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Research on the Evaluation and Spatial–Temporal Evolution of Safe and Resilient Cities Based on Catastrophe Theory—A Case Study of Ten Regions in Western China

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Abstract: In today's highly complex world, urban security has become a focus of attention for people in various positions due to its enormous uncertainty. As an essential path towards urban safety, resilient development can effectively provide emergency management capability for cities when they are exposed to unknown risks. In this study, an evaluation-index system for urban-safety resilience was constructed from the perspective of sustainable urban development. The urban-safety-resilience evaluation model was established with the help of catastrophe theory to study and analyze urban-safety resilience. The corresponding spatial–temporal-evolution analysis used the geographic information system (GIS) and Moran index to evaluate the urban-security resilience of 10 regions in western China. Finally, it was concluded that (1) the urban-safety resilience of most regions in western China showed an increasing trend over time in 2017, 2019, and 2021; (2) the urban-safety resilience of Chongqing, Sichuan, and Shaanxi provinces is at a relatively high level compared to the western region overall; and (3) regions such as Ningxia and Gansu are disaster-prone, and urban infrastructure conditions are relatively backward. Therefore, urban planning and governance should be flexibly transformed to explore and apply appropriate urban-safety-resilience models, with sustainable development as the cornerstone.

Keywords: urban-safety resilience; spatial–temporal-evolution analysis; western China; catastrophe theory

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1. Introduction

As giant and complex systems comprising social, economic, and ecological factors [1], cities' uncertainty and unknown risks will increase with the acceleration of the urbanization process. The vulnerability of urban systems to unknown risk factors, such as climate change, energy crises, natural disasters, international situations, food security, and financial emergencies, is particularly pronounced, and this is one of the critical issues constraining sustainable urban development [2]. In recent years, the term "urban resilience" has emerged with particular frequency in academic and policy contexts [3]. As a new pathway for urban development, "urban resilience" has multiple capabilities in urban systems and their associated socio-technical and socio-ecological networks within dynamic boundaries. These include the capacity to preserve or swiftly reinstate essential operations in response to disruptions, the capacity to adapt to variation, and the capacity to enhance constrained adaptive and resilient systems [4].

To achieve the transition from high-speed to high-quality urban development, the Chinese government has focused on consolidating the concept of safe development, encouraging people-oriented urbanization, and building resilient cities in the 14th Five-Year Plan and the 20th National Congress. From the perspective of enhancing urban resilience to ensure urban safety, resilience and safety are inextricably linked; therefore, urban-safety resilience has received close attention as a new topic [5]. Based on the urban resilience theory, urban-safety resilience focuses on a broader, integrated, and flexible analysis of urban-public-safety events and has been identified as a new paradigm for urban-safety development [6], which helps urban systems to deal with the impact of continuous dynamic changes in internal and external risks in the face of the uncertainty of unknown risks [7]. In addition, as a model for sustainable urban development, the strategic, forward-looking, and integrated nature of urban-security resilience offers an additional practical quality to mega-urban systems. Therefore, urban-security-resilience assessment will become a strategic direction and new model for urban security, and an effective solution for unknown-risk management in sustainable urban development.

The current spatial layout of China's overall urban resilience shows a highly remarkable east–high and west–low divergence pattern that fits the Hu Huanyong line [8]. The western part of China, which accounts for 70.6% of the country's total territory, is overwhelmingly in need of enhanced construction [9]. Moreover, the western region is in the northwest continental disaster zone. The plateau zone and frequent natural disasters have created sensitivity and fragility in the ecosystem of the region [10]. To investigate the current state of urban-safety management and urban-resilience construction in western China, this study analyzed the level and spatial and temporal evolution of urban-safety resilience in 10 regions in western China by constructing an urban-safety-resilience evaluation-index system and quantitatively measured the impact of urban people, urban facilities, and urban management on urban-safety resilience. The contributions of this paper are as follows. Firstly, this paper introduces the catastrophe-level method to analyze the macro-level indicator system, which can not only be used to obtain more accurate evaluations of urban-safety resilience, but can also provide assessment tools for urban safety and resilience development in other regions. Secondly, this paper assesses the urban-safety resilience of 10 regions in western China in three dimensions: personnel, facilities, and management. The findings will help to better understand the variability in the urban-safety-resilience components of the respective regions, as well as helping to provide recommendations for sustainable development in these regions. Finally, in addition to evaluating urban-safety resilience, this paper also uses Moran-index analysis to further explore the spatial and temporal evolution of urban-safety resilience and discusses comprehensive development strategies for cities in western regions from multiple perspectives, to provide policy recommendations for integrated regional urban development.

The remaining sections of this paper are organized as follows. Section 2 presents a literature review and analysis on urban resilience and urban security resilience. Section 3 explains the methodology used for the urban-security-resilience evaluation-index system and the spatial–temporal evolution analysis. Section 4 presents the urban-security-resilience evaluation and spatial–temporal evolution analysis for the 10 regions in western China, and discusses the results. Section 5 presents the conclusions and recommendations.

2. Literature Review

2.1. Related Research on Urban Resilience

Urban safety is essential to maintain social stability and enhance sustainable development in the growing urbanization process. Different scholars have defined the scope of the research on urban safety in varying ways. Krimsky proposed that polycentric theory can be applied to security control in most cities [11]. In contrast, Brugmann argued that research on urban safety should start with resilience, which is the key to sustaining the essential form of sustainable cities [12].

With the formal introduction of the urban-disaster-emergency-response system, urban resilience has gradually become a significant research component in new urban constructions. However, there are differences in its definition in academic circles at present. Jean-Marie and other scholars believed that resilient cities mainly use their internal resources and urban systems to resist different levels of disaster crises through technical and human means and recover quickly after disasters [13]. Asadzadeh et al. argue that a city's security resilience depends on its ability to withstand and recover from the massive damage and unstable chaos caused by disasters [14]. However, Patricia's notion of urban resilience emphasizes the systematic nature of urban resilience, arguing that it should be biased more towards temporal variables, i.e., expressing the process quantity rather than only the outcome quantity of urban resilience. Therefore, urban-resilience management needs to be implemented from the pre-disaster, disaster, and post-disaster perspectives, with a complete cycle of disaster events and response processes considered accordingly [15].

The current body of urban-resilience research covers a wide range of topics, and there are many ways to measure urban resilience. For instance, Lu Hao et al. used the BP neural network with a genetic algorithm to build an urban-resilience-measurement model and used the convergence model to analyze spatial–temporal evolution of the Chengdu–Chongqing urban agglomeration [16]. Ma Fei et al. used the extreme-entropy method to calculate the resilience level of urban agglomerations in China and explored the factors influencing the spatial–temporal evolution using gray correlation analysis [17]. Ma Xuefei et al. assessed the factors affecting urban spatial resilience in the Harbin–Changchun urban agglomeration and the impact of its spatial differentiation using the Geodetector method and obtained the spatial evolutionary characteristics of urban resilience by applying a Jenks inter-natural fault classification [18]. Liu et al. dissected the spatial and temporal evolution characteristics of the urban resilience in 18 cities in Henan province using the entropy method, the Thiel index, and an exploratory spatial data analysis (ESDA), and explored the influencing factors with a spatial econometric model [19]. Furthermore, some scholars and experts have also investigated and studied the framework and application of urban resilience. Many scholars' investigations of urban-resilience frameworks can be roughly divided into two categories: the first is the establishment of an urban-resilience framework in the social, economic, engineering, policy, and organizational dimensions. For example, Shi Yijun and other scholars determined the essential features of sophisticated urban systems by exploring the principles of urban-system operations. They constructed a structure for complicated urban systems with three dimensions, system environment, system elements, and system structure, and explored various aspects of the methodology to evaluate the resilience of urban systems. This method can be used in consultations on the development of urban safety and resilience enhancement [20]. Rina et al. artificially measured the impact of various natural hazards on urban resilience at the coastal scale. They measured the layouts of urban structures in five dimensions: engineering resilience, economic resilience, management resilience, environmental resilience, and social resilience [21]. Mahsa et al. divided the urban-resilience framework into six domains: societal, infrastructure, economy, environment, neighborhood capital, and institution. The performance of the community-tracking model in terms of various aspects of the urban-resilience framework was used to provide an additional reference for city managers on the planning and construction of resilient cities [22]. The second type of framework aims to develop revelatory tools using nonlinear cross-domain knowledge and geographical characteristics by combining sensitivity and vulnerability to guide the development of multi-scale resilience-assessment-indicator systems. Manyena clarified the correlation between the components of resilience, integrated capacity, and the implementation procedure through a comprehensive analysis of the urban-resilience framework and developed an indicator-measurement tool for regional urban resilience [23]. Karen conducted a statistical validation to determine the timeliness of an urban-resilience-measurement tool for flooding [24].

The notion of urban resilience has progressively appeared in national macro-policy and local urban-development-strategy reports, along with studies related to safety-resilience frameworks. For example, the Rockefeller Foundation developed a series of urban-safety-resilience-indicator frameworks, mainly focusing on urban systems and services, the health and well-being of urban residents, government leadership and strategy, and economic and social organization [15]. The United Nations developed the Sendai Framework and the Hyogo Framework, which are composed of four areas: understanding disaster risk, improving disaster-risk management, strengthening disaster-risk preparedness, and building urban resilience [25]. The new European Resilience Management Guidelines (ERMG) encourages the participation of all urban actors in urban governance by developing urban safety strategies. This is intended to achieve a resilient management capacity for cities and an integrated response capacity to strengthen urban-resilience management at all stages.

2.2. Related Research on Urban-Safety Resilience

At present, urban resilience is still a common international academic concept. Urban-safety resilience is based on urban resilience, focusing on the new situation faced by urban safety development. Research on urban-safety resilience is still limited to the theoretical results related to urban resilience, and there is a lack of targeted urban-safety-resilience research. In recent years, with the deepening of urban-safety-resilience research, led by China, scholars and experts in related fields have gradually achieved results in exploring the application strategies and evaluation schemes of urban-safety-resilience practices.

The current research on the evaluation methods for urban-safety resilience is qualitative. This qualitative research primarily focuses on establishing a theoretical evaluation frame for urban-safety resilience and highlighting the core components of urban-safety resilience.

In their evaluation study of urban-safety resilience, Huang Lang et al. built a specific conceptual model of urban-system-safety resilience. They determined key considerations in urban-system-safety resilience, such as the link between the elements of the municipal system, covering characteristics and functional characteristics, etc. [26]. Based on the context of urban-emergency and disaster prevention and safety development, scholars such as Fang proposed four points of urban-safety resilience: social resilience, institutional resilience, technological resilience, and project resilience [27]. Chen An et al. established a dynamic evolution mechanism of urban-safety resilience in the context of external risk-based perturbations, providing a new method of thinking for subsequent research on urban-safety-resilience evaluation [28]. Fan Weicheng established a urban-safety-resilience-system framework from the public-security perspective and argued for the strengthening of urban-safety resilience through science and technology, culture and management, the consolidation of the urban public-security-governance system, and the modernization of urban governance [7]. Based on the perspective of public health security, Julia Wang explored the disaster-response ability of China's urban-safety-resilience construction in terms of management mechanisms, spatial planning, culture and education, and material security [29]. Hu et al. found that China's urban-safety resilience suffers from a lack of a complete organizational structure and institutional system, insufficient innovation and digital transformation, a lack of regional differences in spatial planning, and a lack of redundancy in urban infrastructure. They proposed an architectural system for the whole-cycle resilience management of large urban systems that includes the dimensions of subject, space, mode, and process [30]. Some scholars believed that the urban-security-resilience framework should be further studied quantitatively using both quantitative and qualitative indicators. That is, an evaluation model of the urban-security-resilience-index system should be established. This research method is China's most widely used tool for urban-safety-resilience evaluation [31]. Guo Yuyu et al. believed that we should combine the implication of urban-safety resilience and the characteristics of drawing power, resilience, and adaptability and build an evaluation-index system for urban-safety resilience in four dimensions: social resilience, economic resilience, environmental resilience, and infrastructure resilience [32]. By analyzing the concept and connotations of urban resilience, Chen Changchun et al. established an evaluation-index system for urban-safety resilience using the three dimensions of resilience, recovery, and adaptation during flood and rainstorm disasters [31]. In the framework of the evaluation-index system of urban-safety resilience, Tian Jiefang et al. used the four dimensions of urban-infrastructure subsystem, social subsystem, organizational subsystem, and economic subsystem as a basis on which to assess the urban-safety resilience of all subjects and dimensions in the face of various disasters [33]. In specific studies on urban-safety-resilience-index systems, scholars mainly focused on natural, social, economic, institutional, and infrastructural aspects. From the perspective of nature, Zhang Hongmei et al. selected 11 indicators in terms of disasters, resources, and socio-economics and measured the level of protection of environmental ecology in Fuzhou [34]. Pang Sha et al. provided and selected 16 indicators from four dimensions, ecological sensitivity, adaptive capacity, natural ecology, and human disturbance, and adopted the comprehensive index-evaluation method to derive the corresponding values of these indicators based on specific environmental problems. They then established the environmental-resilience-indicator-evaluation system [35]. From the perspective of society, scholars such as Ge Lingling used social structure, demographics, and culture as dimensions to construct a social-resilience-evaluation system, focusing on social resilience [36]. From an economic perspective, Zhao Guojie et al. selected indicators from four perspectives: carrying capacity, resilience, sensitivity, and stability. These were used to evaluate the economic resilience of the coastal zone in Hebei Province [37]. Su Fei measured economic resilience by dividing the corresponding indicators into sensitivity, exposure, and coping capacity [38]. From the perspective of urban systems, Na Wei et al. selected indicators with which to establish an urban-system-resilience-index systemin three dimensions: sensitivity, loss, and stability [39]. By exploring the connotations of urban-safety resilience and the sustainable development model, Li Bo et al. considered the issue of urban-safety resilience. They selected 20 indicators to qualitatively and quantitatively analyze the three aspects of sensitivity, exposure, and resilience [40]. Liu Hui et al. created an indicator-evaluation system of firefighting resilience based on the following indicators: disaster resistance, disaster recovery, and disaster resilience [41].

