to build a complete emergency command system in advance. This will ensure the smooth flow of information between organizations, realize the sharing of government emergency resources, and enhance the emergency preparedness capacity [21]. Xianhua Wu [22] et al. pointed out that one of the most important ways of disaster management is to prevent disasters and reduce disaster losses through government financial expenditures. Therefore, they developed a resident-manufacturer-government decision model and calculated the optimal ratio of governmental disaster prevention and mitigation expenditures under different conditions. Jun Tian et al. also proposed that emergency response capacity building focuses on improving the dynamic organization and coordination of the emergency response process and strengthening ex-ante prevention [23].

Environmental elements are the external basis for improving the government's emergency preparedness capacity. Social resources can play a full role in emergency management. Barbara Ryan [24] pointed out that local governments can raise the public's awareness of risk prevention and assist government departments in jointly responding to emergencies through consultations, expert forums, disaster simulation exercises. Zhijie Wang et al. found that popularizing disaster risk and response knowledge among the public and creating a favorable social culture can help government departments respond to disasters more efficiently and cost-effectively [25]. Jan also found that government capacity, social cohesion, and trust in government have an impact on emergency management capabilities [26]. Samole [27] believes that strengthening education and raising public awareness of preparedness can improve the efficiency and effectiveness of emergency management. Wengang Lu [28] et al. described the Jinwan emergency management model in detail and suggested that it is necessary to pay attention to the public in the grassroots reform. It is also necessary to pay attention to the public's rating of the organization, which will promote the improvement of the competence and quality of government departments.

2.3. Smart emergency management

Emergency management is about public safety, national security, and it takes on the vital responsibility of preventing and resolving various disasters and accidents [29]. The smart emergency is a major strategic initiative to promote the modernization of emergency management capability by relying on scientific and technological innovation. It is an upgraded version of emergency management informatization in response to the requirements of the new development stage and the general trend of intelligence [30]. The current research on smart emergencies mainly focuses on smart emergencies' connotation analysis and application design. Sahih points out that smart emergency management (SEM) contains big social data (SBD)– emergency data sources from physical and social sensors [31], computing technology (CT)– methods of processing and analysis, such as machine learning (ML) and data mining (DM), emergency management (EM)– a strategic procedures for using information and knowledge to deal with emergencies [32], and to some extent intersects. Currently, research is focused on SBD as a source of information in SEM, especially as a real-time data source to track disaster situations in order to deal with emergencies more effectively [33]. Dimakis [34] built a distributed building evacuation simulator for smart emergency management, which plays a role in production safety and social security emergencies. Xiaoqiang Kong [35] et al. analyzed emergency management informatization. Specifically, they proposed the construction content and construction plan of an intelligent emergency management information system for petroleum and petrochemical enterprises. It mainly consists of four modules: site monitoring, emergency planning, alarm command, and emergency response. Smart emergency response to natural disasters refers to the deep integration of new generation information technologies such as 5G, AI, big data, and cloud computing with emergency management to prevent natural disasters [36]. At present, China's smart emergency response to natural disasters is mainly reflected in the hierarchical construction of natural disaster monitoring and warning system. The Ministry of Emergency Management builds a comprehensive monitoring and warning system for natural disasters, which unifies monitoring and early warning information from various places and related departments. Emergency management departments at the provincial, municipal and county levels have established natural disaster monitoring and early warning systems in their respective regions [37].

2.4. Literature review summary

In summary, The research on emergency preparedness shows a "field deficiency", as the existing literature focuses on public health, production safety, and social security events and lacks research on emergency preparedness for natural disasters. It also shows a "subject deficiency", focusing more on the emergency preparedness of individuals, special groups, and communities and not enough on the emergency preparedness of government departments. Most of the research on smart emergency preparedness is only at the descriptive and conceptual level, and the interdisciplinary nature of this field still requires multiple approaches to adapt to it. Therefore, this paper constructs an analytical framework for governmental emergency preparedness based on TOE (Technology-Organization-Environment) theory and uses 10 pilot provinces (municipalities directly under the central government) as the research objects. The study intends to provide a paradigm and reference ideas for promoting smart emergency preparedness for natural disasters.

3. Theoretical analysis and research methods

3.1. Theoretical model

Tornatizky and Fleischer first proposed the TOE framework in their book "*The Process of Technological Innovation*". This model systematically constructs the factors affecting an organization's technological innovation in three dimensions: technology, organization, and environment, which is both systematic and flexible [38]. In terms of disaggregation, Technology emphasizes itself and the infrastructure it drives; Organization focuses on the structural characteristics of the organization as well as institutions, mechanisms, and financial investment; and Environment focuses on the objective external environment and social support, such as social evaluation and external pressure [39]. Based on the TOE framework, scholars have examined the performance differences in the construction of local government websites in China [40], the factors influencing the digital governance of provincial governments and the implementation path [41], and the factors influencing the government in terms of e-service capacity [42]. The above studies show that the TOE framework has explanatory solid power and applicability in the digital governance and e-government field in China.

With the changing times, natural disasters present new characteristics, and the difficulty of prevention and response is constantly escalating. At the same time, due to the cross-impact of various emergencies, the situation is becoming more and more complex [43]. Carrying out effective disaster preparedness can be completed on time and enhancing the government's emergency preparedness has become a top priority in preventing and controlling natural disasters [44]. Responding to natural disasters is a complex process with multiple elements synergistically linked. The intertwining of technical, organizational, and environmental factors influences the government's emergency preparedness. IoT technology extensively connects physical space, social space and information space to achieve real-time dynamic data collection. It provides timely and accurate information for monitoring and early warning of natural disasters. Digital technologies and the interconnection of information across sectors and regions have multiplied emergency preparedness capabilities [45]. Big data provides essential technical support for social participation, and the openness of innovative technology pushes the cooperation between government and citizens, which is conducive to the transformation from government-led to emergency co-governance. In conclusion, the theoretical framework of TOE is suitable for studying the government's emergency preparedness capacity in the context of natural disasters.

