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Evaluating Earthquake Resilience through a Quantitative Decision-Support Index: An ND-GAIN-Based Assessment of China's Vulnerability and Preparedness

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ABSTRACT

A quantitative decision-support framework was established to improve the scientific robustness and precision of resource allocation for earthquake prevention and disaster reduction. Based on the Notre Dame Global Adaptation Index (ND-GAIN) model, the framework systematically evaluates China's Earthquake Disaster Prevention and Reduction Capability Index (CEDPRCI) from two principal dimensions: the vulnerability of disaster-prone bodies and their preparedness. By integrating these dimensions, the framework provides a model-based basis for formulating differentiated prevention and reduction strategies. The results show that, despite temporal fluctuations and notable gains towards the end of the study period, China's earthquake prevention and disaster reduction capability remained at a lower-middle level between 2014 and 2023. Infrastructure vulnerability constituted the dominant factor influencing the vulnerability of disaster-prone bodies, while preparedness in terms of social and economic capital played a particularly important role in strengthening overall earthquake prevention and disaster reduction capability. Regional and provincial capabilities improved over time; however, pronounced spatial disparities persisted. Comparatively stronger capabilities were generally observed in the eastern region, whereas the northern region displayed weaker performance. At the provincial scale, Sichuan and Shandong exhibited relatively high capabilities, while Ningxia and Jilin remained among the provinces with comparatively limited capabilities.

1. Introduction

China is among the countries with considerable exposure to earthquake hazards worldwide. Major seismic events have repeatedly resulted in substantial losses of life and damage to housing and infrastructure, while also disrupting regional development. In 2023, the magnitude 6.2 Jishishan earthquake in Gansu Province resulted in 151 deaths and 983 injuries across Gansu and Qinghai. Approximately 70,000 houses collapsed, 99,000 sustained serious damage, and 252,000 experienced general damage, with direct economic losses estimated at CNY 14.612 billion [1]. In

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2024, the Chinese mainland experienced 25 earthquakes of magnitude 5.0 or above, concentrated mainly in Xinjiang. Among these events, the magnitude 7.1 Wushi earthquake caused three deaths and led to the collapse of more than 900 houses. Overall, earthquake disasters across China during 2024 affected approximately 114,000 people, damaged around 63,000 houses, and resulted in direct economic losses of CNY 3.79 billion [2].

The significance of these events extends beyond their immediate human and economic impacts. They have revealed persistent weaknesses in the seismic resilience of buildings in both urban and rural areas, alongside limitations in existing emergency response mechanisms. Such deficiencies create a critical decision-making challenge: determining how limited resources can be directed towards the most vulnerable components of the national disaster prevention system. In response, the Chinese government has placed substantial emphasis on disaster prevention and mitigation through a series of policy measures intended to strengthen national earthquake prevention and disaster reduction capability. For example, the 14th Five-Year Plan for National Comprehensive Disaster Prevention and Reduction identifies the comprehensive improvement of China's earthquake prevention and disaster reduction capabilities as a key objective. Complementary measures have also been introduced at the regional level, including the Implementation Plan for Strengthening Building Facilities in Earthquake-prone Areas. Collectively, these initiatives aim to improve the seismic resistance of housing and infrastructure, thereby reducing earthquake-related risks and potential hazards.

Nevertheless, translating broad national policy objectives into targeted and efficient resource-allocation decisions remains a significant challenge. To bridge this gap, the present study develops a decision-support framework for evaluating earthquake prevention and disaster reduction capability. The framework is conceptually grounded in the Notre Dame Global Adaptation Index (ND-GAIN) and constructs a quantitative decision model around two principal dimensions: the vulnerability of disaster-prone bodies and their level of preparedness. Combining these dimensions within a composite index enables complex, multidimensional information to be transformed into an interpretable quantitative measure [3], allowing earthquake prevention and disaster reduction capability to be examined systematically across locations and over time. More specifically, the proposed decision analytics framework supports strategic decision-making by identifying critical areas of vulnerability and revealing spatial disparities, thereby providing an evidence-based foundation for directing limited disaster prevention and reduction resources more effectively.

2. Status of Research on Earthquake Prevention and Disaster Reduction Capability

Against the background of the International Decade for Natural Disaster Reduction (IDNDR) and the International Strategy for Disaster Reduction (ISDR), earthquake prevention and disaster reduction capability has been investigated from diverse analytical perspectives. One established seismic-resilience framework represents community resilience through technical, organisational, social, and economic dimensions, with resilience characterised by robustness, redundancy, resourcefulness, and rapidity [4]. Economic approaches have instead focused on the effects of lifeline-service interruptions and the ability of regional economies to withstand and recover from disaster-induced shocks [5; 6]. Multidimensional assessments of urban seismic vulnerability have incorporated socio-economic characteristics, structural conditions, site characteristics, and access to essential services [7]. At the global level, probabilistic seismic-risk modelling combines hazard, exposure, fragility, and vulnerability information to estimate potential earthquake losses and inform risk-reduction decisions [8]. Local-government earthquake disaster-risk-reduction capacity has also

been investigated in Malaysia, revealing critical capacity deficiencies and variations among localities [9].

At the community level, earthquake disaster management research has increasingly emphasised adaptive capacity. Community resilience has been represented through interconnected capacities related to economic development, social capital, information and communication, and community competence, thereby connecting pre-disaster preparedness with post-disaster adaptation [10]. This approach was subsequently broadened through community-based earthquake disaster management (CBEDM), which incorporates social, environmental, and political dimensions. Within this framework, residents' preferences, adaptive behaviour, and willingness to participate in CBEDM scenarios were quantified to enable disaster-management strategies to correspond more closely with community preferences [11]. Quantitative assessment represents another major strand of research on earthquake prevention and disaster reduction capability. Composite evaluation systems have assessed urban capability through indicators such as casualties, economic losses, and post-earthquake recovery time, while incorporating multiple factors that influence overall performance [12].

Analytical resilience models have similarly measured post-earthquake performance by examining functionality loss and subsequent recovery trajectories, explicitly relating the recovery process to technical and human resources, societal preparedness, and public policy [13]. More recent frameworks for urban seismic emergencies encompass the entire disaster-management cycle, including mitigation, preparedness, response, and recovery [14]. Decision-support systems have also been developed to facilitate the hierarchical distribution of disaster-management resources and responsibilities [15]. Spatially focused studies have examined earthquake prevention and disaster reduction capability at both city and county scales using place-based and quantitative approaches. Place-based resilience frameworks integrate social, economic, institutional, infrastructure, and community indicators to establish baseline capacities, facilitate comparisons among localities, and reveal spatial disparities [16]. In Gansu Province, county-level assessments have evaluated earthquake prevention and disaster reduction capability while examining the contributions of environmental conditions, infrastructure, and resource support [17]. Research conducted across counties affected by the Wenchuan earthquake has quantified resilience using demographic, social, economic, health, and social-welfare indicators, identifying factors including sex ratio, per-capita GDP, and medical facilities as important determinants [18]. At a finer urban scale, seismic vulnerability has been spatially mapped by combining building fragility with socioeconomic characteristics, building and population densities, and accessibility to assembly areas [19].

Specific components of earthquake prevention and disaster reduction capability have also received considerable attention, particularly the planning of emergency shelters. Mixed-integer and geographic information system (GIS)-based decision models have supported temporary shelter selection by considering site capacity, allocation of affected populations, accessibility, and utilization [20; 21]. Multi-criteria approaches have further incorporated safety, connectivity, accessibility, and land-use suitability into shelter location-allocation decisions [22]. Systematic reviews of post-earthquake shelter planning consistently identify accessibility, proximity to affected populations, site size, distance from hazardous areas, access to medical services, water availability, and security as important criteria for site selection [23]. Drawing on these considerations, multi-criteria, multi-objective, and multi-scenario location-allocation models have been developed to guide the renovation and expansion of earthquake emergency shelters [22]. Network-based multi-

criteria optimisation approaches have likewise been applied to strengthen the efficiency of post-earthquake shelter deployment [24].

Table 1

Statistics of Different Index Systems

Method	Target Layer	Indicator Level
Cimellaro et al. [13]	Disaster resilience	Functionality loss and recovery; technical and human resources; societal preparedness; public policy
Cutter et al. [25]	Community disaster resilience	Social, economic, institutional, infrastructure, and community capacities
Zhang et al. [12]	Urban earthquake prevention and disaster reduction capability	Seismic hazard assessment; monitoring and prediction; engineering resistance; socio-economic and non-engineering capacity; emergency and recovery capability
Wang et al. [14]	Urban seismic emergency capability	Mitigation, preparedness, response, and recovery
Chen et al. [17]	County-level earthquake prevention and disaster reduction capability	Environmental support, infrastructure support, and resource support
Li et al. [18]	County earthquake resilience	Demographic, social, economic, health, and social-welfare indicators
Ma et al. [22]	Earthquake emergency shelter planning	Safety, connectivity, accessibility, and land-use suitability
Kilci et al. [20]	Temporary post-earthquake shelter planning	Shelter location, capacity, affected-population assignment, and utilisation
Soltani et al. [23]	Post-earthquake shelter site selection	Accessibility, site size, hazard separation, medical services, water supply, security, and feasibility

Table 1 summarises the indicators employed in existing evaluation systems for assessing earthquake prevention and disaster reduction capabilities. Previous studies have addressed a wide range of application contexts, encompassing not only urban areas but also counties, non-engineering measures, and emergency shelters. This breadth demonstrates the importance of evaluating such capabilities across varying geographical contexts and facility types. Another prominent feature of the literature is the widespread adoption of hierarchical indicator structures, in which multi-level systems are used to organise and assess the numerous factors influencing earthquake prevention and disaster reduction capabilities. The selection of indicators has also evolved from multiple perspectives, including interpretations of disaster prevention and reduction, different phases of earthquake disasters, and the natural characteristics of seismic events. Accordingly, capability assessments have progressively expanded beyond the physical properties of earthquakes to account for social, economic, cultural, and other contextual factors.