Some scholars studied different types of city in terms of their urban-safety resilience because the scope of urban-safety resilience differs for different city types. Inspired by the experiences of such mega-cities as New York, Tao Xidong believed that domestic mega-cities should organize innovations in urban-resilience construction, implement a financial investment system to support infrastructure renewal and maintenance, optimize the design of the urban energy-supply chain and its spatial layout, and create a framework for urban-community safety and resilience [42]. By setting up an indicator system for the rating of urban-safety resilience in the Pearl River Delta during tropical cyclone disasters, Du Jinying suggested the development of urban-safety resilience in the Pearl River Delta by targeting ecological conditions, development levels, and organizational safeguards [43]. Focusing on a coastal city cluster with a high risk of rainfall and flooding, Tian Jian et al. used multi-source data and the intelligent analysis of rain- and flooding-hazard-identification technology to build a multi-faceted collaborative urban-safety-and-resilience layout plan [44].

2.3. Methods, Scales, and Gaps in Current Urban-Safety Resilience

Urban resilience continues to be a major topic internationally. Furthermore, many scholars have conducted a series of studies on the concept, definition, and evaluation of urban resilience. Most of these scholars used methods such as conceptual definition and connotation definition to argue that urban resilience is urban systems' ability to prevent, respond, and recover from disasters by working with residents, organizations, and governments [13–15]. Meanwhile, some scholars use a variety of different methods to evaluate urban resilience and urban-security resilience, including the entropy method [16,18,32], improved entropy method [8], TOPSIS method [45,46], and extreme-entropy method [17]. They assess the security resilience of each city from social, economic, engineering, environmental, management, infrastructure, and institutional perspectives to effectively analyze different cities and improve the construction of their urban-security resilience through appropriate measures. However, the vast majority of previous research focused on assessing urban resilience from a static perspective, with less research on the spatial and temporal evolutionary characteristics of urban resilience. From the literature on the spatial-temporal evolution of urban resilience [16–19], it can be concluded that the assessment of urban resilience from a dynamic perspective can provide a more comprehensive analysis of the factors influencing the differences in different cities' resilience levels.

Some countries, led by China, have conducted a series of studies on urban-safety resilience in recent years. Most of these studies focused on the evaluation of urban-safety resilience in mega-cities and developed economic zones, and most of the evaluated dimensions were reviewed in terms of economic, social, and institutional aspects. The comprehensiveness of the coverage needs to be improved, and more potential urban-safety resilience dimensions need to be comprehensively evaluated.

By combining studies from the literature related to urban resilience and urban-security resilience, the following problems were found to still exist in the current research on urban-safety resilience in China.

First, most of the studies on urban-safety resilience in China were based on examples from developed regions, such as the eastern areas. Few explored urban-safety resilience in China's western or northwestern areas.

Second, the application of urban-safety resilience is comprehensive and discipline-spanning. It is often difficult for relevant studies to effectively support the decision assessment, making it difficult for urban-planning decision makers to properly understand the relevant urban-safety-resilience evaluation results.

Third, urban-safety resilience is highly susceptible to coercive factors, systemic structural and chronic stresses, and perturbations from various natural and social perspectives. Previous studies did not offer progress on the issue of urban-safety resilience caused by the impact of such multiple stresses.

Therefore, based on the perspective of sustainable development, this paper evaluates and analyzes the urban-safety resilience and spatial–temporal evolution of 10 regions in western China from a macro perspective. In terms of evaluation objects, most scholars choose cities and regions with high economic levels for evaluation, and relatively little attention is paid to western China. This study makes up for the current lack of a wide range of urban-security-resilience studies to a certain extent and uses GIS, space weights, and Moran's index to analyze the spatial–temporal-evolution characteristics of the regions and to explore the changes in the evolution patterns and the correlations between patterns of urban-security resilience in the past.

3. Methodology

3.1. Urban-Safety Resilience

3.1.1. Concept and Connotation

Since the 14th Five-Year Plan, building of resilient cities based on the concept of safety development in China has been a new aim. Urban-safety resilience adds the concept of urban-safety development to urban resilience. Few scholars have studied urban-safety resilience because it has been proposed for a relatively short time. The definition and connotations of the concept have not been unified. The definition and connotations of urban-safety resilience are defined through two aspects: the first is based on the definition of urban resilience, and the second is based on the connotations of urban safety.

The main studies using the first perspective are as follows. Rina et al. differentiated urban resilience into engineering resilience, economic resilience, management resilience, environmental resilience, and social resilience to improve the structural layouts of cities [21]. Mahsa, on the other hand, made additional references to urban-resilience building in terms of social resilience, infrastructure resilience, economic resilience, environmental resilience, community-capital resilience, and physical resilience [22].

The main studies conducted from the perspective of the second category are as follows. Against the background of urban-emergency and disaster prevention and safety development, scholars such as Fang believed that the connotations of urban safety resilience should include social personnel safety, engineering safety, and technical safety [27]. Fan et al. believed that urban-security resilience should be strengthened from the perspective of public security in terms of science and technology, culture and management, and strengthening of the urban public-security-governance system [6]. Ge et al. believed that the connotations of urban-security resilience should include social structure, social demographics, and social culture [36].

Using the research reference *Guide for safety resilient city evaluation* [47], and systematizing the literature review, this paper defines urban-security resilience as cities' ability to cope with and recover from disasters throughout the whole process, with the concept of security development as the guiding principle and population, facilities, and management as the basis of development. Its connotations should include the following elements.

(1) Resilience of urban-personnel safety

Urban-personnel-security resilience is the ability of the urban population to secure basic livelihood security before and after a disaster. It is based on a people-oriented concept, involving judgments on the primary livelihood conditions of the city. It aims to ensure that urban populations can cope with unknown risks before facing disasters, mitigate the damage caused when disasters occur, and recover quickly after experiencing such disasters.

(2) Resilience of urban-facility safety

Urban-facility-safety resilience refers to urban facilities' ability to maintain basic operations in response to disasters. In studies on urban-safety resilience, the urban-infrastructure network is a prerequisite for a city's ability to resume operations after a disaster. Its loss of function can lead to significant social effects and economic losses [48]. The urban-infrastructure network mainly includes the water-distribution network, power-distribution network, transportation network, and communication-distribution network. In addition, infrastructure that can prepare for construction works, urban-disaster-emergency prediction, and emergency security also belongs to the urban-facility-safety-resilience category. As noted by Fang et al, cities should aim to enhance their urban security and resilience, urban-disaster-risk monitoring and early-warning systems, urban infrastructure, lifeline-engineering security, emergency-communication-security-project construction, etc., and strengthen their disaster-emergency response and rescue, as well as their material and equipment security [27].

(3) Resilience of urban-management safety

Urban-management-security resilience refers to urban systems' ability to prevent and respond to disasters. Urban governance plays a pivotal role in urban-safety resilience [49]. The resilience of urban-management safety requires the ability to provide basic security and emergency supplies in the event of a disaster and offer certain supplies and medical support in the event of an unknown risk. In the security-management process, the type, frequency, and extent of regional risks should be assessed and controlled to prevent unpredictable damage and losses to cities from disasters.

3.1.2. Principles for Constructing the Indicator System

The reasonable degree of the index system of urban-security resilience directly affects the objective accuracy of the evaluation results, and the construction of a reasonable index system is a key step in the evaluation. The construction of the urban-security-resilience-evaluation-index system follows the following principles:

(1) Objectivity

In addition to serving as a basis for evaluation, the evaluation-index system of urban-security resilience can also be used as the basis for regional planning and urban-security-resilience-information platforms in subsequent research. At the same time, the construction of an urban-security-resilience-evaluation-index system should be based on profound analysis and scientific research on the scope and characteristics of urban-security resilience to produce a practical and scientific index system. By analyzing the connotations of urban-security resilience, this study establishes the mechanism of urban-security resilience and uses it as a guarantee of the objectivity of the index system.

(2) Quantitative

When selecting the indicators which can be reflected by data directly or by data after quantification, the objectivity of the indicators should be emphasized. This paper uses spatial and temporal evolution analyses, and strictly considers the changes in the indicators in each year. Since it is difficult to quantify qualitative indicators, in this research, qualitative indicators were avoided as much as possible when constructing the indicators.

(3) Systemic

When selecting urban-safety-resilience-evaluation indicators, various factors influencing urban-safety resilience should be considered comprehensively in terms of the specific purpose and the definition of relevant resilience levels at each stage. Moreover, when selecting indicators, not only should the safety-resilience-related indicators of the city itself be considered, but also the ecological, economic, and development issues of the city. At the same time, there should be a certain logical relationship among the indicators in order to ensure that each indicator has a specific role and to avoid duplication.

(4) Authoritativeness

With the growing demand for urban-safety-resilience development, the need to enhance the capacity for rapid recovery from urban disasters and risk-response capacity has become increasingly urgent. The evaluation indexes should be authoritative. If some data are missing, reasonable mathematical methods should be used to make reasonable predictions.

3.1.3. Establishment of an Urban-Safety-Resilience-Index System

The evaluation system requires not only a definition of the connotations of indicators as a theoretical basis, but also the construction of a practical set of indicators to achieve a specific evaluation. The structure of the index system in this paper mainly combines the definition of connotations and draws on the *Guide for safety resilient city evaluation* [47] and some of the related research to assess urban-security resilience in terms of people, facilities, and management in three areas: the security resilience of urban people mainly reflects the preparedness of urban populations to cope with disasters. After the challenges of COVID-19, the importance of population resilience is obvious [50], so in this paper, we selected three Tier 2 indicators and nine Tier 3 indicators to reflect the carrying capacity of the city and the ability to guarantee safety [16,17,51]; the security resilience of urban facilities mainly reflects the ability of a city to maintain the normal operation of its facilities. Most of the evaluation studies in this field have taken the facility dimension as the assessment criterion [16,33], so in this paper, we selected five Tier 2 indicators and fifteen Tier 3 indicators to reflect the city's supply capacity, disaster-warning capacity, and facility-guarantee capacity [31,32]; urban-management-security resilience mainly reflects the coordination ability of a city's regional disaster scale and input guarantee, the ability of the economic input to correctly respond to the risk of shock and to reduce the losses to a certain extent [52], and the balance between urban disasters. Therefore, this paper selects 2 Tier 2 indicators and 6 Tier 3 indicators to reflect the economic strength and disaster resistance needs of cities [16,32].

To ensure that the differences between urban and rural spaces were clearly described, the selection of indicators in this paper took into consideration the fact that the urban population has a high aggregation, as well as the observation that the rural population is older than the urban population [53], which affects the degree of differentiation of human security. Therefore, the indicators with the greatest impact on urban resilience were chosen [54]. Urban areas are complex and giant systems compared with rural areas, and their disaster-prevention facilities and management systems are more extensive and have a more significant impact than those in rural areas. The indicators in this paper were chosen to ensure the urban characteristics and achieve as much of an urban–rural distinction as possible. The evaluation-index system in this paper is shown in Table 1. The corresponding indicator descriptions are shown in Appendix A.

Table 1. Evaluation-index system of urban-safety resilience.

General Goal	Tier 1 Indicators	Tier 2 Indicators	Tier 3 Indicators
Urban-safety resilience (A)	The resilience of urban-personnel safety (B1)	Basic population attributes (C1)	The resident-population density in built-up areas (D1)
			Level of basic medical insurance for urban workers (D2)
			Percentage of transient population (D3)
		Social participation preparation (C2)	Level of urban-health-technology talent pool (D4)
			Number of hospitals (D5)
			Social-organization-unit level (D6)
		Sense of security and security culture (C3)	Personal-accident-insurance income (D7)
			Urban commercial-insurance income (D8)
			Number of employees involved in work-related-injury-insurance coverage (D9)
	The resilience of urban-facility safety (B2)	Construction (C4)	Land-development intensity (D10)
			The proportion of land area in security-vulnerable areas (D11)
			Number of employees in construction-industry enterprises (D12)
		Traffic facilities (C5)	Road-network density (D13)
			Level of urban traffic-lighting facilities (D14)
		Lifeline project amenities (C6)	Cell-phone penetration rate (D15)
			Number of fixed-broadband households (D16)
			Level of gas-supply facilities (D17)
		Monitoring and warning facilities (C7)	Level of seismic-monitoring facilities (D18)
			The public reach of meteorological hazard monitoring and anticipation of early alert messages (D19)
			Urban intelligent-pipe-network density (D20)
		Emergency-security facilities (C8)	Shelter area per capita (D21)
			Storage area of disaster-relief-reserve institutions per 10,000 people (D22)
			Number of beds in healthcare facilities for 10,000 people (D23)
			Greenery coverage (D24)
	The resilience of urban-management safety (B3)	Risk-control level (C9)	The hazard-related mortality rate per million population (D25)
			Annual direct financial damage resulting from catastrophes as a percentage of area GDP (D26)
			Annual percentage of people affected (D27)
		Support-security input (C10)	Public-security financial expenditure (D28) Healthcare financial expenditure (D29)
			Transportation financial expenditure (D30)

3.1.4. Study Area and Time

In this paper, to explore the level of development of safe and resilient cities in western China, the 10 regions of Chongqing, Sichuan, Yunnan, Guizhou, Shaanxi, Gansu, Qinghai, Ningxia, Guangxi, and Inner Mongolia were selected according to the preferability and feasibility of regional development and due to the unavailability of some indicator data in Xinjiang and Tibet. At present, China's development is still unbalanced, but there is a significant focus on the development of the western district at the national level. Many financial and material resources have been invested in urban construction, and its development potential is enormous. However, there is scant research on urban-safety resilience in China's western region. Therefore, in this paper, we study the security resilience of cities in western China.