Therefore, this paper extracts factors affecting the government's emergency preparedness capacity based on the TOE theoretical framework. We will combine existing research and the current development status of ten pilot provinces (municipalities directly under the central government) for smart emergency. Relevant variables affecting the government's emergency preparedness for natural

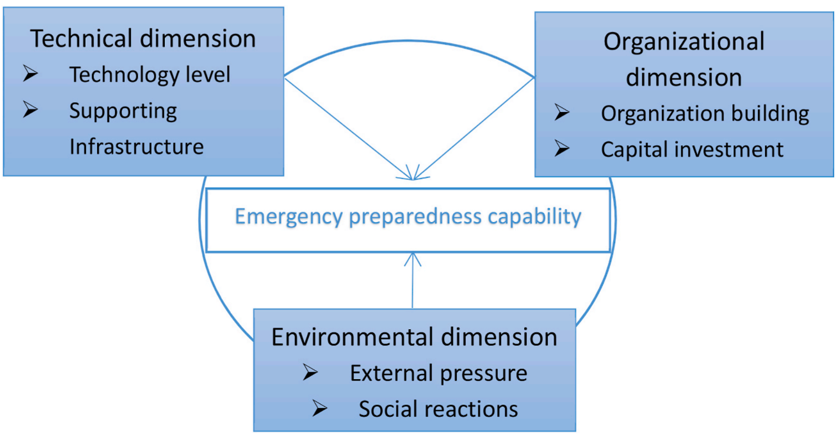

Fig. 1. TOE framework for the government's natural disaster preparedness capabilities.

disasters are set at the technical, organizational, and environmental levels. The technical dimension selects the technical level and supporting infrastructure, The organizational dimension selects organizational construction and capital investment, and the environmental dimension selects external pressure and social repercussions. This paper constructs a TOE expansion framework for the government's natural disaster preparedness capabilities, as shown in Fig. 1.

3.2. Research methodology

This paper uses a fuzzy set qualitative comparative analysis to study the driving paths of natural disaster emergency preparedness capacity enhancement. Qualitative comparative analysis (QCA) is an empirical method for studying complex social problems caused by multiple antecedents, using Boolean algebra to explore combinations of problems. QCA adopts a holistic perspective rooted in configuration thinking, which is more in line with the interdependence and multiple linkage causality of management practices. QCA thinking that "organizations cannot be understood by analyzing components in isolation, but rather as clusters of interrelated structures and practices rather than as subunits or loosely bound entities." This paper uses the fsQCA method for the following reasons: emergency preparedness is affected by multiple concurrent factors, and the process of responding to natural disasters is complex. QCA does not consider the net effect of individual variables on outcome variables, but instead focuses on similar or different configurations of multiple factors that have explanatory power on outcome variables. The fsQCA approach requires a low number of cases and has an outstanding advantage in small and medium samples of 10–60 cases for analysis [46]. The number of cases in the selected smart emergency pilot unit in this paper is 10, which meets the basic requirements of the fsQCA method for the number of cases. In addition, the antecedent variables are challenging to be fully defined by a binary assignment of 0 or 1. While the fsQCA can apply continuous or interval scale variables, which effectively compensates for the shortcomings of binary assignment.

Table 1
Results of principal component analysis.

	Secondary indicators	main component	KMO value	Significance	Variance contribution rate (%)	Literature Sources
T	Provincial Digital Government Data Disclosure Index 5G base station construction Provincial digital government governance coverage and penetration	Technology level	0.600	0.00	73.0	PANPAN LI, PENG BI[a]
	Public coverage of disaster warning information dissemination Radio and television coverage Meteorological observation capacity (including satellite cloud map reception, weather radar observation, lightning positioning reception operations, the number of conventional meteorological observation stations)	Supporting Infrastructure	0.639	0.00	76.7	Mikalef Patrick, Krogstie John[b]
O	R&D staff volume Provincial Digital Government Platform Management Assessment Index Provincial Digital Government Organizational and Institutional System Assessment Index Number of emergency management related policies and regulations	Organization building	0.600	0.009	74.0	Fan Bo, Li Zhoupeng, Desouza Kevin C[c] Maor, Moshe[d]
	Disaster prevention and emergency management expenditures Natural resources, marine meteorology and other expenditures Science and technology expenditures	Capital investment	0.660	0.010	75.0	
E	Natural disaster economic loss situation Population affected by natural disasters Area affected by natural disasters	External pressure	0.667	0.010	82.0	Zhou Guanglan, Zhang Zhening, Fei Yulian[e]
	Provincial Digital Government Satisfaction Government service rating Provincial government interaction index	Social reactions	0.700	0.00	81.4	Gao Shan, Zhang Ye, Liu Wenhui[f]

[a] PANPAN LI, PENG BI. Study on the Regional Differences and Promotion Models of Green Technology Innovation Performance in China: Based on Entropy Weight Method and Fuzzy SetQualitative Comparative Analysis[J]. IEEE ACCESS,2020.

[b] Mikalef Patrick, Krogstie John. Examining the interplay between big data analytics and contextual factors in driving process innovation capabilities [J]. European Journal of Information Systems,2020,29(3).