These characteristics of the literature give rise to two central research questions. First, can an alternative indicator system and evaluation model be constructed to assess China's earthquake prevention and disaster reduction capabilities by introducing additional dimensions? Second, can the fundamental concept underlying a disaster resilience index be incorporated into the evaluation process to quantify these dimensions and construct an integrated model for systematically assessing China's earthquake prevention and disaster reduction capabilities? These questions constitute the primary motivation for the present study. Growing scholarly interest has focused on disaster-resilience indices and benchmarking frameworks as instruments for comprehensive assessment [25-29]. A representative example is the disaster resilience index developed by the University of Notre Dame in the United States. ND-GAIN evaluates, at the national level, the capacity

of countries or regions to withstand and adapt to climate-related hazards [26]. Its framework is organised around two principal dimensions. Vulnerability is assessed through food, water, health, ecosystem services, human habitat, and infrastructure, whereas readiness encompasses economic, governance, and social readiness [26]. Other disaster-resilience frameworks similarly recognise the importance of multidimensional capacities spanning social, economic, institutional, infrastructure, community, and environmental domains [25; 27-29].

The relevance of ND-GAIN to the development of a seismic-resilience decision-support model can be considered from both conceptual and decision-making perspectives. Conceptually, systemic risk is represented through vulnerability, reflecting exposure and sensitivity, alongside preparedness, which captures adaptive capacity. This structure offers a transferable basis for examining disaster risk. Earthquakes can produce severe consequences when vulnerabilities exist within physical and social systems, while the extent of resulting losses is also shaped by the preparedness of affected societies. This interaction is closely aligned with the conceptual architecture of ND-GAIN. From a decision-making perspective, a further advantage lies in its capacity to consolidate multidimensional information into a composite index. Quantification in this form enables benchmarking, analysis of temporal trends, and comparative prioritisation, thereby supporting the allocation of limited resources and the development of targeted disaster risk reduction policies. Adapting this structure consequently enables CEDPRCI to serve not merely as a descriptive measure, but as a structured decision-analytic instrument for determining priorities and directing interventions towards areas facing elevated risk.

Drawing on the conceptual architecture of ND-GAIN, the present study contextualises its fundamental principles for application in China. The vulnerability of disaster-prone bodies and preparedness are therefore established as the two fundamental dimensions underpinning an index-based evaluation system and model, supplemented by relevant indicator structures identified in previous research. This constitutes the third motivation for the study. Through this framework, the study seeks to systematically evaluate China's earthquake prevention and disaster reduction capability, investigate the spatiotemporal patterns and evolutionary trends of CEDPRCI, identify the principal constraints affecting capability development, and propose targeted policy recommendations to further strengthen national earthquake prevention and disaster reduction capability.

3. Evaluation System of Earthquake Prevention and Disaster Reduction Capability Index in China

The study is aligned with the 14th Five-Year Plan for National Comprehensive Disaster Prevention and Reduction, the Modernization Outline for Earthquake Prevention and Reduction in the New Era (2019-2035), and the Top-level Design Plan for the Reform of the Earthquake Disaster Risk Prevention and Control System. Its methodological basis integrates disaster system theory, the ND-GAIN framework, and multidimensional disaster-resilience concepts, complemented by evidence from relevant English-language research on seismic resilience and emergency capability [4; 12-19; 25-30]. Building on these foundations, CEDPRCI is constructed to enable a systematic assessment of national earthquake prevention and disaster reduction capability. CEDPRCI comprises two complementary sub-indices representing distinct dimensions of disaster resilience: The Earthquake Vulnerability Index (EVI) and the Earthquake Preparedness Index (EPI) of disaster-prone bodies, as detailed in Table 2. Table 3 provides the complete set of symbols and abbreviations used throughout the study.

Table 2

The Indicator System Alternative Library of China's Earthquake Disaster Prevention Reduction Capability

First-Level Indicator	Secondary Indicator		Third-Level Indicator			
The Vulnerability of Disaster-Prone Bodies	Population Vulnerability		Exposure Population density [18; 30] Proportion of urban population [18; 30] Proportion of rural population [25; 30]	Sensitivity Proportion of vulnerable groups [19; 30] Illiteracy rate [30; 31] Proportion of female population [19; 30]	Adaptability Proportion of working-age population (15-64 years) [18; 30] Proportion with high-school education or above [18; 25]	
	Infrastructure Vulnerability	Building (structure)	Expected building-loss density (CNY 10,000/km²) [8; 32] Building density [19; 30] Building floor-area density [19; 30]	Building structural type [8; 19; 30]	Seismic resistance and code compliance of buildings [14; 19; 30]	
		Lifeline Engineering	Density of lifeline engineering pipelines [4; 33] Road network provision / per-capita road area [25; 30] Number or density of bridges [4; 30] Infrastructure stock / fixed assets [25; 27]	Number of large reservoirs or dams [34] Number of hazardous industrial facilities [35]	Seismic resistance of lifeline systems (water, electricity, gas) [4; 33] Communication-network coverage [10; 25] Emergency shelters and assembly areas [20; 23] Construction governance and regulatory capability [14; 25]	
	Ecological Vulnerability		Seismic intensity and fault-zone exposure [8; 32]	Frequency of moderate-to-strong earthquakes [8; 32]	Per-capita urban green space [19; 27] Green coverage of built-up areas [19; 27] Forest / vegetation cover [27] Disaster-risk-reduction and environmental-protection expenditure [14; 25]	
	The Degree of Preparedness	Social Capital		Earthquake emergency rescue capability [14; 31] Medical assistance capacity (institutions and beds per 10,000 people) [18; 25] Employment [18; 25] Education [18; 25; 31] Social-security and health-insurance coverage [25] Social donations and volunteering [10; 31] Residents' disaster-awareness, education, and training [11; 35]		
		Economic Capital		GDP [18; 27] Per-capita GDP [18; 25] Per-capita disposable or household income [19; 25] Per-capita savings [18] Disaster-prevention investment / fiscal capacity [14; 25] Share of secondary and tertiary industries [18] Catastrophe / household insurance coverage [36]		
		Physical Capital		Seismic monitoring-network coverage [37; 38] Number / density of earthquake observation stations [37; 38] Earthquake emergency material reserves [14; 31]		
		Human Capital		Number of earthquake emergency rescue teams / personnel [14; 31] Specialised disaster-reduction researchers and technical personnel [4; 14; 39] Construction and engineering human resources [4; 25; 39] Working-age population share [18; 25]		

The vulnerability dimension reflects the degree to which disaster-prone bodies are exposed and susceptible to adverse impacts and is therefore inversely related to earthquake prevention and disaster reduction capability. Seismic risk arises not only from the occurrence and characteristics of earthquakes but also from the exposure and vulnerability of populations, buildings, infrastructure, and the broader built environment. International studies of earthquake vulnerability have consistently recognised demographic susceptibility, building fragility, urban density, and lifeline-system performance as major determinants of seismic vulnerability [7; 8; 19; 30; 32; 33]. Based on these considerations, this study evaluates the vulnerability of earthquake disaster-prone bodies across three dimensions: population, construction engineering, and ecological environment. Preparedness, in contrast, reflects the resources and capabilities available within a system or disaster-prone body to respond effectively to natural hazards. Higher levels of preparedness contribute to greater disaster resilience through economic, social, institutional, infrastructure, communication, and community capacities [10; 25-29]. Regional preparedness is assessed using the Sustainable Livelihoods Framework (SLF), which is commonly structured around five forms of capital: human, social, natural, physical, and financial/economic capital [39]. Given the comparatively limited direct contribution of natural capital to operational earthquake preparedness within the present index design, the assessment focuses on four forms of capital: social, economic, physical, and human capital.

Table 3

Nomenclature

Abbreviations		
ND-GAIN		Notre Dame Global Adaptation Index
CEPDRCI		China's Earthquake Prevention and Disaster Reduction Capability Index
EVI		Earthquake Vulnerability Index
EPI		Earthquake Preparedness Index
PV		Population Vulnerability
IV		Infrastructure Vulnerability
EV		Ecological Vulnerability
SP		Social Capital
EP		Economic Capital
PP		Physical Capital
HP		Human Capital
Symbols		
	x_{ij}	The value of the j -th indicator standard of the i -th evaluation object
	v_{ij}	The original value of the j -th indicator standard of the i -th evaluation object
m		The number of objects evaluated as indicators
	r_{ij}	The correlation coefficient between the i -th and j -th indicators
	z_{ij}	The value of the k -th indicator of the i -th evaluation object
	$\bar{z}_i$	The average value of the i -th indicator
H		The amplitude of indicator translation
	e_j	The entropy value of the j -th indicator
	d_j	The information entropy redundancy (coefficient of variation) of the j -th indicator
	w_j	The weight values of the j -th indicator

3.1 Preliminary Screening of China's Earthquake Prevention and Disaster Reduction Capability Index Evaluation System

The preliminary screening process focused on retaining indicators that were measurable, empirically supported by available data, and sufficiently independent from one another. Indicators were excluded when the necessary data were unavailable, dependable quantification was not

feasible, or adequate reliability and validity could not be established. This process strengthened both the practical applicability and methodological robustness of the initial evaluation system.

3.1.1 Standardization Processing of Indicator Data

As an initial step, all indicator data are standardised to eliminate the influence of differing measurement scales and dimensions on the evaluation results. When observations for a particular province and year are unavailable, the missing values are estimated using linear interpolation. Indicators positively associated with earthquake prevention and disaster reduction capability are subjected to positive-direction standardisation, while those exhibiting an inverse relationship are treated using negative-direction standardisation. The standardisation equations applied to positive and negative indicators are presented below:

$$x_{ij} = \frac{v_{ij} - \min_{1 \leq i \leq m}(v_{ij})}{\max_{1 \leq i \leq m}(v_{ij}) - \min_{1 \leq i \leq m}(v_{ij})}, \quad (1)$$

$$x_{ij} = \frac{\max_{1 \leq i \leq m}(v_{ij}) - v_{ij}}{\max_{1 \leq i \leq m}(v_{ij}) - \min_{1 \leq i \leq m}(v_{ij})}, \quad (2)$$

Where, x_{ij} is the value of the j -th indicator standard of the i -th evaluation object; v_{ij} is the original value of the j -th indicator standard of the i -th evaluation object; m is the number of objects evaluated as indicators.