When selecting the research time, to prevent the data obtained by selecting consecutive years from not significantly reflected the changing trends, we studied the relevant data by selecting intervals of years, which made the changes in the data more accurate and the changes in the trend more intuitive. Since relevant statistics for 2022 have not yet been published, the most recent year in this study is 2021. The concept of a safe and resilient city is relatively recent, so the primary data from three years, 2017, 2019, and 2021, were selected for the evaluation of safe and resilient city development in western China based on careful consideration and reasonable verification.

3.2. Catastrophe-Progression Method

The main evaluation methods included the ANP network, fuzzy comprehensive evaluation, hierarchical analysis, and catastrophe progression. To distinguish the advantages and disadvantages of each evaluation approach and the suitability of each method for this study, the primary evaluation methods' advantages, weaknesses, and applicability are summarized in Table 2.

Table 2. Comparison of evaluation methods.

Evaluation Methodology	Advantages	Disadvantages	Scope of Application
Fuzzy integrated evaluation	Explicit and systematic results that translate qualitative metrics into quantitative metrics	Insufficient use of the volatility of the change in its evaluation results when the affiliation degree changes, mainly because of the considerable subjectivity in the evaluation process	The nature of the influential parameters and the difficulty in quantifying the assessment of the activity
Hierarchical analysis	Translation of qualitative metrics into quantitative metrics	Failure to consider the interplay between different levels of decision-making or the same level	No cross-talk between factors and between levels
ANP-network analysis	Superior flexibility, considering both the factors and the dependencies between the superordinate factors of each factor	More cumbersome to use in complex decision-making processes	Less computationally intensive and relatively deterministic risk-evaluation problem
Object element model	Flexible indicators, simple process, more systematic and refined results	The hand must be a relatively definite value	Multiple phases of evaluation of numerous evaluation objects identified by indicators
Monte Carlo	Errors and problems are independent of the number of dimensions; problems with statistical properties can be solved directly; Issues of a continuous nature do not need to discretize	Inability to fully reflect the interactions between project risk factors Deterministic problems need to transform into stochastic problems	Evaluation questions are relatively simple and defined
Catastrophe progression	It can be used to analyze indicator systems with complex influencing factors that produce unclear catastrophe points; Not overly dependent on weights	Due to its model characteristics, the definition of the risk level interval is more complicated	Study of systems with complex internal structures or unknown mechanisms of interaction of internal factors

The catastrophe theory has the following main advantages. ① The catastrophe-level method is systematic and can better cover all aspects of urban-safety-resilience evaluation. ② The catastrophe-level method is organized and can better protect all aspects of urban-safety-resilience evaluation. ③ A good evaluation of complex structures can lead to a more accurate evaluation of the more complex evaluation-index system of urban-safety resilience. ④ With significant hysteresis, the catastrophe-level method can allow the more precise evaluation of changing trends in urban-safety resilience. Therefore, this paper mainly uses the catastrophe theory for urban-safety-resilience evaluation.

Catastrophe theory, as a general theoretical approach that acts specifically to represent changes in the state of a system, usually simulates changes in the system's state in various periods with the help of constructive function models [55]. The function model in the catastrophe theory is a latent feature, which reflects the system's state. The possible positions corresponding to different models represent very different meanings.

Before applying the catastrophe theory, an evaluation pattern needs to be constructed based on the catastrophe-progression approach for the urban-safety-and-resilience-index system, as follows.

(1) Data Sources

In this study, to strictly ensure that original data sources could be supported for an evaluation of urban-safety resilience in western China, raw data were collected from the National Bureau of Statistics, Chongqing Municipal Bureau of Statistics, Sichuan Provincial Bureau of Statistics, Yunnan Provincial Bureau of Statistics, Guizhou Provincial Bureau of Statistics, Shaanxi Provincial Bureau of Statistics, Gansu Provincial Bureau of Statistics, Qinghai Provincial Bureau of Statistics, Ningxia Hui Autonomous Region Bureau of Statistics, Guangxi Zhuang Autonomous Region Bureau of Statistics, Inner Mongolia Autonomous Region Bureau of Statistics, China Urban Construction Statistics Yearbook, and health statistics yearbooks of each province, as well as other official channels. After the data for 2017, 2019, and 2021 were obtained, they were collected and organized, leading to the initial data shown in Appendix B.

(2) Data Processing

Before calculating the data related to the indicator system of urban-safety resilience constructed in the paper, the data were normalized and transformed into the same range by dimensionless transformation because of their different units, different numerical sizes, and significant differences in the forward and backward directions. In dimensionless conversion, the range-transform method is generally used to process all data into dimensionless and comparable values in the interval of [0, 1] [56].

The range-transform method can divide data into three categories, according to the positive and negative nature of their indicators:

Positive indicators correspond to the formula:

$$y_j = \frac{x_j - {x_j}^{min}}{{x_j}^{max} - {x_j}^{min}} \tag{1}$$

Inverse indicators have the corresponding formula:

$$y_j = \frac{{x_j}^{max} - x_j}{{x_j}^{max} - {x_j}^{min}} \tag{2}$$

Interval optimal indicators have the corresponding formula:

$$y_j = \begin{cases} 1 - \frac{a - x_j}{a - {x_j}^{min}}, \left({x_j}^{min} \le x_j < a\right) \\ 1, \left(a \le x_j \le b\right) \\ 1 - \frac{x_j - b}{{x_j}^{max} - b}, \left(b < x_j \le {x_j}^{max}\right) \end{cases} \tag{3}$$

Equation: x_j—the raw index data; $x_j{}^{max}$—the maximum value of the index data; $x_j{}^{min}$—the minimum value of the indicator data; y_j—the transformed indicator value. The optimal interval for the indicator data is $[a, b]$.

(3) Model Selection

After completing the dimensionless calculation of the raw data of indicators, the catastrophe-level values of needles at different levels were calculated by the matching catastrophe model corresponding to the normalization formula. Net, the catastrophe-level values of hands at each station were calculated upward and individually based on the framework of the indicator system. Finally, the catastrophe-level values of the total urban-safety resilience were obtained.

Since the normalization formula needed to be selected following the principle of matching the number of control variables and state variables with the corresponding normalization formula, several correspondence methods covered in this paper are shown in Table 3.

Table 3. This paper involves the normalization formula and the corresponding table of state variables and control variables.

Catastrophe Type	Status Variable	Control Variable	Potential Function	Normalized Formula
cusp catastrophe	1	2	$F(x) = x^4 + ax^2 + bx$	$x_a = \sqrt{a}, x_b = \sqrt[3]{b}$
swallowtail catastrophe	1	3	$F(x) = x^5 + ax^3 + bx^2 + cx$	$x_a = \sqrt{a}, x_b = \sqrt[3]{b}$, $x_c = \sqrt[4]{c}$
butterfly catastrophe	1	4	$F(x) = x^6 + ax^4 + bx^3 + cx^2 + dx$	$x_a = \sqrt{a}, x_b = \sqrt[3]{b}$, $x_c = \sqrt[4]{c}, x_d = \sqrt[5]{d}$
hut catastrophe	1	5	$F(x) = x^7 + ax^5 + bx^4 + cx^3 + dx^2 + ex$	$x_a = \sqrt{a}, x_b = \sqrt[3]{b}, x_c = \sqrt[4]{c}$, $x_d = \sqrt[5]{d}, x_e = \sqrt[6]{e}$

Specifically, x is the state variable, a, b, c, d, and e are the control variables, and $F(x)$ is the system state and the potential energy condition of the whole system when the state variable is x. The control variable is determined by the number of similar indicators, and the normalized formula is determined by the weighting of the indicators.

After determining the corresponding model by the number of control variables and their state variables, the specific correlation formula was determined by ranking the weights of indicators within the same level and determining the correlations between the indicators. The weighted ranking is shown in Table 4.

Table 4. Ranking of the weighting of urban-safety and -resilience indicators.

Upper-Level Indicators	Indicators	Indicator Ranking of the Same Higher-Level Indicators
Basic population attributes (C1)	The resident population's density in built-up areas (D1)	3
	Level of basic medical insurance for urban workers (D2)	1
	Percentage of transient population (D3)	2
Social-participation preparation (C2)	Level of urban-health-technology talent pool (D4)	1
	Number of hospitals (D5)	3
	Social-organization-unit level (D6)	2
Sense of security and security culture (C3)	Personal-accident-insurance income (D7)	3
	Urban-commercial-insurance income (D8)	1
	Number of employees involved in work-related-injury-insurance coverage (D9)	2

Table 4. *Cont.*

Upper-Level Indicators	Indicators	Indicator Ranking of the Same Higher-Level Indicators
Construction (C4)	Land-development intensity (D10)	2
	The proportion of land area in security-vulnerable areas (D11)	1
	Number of employees in construction-industry enterprises (D12)	3
Traffic facilities (C5)	Road-network density (D13)	1
	Level of urban-traffic-lighting facilities (D14)	2
Lifeline-project amenities (C6)	Cell-phone penetration rate (D15)	3
	Number of fixed-broadband households (D16)	2
	Level of gas-supply facilities (D17)	1
Monitoring and warning facilities (C7)	Level of seismic-monitoring facilities (D18)	3
	The public reach of meteorological hazard monitoring and anticipation of early alert messages (D19)	2
	Urban intelligent-pipe-network density (D20)	1
Emergency security facilities (C8)	Shelter area per capita (D21)	1
	Storage area of disaster-relief-reserve institutions per 10,000 people (D22)	2
	Number of beds in healthcare facilities for 10,000 people (D23)	3
	Greenery coverage (D24)	4
Risk-control level (C9)	The hazard-related mortality rate per million population (D25)	3
	Annual direct financial damage resulting from catastrophes as a percentage of area GDP (D26)	2
	Annual percentage of people affected (D27)	1
Support-security input (C10)	Public-security financial expenditure (D28) Healthcare financial expenditure (D29)	1
	Transportation financial expenditure (D30)	2
The resilience of urban-personnel safety (B1)	Basic population attributes (C1)	1
	Social-participation preparation (C2)	3
	Sense of security and security culture (C3)	2
The resilience of urban-facility safety (B2)	Construction (C4)	3
	Traffic facilities (C5)	2
	Lifeline-project amenities (C6)	1
	Monitoring and warning facilities (C7)	4
	Emergency security facilities (C8)	5

Table 4. *Cont.*

Upper-Level Indicators	Indicators	Indicator Ranking of the Same Higher-Level Indicators
The resilience of urban-management safety (B3)	Risk-control level (C9)	2
	Support-security input (C10)	1
Urban-safety resilience (A)	The resilience of urban-personnel safety (B1)	2
	The resilience of urban-facility safety (B2)	1
	The resilience of urban-management safety (B3)	3

According to the different catastrophe-level algorithms, there are two types of relationship between indicators of the same class in terms of correlation: "complementary" and "non-complementary." Through consultations with experts, this paper establishes the internal connections and structural integrity of the indicator-evaluation system for urban-safety resilience. The relationships between the indicators in the same layer are shown in Table 5.

Table 5. Internal-relationship table of indicators at the same level.

Indicator Levels	Hierarchical Internal Metrics	Internal Relations
Tier 1 Indicators	B1, B2, B3	Complementary
Tier 2 indicators	C1, C2, C3	Complementary
	C4, C5, C6, C7, C8	Non-complementary
	C9, C10	Complementary
Tier 3 indicators	D1, D2, D3	Complementary
	D4, D5, D6	Complementary
	D7, D8, D9	Complementary
	D10, D11, D12	Non-complementary
	D13, D14	Complementary
	D15, D16, D17	Non-complementary
	D18, D19, D20	Complementary
	D21, D22, D23, D24	Complementary
	D25, D26, D27	Non-complementary
	D28, D29, D30	Complementary

Based on the normalized formula, indicator weights, and indicator-relationship principles, the overall urban-safety-resilience model is shown in Figure 1.

The total catastrophe level was obtained by calculating each indicator from the bottom to the top.

(3) Interval division

After the catastrophe model obtained the evaluation results, the results needed to be refined by an interval segmentation of the model. Compared with the mean segmentation, uniform distribution, and quantile methods, the K-means clustering algorithm can better obtain the rank variability in evaluation results and is unaffected by the absolute aggregation effect. In contrast, the high aggregation of the catastrophe model's evaluation results means that the K-means clustering algorithm can be used as the interval-division method for catastrophe models.

The main steps in the K-means clustering algorithm are as follows: ascertain the number of cluster centroids K, group the K-cluster centers and calculate the distance between each factor to obtain the cluster-center-class group with the shortest distance; next, obtain the corresponding K-class groups through classification and, finally, iterate and loop this process until the termination condition is satisfied [57].