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[e] Fan Bo, Li Zhoupeng, Desouza Kevin C. Interagency Collaboration in City Emergency Management Network: a Case Study on the Super Ministry Reform in China. [J]. Disasters,2021,46(2).

[f] Gao Shan, Zhang Ye, Liu Wenhui. How Does Risk-Information Communication Affect the Rebound of Online Public Opinion of Public Emergencies in China? International Journal of Environmental Research and Public Health,2021,18(15).

4. QCA analysis of natural disaster emergency preparedness capabilities

4.1. Case selection

To promote the modernization of emergency management by informatization, the smart emergency is not only the hope of emergency management innovation in the new development stage but also the upgrade of emergency capability. The use of promising digital technology helps to make emergency preparedness more adequate. This paper takes the smart emergency pilot units announced by the Ministry of Emergency Management in 2020 as the research objects, namely Tianjin, Hebei, Heilongjiang, Jiangsu, Anhui, Jiangxi, Shandong, Hubei, Guangdong and Yunnan. By the end of 2021, the pilot construction targets have been completed, and the construction results are promising. This paper will explore how technology, organization, and environment factors synergistically affect natural disaster preparedness capabilities under the smart emergency development model.

4.1.1. Variable settings and data sources

(1) Resulting variables

The outcome variable of this study is natural disaster emergency preparedness capacity, a general term for the ability to take all preparatory actions to respond effectively to natural disasters, minimize losses, and improve emergency response mechanisms. Although there are a certain number of emergency preparedness evaluation systems in the academic community, there is yet to be an emergency preparedness evaluation system that focuses only on natural disasters. Therefore, this paper constructs an evaluation system of emergency preparedness capacity for natural disasters in three dimensions: technical, organizational, and environmental. Determine the weights of indicators by entropy weighting method to score the emergency preparedness capacity of ten pilot units. The specific steps are as follows:

First, Indicator extraction. Based on the existing literature and TOE framework, 19 secondary indicators were extracted from three levels: technical, organizational, and environmental (see Table 1). The KMO and Bartlett's spherical tests were done for six data groups. The KMO value of each group was greater than 0.6, Bartlett's spherical test was significant, and the cumulative variance contribution rate was greater than 70.0 %. The above results indicated that the data met the requirements of principal component analysis. Six main variables were extracted by the principal component method, named in order: technology level, supporting infrastructure, organization and construction, financial investment, external pressure, and social reactions.

Second, Calculation of weights. The entropy weighting method determines the respective weights of technical level, supporting infrastructure, organization and construction, financial investment, external pressure, and social repercussions. Based on the degree of change of each indicator, the entropy method uses information entropy to calculate the entropy weight of each indicator. Then the entropy weight is used to correct the whole indicator to obtain a more objective weighted value of the indicator (see Table 2). Finally, the emergency preparedness score of each pilot wisdom emergency units was calculated and ranked (see Table 3). The calculation steps are as follows:

1. Construct the original matrix. Construct the original matrix with m objects and n indicators:

$$X = \left[x_{ij}\right]_{m\times n}$$

2. Standardization of raw data. This paper uses the extreme difference method to standardize the indicator values and compress them to the interval [0 to 1]. For positive and negative indicators, the standardization process was performed with the following equations, respectively:

$$x'^{ij} = \frac{x^{ij} - \min\left(x^{ij}\right)}{\max\left(x^{ij}\right) - \min\left(x^{ij}\right)};\ x'^{ij} = \frac{\max\left(x^{ij}\right) - x^{ij}}{\max\left(x^{ij}\right) - \min\left(x^{ij}\right)}$$

The x_{ij} is the original value of the j-th indicator of the i-th unit, and x'_{ij} is the j-th indicator of the i-th unit after normalization.

Table 2
Natural disaster emergency preparedness capabilities evaluation indicators and weights.

Dimensionality	Tier 1 Indicators	Weights
T	Technology level	0.1576
	Supporting Infrastructure	0.2134
O	Organization building	0.1534
	Capital investment	0.1730
E	External pressure	0.1109
	Social reactions	0.1918

Table 3
Emergency preparedness capabilities scores and rankings by province.

Ranking	Pilot units	Emergency preparedness capabilities score
1	Guangdong	0.9509
2	Jiangsu	0.7884
3	Anhui	0.5976
4	Shandong	0.5753
5	Jiangxi	0.5560
6	Hubei	0.5105
7	Tianjin	0.4437
8	Heilongjiang	0.2439
9	Hebei	0.2359
10	Yunnan	0.0801

3. Calculate the index information entropy value e_j and information utility value d_j :

$$\overset{j}{e} = -k\left[\sum_{i=1}^{n} p\ln\left(p\right)\right] \; ; \; \overset{j}{\mathrm{d}} = 1 - \overset{j}{e}$$

The e_j is the information entropy value of the j-th indicator. The smaller the information entropy of a certain indicator, the more information it can provide and the larger the weighting value. Conversely, the larger the entropy value of the indicator, the less information the indicator can provide and the smaller the weight.

4. Calculate index weights

$$W_{\mathrm{j}} = (1 - e_j) \Big/ \sum_{j=1}^{n} (1 - e_j)$$

where 1-e_j denotes the information entropy redundancy.

(2) Conditional variables

Based on the TOE framework, explore the influencing factors of emergency preparedness from three aspects: technical, organizational, and environmental.

First, Technology level. Referring to the studies of PANPAN LI, PENG BI, Patrick, John et al. the technical level and supporting infrastructure were selected for measurement. The technical level was measured by the provincial digital government data disclosure index, the construction of 5G base stations, and the coverage and penetration of provincial digital government governance. Supporting infrastructure was measured by public coverage of disaster warning information dissemination, radio and television coverage, and meteorological observation capability.