3.1.2 Correlation Analysis of Indicator Screening

After standardizing the data of each indicator, the correlation coefficient r_{ij} is calculated for correlation analysis to evaluate the degree of correlation between each indicator and eliminate indicators with strong correlation. The calculation formula is:

$$r_{ij} = \frac{\sum_{k=1}^n (z_{ki} - \bar{z}_i)(z_{kj} - \bar{z}_j)}{\sqrt{\sum_{k=1}^n (z_{ki} - \bar{z}_i)^2 (z_{kj} - \bar{z}_j)^2}}, \quad (3)$$

Where, r_{ij} is the correlation coefficient between the i -th and j -th indicators, z_{ki} is the value of the k -th indicator of the i -th evaluation object, and $\bar{z}_i$ is the average value of the i -th indicator. Secondly, set a critical value $M=0.8$, and if $|r_{ij}| \geq M$, delete one of the indicators; If $|r_{ij}| < M$, both are retained. Pearson correlation analysis is conducted using SPSS to identify potential redundancy among indicators within the same indicator layer. Indicators with strong intercorrelations are subsequently excluded to minimise information redundancy and ensure that the remaining indicators contribute sufficiently distinct information to the evaluation system.

3.2 Evaluation Model of Earthquake Prevention and Disaster Reduction Capability Index in China

Indicators characterised by substantial intercorrelation or insufficient quantifiability were removed through preliminary assessment and quantitative screening. This process resulted in the retention of 33 tertiary indicators from the original candidate set, which collectively constitute the evaluation index system for CEDPRCI, as presented in Table 4.

Table 4

The Index of China's Earthquake Prevention and Disaster Reduction Capability

China's Earthquake Prevention and Disaster Reduction Capability	The Vulnerability of Disaster-Prone Bodies	Population Vulnerability	Population Density
			Proportion of rural population
			Proportion of vulnerable groups
			Illiteracy rate
			Proportion of female population
			Proportion of high school education or above
			Density of lifeline engineering pipelines
			Per capita road area
			Infrastructure construction investment
			Number of bridges
			Number of large reservoirs
			Proportion of different types of buildings
			Seismic resistance of building structures
			Telephone network coverage rate
			Number of parks
			Construction project governance capability
			Number of occurrences of moderate to strong earthquake disasters
			Per capita garden green area
			Green coverage rate of built-up areas
			Environmental protection expenditure
			Earthquake emergency rescue capability
			Employment
			Education
			Number of urban medical insurance participants
			GDP
			Per capita disposable income
			Local fiscal public security expenditure
			Proportion of the composition of the secondary and tertiary industries
			Construction of seismic network
			Number of earthquake observation points
			Earthquake emergency material reserve
			Number of researchers in the earthquake prevention and disaster reduction industry
			Production and Construction Human Resources

3.2.1 Weight Determination of Evaluation Indicators for Earthquake Prevention and Disaster Reduction Capability Index

To reduce subjectivity in the weighting process, the entropy weight method is applied to derive objective weights for each indicator. After standardisation, the data are subjected to a translation adjustment to avoid excessively small or negative values. The calculation formula is expressed as follows:

$$x'_{ij} = x_{ij} + H, \quad (4)$$

Where, H is the amplitude of indicator translation, without loss of generality, and $H=1$ is taken in this paper. Firstly, calculate the entropy value e_j of the j -th indicator using the following formula:

$$e_j = -k \sum_{i=1}^m P_{ij} \ln P_{ij}, \quad (5)$$

Where, $P_{ij} = x'_{ij} / \sum_{i=1}^m x'_{ij}$, $k = 1 / \ln m$. Furthermore, the information entropy redundancy (coefficient of variation) d_j of the j -th indicator and the weight values w_j of each indicator are calculated using the following formula:

$$d_j = 1 - e_j, \quad (6)$$

$$w_j = \frac{d_j}{\sum_{j=1}^n d_j}. \quad (7)$$

3.2.2 Establishment of Evaluation Model for Earthquake Prevention and Disaster Reduction Capability Index

CEDPRCI is constructed by integrating two complementary components, EVI and EPI. Accordingly, the overall index is calculated as a linear combination of these two dimensions, as expressed below:

$$CEPDRCI = F(EVI, EPI), \quad (8)$$

Here, EVI denotes the vulnerability of disaster-prone bodies, whereas EPI reflects their preparedness. Because CEPDRCI is inversely associated with EVI, the corresponding non-vulnerability measure, expressed as $(1 - EVI)$, has a positive relationship with CEPDRCI. The overall index is therefore jointly determined by non-vulnerability and preparedness. Consistent with the conceptual structure of ND-GAIN, CEPDRCI is calculated as follows:

$$CEPDRCI = (1 - EVI) + EPI, \quad (9)$$

EVI is derived from PV, IV, and EV, while EPI is constructed from SP, EP, PP, and HP. Accordingly, EVI and EPI are calculated using the following formulas:

$$EVI = PV + IV + EV, \quad (10)$$

$$EPI = SP + EP + PP + HP, \quad (11)$$

The values of PV, CV, EV, and the remaining secondary indicators are obtained by applying a weighted summation to their corresponding tertiary indicators, as follows:

$$PV = \sum_{j=1}^n x'_{ij} w_j. \quad (12)$$

To facilitate comparison, CEPDRCI is converted to a percentage-based scale by multiplying the index value by 50, resulting in a range from 1 to 100. Following this transformation, the CEPDRCI evaluation model is expressed as follows:

$$CEPDRCI = [(1 - EVI) + EPI] \times 50, \quad (13)$$

The corresponding indicator weights are reported in Table 5, while Figure 1 presents the overall assessment and decision-support framework.

Table 5

The Index Weight of China's Earthquake Prevention and Disaster Reduction Capability

China's Earthquake Prevention and Disaster Reduction Capability	The Vulnerability of Disaster-Prone Bodies	Population Vulnerability (0.15)	Population Density (0.0129)
			Proportion of rural population (0.0227)
			Proportion of vulnerable groups (0.04367)
			Illiteracy rate (0.0125)
			Proportion of female population (0.0296)
			Proportion of high school education or above (0.0296)
		Infrastructure Vulnerability (0.289)	Density of lifeline engineering pipelines (0.021)
			Per capita road area (0.030)
			Infrastructure construction investment (0.033)
			Number of bridges (0.0204)
			Number of large reservoirs (0.0268)
			Proportion of different types of buildings (0.0308)
			Seismic resistance of building structures (0.0238)
			Telephone network coverage rate (0.0345)
			Number of parks (0.0256)
			Construction project governance capability (0.0433)
		Ecological Vulnerability (0.106)	Number of occurrences of moderate to strong earthquake disasters (0.02)
			Per capita garden green area (0.028)
			Green coverage rate of built-up areas (0.025)
			Environmental protection expenditure (0.033)
	The Degree of Preparedness	Social Capital (0.151)	Earthquake emergency rescue capability (0.0408)
			Employment (0.0349)
			Education (0.0331)
			Number of urban medical insurance participants (0.0421)
		Economic Capital (0.132)	GDP (0.04)
			Per capita disposable income (0.0408)
			Local fiscal public security expenditure (0.027)
			Proportion of the composition of the secondary and tertiary industries (0.0247)
		Physical Capital (0.096)	Construction of seismic network (0.0315)
			Number of earthquake observation points (0.0385)
			Earthquake emergency material reserve (0.0261)
		Human Capital (0.076)	Number of researchers in the earthquake prevention and disaster reduction industry (0.032)
			Production and Construction Human Resources (0.0439)

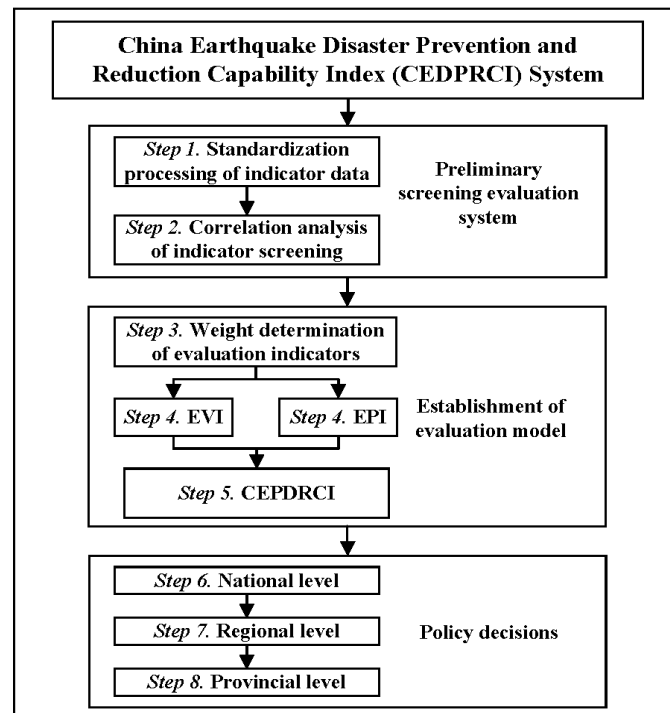


Fig.1: Flowchart of China's Earthquake Prevention and Disaster Reduction Capability Assessment and Decision Support Framework

4. Overview of the Research Area and Data Sources

4.1 Overview of the Research Area

The analysis encompasses 31 provinces, municipalities, and autonomous regions across China to evaluate CEDPRCI and identify weaknesses in disaster prevention and reduction capacity at the provincial level. For a more systematic assessment of spatial disparities, the 31 administrative units are grouped into seven geographical zones, as illustrated in Figure 2.



Fig.2: Seven Geographical Regions of 31 Provinces in China

*Based on the standard map service website of the Ministry of Natural Resources with the approval number GS (2023) 2767, the base map boundary has not been modified

4.2 Data Source

The study covers the period from 2014 to 2023. Social, economic, demographic, and disaster-loss data are primarily drawn from annual and regional statistical publications issued by the National Bureau of Statistics, including the China Statistical Yearbook (2014-2023), regional statistical yearbooks, and natural disaster databases. Seismic data are obtained from the National Seismological Science Data Center of the China Earthquake Networks Center, while information relating to construction projects is sourced from the China Urban and Rural Construction Statistical Yearbook (2014-2023), published by the Ministry of Housing and Urban-Rural Development of the People's Republic of China.