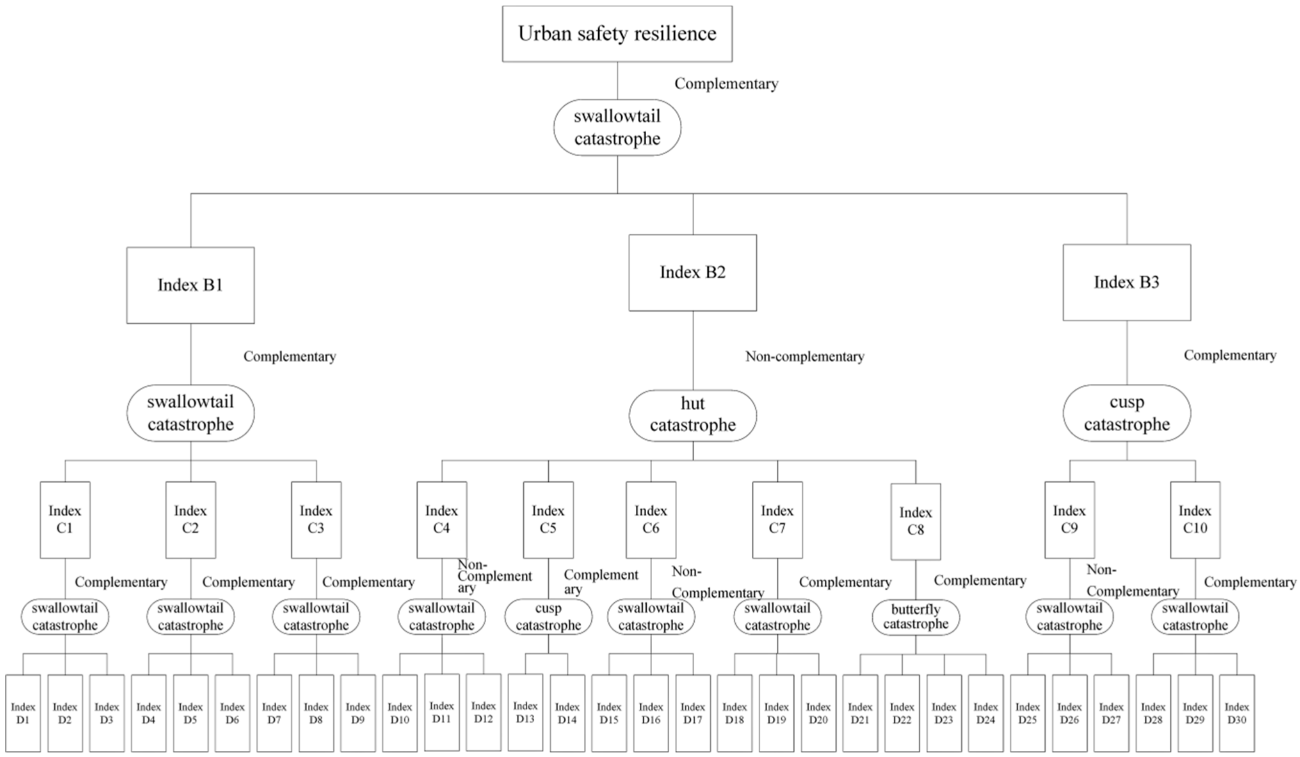


Figure 1. Catastrophe model of urban-safety resilience.

According to the K-means clustering algorithm, it is assumed that there is a gradient category of urban-safety-and-resilience-evaluation results, and its criterion function is:

$$J = \sum_{j=1}^{k} \sum_{i=1}^{N_j} \|X_i - Z_j\|^2, X_i \in S_j \tag{4}$$

where J is the sum of the squares of the distances from the sample points of each evaluation result in the cluster to the center of the class, S_j is the set of sample points for each evaluation result, Z_j is the set of sample points for each evaluation result, the center point of the S_j, and N_j is the sample size of the set of sample points for each evaluation result.

The algorithm aims to find the minimum value of the criterion function and the square's minimum value. The J_j of the distance from each evaluation-result sample point to the center of the class. This can be used to solve the following equation:

$$\frac{\partial J_j}{\partial Z_j} = 0 \tag{5}$$

The meaning of the letters in the formula is the same as in Formula (4).

Substituting Formula (5) into Formula (6):

$$\frac{\partial}{\partial Z_j} \sum_{i=1}^{N_j} \|X_i - Z_i\|^2 = \frac{\partial}{\partial Z_j} (X_i - Z_i)^T (X_i - Z_i) = 0 \tag{6}$$

The letters in the formula mean the same as in Formula (4).

The solution of Formula (6) yields the centroid. The Z_j of the sample-point set S_j of the evaluation results is as follows:

$$Z_j = \frac{1}{N_j} \sum_{i=1}^{N_j} X_i, X_i \in S_j \tag{7}$$

The letters in the formula mean the same as in Formula (4) [58].

The above is the theoretical solution model, which is challenging to operate in the actual solution, so the exact resolution is mainly calculated using an iterative operation. The main steps are as follows: ① K samples are arbitrarily selected as clustering centers; ② the distance between the samples, and each cluster center is calculated; ③ the average value of the samples of each category is determined as the new cluster center; ④ if the cluster center does not change after an iteration or reaches the maximum iteration number, the process concludes with the cluster center. Otherwise, it is necessary to return to step ② [59].

The iterative algorithm above can divide the city-safety-and-resilience-evaluation results into zones and form an echelon of the development levels in the western region.

3.3. Spatial Statistical Theory

(1) Geographic Information System (GIS)

According to a broad definition, a GIS is an information system used to process geographic and spatial data [60]. Data collection, processing, storage, and analysis are usually performed with geographic data as the core [61]. So far, GIS has been adopted in various domains, and it has become a standard tool for analyzing problems with spatial attributes. This paper constructs geographic layers by placing the evaluation results as elements in layers.

(2) Space weights

In this paper, the correlation between levels of urban-safety resilience is mainly established using the spatial analysis software, GeoDa. At present, the four main spatial matrices used in GeoDa software are the queen-contiguity type, rook-contiguity type, threshold-distance type, and K-nearest-neighbors type. The specific spatial matrix relationships are shown in Table 6.

Table 6. Spatial matrix relationships.

Spatial Matrix Type	Spatial Matrix Relationship
Rook-contiguity type	It is generally used to construct a spatial matrix with the help of the spatial relationship between two factors, that have joint edges.
Queen-contiguity type	It is generally used to construct a spatial matrix using the spatial relationship between two factors that have typical edges or common points.
K-nearest-neighbors type	Generally, the spatial matrix is constructed by using the distance between two elements after fixing the number of adjacent elements.
Threshold-distance type	It is generally used to construct a spatial matrix regarding the distance between two elements.

The model constructed in ArcGIS in this paper does not involve the location of each point in space but studies the relationship between the geographic distance between each local unit and the high-quality development of the construction industry. Therefore, the spatial matrix should be selected with a fuller consideration of the neighboring relationship between each province and autonomous region in the western area, reflecting the macro-level spatial-distribution relationship. In addition, the areas selected for this study were all adjacent to typical edges, and there was no common-point adjacency. The rook-contiguity type mainly reflects the spatial-distribution relationship through the adjacency relationship between two factors. It is more appropriate to choose to construct this type of spatial matrix. The spatial weight matrix corresponding to this matrix is generally determined according to the spatial adjacency function [62], referring to the space-matrix construction of the queen-contiguity type. The construction of the space matrix in this paper is as follows:

$$W = \begin{pmatrix} \omega_{11} & \omega_{12} & \cdots & \omega_{1n} \\ \omega_{21} & \omega_{22} & \cdots & \omega_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \omega_{n1} & \omega_{n2} & \cdots & \omega_{nn} \end{pmatrix} \tag{8}$$

where $\omega_{ij} = \begin{cases} 1, \text{Two units adjacent to each other} \\ 0, \text{Two units are not adjacent to each other} \end{cases}$.

(3) Moran's index

The Moran Index is divided into the global Moran Index [63] and the local Moran index [64].

The global Moran index in this paper portrays the overall trend of the spatial correlations in urban-safety resilience across the study area and is calculated as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j}z_i z_j}{S_0\sum_{i=1}^{n} {z_i}^2} \tag{9}$$

where z_i is the deviation of the attribute value of urban-safety resilience from the mean, $w_{i,j}$ is the spatial weight of urban-safety resilience in an area, n is the total number of areas, and S_0 is the set of all urban-safety-resilience spatial weights.

The local Moran index measures the spatial correlation between the safety resilience of a regional city and the safety resilience of its neighboring towns, and its model equation is as follows:

$$I_n = \frac{Z_i}{S^2}\sum_{j\neq i}^{n} w_{ij}Z_j \tag{10}$$

Next, $Z_i = \mathrm{y_I} - \overline{\mathrm{y}}, Z_j = \mathrm{y_j} - \overline{\mathrm{y}}, \mathrm{S}^2 = \frac{1}{\mathrm{n}}\sum(\mathrm{y_i} - \overline{\mathrm{y}})^2$, w_{ij} is the spatial weight, and n is the total number of factors.

Moran's I provide a correlation basis for the spatial distribution of urban-safety resilience in the western region of this study. When the value is greater than zero, this represents a positive spatial association; when Moran's I is less than zero, this represents a negative spatial association; when Moran's I is zero, the space is spatially random [65].

4. Results

4.1. Evaluation Results

The raw data of the calculation variables of each year's index calculated by the calculation method above are shown in Appendix C. The urban-security-resilience catastrophe-level values for the 10 regions in western China in 2017, 2019, and 2021 are shown in Appendix D. The urban-safety-resilience levels of the personnel, facilities, and management are showcased in Figures 2–5 below.

In this study, the K-means-cluster analysis was performed using SPSS Statistics 27 software to determine the urban-safety-resilience-grade-evaluation results and the resilience grade by using the urban-safety-resilience catastrophe-level values for 2017, 2019, and 2021 in the 10 regions in western China as clustering factors. After the iteration, the cluster centers were obtained, as showcased in Table 7.

4.2. Spatial Evolution Analysis of Urban-Safety Resilience

For the spatial analysis, we mainly used ArcGIS 10.6 and GeoDa 1.2 software to produce national basic geographic information data at a scale of 1:1 million using ArcGIS software. The standard map for 2022 released by the Ministry of Natural Resources of China was combined with geographic maps of 10 regions in western China and urban-security-resilience-evaluation data to build a GIS model of urban-security resilience in the 10 regions in western China.

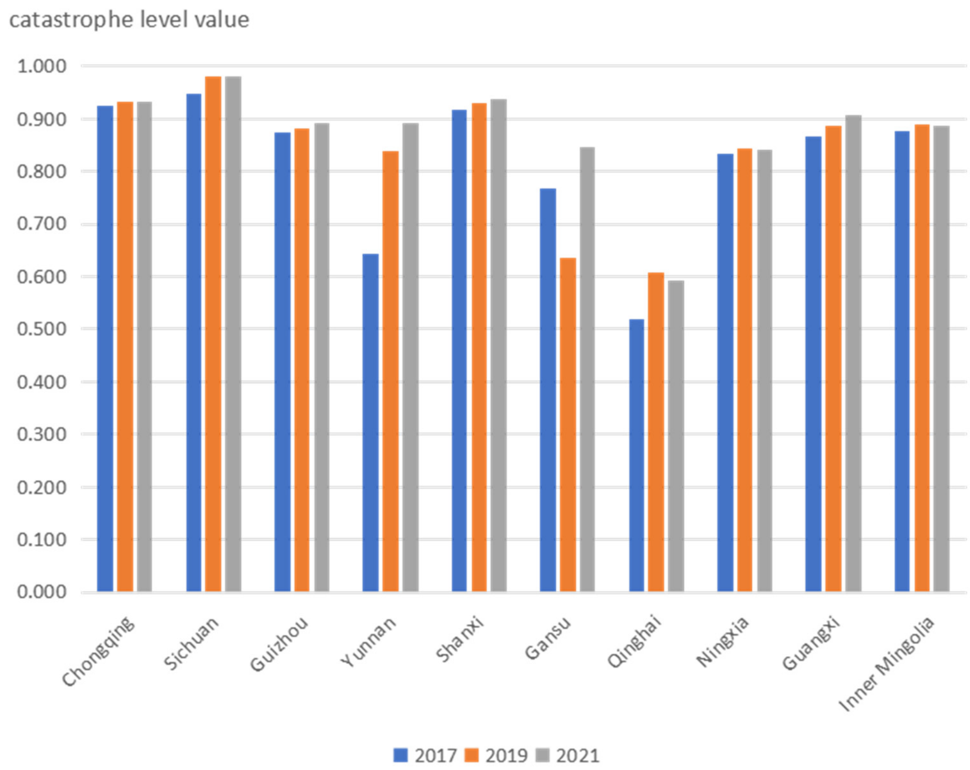


Figure 2. Urban-safety-resilience levels in western China in 2017, 2019, and 2021.

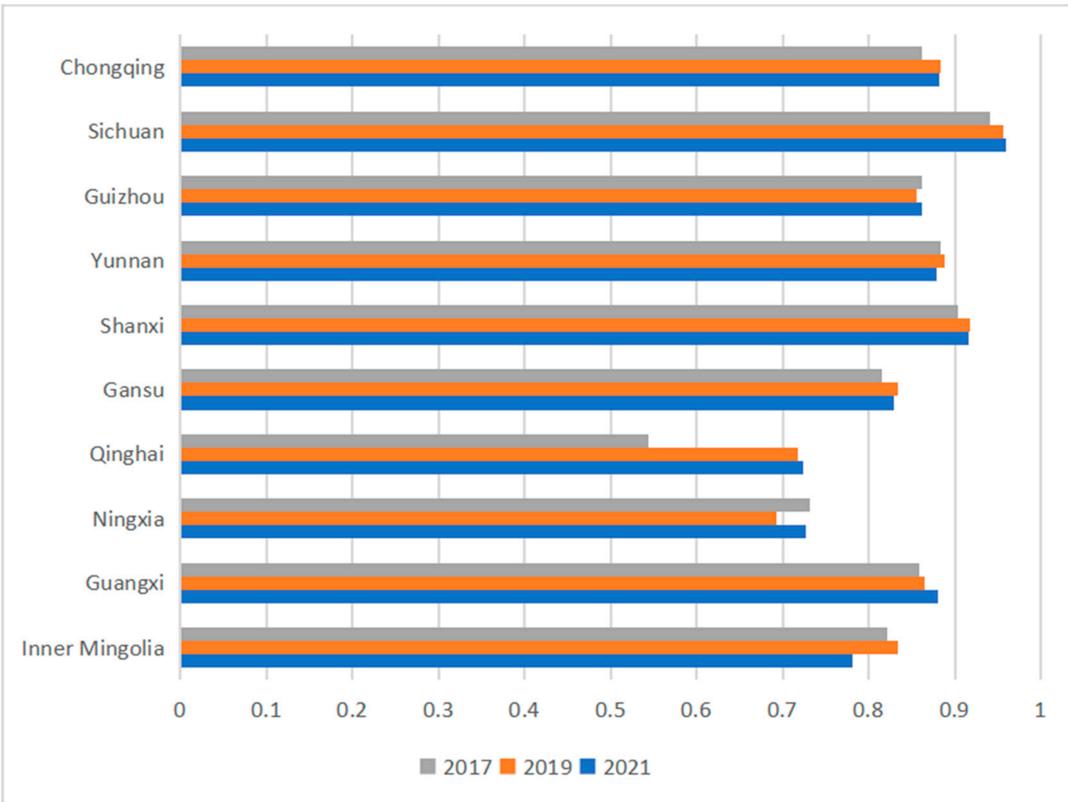


Figure 3. Resilience levels of urban-personnel safety in western China in 2017, 2019, and 2021.