Second, organizational level. Referring to Fan Bo, Maor, Moshe et al.'s study, organizational construction, and financial investment were selected for measurement. Organization construction was measured by R&D personnel, provincial digital government platform management evaluation index, provincial digital government organization and system evaluation index, and emergency management related policies and regulations. The financial investment was measured through disaster prevention and emergency management expenditures, natural resources, marine meteorology and other expenditures, and science and technology expenditures.

Third is the environmental dimension. Referring to the study of Zhou Guanglan, Gao Shan, and others, two indicators, external pressure and positive and negative social reactions, were selected for measurement. External pressures were measured by selecting the economic losses of natural disasters, the population affected by natural disasters, and the area affected by natural disasters. Social repercussions were measured by selecting provincial digital government satisfaction, government service rating, and provincial government interaction index. The above data were obtained from *the China Digital Government Development Research Report 2020*,

Table 4
Data calibration anchor points.

	Variables	Fully affiliated	Intersections	Unaffiliated
Result Variables	Emergency preparedness	0.825	0.575	0.255
Technical dimension	T1	0.6386	0.0652	−0.7474
	T2	0.9852	−0.1717	−0.4332
Organizational dimension	O1	0.6142	−0.1116	−0.9047
	O2	0.7719	−0.1389	−0.9135
Environmental dimension	E1	0.8645	0.2190	−0.8121
	E2	1.2829	−0.3980	−0.7620

China Statistical Yearbook 2020, *China Smart Emergency Status and Development Report*, Government Report Work Overview, and search engines.

4.2. Empirical analysis

4.2.1. Data calibration

Data calibration is a prerequisite for implementing the qualitative comparative analysis of fuzzy sets. It aims to transform the raw values into fuzzy affiliation scores ranging from 0.0 to 1,0, setting three anchor points for each variable: total affiliation threshold, intersection threshold, and full disaffiliation threshold. Refer to the calibration standards of Du Yunzhou (2017) and Wu Qin et al. (2019) and the actual situation of the case. The upper quartile (25 %), the mean (50 %), and the lower quartile (75 %) were taken as calibration values, respectively, about the academic practice, and the specific calibration anchor points are shown in Table 4.

4.2.2. Necessity test

Before conducting the group analysis, a necessity test of the condition variables is required to determine if any individual factor is necessary to achieve a high emergency preparedness capability. Running with the fsQCA 3.0 software, it can be seen from Table 5 that the level of Consistency for all variables is below 0.9. According to the test proposed by Ragin and Fiss (2008), this suggests that none of the factors alone contribute to an increase in emergency preparedness capability. This reflects the complexity of natural disaster response, so it is necessary to consider the linkage impact of various conditional variables.

4.3. Conditional configuration analysis

The necessity test is to determine whether a certain condition is necessary for the realization of the result. The configuration analysis is the adequacy analysis of whether different configurations composed of multiple antecedent conditions can trigger the result. After data correction and necessity testing, a truth table was created to define the sample distribution. According to the specific research context, different consensus thresholds have been used in existing studies, such as 0.76 (Zhang et al., 2019) and 0.8 (Cheng Cong and Jia Liangding, 2016). Considering the sample size, the case frequency threshold was set to 1, and the consistency threshold was set to 0.8. To reduce inter-configuration contradictions, set the PRI conformance threshold to 0.65. After setting the relevant parameters, Boolean algebra operations are used to obtain the configuration results of high emergency preparedness and non-high emergency preparedness capabilities (See Tables 6 and 7).

4.3.1. Analysis of high emergency preparedness grouping

According to the condition classification of Fiss (2008), the conditions in the parsimonious solution were defined as core conditions. The conditions that appeared in the intermediate solution but were excluded from the parsimonious solution were defined as marginal conditions. Finally, four conditional configurations with high emergency preparedness were obtained. Table 6 shows the explanatory forces of each group of states and the relative importance of each condition variable in different configurations. Schneider and Wagemann (2012) state that the level of agreement in determining adequacy should not be less than 0.75. Specifically, the overall consistency was 0.964, indicating that 96.4 % of the cases meeting these four conditional groupings had high emergency preparedness capabilities. The overall coverage was 0.700, indicating that the four conditional groupings explained 70.0 % of the cases. The consistency and coverage of the solutions are higher than the critical values, indicating that the analysis results are valid. According to the core conditions, the four groupings can be categorized into two models, organization-environment dual-drive and technology-organization-environment triple-drive, which are analyzed below.

(1) Model 1: Organizational and environmental dual-drive type

The organization-environment dual-drive model consists of both H1 and H2. The organizational and environmental dimension play

Table 5
Necessary conditions analysis.

	High emergency preparedness capabilities		Non-high emergency preparedness capabilities	
Conditional variable	Consistency	Coverage	Consistency	Coverage
T1	0.804	0.785	0.412	0.402
~T1	0.388	0.398	0.780	0.799
T2	0.586	0.559	0.624	0.595
~T2	0.576	0.605	0.538	0.565
O1	0.868	0.873	0.320	0.322
~O1	0.326	0.324	0.874	0.869
O2	0.648	0.628	0.458	0.444
~O2	0.426	0.440	0.616	0.636
E1	0.796	0.788	0.390	0.386
~E1	0.380	0.384	0.786	0.794
E2	0.644	0.671	0.422	0.440
~E2	0.462	0.444	0.684	0.658

Table 6
High emergency preparedness capabilities configuration.