5. Results and Analysis

China's earthquake prevention and disaster reduction capability is assessed at three spatial levels: national, regional, and provincial.

5.1 Evaluation of National Earthquake Prevention and Disaster Reduction Capability Index

5.1.1 Analysis of the Overall Earthquake Prevention and Disaster Reduction Capability Index

Based on Equations (8)-(13), CEDPRCI, EVI, and EPI are calculated for China over the 2014-2023 period, with the results presented in Figures 3 and 4. Figure 3 shows that CEDPRCI remained within the range of 40-60 throughout the study period, indicating an overall medium-to-low capability level. Its temporal evolution can be divided broadly into two stages: a period of fluctuation between 2014 and 2021, followed by rapid improvement from 2021 to 2023. Between 2014 and 2021, repeated seismic activity, including numerous moderate-to-strong earthquakes, exerted substantial pressure on infrastructure and emergency response systems in several regions, contributing to pronounced fluctuations in CEDPRCI. The periods 2014-2015 and 2019-2020 coincided with the concluding years of the 12th and 13th Five-Year Plans, respectively, during which government expenditure and technological investment increased. These investments supported infrastructure development and strengthened earthquake prevention and disaster reduction capability. A distinct upward trajectory emerged after 2021, when the 14th Five-Year Plan for National Comprehensive Disaster Prevention and Reduction introduced more clearly defined objectives for disaster prevention and reduction. At the same time, the National Earthquake Science and Technology Development Plan (2021-2035) set the objective of advancing intelligent earthquake monitoring and early warning technologies to internationally advanced levels by 2025. Together, these policy and technological initiatives contributed to the accelerated improvement observed in China's earthquake prevention and disaster reduction capability.

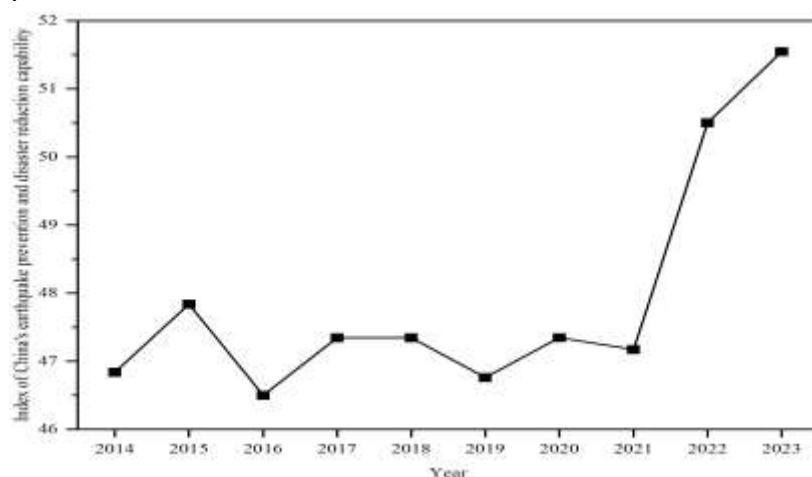


Fig.3: Index Curve of China's Earthquake Prevention and Disaster Reduction Capability

5.1.2 Analysis of the Overall Vulnerability Index and Preparedness Index

Figure 4 presents the temporal evolution of EVI and EPI. The pattern of EVI is broadly inverse to that of CEDPRCI, showing that the strengthening of China's earthquake prevention and disaster reduction capability coincided with a decline in the vulnerability of disaster-prone bodies. This reduction is associated with sustained policy support, continued infrastructure development, and technological progress in earthquake-related fields. As illustrated in Figure 4(b), EPI generally followed an upward trajectory, interrupted by a temporary decline during 2018-2019 before recovering markedly and increasing rapidly after 2021. The overall improvement reflects the continued emphasis on disaster prevention and reduction under the 12th and 13th Five-Year Plans, accompanied by greater financial and technological support for preparedness. The decline observed during 2018-2019 may be associated with several extreme natural disasters in China, including typhoons and floods, which potentially diverted resources and institutional attention towards competing emergency requirements. Thereafter, government policies and development plans increasingly reinforced disaster prevention and reduction as strategic priorities, while technological advances in earthquake monitoring and early warning further enhanced preparedness. Collectively, these developments contributed to the substantial increase in EPI after 2021.

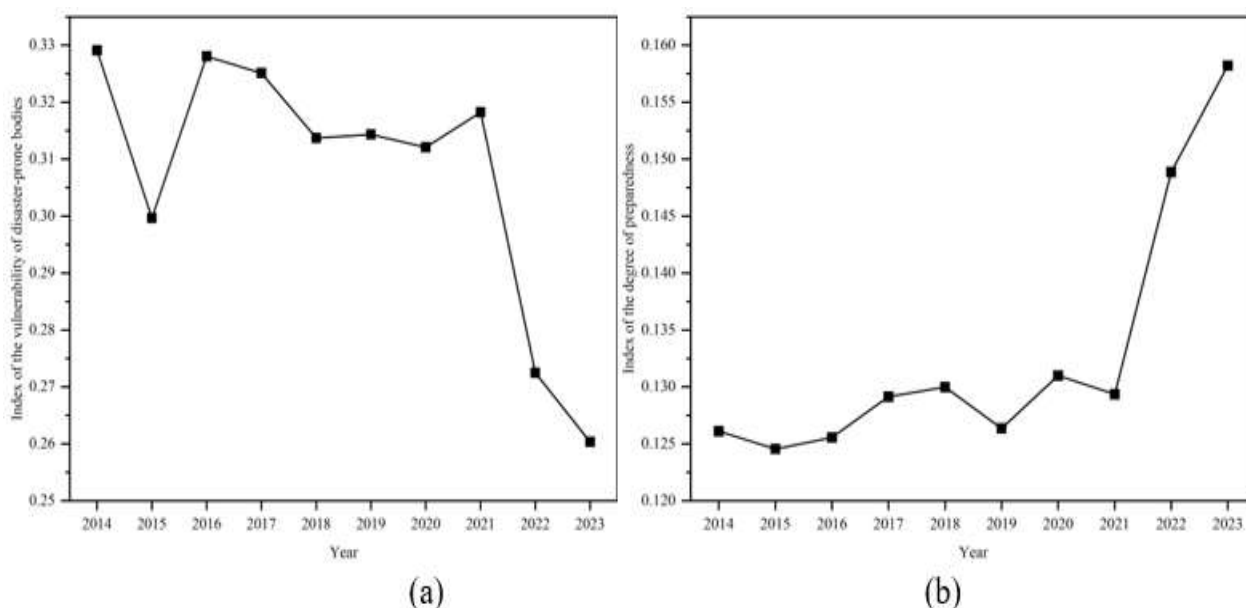


Fig.4: Index Curve of the Vulnerability and Preparation Degree

5.1.3 Analysis of the Constituent Elements of Earthquake Prevention and Disaster Reduction Capabilities at National Level

Figure 5 depicts the temporal evolution of the principal indicators from 2014 to 2023. As presented in Figure 5(a), IV consistently exceeds PV and EV across the study period, identifying infrastructure as the dominant source of vulnerability among disaster-prone bodies. Both IV and EV follow gradual downward trends, while PV initially fluctuates, subsequently becomes relatively stable, and ultimately declines. The persistently high IV is largely associated with the continued existence of older buildings constructed without adherence to contemporary seismic standards. Nevertheless, the progressive enforcement of seismic design codes and advances in seismic engineering technologies have contributed to a sustained annual reduction in IV. A similar downward pattern is observed for EV, potentially reflecting the inherent recovery capacity of ecosystems, the comparatively gradual manifestation of disaster impacts, and improvements in

ecological protection policies, monitoring, and early warning systems. PV, by contrast, initially increased alongside rapid urbanisation. As the national emergency management system, institutional arrangements, and earthquake prevention and disaster reduction measures were progressively strengthened, PV stabilised and subsequently entered a sustained decline.

Figure 5(b) shows that SP and EP remain substantially higher than PP and HP. SP and HP increase consistently over time, whereas EP remains relatively stable and PP exhibits pronounced fluctuations. Continued economic growth has expanded the capacity of national and local governments to invest in earthquake prevention and disaster reduction, thereby maintaining EP at a comparatively high level. Economic development has also facilitated the expansion of educational resources and the training of specialised personnel, supporting progressive improvements in SP and HP. In contrast, uneven infrastructure development across regions has contributed to considerable variation in PP. These results indicate the need to further strengthen human and physical capital preparedness. Expanding relevant academic programmes could increase the availability of specialised professionals, while greater infrastructure investment in economically less-developed regions could help narrow existing disparities. Coordinated progress in these areas would reduce regional inequalities and enhance overall preparedness associated with PP.