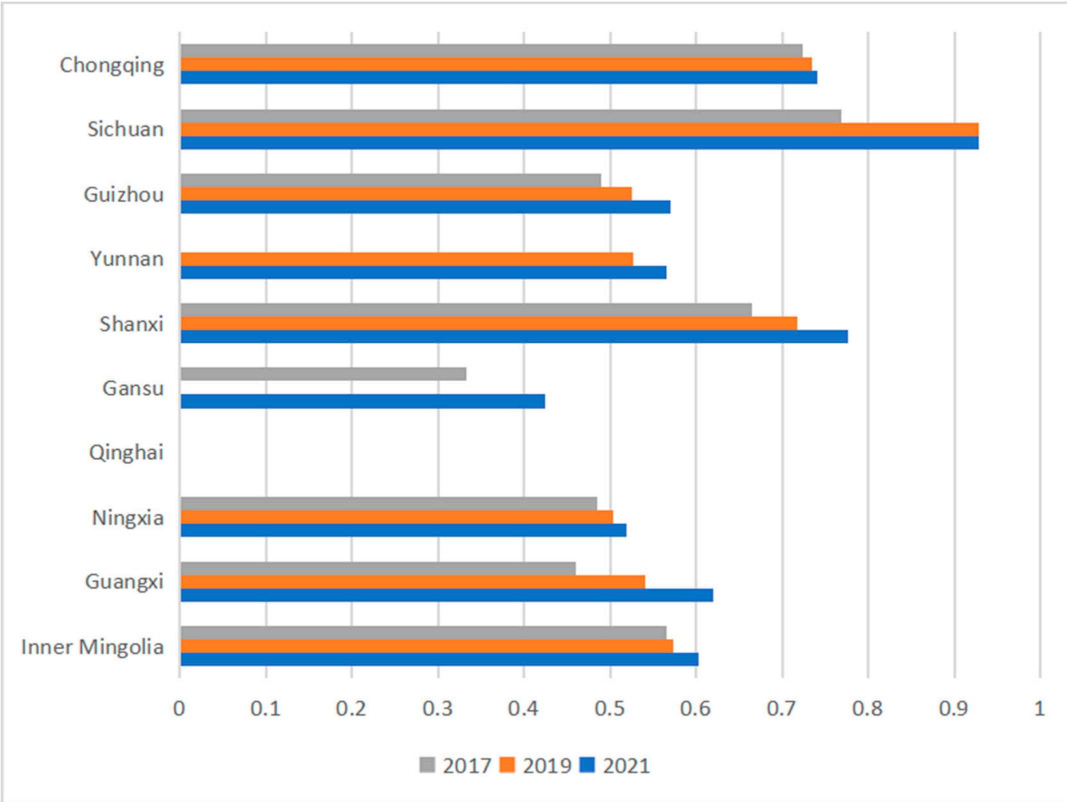


Figure 4. Resilience levels of urban-facility safety in western China in 2017, 2019, and 2021.

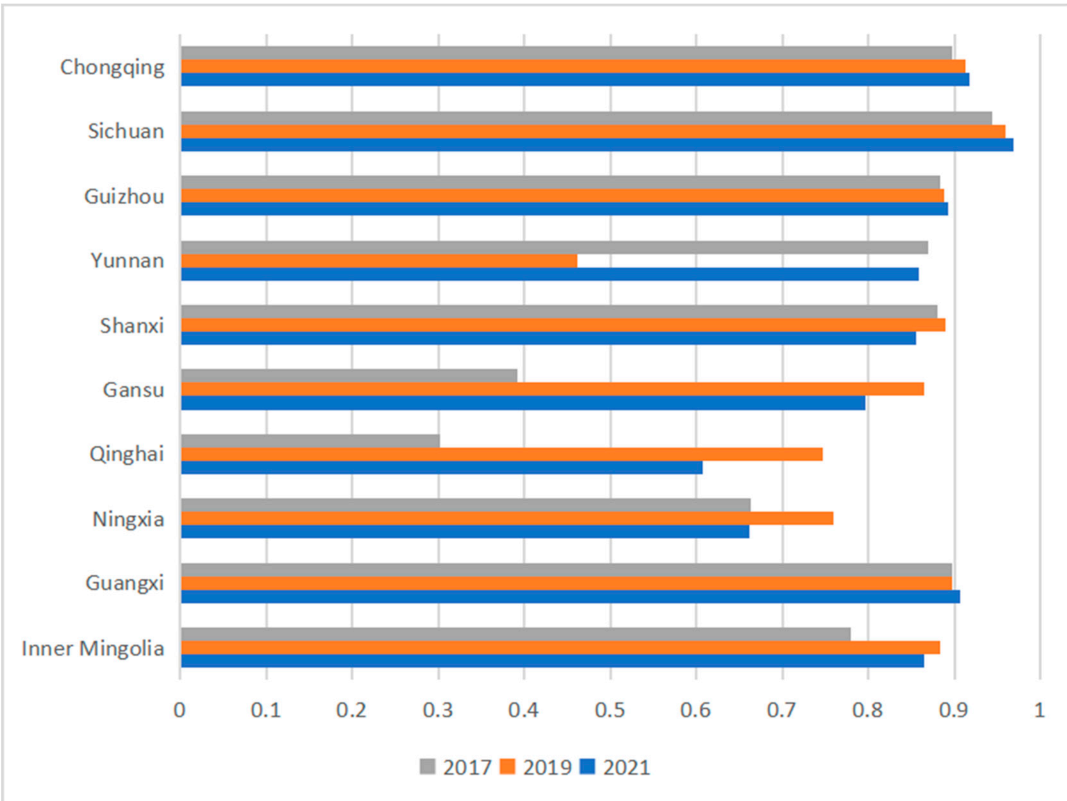


Figure 5. Resilience levels of urban-management safety in western China in 2017, 2019, and 2021.

Table 7. Assessment results for urban-safety resilience in the western region in 2017, 2019, and 2021.

2017			2019			2021		
Region	**Evaluation Results**	**Resilience Level**	**Region**	**Evaluation Results**	**Resilience Level**	**Region**	**Evaluation Results**	**Resilience Level**
Chongqing	0.925	High	Chongqing	0.932	High	Chongqing	0.933	High
Sichuan	0.947	High	Sichuan	0.980	High	Sichuan	0.981	High
Guizhou	0.873	Relatively high	Guizhou	0.882	Relatively high	Guizhou	0.893	Relatively high
Yunnan	0.642	Relatively low	Yunnan	0.837	Relatively high	Yunnan	0.891	Relatively high
Shaanxi	0.917	High	Shaanxi	0.930	High	Shaanxi	0.938	High
Gansu	0.767	Moderate	Gansu	0.635	Relatively low	Gansu	0.845	Relatively high
Qinghai	0.519	Low	Qinghai	0.608	Relatively low	Qinghai	0.594	Relatively low
Ningxia	0.833	Relatively high	Ningxia	0.843	Relatively high	Ningxia	0.841	Relatively high
Guangxi	0.867	Relatively high	Guangxi	0.887	Relatively high	Guangxi	0.907	High
Inner Mongolia	0.876	Relatively high	Inner Mongolia	0.889	Relatively high	Inner Mongolia	0.887	Relatively high

4.2.1. Analysis of the Spatial Distribution

(1) Spatial distribution of urban-safety-resilience-evaluation results

Based on the urban-safety-resilience GIS models of 10 regions in western China in 2017, 2019, and 2021, the urban-safety-resilience-level-division intervals were imported through ArcGIS software. Figure 6 was collated based on the urban-safety-resilience-level-distribution map.

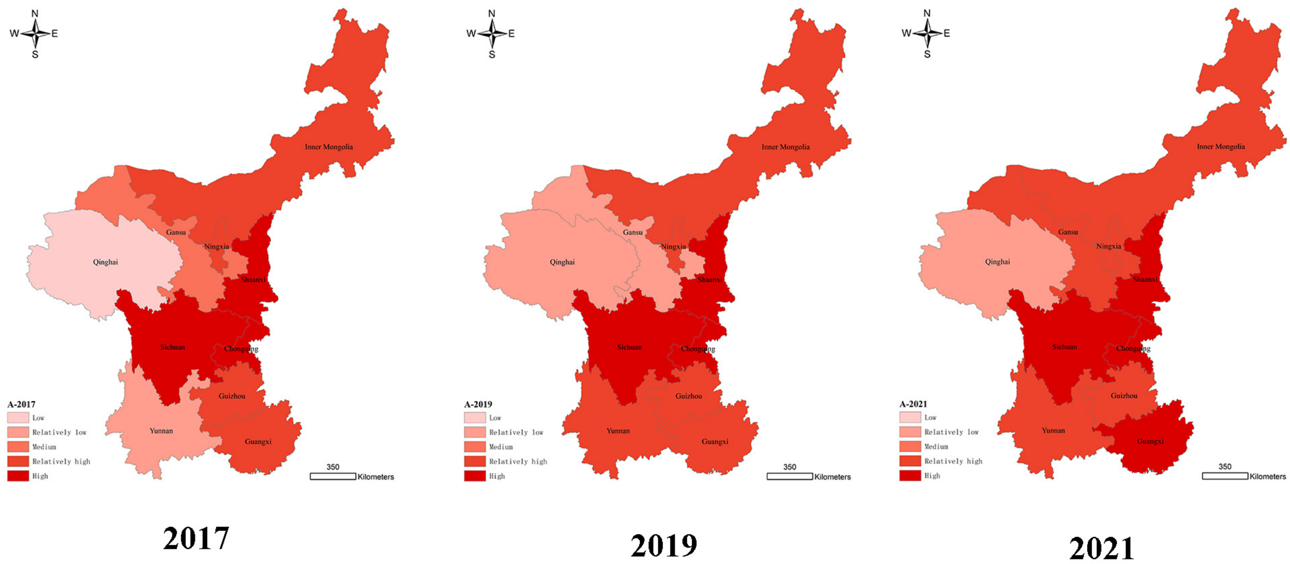
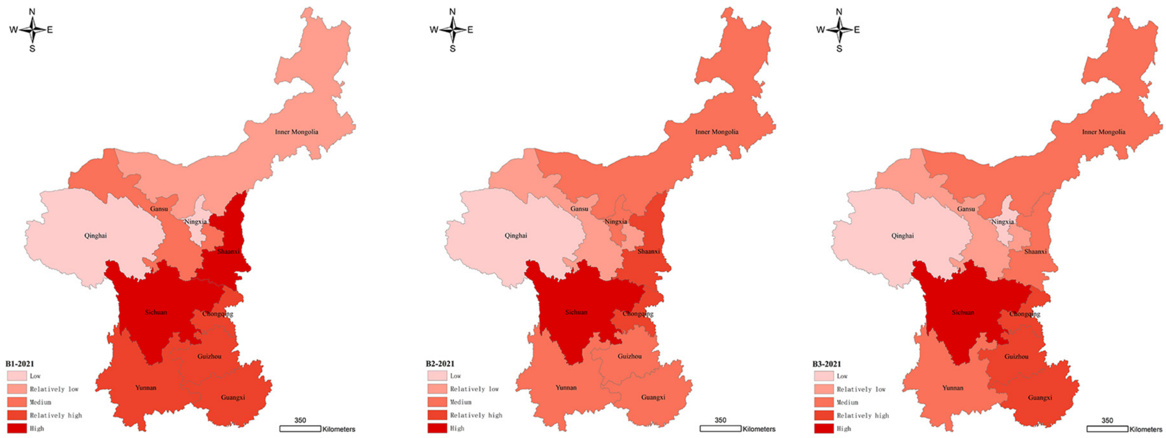


Figure 6. Urban-safety-resilience-grade distribution in the western region in 2017, 2019, and 2021 (since data on some indicators for Xinjiang and Tibet in western China could not be collected, these two regions are not included in this figure).

According to the preliminary analysis in Figure 6, the urban-safety-resilience levels in the three years of 2017, 2019, and 2021 had a spatial-distribution trend ranging from low to high roughly from east to west; the provinces with high resilience levels were mainly in the three regions of Chongqing, Sichuan, and Shaanxi. The three main regions with lower and low resilience levels were Qinghai, Yunnan, and Gansu, and there was a trend of weakening in the three core provinces of Chongqing, Sichuan, and Shaanxi compared to the surrounding areas. There were several reasons for this. Firstly, regarding economic development, the total GDP of Chongqing, Sichuan, and Shaanxi is the highest in the whole western region, so the economic level of these areas guarantees the construction of safe and resilient cities. Secondly, regarding geographical location, Chongqing, Sichuan, and Shaanxi are in the central–eastern position; they are both hubs of the connection between the western region connected and the Middle East, and they occupy an advantageous geographical location within the region generally, so the development of their urban-security resilience can drive that of the surrounding areas. Thirdly, from the perspective of city promotion, Chongqing, Chengdu, and Xi’an are currently the core cities with the most advanced development in the western region and in the country in general. This undeniably drives the growth of cities in the whole province and encourages the development of safety-resilient cities around the entire western region. In conclusion, the regional variability in western China currently shows a relative imbalance in the development of safe and resilient cities.