Antecedent conditions		Dual drive type		Triple drive type	
		HI	H2	H3	H4
Technical dimension	Technology level	×	×	●	●
	Supporting Infrastructure	×	●	×	●
Organizational dimension	Organization building	●	●	×	●
	Capital investment	×	●	●	●
Environmental dimension	External pressure	●	×	●	●
	Social reactions	●	●	●	×
Consistency		1.000	0.965	0.898	1.000
Original coverage		0.214	0.164	0.176	0.256
Unique coverage		0.172	0.112	0.106	0.228
Overall consistency		0.964			
Overall coverage		0.700			

Note: ● or × is the core condition, ● or × is the edge condition; ● or ● is the condition exists, × or × is the condition does not exist.

Table 7
Non-high emergency preparedness capabilities grouping analysis.

Antecedent conditions		H5	H6	H7
Technical dimension	Technology level	×	●	●
	Supporting Infrastructure	●	×	●
Organizational dimension	Organization building	×	×	●
	Capital investment		×	×
Environmental dimension	External pressure	×	●	×
	Social reactions	×	×	●
Consistency		1.000	1.000	0.957
Original coverage		0.464	0.176	0.132
Unique coverage		0.436	0.154	0.102
Overall consistency		0.992		
Overall coverage		0.724		

Note: ● or × is the core condition, ● or × is the edge condition; ● or ● is the condition exists, × or × is the condition does not exist.

a huge role in this, making governments with such conditions show a good posture in emergency preparedness capabilities. In Model 1, the core conditions are organization building, financial investment, external pressure, and social reaction. In the process of improving emergency preparedness, governments in this category pay more attention to the construction of organizational and institutional systems for "smart" emergency management, the formation of expert teams, the introduction of smart emergency-related policies, the provision of financial support, external natural disaster pressure, and public satisfaction with the government's emergency management efforts. The provincial governments in this development model focus on top-level design, organizational change, financial support, environmental change, and citizen needs. They captured the internal needs and external pressures for smart government emergency management change and followed the objective laws of government governance, both internally and externally. This

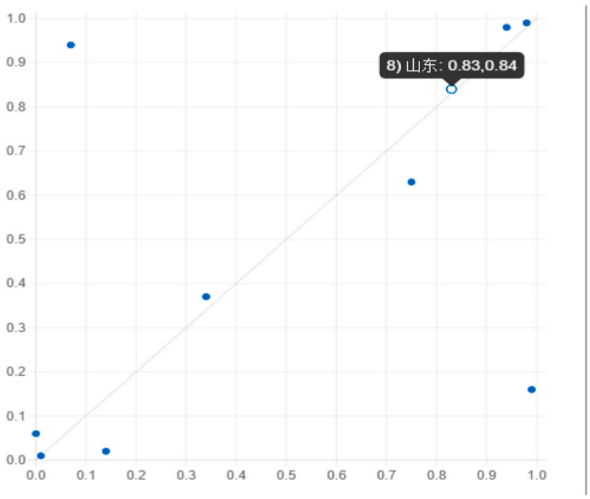

Fig. 2. Explanation example of H1.

paper's conditional groupings with such characteristics are collectively called organization-environment dual-drive (organization-driven dual-drive and environment-driven dual-drive). However, H1 and H2 also show certain differences and a specific analysis follows.

H1. Environment-driven dual-drive– Smart emergency development path using Shandong Province as a template

H1 (~Technology levell,~Supporting Infrastructure, Organization building, External pressure, Social reactions) Organizational building, external pressure, and social response as the core conditions. Specifically, the environmental dimension plays a significant leading role. H1 shows that under the high pressure of natural disasters, if the government attaches importance to organizational building and social response, its emergency preparedness for natural disasters can be maintained at a high level, even if the technical level and infrastructure are weak. The consistency of H1 is 1.00, indicating reliable explanatory power. The coverage of the solution is 0.214, indicating that the conditional configuration existed in nearly 21.4 % of cases with high emergency preparedness and the only coverage reached 0.172. The analysis of the results shows that the smart emergency model in Shandong Province fits well with H1 (see Fig. 2). Specifically, the Shandong provincial government's technical level and synchronous supporting facilities score are in the middle and lower reaches, ranking fifth and ninth among the ten smart emergency pilot provinces. But its organizational construction, external pressure, and social response scored high. In 2020, Shandong Province lost 10.25 billion yuan due to natural disasters. Under such a severe external environment, a close cooperation model of emergency management informatization in Shandong Province was explored. The province has formed a leading group for the promotion of informatization, which is synchronized from top to bottom. All 24 tasks, including command information network, knowledge base, and natural disaster risk detection and early warning, have been completed and used. Responsible departments and units jointly promote the construction of each smart emergency pilot work.

H2. Organization-driven dual-drive– Smart emergency development path using Anhui Province as a template

H2 (~Technology level, Organization building, Capital investment, Social reactions) Organization building, financial investment, and social reactions are the core conditions, and the organizational dimension plays a leading role. H2 shows that if the government attaches importance to organizational system building and social repercussions, and has strong financial support, its emergency preparedness for natural disasters can be maintained at a high level, even if the level of digital technology is weak. The consistency of H2 is 0.965, indicating solid explanatory power. The coverage of the solution is 0.164, indicating that the conditional configuration existed in nearly 16.4 % of cases with high emergency preparedness and the only coverage is 0.112. Anhui Province's smart emergency development model fits well with H2 (see Fig. 3). It ranks low among the ten pilot smart emergency provinces regarding digital technology level but ranks high regarding financial investment and social response. 2020 Throughout the year, Anhui province spent 5.781 billion yuan on disaster prevention and emergency management and launched 24 emergency management-related policies. Although technologies such as big data, edge computing, algorithm models, and IoT perception are not deeply applied, a benign working mechanism has been established. The science and information department has a benign working mechanism for overall coordination, review and control, and has set up an information-based operation and maintenance support team and monitoring team. Anhui Province has built an "all-field" smart monitoring and early warning system and an "all-round" smart mobilization mechanism. This has formed a new smart emergency response model of global perception, dynamic research and judgment, rapid disposal, and accurate service. Promote the modernization of emergency management with informatization.