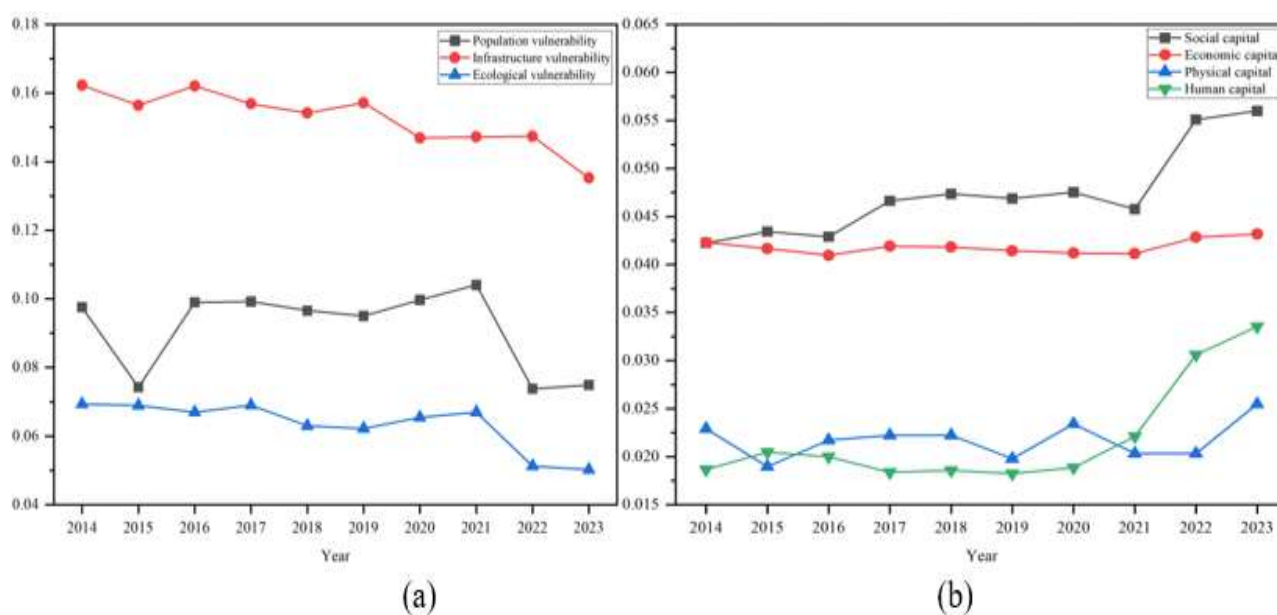


Fig.5: Change Curve of Each Sub Item Index of China's Earthquake Disaster Prevention Reduction Ability

5.1.4 National Level Decision Implications

CEDPRCI offers a quantitative foundation for strategic decision-making and policy evaluation. At the macro level, it can support the assessment of policy effectiveness and the monitoring of implementation progress. The marked shift in CEDPRCI around 2021 provides quantitative evidence of improvements associated with national comprehensive disaster prevention and reduction initiatives during the 14th Five-Year Plan period. CEDPRCI can therefore function as a performance indicator for tracking medium- and long-term progress towards national earthquake prevention and reduction objectives, allowing decision-makers to detect emerging trends and adjust implementation strategies where required. The framework also facilitates the identification of systemic constraints. The persistent dominance of IV within the vulnerability dimension indicates that existing building stocks and lifeline engineering remain major weaknesses in national earthquake resilience. This evidence can inform investment and regulatory priorities by directing

greater attention towards physical-risk interventions, including revisions to mandatory standards, large-scale structural reinforcement programmes, and dedicated funding mechanisms.

CEDPRCI can further inform the strategic distribution of resources between reducing vulnerability and strengthening preparedness. The sustained increase in EPI reflects the effectiveness of investment in social and economic preparedness, while the comparatively gradual decline in EVI indicates that physical risk reduction requires continued and capital-intensive investment. These patterns enable decision-makers to balance long-term vulnerability mitigation against short- and medium-term resilience enhancement, thereby improving the efficiency of national disaster prevention and reduction investment. In addition, the framework provides a quantitative basis for policy scenario analysis. Competing investment priorities can be evaluated by estimating their potential influence on the component indices and overall CEDPRCI before substantial resources are committed. This scenario-based approach allows alternative strategic options to be compared in terms of their potential costs and benefits, supporting more evidence-based, efficient, and forward-looking national planning.

5.2 Evaluation of Earthquake Prevention and Disaster Reduction Capability Index at Regional Level

China's vast geographical extent is characterised by considerable variation in physical conditions and earthquake disaster risks, highlighting the importance of evaluating earthquake prevention and disaster reduction capability at the regional level. Accordingly, the 31 provinces, municipalities, and autonomous regions are grouped into seven geographical zones based on their spatial locations, as illustrated in Figure 2. CEDPRCI is subsequently used to assess and compare earthquake prevention and disaster reduction capability across these regions.

5.2.1 Analysis of the Earthquake Prevention and Disaster Reduction Capability Index at Regional Level

Regional CEDPRCI generally decreased during 2015-2016 and subsequently entered a period of fluctuation, before showing substantial improvement from 2021 onwards. In terms of capability, the regions follow the order: East China > Central China > South China > North China > Southwest China > Northwest China > Northeast China. As illustrated in Figure 6, this distribution reveals a distinct spatial pattern, with comparatively stronger capability in the east and weaker capability in the north.

East China exhibits the strongest overall capability. Most provinces within the region are located in relatively stable tectonic settings, with comparatively lower seismic risk and limited historical seismic activity. Its advanced economic conditions also facilitate stricter enforcement of building standards, more developed disaster management systems, and stronger emergency response mechanisms. Together, these advantages contribute to the region's comparatively high earthquake prevention and disaster reduction capability. In contrast, Northwest and Northeast China demonstrate relatively weaker performance. Seismic activity is comparatively frequent in the Northwest, particularly in Xinjiang, where recurrent earthquakes impose substantial demands on local disaster prevention and reduction systems despite relatively low population density. Both regions are additionally constrained by comparatively lower levels of economic development, inadequate infrastructure, and a substantial stock of older buildings lacking sufficient seismic reinforcement. Collectively, these conditions restrict further improvement in earthquake prevention and disaster reduction capability.

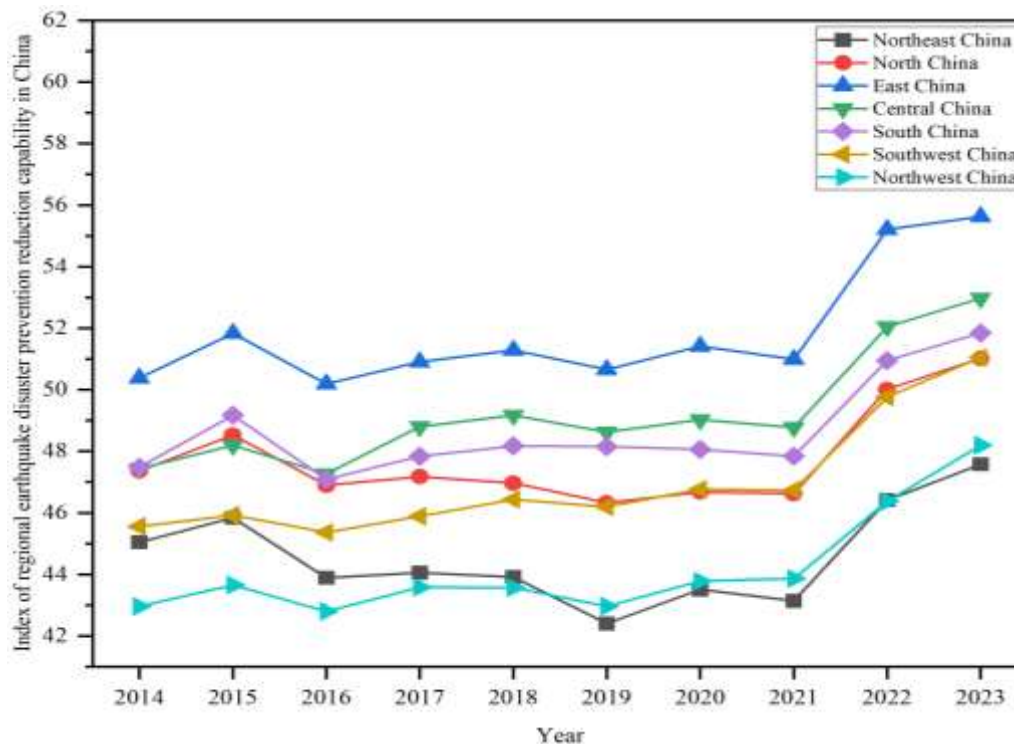


Fig.6: Integrated Analytical Process: Combining ADO

5.2.2 Analysis of the Vulnerability Index and Preparedness Index at Regional Level

Figure 7 illustrates regional differences in EVI (Figure 7(a)) and EPI (Figure 7(b)) across China. Overall, EVI follows a downward trajectory, although relatively higher levels persist in North and South China, while Central China exhibits the lowest vulnerability. In contrast, EPI generally improves over time. East China records the highest preparedness level, whereas Northwest and Northeast China remain comparatively less prepared. In terms of vulnerability, North China combines high population density with extensive urbanisation, increasing the concentration of people and high-rise buildings exposed to potential seismic impacts and, consequently, the risk of earthquake-related casualties. Building-quality disparities also contribute to vulnerability in both North and South China. Urban villages, ageing housing stock, and unreinforced self-built dwellings remain prevalent in some areas, increasing exposure to seismic impacts and reinforcing regional vulnerability.

With respect to preparedness, East China benefits from greater financial capacity, extensive disaster management experience, and stronger public awareness of disaster prevention, collectively contributing to its comparatively high EPI. Despite its substantial natural resource endowment, Northwest China is constrained by geographical remoteness, harsh climatic conditions, and comparatively limited economic development. These conditions contribute to deficiencies in social, economic, physical, and human capital, thereby restricting preparedness. Northeast China faces related challenges associated with its position as an established industrial base, where industrial decline has reduced fiscal revenues. Although seismic activity is comparatively limited, the relatively low hazard level may have contributed to lower levels of attention to earthquake prevention and disaster reduction among LGs and the public. Moreover, pronounced population ageing in some areas has weakened human capital preparedness, further limiting the region's overall preparedness capacity.