(2) Spatial distribution of evaluation results of first-level indicators

After the Tier 1 spatial analysis of the urban-safety resilience, the spatial distribution of specific aspects of urban-safety resilience was analyzed again, using the first-level-indicator evaluation level as a starting point. As in the previous section, we used the element-differentiation function in ArcGIS software to classify the urban human-safety resilience, urban-facility-safety resilience, and urban-management-safety resilience in the 10 regions of western China in 2021. In this paper, the natural crack-classification method, which is similar in principle to K-means cluster analysis, was used to perform the classification. After forming the spatial distribution maps of the safety resilience of people, the safety resilience of urban facilities, and the safety resilience of urban management in the 10 western regions in 2021, Figure 7 was produced.



(a) (b) (c)

Figure 7. (**a**) Resilience levels of urban-personnel safety in 2021; (**b**) resilience levels of urban-facilitiy safety in 2021; (**c**) resilience levels of urban-management safety in 2021 (since data on some indicators for Xinjiang and Tibet in western China could not be collected, these two regions are not included in this figure).

According to Figure 7, the distribution of each Tier 1 indicator showed an enormous difference from the others. For example, the safety resilience of urban people in western China roughly decreased from south to north, which was because the geographical environment and habitation conditions in the southwest are better than those in the northwest; furthermore, the safety resilience of urban facilities in the western region of China decreased from the middle to both sides, since the safety resilience of urban facilities is not only affected by the local financial level. It is evident that the urban facilities' safety resilience in Sichuan, Chongqing, and Shaanxi was higher than in the rest of the western region; the urban-management-safety resilience of the territory of the west of China showed a decreasing trend from the southwest to the northwest, which was due to the frequent occurrence of natural disasters in the northwest and the lack of disaster-detection facilities, as well as the relatively low investment levels of emergency funds compared to the southwest. According to the distribution of these three level indicators, it can be seen that although the overall urban-safety resilience in Chongqing, Sichuan, and Shaanxi was relatively high, it did not significantly drive the development of urban-safety resilience in some neighboring regions.

4.2.2. Spatial Correlation Analysis

Because spatial analysis requires macroscopic analysis and quantitative analysis, which can reflect spatial spillover and aggregation effects, the spatial-distribution analysis of the urban-safety resilience in the western region needed to be accompanied by spatial-correlation analyses, including a global spatial-correlation analysis and a local spatial-correlation analysis.

(1) Global correlation

In this paper, the urban-safety resilience of the 10 western regions in 2017, 2019, and 2021 was calculated to obtain the Moran index and its related indexes. The results are shown in Figures 8–13.

As can be seen in Figure 8, the median value of the Moran index of the spatial-distribution of the safety and resilience of the cities in the western region in 2017 was −0.009, within the interval from −1 to 1, and not equal to 0, which represents the possibility of spatial aggregation. However, this value is low; the importance of 0.491 suggests the probability of the random generation of spatial data, which indicates that the likelihood of data aggregation is greater than the possibility of random data distribution. However, the null hypothesis cannot be rejected. A score of 0.688 is more significant than −1.65 and a score of less than 1.65 indicates that there is no significant spatial correlation, and that the possibility of aggregation is very low, or even zero.

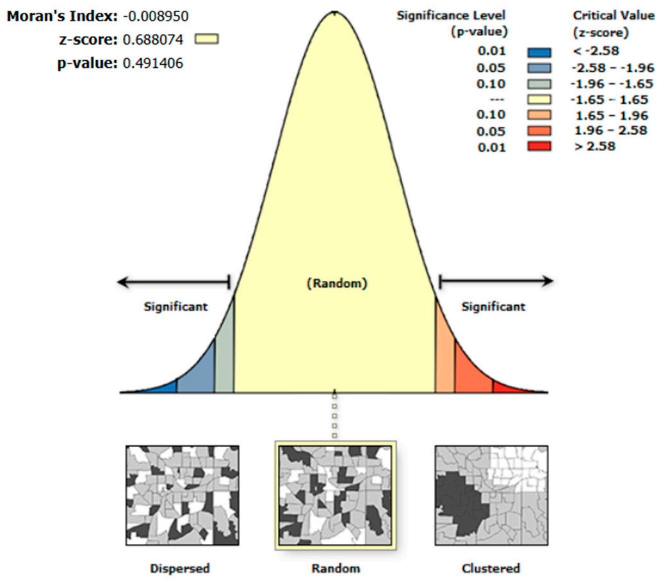


Figure 8. The results of the global spatial-correlation analysis for 2017.

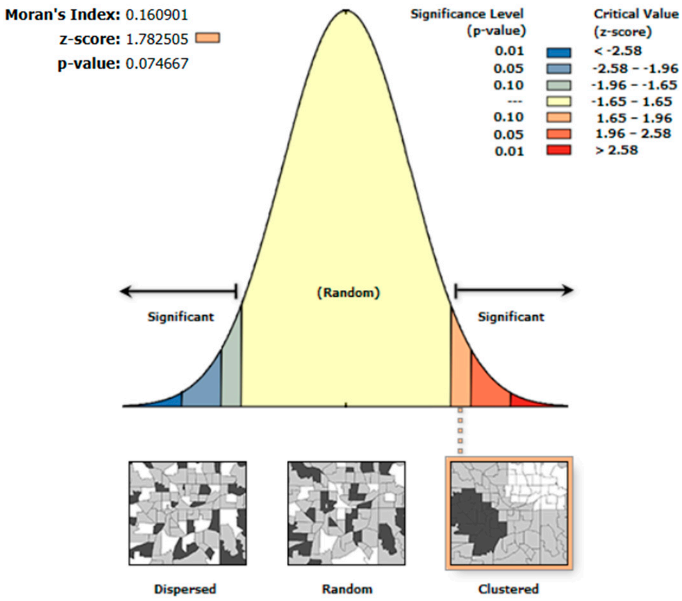


Figure 9. The results of the global spatial-correlation analysis for 2019.

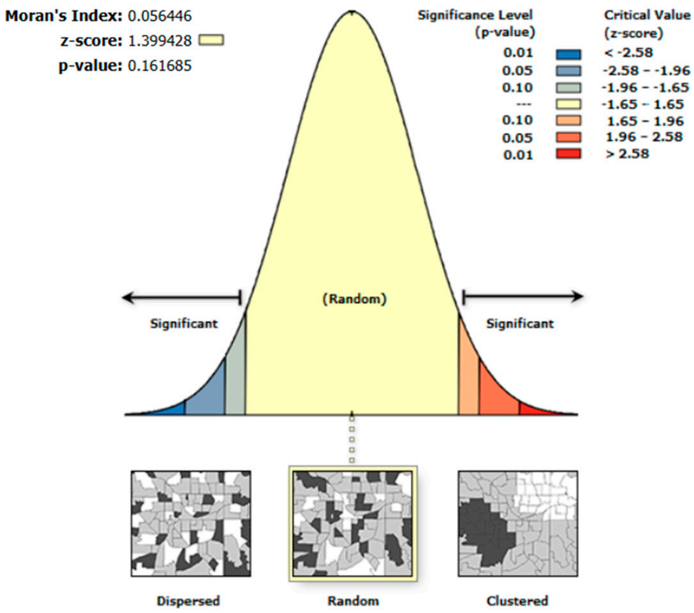


Figure 10. The results of the global spatial correlation analysis for 2021.

As can be seen in Figure 9, the median value of the Moran index of the spatial distribution of the safety and resilience of the cities in the western region in 2019 was 0.161, within the interval from −1 to 1 and not equal to 0, representing the possibility of spatial aggregation; the value of 0.075 represents the probability of the random generation of spatial data, indicating that the likelihood of data aggregation was greater than the possibility of random data distribution, but the null hypothesis cannot be significantly rejected. A score of 1.782 is greater than 1.65; a score of less than 1.96 indicates significant spatial correlation and the existence of some aggregation, although this aggregation was weak.

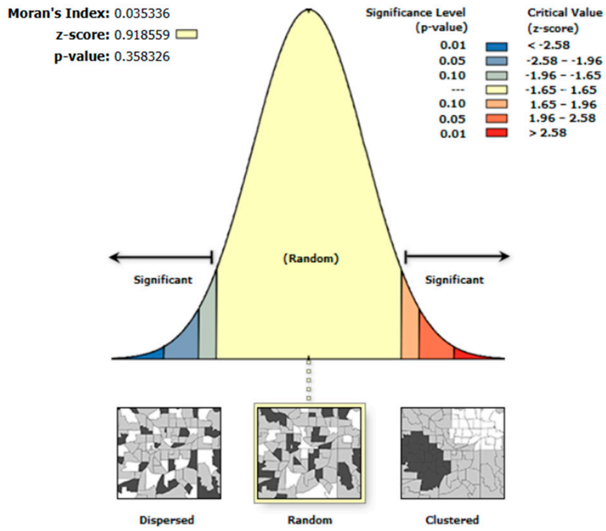


Figure 11. Moran index of resilience levels of urban-personnel safety for 2021.

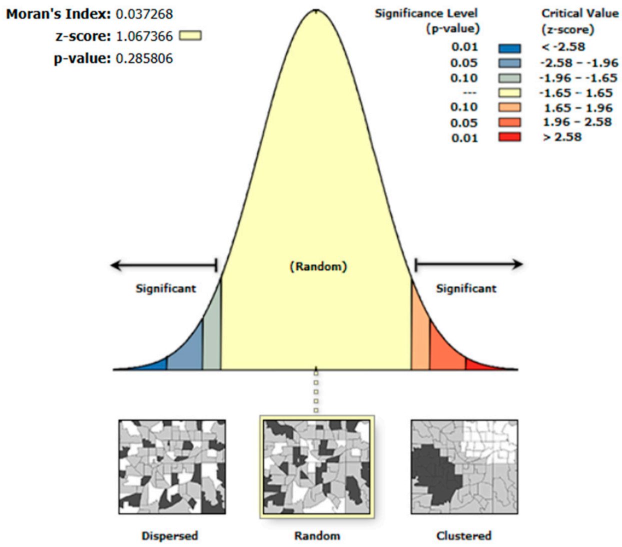


Figure 12. Moran index of resilience levels of urban-facility safety for 2021.

Figure 10 shows that the median value of the Moran index of the global distribution of secure and resilient cities in the western region in 2021 was 0.056, within the interval from −1 to 1 and not equal to 0, representing the possibility of spatial aggregation. However, this value is low, and the likelihood of spatial aggregation is small. The value of 0.162 means the probability that the spatial data were randomly generated, indicating that the likelihood of data aggregation was greater than that of a random distribution of data. The value of 1.399 is more significant than that of −1.65, and a value of less than 1.65 indicates that there is no significant spatial correlation, and that the likelihood of aggregation and non-aggregation is very low.

As can be seen in Figure 11, the Moran index of the global distribution of urban-personnel-safety resilience in the western region in 2021 was 0.035 in the interval, representing a positive spatial correlation and the possibility of spatial aggregation. The value of 0.36 represents the probability that the spatial data were randomly generated, indicating that the spatial data were less random, but the null hypothesis cannot be significantly rejected. The score of 0.92 was more significant than that of −1.65, and a score of less than 1.65 indicated that there was no spatial correlation and a random distribution.

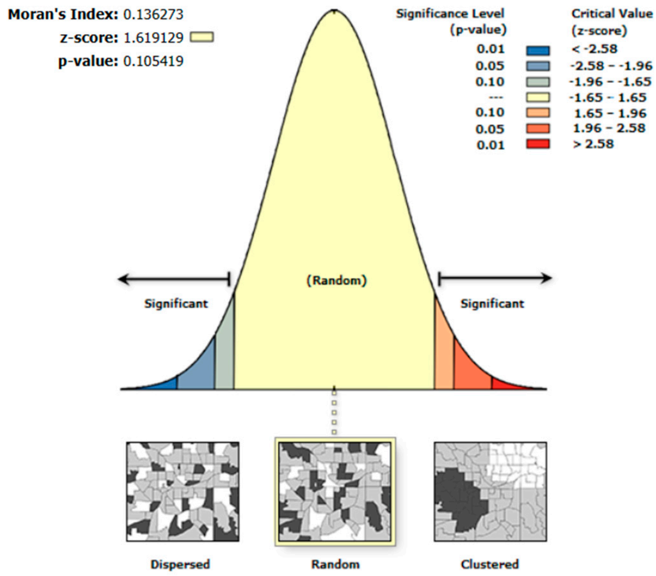


Figure 13. Moran index of resilience levels of urban-management safety for 2021.

As can be seen in Figure 12, the Moran index of the global distribution of the urban-facility-safety resilience in the western region in 2021 was 0.037 in the interval, representing a positive spatial correlation and the possibility of spatial aggregation. The value of 0.28 represents the probability that the spatial data were randomly generated, indicating that the spatial data were less random, but the null hypothesis cannot be significantly rejected. A score of 1.07 is greater than −1.65 and a score of less than 1.65 indicates that there is no spatial correlation and a random distribution.

As can be seen in Figure 13, the Moran index of the global distribution of urban-management-safety resilience in the western region in 2021 was 0.136 in the interval, representing a positive spatial correlation and the possibility of spatial aggregation. The value of 0.11 represents the probability that the spatial data were randomly generated, indicating that the spatial data were less random, but the null hypothesis cannot be significantly rejected. A score of 1.62 is greater than −1.65, and a score of less than 1.65 indicates that there is no spatial correlation and a random distribution.

(2) Local Correlations

For the correlation analysis of the local correlations in urban-safety resilience, we imported the shp file obtained through ArcGIS into the GeoDa software. Next, we used the correlation-spatial-weight matrix to analyze the local spatial correlations. The results obtained after the univariate spatial analysis were as follows.