(2) Model 2: Technology-organization-environment triple-drive type

The technology-organization-environment triple-drive type contains H3 and H4, where the technology, organization, and environment dimension all play a role in the high emergency preparedness grouping. In Model 2, the core conditions are technical level,

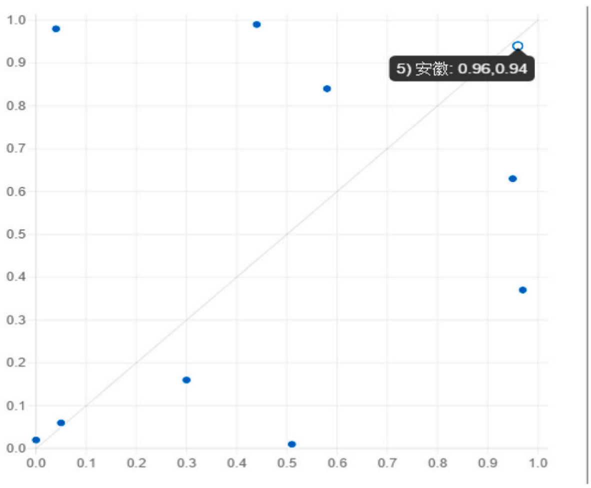

Fig. 3. Explanation example of H2.

organization building, capital investment, external pressure and social reactions. Compared with Mode 1, Mode 2 emphasizes data sharing, builds a highly integrated emergency management big data resource pool, and builds a unified and comprehensive emergency management platform. The government under this development model attaches importance to the overall breakthrough role of science and technology, and has a high technical level. They also recognize the intrinsic supporting role of the organizational level in enhancing emergency preparedness capabilities and give sufficient support in terms of organizational system construction and financial resource supply. They also pay attention to the external influence of environmental pressure and citizens' demands. This article refers to configurations with such characteristics as the technology-organizational-environment triple-drive type (environment-driven triple-drive, organization-driven triple-drive). However, H3 and H4 also show certain differences and a specific analysis follows.

H3. Environment-driven triple drive– Smart emergency development path using Guangdong Province as a template

H3 (Technology level,~Supporting Infrastructure, Capital investment, External pressure, Social reactions) Technology level, capital investment, external pressure, and social response are the core conditions, and the environmental dimension plays a significant leading role. H3 shows that under the high pressure of natural disasters, if the government has a high technical level, strong financial support and good social response, its emergency preparedness for natural disasters can be maintained at a high level, even if the synchronous supporting facilities are not in place. The consistency of model 3 is 0.898, indicating a strong explanatory power. The coverage of the solution is 0.176, indicating that the conditional configuration is present in 17.6 % of the cases with high emergency preparedness, with a unique coverage of 0.106. Guangdong Province's smart emergency development model fits well with H3 (see Fig. 4). The province's synchronous supporting facilities ranked eighth among the ten smart emergency pilot units, and there were few provincial conventional meteorological observation stations and macro observation points of seismic monitoring points. But it is in the middle and upper reaches of the technical level, financial investment and social response. Finally, the prevention and emergency preparedness capability scores first. Guangdong Province adopts the technical route of microservice architecture, data visualization services, intelligent auxiliary decision-making technology with multi-source information overlay, and extensive data analysis and image intelligence recognition technology to realize the convergence of resources in the province.

H4. Organization-driven triple drive–Smart emergency development path using Jiangsu Province as a template

The core conditions are technology level, organization building, capital investment, and external pressure, the organizational dimension plays a leading role in this H4 (Technology level, Organization building, Capital investment, External pressure). H4 shows that the government can maintain a high level of emergency preparedness for natural disasters even under high pressure of natural disasters if it has a high level of technology and adequate support in terms of financial resources supply and institutional set-up. The consistency of H4 is 1.00, indicating solid explanatory power. The coverage of the solution is 0.256, indicating that the conditional configuration is present in 25.6 % of the cases with high emergency preparedness, with a unique coverage of 0.228. The model of smart emergency development in Jiangsu Province fits well with H4 (see Fig. 5). It can be said that Jiangsu Province is an all-round type in the development of emergency management, and it blooms at multiple points. It not only has a high technical level, but also has excellent organizational construction, strong financial support, and a good social and cultural atmosphere. The technical level of Jiangsu Province ranks first among the ten pilot units of smart emergency. It has built an air-space-ground integrated emergency tactical Internet, a resource pool that gathers a large amount of basic data, and a provincial comprehensive application platform for emergency management. Regarding organization and construction, the information technology work is consistent up and down but also considers the regional aspects, forming a "provincial unified construction, graded deployment, and respective expansion" operation mechanism.