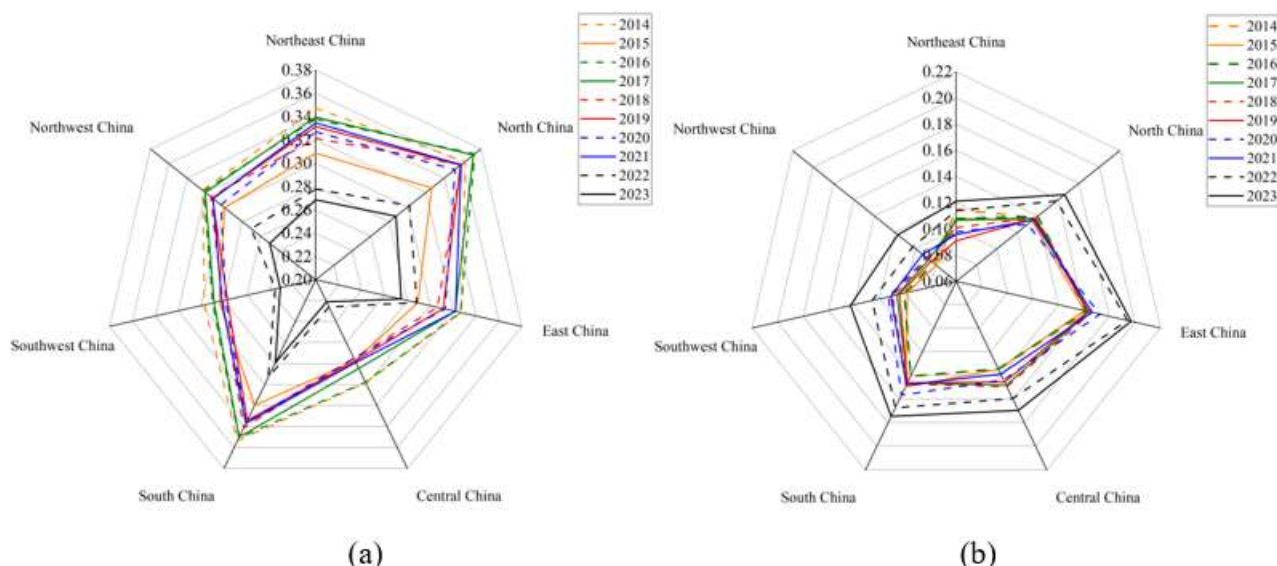


Fig.7: Radar Chart of China's Regional Vulnerability and Preparation Degree

5.2.3 Analysis of the Constituent Elements of Earthquake Prevention and Disaster Reduction Capabilities at Regional Level

Figure 8(a) shows that infrastructure is the most vulnerable component across all regions, with its vulnerability consistently exceeding both population and ecological vulnerability. Overall vulnerability is comparatively greater in North and South China, while Central and Southwest China display lower levels. Infrastructure vulnerability is particularly high in Northeast, North, South, and Northwest China, whereas Central China records the lowest level. Population vulnerability is greatest in North China and lowest in Southwest China. Similarly, ecological vulnerability reaches its highest level in North China but remains lowest in Northwest China.

- 1. Infrastructure Vulnerability:** Central China benefits from comparatively stable geological conditions alongside rapid economic development in recent years. A substantial proportion of its newer infrastructure has been developed under relatively stringent construction standards, contributing to lower vulnerability. In contrast, variations in geographical conditions and levels of economic development contribute to greater infrastructure vulnerability in Northeast, North, South, and Northwest China.
- 2. Population Vulnerability:** High population density combined with pronounced population ageing contributes substantially to the elevated vulnerability observed in North China. Conversely, Southwest China exhibits lower vulnerability, as its complex terrain encourages more dispersed settlement patterns, while residents generally demonstrate comparatively strong awareness of self-protection and capacity to respond to disasters.
- 3. Ecological Vulnerability:** North China experiences intensive human activity alongside persistent air-quality concerns and frequent haze events, particularly in Beijing, contributing to greater ecological fragility. By comparison, Northwest China is characterised predominantly by grasslands, deserts, and high-altitude mountainous environments. Vegetation adapted to drought and cold conditions possesses comparatively strong self-recovery capacity, contributing to lower ecological vulnerability.

Figure 8(b) demonstrates that preparedness is strongest in East China and weakest in Northeast and Northwest China. Across the four preparedness dimensions, social capital is comparatively strong in East, Central, and South China but remains weaker in Northeast and Northwest China.

Economic capital reaches its highest level in North China and its lowest levels in Northeast and Northwest China. Physical capital is relatively balanced across most regions, although Northwest China displays a comparatively weaker level. Human capital is strongest in North China, whereas Central and Southwest China exhibit comparatively lower levels.

- 1. Social Capital:** East, Central, and South China possess comparatively well-developed emergency management systems, while emergency rescue resources remain relatively insufficient in Northeast and Northwest China.
- 2. Economic Capital:** North China's strong fiscal capacity supports the highest level of economic capital. In contrast, Northeast China is constrained by an ageing industrial structure and relatively weak economic growth, while the comparatively limited economic development of Northwest China similarly restricts its economic capital.
- 3. Physical Capital:** Geographical constraints combined with a relatively weak economic foundation have restricted investment in earthquake prevention and disaster reduction materials in Northwest China. Physical capital remains comparatively balanced across the other regions.
- 4. Human Capital:** North China benefits considerably from its educational resources and talent-related policies. Although Central and Southwest China possess an established human capital foundation, their levels remain below those observed in several other regions, with some areas continuing to experience difficulties in attracting and retaining specialised professionals.

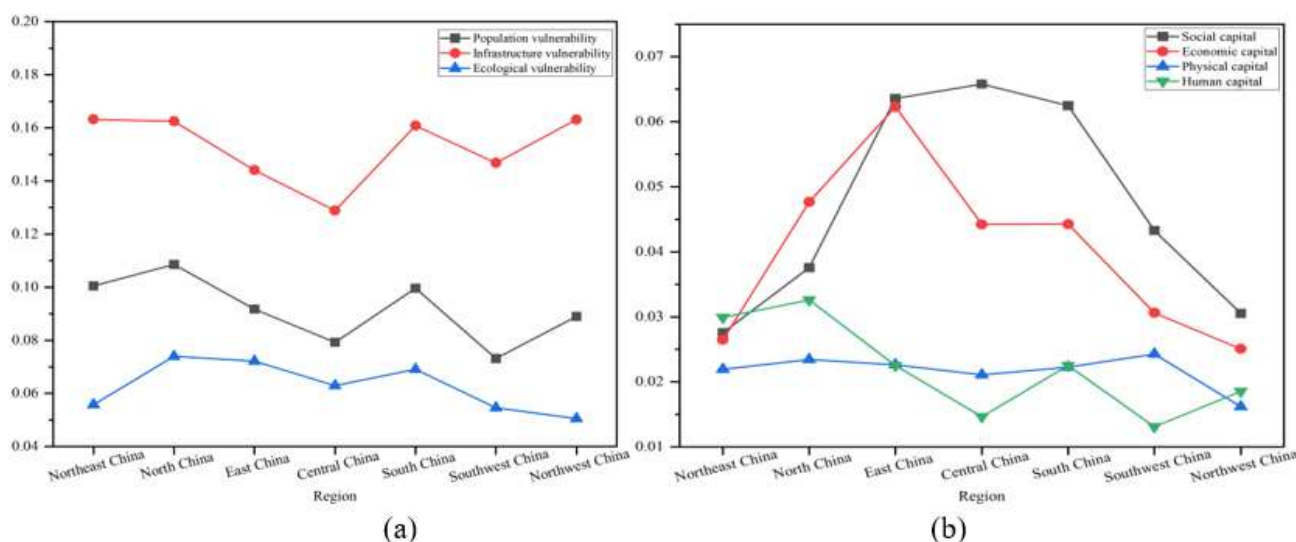


Fig.8: Change Curve of Each Sub Item Index of China's Regional Earthquake Disaster Prevention Reduction Ability

5.2.4 Regional Level Decision Implications

The pronounced regional disparities captured by CEDPRCI provide an empirical foundation for developing differentiated and region-specific governance strategies. The regional ordering, East China > Central China > South China > North China > Southwest China > Northwest China > Northeast China, offers a consistent benchmark for evaluating differences in capability. This comparison not only enables lower-performing regions, particularly Northeast and Northwest China, to identify and adapt effective practices from stronger regions such as East China, but also provides objective evidence for directing greater strategic attention and resources towards areas with comparatively limited capability at the central level.

Further decomposition of CEDPRCI demonstrates that the underlying constraints differ

considerably across regions, allowing policy responses to be tailored to specific capability profiles. In North and South China, where relatively high vulnerability persists despite comparatively adequate preparedness, interventions should primarily focus on risk mitigation, particularly the reduction of infrastructure vulnerability through large-scale seismic reinforcement and resilient urban planning. Conversely, the weaker preparedness observed in Northwest and Northeast China indicates a greater need for capacity development. Targeted fiscal transfers, specialised talent development, and stronger material reserves could address deficiencies in social, economic, physical, and human capital. For higher-performing regions such as East China, policy priorities can gradually move beyond basic capacity enhancement towards innovation and advanced resilience development, including the piloting of advanced earthquake warning technologies and the establishment of stronger interregional assistance mechanisms.

5.3 Evaluation of Earthquake Prevention and Disaster Reduction Capability Index at the Provincial Level

5.3.1 Analysis of the Earthquake Prevention and Disaster Reduction Capability Index at Provincial Level

Figure 9 demonstrates a general strengthening of earthquake prevention and disaster reduction capability across Chinese provinces from 2014 to 2023. Sichuan and Shandong display comparatively strong capability, while Ningxia, Hainan, and Jilin remain among the weaker provinces. Sichuan's repeated experience with major seismic disasters has contributed to the accumulation of substantial expertise in emergency response and post-earthquake recovery. The province has also implemented various measures to enhance the seismic resilience of buildings and improve emergency response mechanisms, supporting its comparatively high capability. Shandong presents a different profile; as seismic activity is relatively limited. The 2023 Mw 5.5 Pingyuan earthquake was particularly notable because no earthquake of comparable magnitude had been recorded in the local region for more than a century [40]. Despite this event, Shandong's relatively stable geological setting and strong economic foundation provide favourable conditions for maintaining a high level of disaster reduction capability.

In contrast, Ningxia, Hainan, and Jilin exhibit comparatively weaker capability. A substantial stock of ageing and seismically vulnerable buildings continues to constrain improvement, while the moderate level of economic development in Ningxia and Jilin restricts the resources available for earthquake preparedness. Although Hainan possesses a comparatively stronger economic foundation, its frequent exposure to typhoons and heavy rainfall places considerable demands on disaster management resources. Governmental attention and resource allocation are therefore directed more extensively towards meteorological hazards, potentially limiting the resources available for earthquake preparedness and contributing to its comparatively lower capability.