① Scatter Chart

The first quadrant in the four quadrants of the scatter diagram indicates "high–high" clustering, suggesting that the urban-safety resilience in this part of the region and the urban-safety resilience of the surrounding areas were both at a high level; the second quadrant indicates "low–high" clustering, suggesting that the urban-safety resilience was at a low level; the third quadrant indicates "low–low" clustering, suggesting that the urban-safety resilience of this part of the region and the urban-safety resilience of the surrounding regions were both at a low level; the fourth quadrant indicates "high–low" clustering, suggesting that the urban-safety resilience of this part of the region was at a high level. Nevertheless, the urban-safety resilience in the surrounding area was at a low level. After the results were obtained through GeoDa software, the local spatial-correlation-analysis scatterplots of urban-safety resilience in 2017, 2019, and 2021 and the urban-safety resilience of people, facilities, and management in 2021 were summarized, and the spatial-correlation scatterplot-analysis table was produced, as shown in Table 8.

Table 8. Spatial-correlation scatter-plot analysis.

Object of Evaluation / Region	2017 Urban-Safety Resilience	2019 Urban-Safety Resilience	2021 Urban-Safety Resilience	2021 Urban-Personnel-Safety Resilience	2021 Urban-Facility-Safety Resilience	2021 Urban-Management-Safety Resilience
Chongqing	H-H	H-H	H-H	H-H	H-H	H-H
Sichuan	H-L	H-L	H-L	H-H	H-L	H-L
Guizhou	H-H	H-H	H-H	H-H	L-H	H-H
Yunnan	L-H	L-H	L-H	H-H	L-H	H-H
Shaanxi	H-H	H-H	H-H	H-L	H-H	H-H
Gansu	L-H	L-H	L-L	L-L	L-L	L-L
Qinghai	L-H	L-L	L-H	L-H	L-H	L-H
Ningxia	H-H	H-L	L-H	L-L	L-H	L-H
Guangxi	H-L	H-H	H-H	H-H	H-L	H-H
Inner Mongolia	H-H	H-L	H-H	L-L	H-L	H-L

② Significance plot and clustering plot

The LISA significance map reflected whether the local spatial aggregation of the urban-safety resilience was significant, as well as the degree of this significance, while the LISA clustering map explored whether there was a substantial local spatial correlation in some areas, which was a further analysis that was carried out after the initial analysis of the local spatial correlations based on the scatter plot.

After analyzing the urban-safety resilience in 2017, 2019, and 2021 and the urban-safety resilience of the personnel, facilities, and management in western China in 2021 using GeoDa software for the local spatial-correlation analysis, the LISA significance maps and LISA clustering maps were obtained, and the results are expressed in Table 9 and Figure 14.

Table 9. Spatial-correlation LISA significance-plot analysis.

Object of Evaluation / Region	2017 UrbanSafety Resilience	2019 Urban-Safety Resilience	2021 Urban-Safety Resilience	2021 Urban-Personnel-Safety Resilience	2021 Urban-Facility-Safety Resilience	2021 Urban-Management-Safety Resilience
Chongqing	Relatively significant	Relatively significant	Relatively significant	Relatively significant	Relatively significant	Insignificant
Sichuan	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Guizhou	Insignificant	Insignificant	Insignificant	Relatively significant	Relatively significant	Relatively significant
Yunnan	Insignificant	Insignificant	Insignificant	Relatively significant	Insignificant	Relatively significant
Shaanxi	Relatively significant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Gansu	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Qinghai	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Ningxia	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Guangxi	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Inner Mongolia	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant

Table 9 and Figure 14 demonstrate that the spatial aggregation of the cities with security resilience in the western region was relatively weak; only Chongqing, Yunnan, Guizhou, and the surrounding areas had a more significant spatial aggregation. Furthermore, the rest of the regions did not form significant aggregation due to the influence of various factors and their high and low surrounding resilience. However, it can be seen from the general distribution that cities in Sichuan, Chongqing, and Shaanxi, near the eastern region, were at relatively high levels of security resilience, while the cities in the westernmost regions, such as Qinghai, were at relatively low levels of security resilience.

4.3. Analysis of Results

According to the ranking of the urban-security-resilience levels of the 10 regions in western China, Sichuan, Chongqing, and Shaanxi were the first, second and, third, respectively, while Qinghai and Gansu ranked tenth and ninth, respectively. The main factors regarding the higher level of urban safety and resilience in Sichuan, Chongqing, and Shaanxi were as follows. Firstly, the Chengdu–Chongqing urban agglomeration is in Sichuan and Chongqing, which is an important platform for the development of the western area, a strategic support for the Yangtze River economic belt, and an important demonstration area for the national promotion of new urbanization. Chengdu and Chongqing have established a full-chain supervision system regarding energy safety and stable supply, fire prevention and control, and the prevention of major food and drug risks, as well as increased penalties for violations to promote service quality and safety and enhance the happiness of citizens. Due to their high economic levels, cities such as Chengdu and Chongqing were able to quickly establish temporary defense facilities for natural disasters during the Yibin earthquake in 2019 and the floods in southern China in 2020, and have more advanced disaster-warning systems, so they suffer fewer disaster-related losses. As Hao et al. noted, the Chengdu–Chongqing urban agglomeration will become a new and important urban agglomeration in China in the next five years, similar to the famous Yangtze River delta, Guangdong, Hong Kong, Macao, and Beijing–Tianjin–Hebei urban agglomerations [16]. Therefore, the priority of the policy is significantly higher than that in other regions. Secondly, from the research by Feng et al., it is known that the development trend of new urbanization and ecological environments, and the comprehensive development level and coordination level of both in Shaanxi are steadily increasing [66]. During the heavy-rainfall-related flood disaster in 2021, the cities showed a better resilience capacity because of Shaanxi's more complete disaster-prevention plans and meticulous hidden-danger-investigation work. The main factors in the lower level of urban-safety resilience in Qinghai and Gansu are as follows. First, the vast geographical areas of Qinghai and Gansu, the low percentage of developable area, and the low infrastructure coverage per unit area. Second, as shown by Deng et al., in the disaster-prone agricultural and pasture areas of Qinghai, the high ratio of losses caused by disasters, as well as the population and economic vulnerability, are extremely significant; therefore, the construction of safe and resilient cities is extremely difficult [67]. The research of some scholars further confirms that the emergency-rescue service capacity in Gansu Province is not comprehensive, the construction of the emergency-lifeline system is lagging, and other factors affect the construction of a safe and resilient city [68]. According to the analysis of the urban personnel, facilities, and management-safety-resilience results, the following conclusions can be drawn:

(1) The security resilience of urban people in the 10 regions of western China is generally at a high level, and most of the provinces show an upward trend each year, which indicates that China pays particular attention to security prevention and control at the social level. As some scholars' studies have shown, the comprehensive population and economic development in western China are steadily increasing [69]. However, the security and resilience of urban populations in Qinghai and Ningxia are relatively low, for the following reasons. Firstly, the aging of the population in Qinghai and Ningxia is more significant, and the age structure of the population in Qinghai and Ningxia is much weaker than that in other regions due to the large migration of young laborers. Secondly, the social security, welfare, and medical support services in Qinghai and Ningxia struggle to cope with the current demographic problems. Finally, the Chinese government is continuing to strengthen the construction of the western region to ensure the safety and health of urban residents and to greatly reduce the incalculable damage caused by disasters.

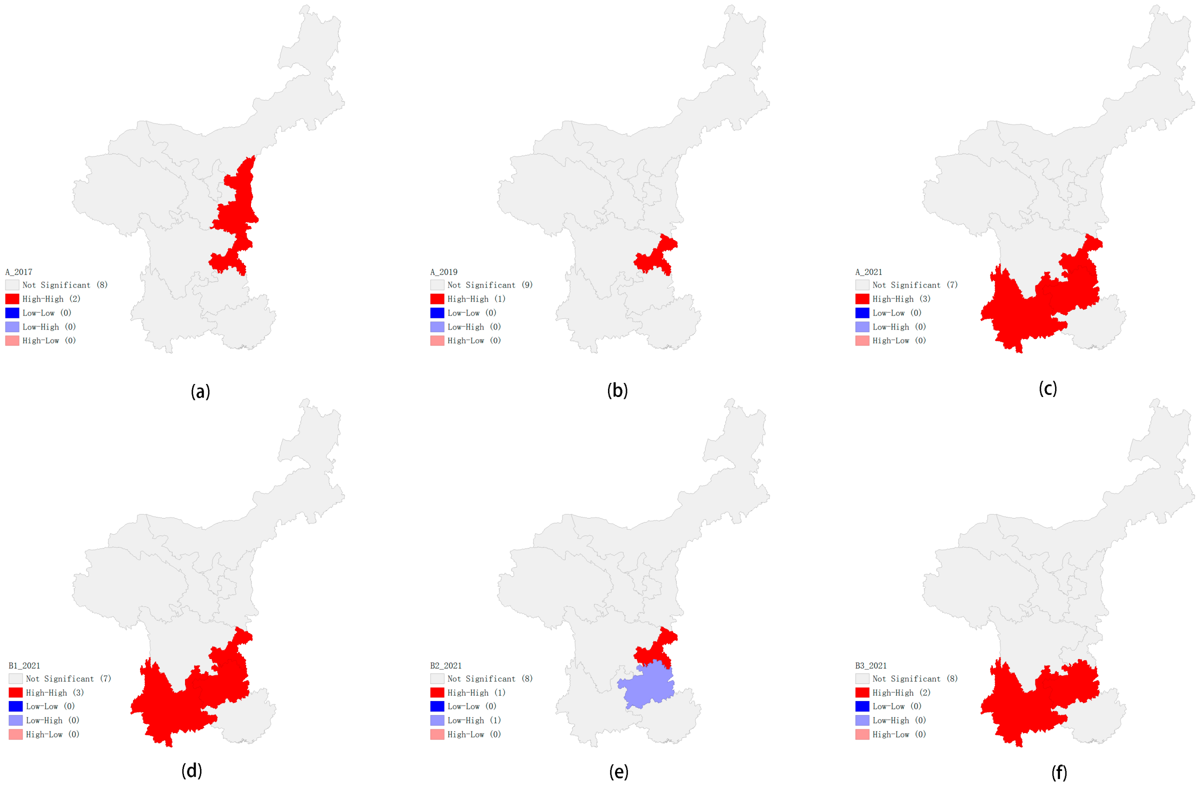


Figure 14. (**a**) Spatial clustering map of the western region in 2017; (**b**) spatial clustering map of the western region in 2019; (**c**) spatial clustering map of the western region in 2021; (**d**) spatial clustering of security resilience of urban personnel in western cities in 2021; (**e**) spatial clustering of security resilience of urban facilities in the western region in 2021; (**f**) spatial clustering of security resilience of urban facilities in the western region in 2021 (since data on some indicators for Xinjiang and Tibet in western China could not be collected, these two regions are not included in this figure).

(2) The resilience of urban facilities in the 10 regions in western China varies significantly from region to region, such as in the Gansu and Qinghai provinces, which are mainly located in the northwest of China and have obvious characteristics of sparsely populated areas. Their urban infrastructure is not updated and maintained promptly due to the harsh climate and economic backwardness, so their urban facilities have low resilience. Qinghai's transportation and disaster-warning facilities significantly affect the overall resilience level. A further analysis revealed that Qinghai is located in a high-altitude region, and that the cost of facility construction and maintenance is much higher than other regions, while the loss of talent makes it difficult for Qinghai to reach a leading level of development. Gansu's construction and lifeline-engineering facilities affect its resilience level because most of Gansu is arid or semi-arid, water resources are more scarce than in other regions, and the urban-network layout has not yet reached the average national standard, while the complexity of the terrain leads to the slow development of its construction industry, and the development and utilization of land are still underdeveloped.

(3) The level of urban-management security resilience in the 10 regions in western China is generally on the rise, with some regions displaying lower levels in some years, such as the Ningxia, Gansu, and Qinghai provinces, which are disaster-prone and struggle to control risks compared to the other provinces. Specifically, the Qinghai and Ningxia regions show a lower level of support regarding security inputs, since their financial level is low, although state subsidies, to a certain extent, relieve local financial pressure, and the impact of several factors led to a more limited financial investment in public safety and transportation. In addition, Qinghai and Gansu suffer from a higher frequency of disasters. Therefore, a more significant issue is the high degree of disaster damage in these areas;

accordingly, the direct economic losses in terms of the proportion of the regional GDP were greater in Qinghai and Gansu, which in turn affected their urban-safety management.

In addition, the overall spatial aggregation of the urban security resilience in the 10 western regions of China is more general. Specifically, Sichuan, Chongqing, and Shaanxi have more obvious spatial spillover to the surrounding areas regarding urban management and facility-security resilience, which can effectively drive the development of these factors in these surrounding areas. However, the level of urban-personnel-security resilience does not reflect this obvious spatial spillover. The reason for this is mainly that Sichuan, Chongqing, and Shaanxi, in terms of demographic structure, have the same problems as other regions, such as serious aging. In terms of infrastructure and management, Shaanxi serves as the center, with its advanced innovation and technological support, as well as the high-speed development of economic support, which clearly radiates to the surrounding areas. At the same time, according to this study, Shaanxi has achieved new progress in ecological construction, and with its advantageous location, bearing east and opening up to the west, Shaanxi's social economy and ecological environment both have a good influence on its surrounding areas [69].

Furthermore, the local spatial correlation of urban security resilience in the 10 western regions of China is relatively general, and there is "high–high" aggregation between Chongqing, Guizhou, Shaanxi, and the surrounding areas, which indicates a certain linkage development in these regions. This mainly occurs in terms of urban personnel and management-security resilience, which show more obvious linkage development. In some regions, there is also "high–low" or "low–high" clustering, which indicates that the sharing of urban-security resilience is not strong in these regions; for example, there is a high level of urban-security resilience in Yunnan in the neighboring regions, but a medium level in the whole western region. The strength of Yunnan is not sufficient to drive the development of its surrounding areas.

5. Conclusions and Recommendations

This paper took 10 provinces, autonomous regions, and municipalities directly under the central government in western China as the research objects and constructed an evaluation-index system using three dimensions, the resilience of urban-personnel safety, the resilience of urban-facility safety, and the resilience of urban-management safety through research statistics and expert consultations. We analyzed the spatial and temporal evolution characteristics of urban-safety resilience using ArcGIS software, and drew the following conclusions.