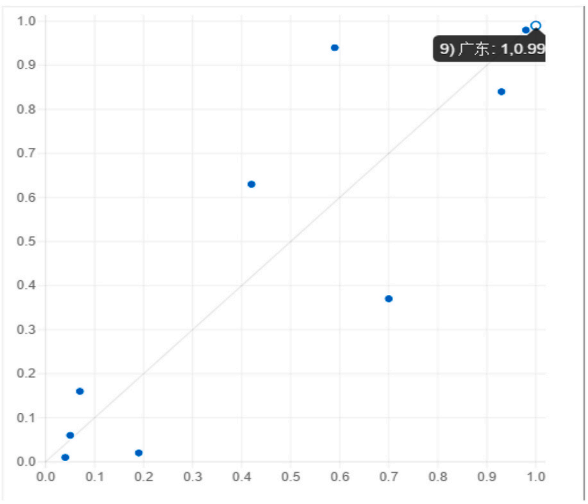

Fig. 4. Example of explanation of H 3.

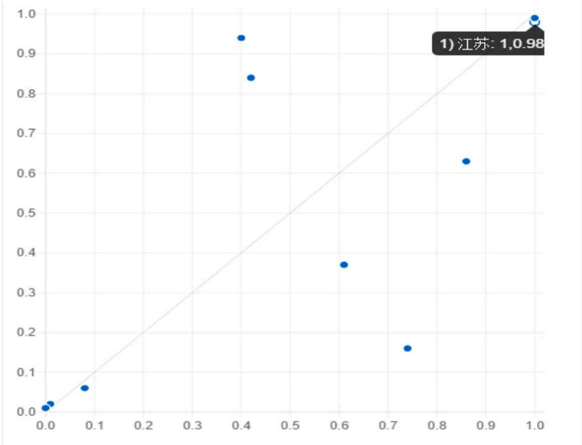

Fig. 5. Example of explanation of H4.

4.3.2. *Substitution effects in high emergency preparedness configurations*

(1) In Model 1, external pressure and financial support can be substituted for each other. Comparing H1and H2, we can see that when the government's organization building and social response are at a high level, and the technical level is weak, as long as one of the two is at a high level, the emergency preparedness capability also shows a high level. It can be shown that external pressure and financial support are among the core conditions for high emergency preparedness capacity. However, neither is enough to promote high emergency preparedness alone. Good organization building and social reaction are needed as other core conditions to promote high emergency preparedness capacity together.
(2) In Model 2, organization building and social response can be substituted. Comparing H3and H4, we can see that when the government's technical level, financial investment, and external pressure are high, organization building and social reaction can improve emergency preparedness by focusing on one of them. It can be shown that organization building and social reaction are core conditions for high emergency preparedness, but neither is necessary for high emergency preparedness. Strong technical level, financial support, and external solid pressure are needed as other core conditions interact with each other to promote high emergency preparedness capacity.

4.3.3. *Non-high emergency preparedness capacity grouping analysis*

Further testing of the configuration that yields non-high emergency preparedness capabilities, there are three paths. The overall consistency reached 99.2 % and the overall coverage reached 72.4 %. H5 indicates that the government's lack of organization and low public satisfaction with it will lead to insufficient emergency preparedness. The original and unique coverage of 0.464 and 0.436 for H5 are significantly higher than H6 and H7. Indicating that H5 is the leading cause of the government's lack of emergency preparedness. Comparing H6 and H7 reveals that inadequate funding may be a key factor in the government's inadequate emergency preparedness capacity. Comparing the high emergency preparedness grouping with the non-high emergency preparedness grouping reveals that the two are not located opposites. Leading to the non-high emergency preparedness of the government is not the opposite of prompting the high emergency preparedness of the government, and the two have asymmetrical characteristics.

4.3.4. *Robustness test*

The qualitative comparative analysis of fuzzy sets can be done by adjusting the consistency thresholds to do robustness tests. According to the existing research results, this paper adjusts the consistency threshold and reprocesses the sample data. The consistency threshold is adjusted from the original 0.65 to 0.70. The configuration obtained at a consistency threshold of 0.70 is the same as the configuration obtained at 0.65, consistent with the previous conclusion. This can indicate that the research conclusions drawn in this paper are relatively robust.

5. Conclusion and discussion

5.1. *Research findings*

Based on TOE theory, this paper constructs an analysis framework for government natural disaster emergency preparedness capability, and establishes an evaluation system for it. Take 10 ″smart emergency" pilot units in China as the research object. Use principal component analysis and entropy value method to measure the emergency preparedness scores of pilot units of smart emergency. Explore the path of improving governmental natural disaster emergency preparedness capability from a group perspective using the fsQCA method. The following conclusions were drawn:

(1) No single factor directly contributes to high natural disaster emergency preparedness capability. The level of technology level, supporting infrastructure, organization building, capital investment, external pressure and social reactions cannot be necessary for high natural disaster emergency preparedness capability. Multiple conditions interact and synergize to form a practical path to enhance the government's natural disaster preparedness capability. This indicates that a simple linear innovation model cannot improve natural disaster emergency preparedness capability. The interpenetration and proper flow between the technical, organizational, and environmental dimensions can effectively improve the government's emergency preparedness capability.

(2) There exist two models for enhancing natural disaster emergency preparedness capability, which is organization-environment dual-drive and technology-organization-environment triple-drive. They contain four paths for enhancing natural disaster emergency preparedness, which is environment-driven dual-drive, organization-driven dual-drive, environment-driven triple-drive, and organization-driven dual-drive. The organizational layer and the environmental layer play an important role in the dual-drive lifting mode, which is different from previous studies. Qiu Zeqi found that technology and organization are the main factors affecting the level of smart city governance [47]. Most scholars also emphasize the important role of technology in enabling smart governance, and digital technology has become an important tool to accelerate the intelligent transformation of society [48], which can effectively improve urban operation efficiency and social governance innovation [49]. In the triple-drive lifting mode, the technical layer becomes an integral part, which is also consistent with existing research. Technology infrastructure is an important part of smart empowerment and digital governance[50, 51]. Technological infrastructure can effectively reduce the transaction cost and information cost of policy formulation, reduce the risk of failure in policy implementation, and provide successful lessons to better coordinate organizational behavior [52].