Figure 9 further highlights an important limitation of the ND-GAIN-based assessment. Guangdong records comparatively strong earthquake prevention and disaster reduction capability, although this outcome does not fully reflect its underlying vulnerability conditions. The province contains substantial numbers of urban villages, ageing buildings, and unreinforced self-built dwellings, while its coastal location results in frequent exposure to typhoons and heavy rainfall. Collectively, these conditions contribute to relatively high vulnerability among disaster-prone bodies. However, Guangdong also exhibits strong preparedness. Its highly developed economy provides considerable financial capacity, while its ability to attract skilled professionals and its comparatively mature emergency response system strengthen preparedness across multiple dimensions, as illustrated in

Figure 10. Consequently, despite persistent vulnerability, Guangdong's strong preparedness substantially offsets these weaknesses, resulting in a comparatively high overall level of earthquake prevention and disaster reduction capability.

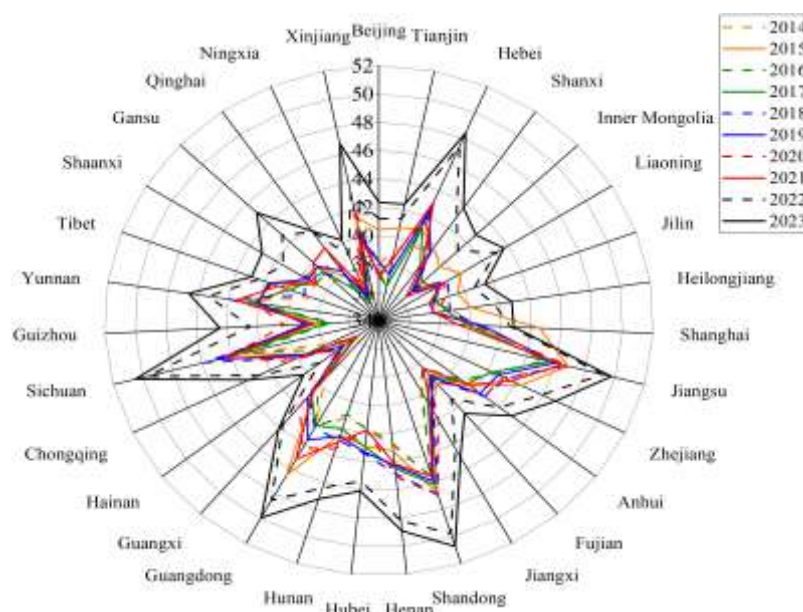


Fig.9: Radar Chart of Provincial Earthquake Disaster Prevention Reduction Ability in China

5.3.2 Analysis of the Vulnerability Index and Preparedness Index at Provincial Level

The disaster resilience matrix offers a more direct comparison of vulnerability and preparedness among disaster-prone bodies at the provincial level, as illustrated in Figure 10. The horizontal axis represents EVI, while the vertical axis denotes EPI. Using the median values of the two indices as classification thresholds, the provinces are divided into four quadrants, each representing a distinct capability profile.

1. The upper-left quadrant comprises provinces with the strongest earthquake prevention and disaster reduction capabilities, including Jiangsu, Shandong, and Sichuan. These provinces are characterised by relatively low vulnerability and high preparedness, reflecting comparatively limited earthquake risk together with well-developed prevention and emergency response systems. They are therefore classified as the overall comprehensive type.
2. The upper-right quadrant includes provinces with relatively strong overall capabilities, such as Beijing, Guangdong, and Shanghai. Although these provinces exhibit high preparedness, substantial vulnerability persists, partly due to the continued presence of unreinforced older buildings and pressures arising from rapid urbanisation. Accordingly, they are categorised as the preparedness-driven type.
3. The lower-left quadrant contains provinces with moderate earthquake prevention and disaster reduction capabilities, including Tibet, Guangxi, and Jiangxi. Both vulnerability and preparedness are relatively low in these provinces. Despite their comparatively limited exposure to earthquake risk, insufficient prevention and preparedness capacity could lead to substantial losses if a seismic disaster occurs. These provinces are therefore classified as the low-preparedness type.
4. The lower-right quadrant consists of provinces with comparatively weak earthquake prevention and disaster reduction capabilities, including Jilin, Inner Mongolia, and Heilongjiang. These provinces combine relatively high vulnerability with low preparedness. Although they are

generally not considered earthquake-prone areas, structural fragility and inadequate preparedness could substantially increase potential losses in the event of an earthquake. They are consequently classified as the overall sensitive type.

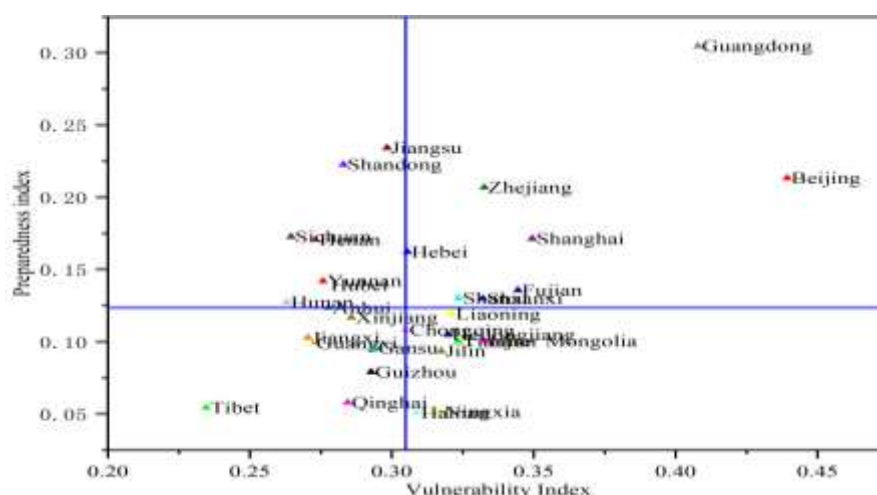


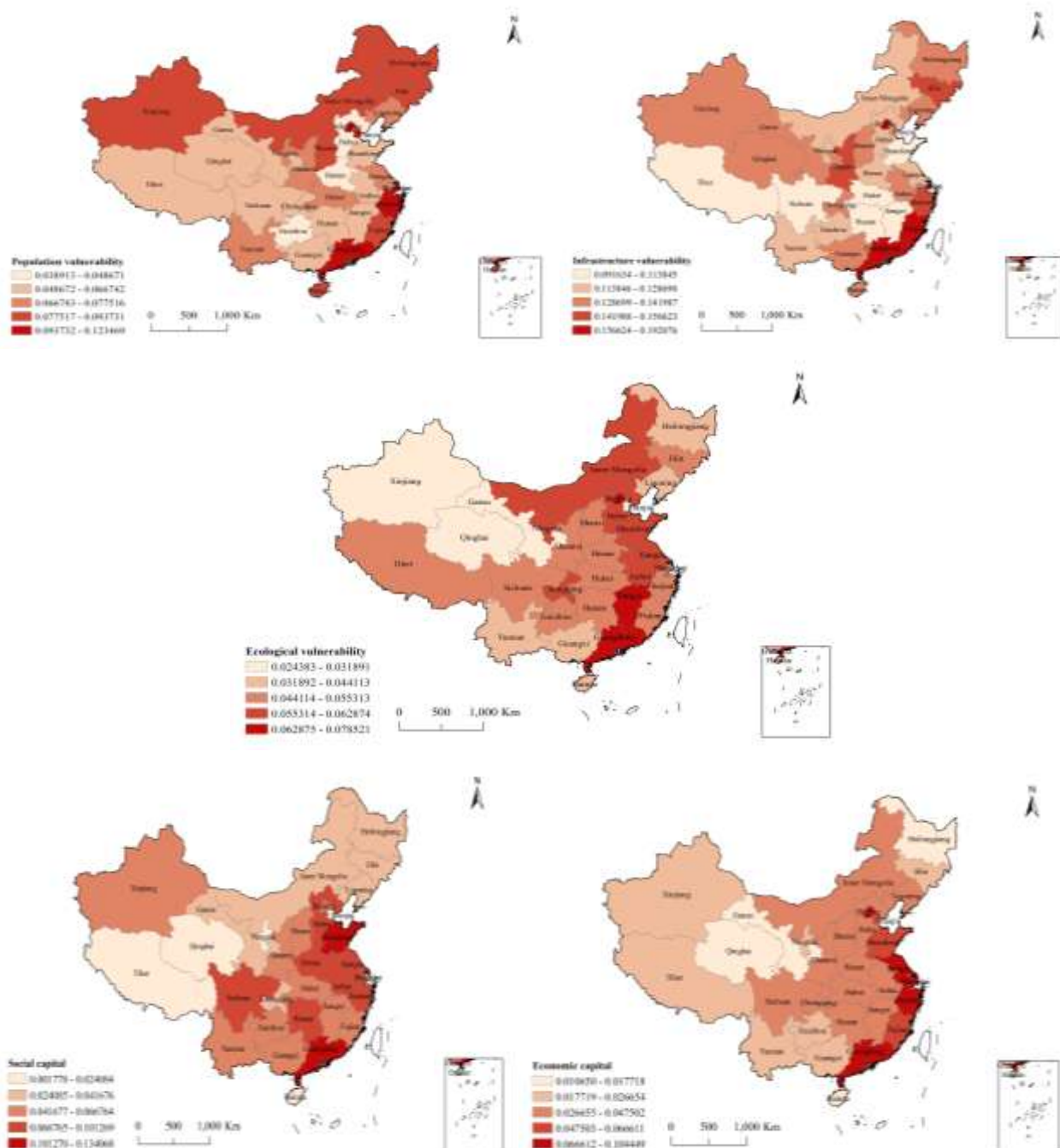
Fig.10: Matrix Diagram of Provincial Earthquake Disaster Prevention Reduction Ability in China

5.3.3 Analysis of the Constituent Elements of Earthquake Prevention and Disaster Reduction Capabilities at Provincial Level

Figure 11 presents a visual comparison of seven dimensions—population vulnerability, infrastructure vulnerability, ecological vulnerability, social capital, economic capital, physical capital, and human capital—to determine the principal weaknesses constraining earthquake prevention and disaster reduction capabilities across China's provinces. The results reveal substantial interprovincial differences across these dimensions.