(3) There are substitution effects in the high natural disaster emergency preparedness grouping. In model 1, external pressure and financial investment substitute for each other. In model 2, organizational construction and social reactions substitute for each other. Li Jiangping also found that there is a substitution effect between conditional variables at the organizational and environmental levels in his study of the development path of provincial government big data in China.

(4) Meanwhile, this paper finds three non-high natural disaster emergency preparedness paths, all of which are characterized by insufficient financial investment. Lack of organizational construction and low social response are also non-high core conditions. This is similar to previous studies, Li Youdong et al. found that the lack of organizational construction is one of the core conditions for low-level smart city governance.

(5) Comparing the high emergency preparedness grouping with the non-high emergency preparedness grouping reveals that the two are not located in opposites. Leading to the fact that the non-high emergency preparedness of governments is not the opposite of prompting the high natural disaster emergency preparedness of governments. The two have asymmetrical characteristics. Each locality should choose an appropriate strategy to enhance its natural disaster emergency preparedness capacity according to its technical, organizational, and environmental configuration.

5.2. Management insights

(1) Empowering the digitalization of smart emergency management

Public decision-making has gradually entered the era of “predictive decision-making”. Smart-enabled emergency management can meet the requirements of using big data and innovative technology to trace the source of risk. Advances in technologies such as the IoT and new media have brought about unprecedented data scale and transmission efficiency, which need to be considered in emergency management. Especially in the environment of sudden and multiple concurrent natural disasters, using big data to collect, analyze and process multi-source heterogeneous data can compensate for the need for emergency management and preparedness capabilities. Therefore, it is necessary to rationally and adaptively use cloud computing, big data, Internet of Things, mobile Internet, artificial intelligence and other technologies to improve emergency preparedness capabilities. Promote the construction of e-government and actively explore the operational mechanism of discussing things with data. In applying big data for natural disaster emergency management, anything can be a source of data, requiring more data authenticity. In response to natural disasters, the use of intelligent technologies to monitor real-time data through the full-coverage information platform for unified management of the total sample of data. The government can find early possible “sources of alarm” and potential disaster warning information, research, and judgment and effectively trace the source of natural disaster risks.

(2) Improve the smart emergency management system

First, it is necessary to break down departmental information silos and integrate information systems to realize the sharing of government emergency resources. If the information is fragmented, it is not easy to form a coordination effect, which will bring more problems to emergency management. Therefore, digital and intelligent technologies should be used to assist communication and collaboration between departments. In addition, emergency managers need to establish big data awareness and broaden their data thinking. Systematically learn about natural disaster generation and its evolution mechanism, disaster prevention, and continuously improve the ability to capture disaster information and monitor early warning. The occurrence and evolution of natural disasters are fleeting, so we should respond quickly and take decisive and effective measures to the requirements of natural disaster emergency plans. Second, the disaster risk and loss assessment system should be improved. This can be done in the following two ways: 1) Build a professional team for disaster assessment. Establish a training system for disaster assessment professionals and promote comprehensive risk assessment of natural disasters. According to the level of economic development and disaster risk of each region, determine a reasonable budget for disaster prevention and mitigation expenditure. 2) Establish a standardized content system for natural disaster damage assessment. It can be done through consultation, expert forums, and simulation exercises in disaster-prone areas based on the damage assessment cases of major natural disasters around the world in recent years. Big data can help us process these data and make emergency management more scientific and precise. We also need to explore the characteristic model of smart emergency management according to local conditions.

(3) Insist on the diversification of the main body of smart emergency management

In the emergency management of natural disasters, it is necessary to obtain the support and participation of the public and adhere to the diversification of emergency management subjects. First, emergency knowledge education for the public should be strengthened through both online and offline processes. On the one hand, through risk identification and emergency education for the public, the general public should be made aware of the hazards of natural disaster-like emergencies; on the other hand, the public's awareness of emergency management measures should be enhanced so that the public can participate in emergency rescue after emergencies while ensuring their safety. Secondly, improve social participation with the support of intelligent technology to form a whole for effectively disposing of natural disaster-like emergencies. Big data can be used to solve problems and give the public as much information as possible on how to use smart devices to send location or feedback in an emergency. Personalized and personalized emergency information advice is pushed to enable the public to find the best path to self-help in a crisis. The application of big data technology can effectively control the impact of emergencies on the safety of public life and property, enable emergency management departments to play a more significant role in reaping the expected results of disaster prevention and mitigation. This will form positive feedback to draw in more diverse social forces into smart emergency management.

5.3. Shortcomings and prospects

1. Identifying factors influencing natural disaster emergency preparedness needs to be more comprehensive. Limited by the QCA method and the availability of data, only six conditional variables were selected in this paper. Future studies may add or subtract conditional variables as appropriate to improve the method and reveal more comprehensively the impact of multi-factor combinations on natural disaster emergency preparedness.
2. This paper only explores the static relationships between the level of technology, supporting infrastructure, organizational development, financial investment, external pressure, social repercussions, and natural disaster emergency preparedness capabilities. Future research can try the time-series QCA approach of system dynamic evolution over time. Explore the dynamic evolutionary process of multiple conditions driving the improvement of natural disaster emergency preparedness capacity.

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Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Wei Liu: Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Jiayu Qian:** Writing – original draft, Software, Methodology, Investigation. **Songjiang Wu:** Supervision, Funding acquisition.

Declaration of competing interest

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