- 1. Population Vulnerability:** Beijing, Tianjin, Shanghai, Zhejiang, and Guangdong display comparatively high population vulnerability, largely reflecting concentrated populations and ageing demographic structures. In contrast, Hebei, Henan, and Guizhou exhibit lower vulnerability, associated with their comparatively dispersed population distributions.
- 2. Infrastructure Vulnerability:** Beijing, Fujian, and Guangdong exhibit relatively high infrastructure vulnerability, primarily because substantial stocks of older buildings remain without adequate seismic reinforcement. Despite frequent earthquake exposure, Sichuan records comparatively low construction vulnerability. Its accumulated experience in seismic engineering and continued technological development have enabled buildings to achieve relatively higher seismic resistance standards than those in many other regions.
- 3. Ecological Vulnerability:** Frequent haze events in Beijing and recurrent exposure to typhoons and heavy rainfall in Guangdong contribute to comparatively high ecological vulnerability. By contrast, the geographical characteristics of Gansu, Qinghai, and Xinjiang support stronger ecological self-recovery capacity, resulting in relatively lower vulnerability.
- 4. Social Capital:** Shandong and Guangdong demonstrate comparatively strong social capital, supported by substantial economic capacity, well-developed emergency rescue systems, and relatively high educational investment. Conversely, Ningxia, Qinghai, and Tibet exhibit weaker performance, as geographical remoteness and comparatively limited economic resources restrict both emergency response capacity and educational expenditure.
- 5. Economic Capital:** Beijing, Shanghai, Jiangsu, Zhejiang, and Guangdong benefit from strong economic foundations and diversified industrial structures, contributing to comparatively high preparedness. Gansu, Qinghai, and Heilongjiang record lower levels because slower economic development constrains their capacity to strengthen preparedness.

6. **Physical Capital:** Hebei, Sichuan, and Xinjiang exhibit comparatively strong physical capital preparedness, supported by extensive emergency response experience and well-developed emergency facilities. In contrast, Qinghai, Ningxia, and Tibet are constrained by weaker economic and infrastructure conditions, together with comparatively limited emergency supply reserves.
7. **Human Capital:** Beijing, Zhejiang, and Guangdong benefit from strong educational resources and supportive policies that facilitate the development of specialised professionals. Guizhou and Guangxi, by comparison, have weaker educational foundations and lower levels of economic development, creating greater difficulties in attracting and retaining skilled professionals and consequently limiting their preparedness.



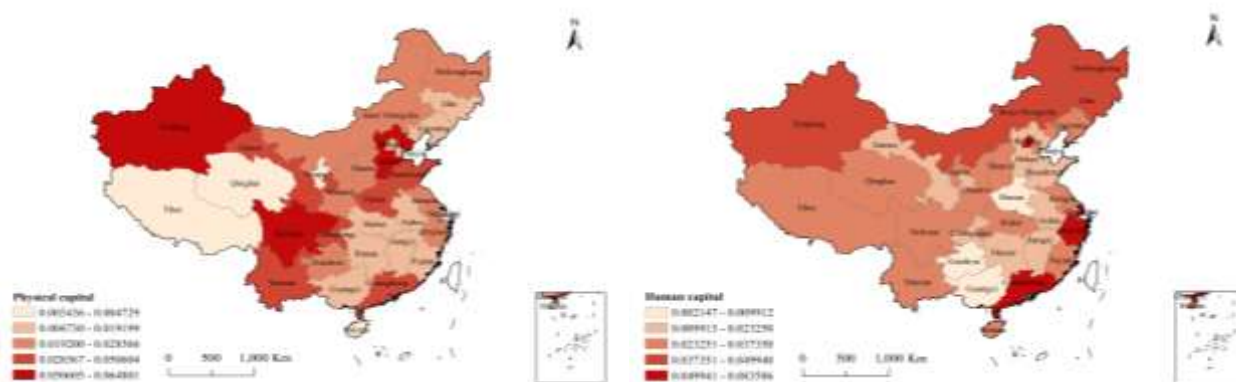


Fig.11: Zoning Map of Constituent Elements of Provincial Earthquake Disaster Prevention Reduction Ability in China

*Based on the standard map service website of the Ministry of Natural Resources with the approval number GS (2023) 2767, the base map boundary has not been modified.

5.3.4 Provincial Level Decision Implications

CEDPRCI provides practical decision support for differentiated and targeted local governance. First, the vulnerability-preparedness resilience matrix presented in Figure 10 establishes a systematic basis for classifying provinces and designing corresponding policy responses. Within this framework, provinces can be categorised as the overall comprehensive type, preparedness-driven type, low-preparedness type, or overall sensitive type, with each profile requiring a different intervention strategy. For overall sensitive type provinces, such as Jilin and Inner Mongolia, policy measures should concentrate on addressing existing deficiencies and strengthening overall capacity. In preparedness-driven type provinces, including Guangdong and Beijing, greater priority should be placed on vulnerability reduction and risk transformation. Interventions should specifically target the underlying sources of vulnerability, particularly through the renovation and seismic upgrading of ageing urban buildings.

Second, the seven-dimensional diagnostic map in Figure 11 allows province-specific constraints to be identified more precisely. This diagnostic information can assist provincial decision-makers in concentrating limited financial and administrative resources on dimensions where intervention is expected to produce the greatest marginal improvement. CEDPRCI can thus serve as a quantitative instrument for target setting, performance monitoring, and policy evaluation throughout the formulation, implementation, and assessment of provincial disaster prevention and reduction plans and measures. Its application can further support the translation of earthquake prevention and disaster reduction strategies into locally appropriate actions while enabling their continuous monitoring and refinement.

6. Conclusions and Management Implications

6.1 Main Findings

This study establishes a quantitative model and decision-support framework for assessing China's earthquake prevention and disaster reduction capabilities. The framework enables systematic, evidence-based identification of capability constraints, prioritisation of resources, and formulation of differentiated strategies across national, regional, and provincial levels. The principal findings are summarised as follows:

1. Between 2014 and 2023, China's overall earthquake prevention and disaster reduction capability remained at a medium-to-low level, although substantial improvement followed an

earlier period of fluctuation. EVI initially fluctuated before declining markedly, whereas EPI maintained an overall upward trajectory. IV emerged as the dominant source of vulnerability, while social and economic capital made important contributions to preparedness and the overall strengthening of national earthquake prevention and disaster reduction capability.

2. Considerable regional disparities were observed. East China demonstrated the strongest overall earthquake prevention and disaster reduction capability, while Northwest and Northeast China remained comparatively weak, revealing a broader spatial pattern of stronger capability in the east and weaker capability in the north. Vulnerability was relatively high in North and South China but comparatively low in Central China. In terms of preparedness, North and South China performed relatively well, whereas Central China remained comparatively weaker. East China possessed particularly strong economic capital compared with other regions, although a substantial imbalance remained between its economic capital and its physical and human capital. Northwest and Northeast China exhibited comparatively limited internal regional variation, yet their overall capability remained relatively low.
3. At the provincial level, earthquake prevention and disaster reduction capability generally strengthened throughout the study period. Sichuan and Shandong exhibited particularly strong performance, whereas Ningxia and Jilin remained comparatively weak. The results further demonstrate that strengthening preparedness represents an important pathway for improving overall earthquake prevention and disaster reduction capability.

Based on these findings, policy responses should be differentiated across governance levels. At the national level, priority should be given to formulating and enforcing relevant policies while ensuring effective implementation. Regional strategies should capitalise on geographical and resource advantages, address identified weaknesses, and promote cross-regional earthquake prevention and disaster reduction alliances to strengthen coordination and resource sharing. At the provincial level, interventions should respond directly to specific capability constraints, with resources concentrated on dimensions offering the greatest potential for improvement. Such differentiated measures can improve the efficiency of resource utilisation and contribute to the overall strengthening of earthquake prevention and disaster reduction capability.

6.2 Management Implications

As a structured, multi-scale decision-support framework, the primary contribution of CEDPRCI lies in its ability to translate quantitative assessment results into actionable management information for decision-makers and stakeholders across different administrative and functional levels, as outlined below:

1. For national decision-makers and central management agencies, CEDPRCI provides quantitative evidence to support macro-level governance and the differentiated distribution of strategic resources. The regional disparities revealed by the assessment, including the broader spatial pattern of stronger capability in the east and weaker capability in the north, together with provincial classification through the vulnerability-preparedness matrix, including overall comprehensive advantage and preparedness-driven types, can guide the spatial allocation of major projects and the development of cross-regional collaborative policies.
2. For provincial governments and disaster management departments, the framework provides a basis for implementing a “one province, one policy” approach to targeted governance. Province-specific constraints can be identified by combining each province’s position in the vulnerability-preparedness matrix in Figure 10 with the seven-dimensional weakness diagnosis map in Figure 11. These diagnostic results allow provincial decision-makers to design interventions that

respond directly to identified weaknesses and concentrate limited financial and administrative resources on areas offering the greatest potential marginal improvement, thereby strengthening provincial disaster prevention and reduction capability.

3. For urban planning and construction management departments, the framework enables broader resilience objectives to be translated into spatial planning priorities and engineering requirements. Urban areas characterised by high risk, concentrated ageing building stocks, and high population density should be prioritised for urban renewal and seismic reinforcement programmes. Simultaneously, more stringent seismic fortification requirements should be incorporated into new construction projects to reduce urban physical risk exposure at its source.
4. For emergency management and response agencies, the framework supports the dynamic adjustment of preparedness measures and resource deployment. Provincial preparedness scores can reveal potential weaknesses in post-disaster response and recovery capacity. These assessments can subsequently inform the refinement of deployment strategies, optimisation of emergency material reserve locations, and adjustment of training and exercise priorities for cross-regional rescue forces according to identified capacity gaps.

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Conflict of Interest

The author declares no competing interests.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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