(1) From the analysis of the urban-safety-resilience evaluation results, more than half of the 10 provinces in western China showed a slow increase each year, which indicates that China is in the initial stage of the construction of safe and resilient cities. Parts of the institutional system and organizational structure are not yet perfect, while some regions lack digital transformation. However, overall, its development is progressing, without major changes. Some regions have fluctuations in their urban-safety-resilience levels due to changes in some indicators, which may be related to serious disasters or changes in certain factors over a specific period. For example, some regions experienced a slowdown in economic development due to the global pandemic's impact on the construction of safe and resilient cities, which reduced the urban-safety-resilience levels. In contrast, some regions experienced changes in their construction industries in some years, leading to a decrease in urban-safety and resilience levels. For example, in some regions, the economic development slowdown due to the global pandemic reduced cities' safety and resilience. In contrast, in other areas, the urban-safety resilience fluctuated due to construction-industry changes in some years.

(2) According to the spatial-evolution analysis for each year, the spatial aggregation of each year was weak. However, the general trend gradually showed Sichuan Province, Chongqing City, and Shaanxi Province as the centers of this aggregation, which progressively dispersed to the surrounding area. From the current perspective, the safe and

resilient cities in the neighboring areas of these three regions are developing more strongly. They play a particular role in the development of regional linkage. The spatial aggregation of safe and resilient cities in China's western region was enhanced each year, but inevitable fluctuations also occurred. During this period, the spatial planning in China's western region showed some homogeneity and non-adaptability, meaning that some social synergism was insufficient. Hence, the aggregation effect in 2017 was not apparent, and 2021 was critical in the fight against the pandemic in China. Consequently, the development of safe and resilient cities in China's western region slowed down. Some areas were more affected by the pandemic than others, which led to fluctuations in the aggregation.

In general, there was a specific correlation between the construction of safe and resilient cities and time and space in the western region, and the level of urban-safety resilience in most of the western territory gradually increased over the years, but the growth rate was slow. Some regions showed fluctuations in their level of urban-safety resilience. This could indicate that the development of urban-safety resilience in most of the western regions is in the initial stage. The development changes are insignificant, and their stability and synergism can improve further.

In this regard, this paper upholds the principle of ecological sustainability and emphasizes the quality of development in the construction of safe and resilient cities from the perspectives of a risk-identification system and resilience-governance planning, construction tasks and objectives, collaborative governance, and the institutional system. The specific recommendations of this paper are as follows.

Firstly, strengthen the security resilience of facilities at the spatial scale in urban areas. The construction of infrastructure public safety should be strengthened in terms of overall design and management. In response to various unknown risks, the design of emergency-infrastructure disaster-prevention functions should be strengthened, and the resilience of the corresponding infrastructure should be dynamically controlled using technologies such as the Internet of Things. The safety and resilience standards for buildings in different disaster-risk areas should also be studied, potential risk buildings should be proactively maintained and reinforced, and the new standards should be applied in the construction of new buildings, such as housing and municipal facilities. Surplus-space resources should be ensured, an open-space skeleton should be built, the flexibility and effectiveness of the integrated transportation system should be enhanced, and the layouts of emergency-evacuation sites should be optimized.

Secondly, there should be a reasonable increase in public financial investment to improve the level of urban-security facilities. Special funds should be set up for the construction of safe and resilient cities; the use of these special funds should be coordinated, the effectiveness of their use should be improved, and the provision of key projects and funding for safe and resilient cities should be guaranteed. The layout of the urban spatial structure should be optimized, and cities should be guided to shift from monocentric to polycentric and from circled to distributed forms. Overly centralized urban functions should be prevented. The planning of current urban facilities should be upgraded and strengthened, and a multi-selective urban-transportation system should be built. Disaster prevention and emergency planning should be strengthened and the rational use of basic public-service resources in cities should be increased so that cities can maintain a robust and sustainable development momentum in various environments.

Thirdly, multi-dimensional synergistic linkage should be developed. Safe and resilient city governance should make use of the collaborative governance theory to achieve complementary advantages through data collection or practical testing, the participation of social forces and the synergy of various social stakeholders should be encouraged, and the overall level of social governance should be improved. In city-related security-and-resilience public affairs, the government should play the role of coordinator, leader, and commander, enhance emergency linkage-management capacity through cooperative operations with all social parties, and ultimately improve urban security and resilience-management capacity.

Fourthly, emergency laws and regulations should be improved, and the social governance system should be strengthened. Urban-security resilience should be raised to the strategic level of maintaining national economic security and development, the relevant policies and standards for the construction of secure and resilient cities should be improved, local normative documents for rescue and relief should be formulated and revised, comprehensive approaches to disaster mitigation, post-disaster reconstruction, disaster relief, etc., should be established, and a corresponding rule-of-law guarantee should be provided for the construction of secure and resilient cities. The emergency management system should be improved, an up-and-down, responsive urban emergency network should be established, and a practical emergency-disposal model should be built. An all-weather digital comprehensive risk-prediction-and-management information-sharing platform should be built, as well as a mechanism for digital urban-security-risk monitoring and early warning, to enhance the ability to prevent various risks and comprehensively improve urban emergency-response and risk-management capabilities.

The evaluation indexes and models selected in this study do not fully cover the urban-security-resilience system, and the evaluation indexes will be periodically re-evaluated as the cities develop. According to the conclusions of this study, it is necessary to focus on the security resilience of urban facilities and adjust the urban-security-resilience-evaluation system according to specific situations. At the same time, as the technical conditions of smart cities become more mature, it is beneficial to explore the security resilience of smart cities. Future research should consider the regional differences and coordination of various subjects in the construction of security resilience through the development of smart cities and focus on the security-resilience characteristics of such cities.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Initial evaluation indicators and description of urban-safety resilience.

Tertiary Indicators	Unit	Indicator Description	Indicator Type
The resident-population density in built-up areas	10,000 people/km^2	The ratio of the number of the resident population in the built-up zone to the area of the built-up zone, calculated as the number of the resident population in the built-up zone/area of the built-up zone	Positive
Level of basic medical insurance for urban workers	10,000 people	Refers to the number of people who participate in corresponding basic medical insurance for urban workers according to the relevant national regulations	Positive
Percentage of transient population	%	The number of transient urban population as a percentage of the total urban population, calculated as the number of urban transient population/(total urban resident population + number of transient urban population) × 100%	Reverse

Table A1. *Cont.*

Tertiary Indicators	Unit	Indicator Description	Indicator Type
Percentage of the population with disabilities	%	The number of people with disabilities as a percentage of the total urban resident population, calculated as the number of people with disabilities in the urban resident population/total urban resident population × 100%	Reverse
Level of urban-health-technology talent pool	people	Refers to the number of health technicians per 10,000 residents in the city	Positive
Number of hospitals	Block/100 km^2	Refers to the ratio of the number of hospitals to the total area of the city's administrative zone; calculated as the number of hospitals/total area of the city's administrative zone	Positive
Social-organization-unit level	size	Refers to the number of social organization units in the city in a certain period	Positive
Personal-accident-insurance income	CNY 10,000	Refers to the income from urban personal accident insurance in a certain period	Positive
Urban commercial insurance income	CNY 10,000	Refers to the city's commercial insurance revenue for a certain period	Positive
Number of people covered by work-injury insurance	10,000 people	Refers to the number of persons insured against work injuries at the end of the year in a certain period	Positive
Land-development intensity	%	The ratio of urban-construction-land area to the total area of the urban administrative zone, calculated as urban-construction-land area/total area of urban administrative zone × 100%	Positive
The proportion of land area in security-vulnerable areas	%	Refers to the weak-security land area as a percentage of the built-up-zone construction-land area, calculated as weak-security-area land area/built-up-zone construction-land area × 100%	Reverse
Number of employees in construction-industry enterprises	10,000 people	Refers to the number of construction enterprises employed in the city in a certain period.	Positive
Road-network density	%	The ratio of the road area of the municipal district to the total resident population of the municipal district, calculated as the road area of the municipal district/the total resident population of the municipal district × 100%	Positive
Road length per 10,000 people	km/10,000 people	The length of roads per 10,000 residents in a city, calculated as the length of roads/total resident population in a city	Positive
Level of urban traffic-lighting facilities	Marigold	Refers to the number of street lightis in the city in a certain period.	Positive
Cell-phone penetration rate	size/100 people	Refers to the average number of cell phones per 100 people in the total population of the administrative area.	Positive
Number of fixed-broadband households	10,000 households	Refers to the number of households with fixed broadband in a city over a certain period.	Positive
Level of gas-supply facilities	Kilometers	Refers to the lengths of urban natural-gas pipelines in a certain period.	Positive
Level of seismic-monitoring facilities	Block/10,000 km^2	Refers to the ratio of the number of seismic stations to the total area of the urban administrative zone, calculated as the number of seismic stations/total area of the urban administrative zone (10,000 square kilometers)	Positive
Public coverage of meteorological disaster monitoring and forecasting early-warning information	pcs/100 km^2	Refers to the ratio of automatic weather stations to the total area of the administrative zone of the city, calculated as automatic weather stations/total area of the administrative area of the city (hundred square kilometers)	Positive
Urban intelligent-pipe-network density	/km	Refers to the ratio of the length of fiber-optic cable lines to the total area of the administrative zone of the city; calculated as the length of fiber-optic cable lines/total area of the administrative zone of the city	Positive
Shelter area per capita	m^2/people	The ratio of urban emergency-shelter area to total urban resident population. calculated as urban emergency-shelter area (square meters)/total urban resident population (people)	Positive

Table A1. *Cont.*

Tertiary Indicators	Unit	Indicator Description	Indicator Type
Storage area of disaster-relief-reserve institutions per 10,000 people	m^2/10,000 people	Refers to the ratio of the area of the emergency-supplies reserve to the total resident population of the city (10,000 people), calculated as the area of the emergency-supplies reserve (square meters)/total resident population of the city (10,000 people)	Positive
Number of beds in medical and health institutions per 10,000 people	pcs/10,000 people	The ratio of the number of beds in various medical and health institutions to the total urban resident population (10,000 people), calculated as the number of beds in various medical and health institutions/total urban resident population	Positive
Greenery coverage	%	Refers to the percentage of the total area covered by greenery in the built-up area of the city.	Positive
The disaster-related-death rate per million population	%	Refers to the ratio of annual disaster-related deaths to the total urban resident population (million), calculated as annual disaster-related deaths/total urban resident population (million) × 100%	Reverse
Annual direct economic losses due to disasters as a percentage of regional GDP	%	Refers to the ratio of annual direct economic losses due to disaster to regional GDP, calculated as annual direct economic losses due to disaster/regional GDP × 100%	Reverse
The mortality rate of class A and B statutory infectious diseases		The ratio of the number of deaths from class A and B infectious diseases to the total urban resident population (100,000 people), calculated as the number of deaths from class A and B infectious diseases/total urban resident population	Reverse
The fire-death rate per 10,000 people	%	Refers to the annual number of fire deaths as a percentage of the total urban resident population (10,000 people), calculated as the annual number of fire deaths/total urban resident population × 100%	Reverse
Incidence of criminal cases per 10,000 people		The ratio of the annual number of criminal cases to the total urban resident population (10,000 people), calculated as the annual number of criminal cases/total urban resident population	Reverse
Percentage of people affected in a year	%	The ratio of the annual disaster population to the total resident population of the city, calculated as annual disaster population/total resident population of the city × 100%	Reverse
Public-aecurity financial expenditure	CNY 100 million	Refers to the city's public-safety financial expenditure in a certain period	Positive
Healthcare financial expenditure	CNY 100 million	Refers to the financial expenditure on urban healthcare in a certain period	Positive
Transportation financial expenditure	CNY 100 million	Refers to the financial expenditure on urban transportation in a certain period	Positive

Appendix B

Table A2. Table of raw data for each indicator in 2017.

Data Name	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
The total area of the urban built-up zone	km^2	1423	2832	986	1142	1287	869	200	458	1414	1269
Number of permanent residents in the built-up zone	10,000 people	1121.62	2065.83	624.66	857.69	1000.46	532.31	175.08	233.50	896.60	670.09
The population of urban workers with basic medical insurance	10,000 people	640.30	1526.40	410.40	491.30	619.80	320.20	94.00	123.50	556.70	495.10
Number of temporary urban residents	10,000 people	504.31	569.72	128.82	131.50	98.79	150.67	23.36	71.04	252.16	236.20
The total urban resident population	10,000 people	2489.92	4127.32	1371.70	1658.18	1740.14	895.88	226.85	341.37	2392.78	982.27
Number of urban health technicians per 10,000 people	people	79	85	156	146	116	87	220	106	91	130
Number of hospitals	size	749	2219	1270	1252	1150	526	212	209	589	720
Social organization units	size	16,824	42,282	12,700	23,184	24,725	27,079	5291	6548	24,567	15,116
Life-insurance-premium income	CNY 100 million	560.13	1441.28	210.05	357.52	654.8	254.06	46.86	109.25	369.13	390.23
City commercial-insurance revenue	CNY 100 million	744.00	1937.64	389.31	612.66	869.01	366.38	80.20	165.29	565.11	570.06
Number of worker-compensation-insurance participants at the end of the year	10,000 people	504.61	876.04	332.48	383.67	459.35	198.58	64.85	90.35	388.79	307.76
City area	km^2	7440	8359	3184	3157	2621	1591	688	2159	5789	4885
The total area of the city's administrative zone	km^2	43,263.10	82,433.06	34,176.60	84,818.32	49,054.71	87,442.07	166,331.50	23,697.42	68,539.76	147,077.45
Area of land in areas with weak security (industrial land + logistics and storage land)	km^2	275.57	521.67	183.18	159.08	173.12	201.72	26.65	56.08	272.93	209.66
Construction-industry employees	10,000 people	224.79	352.83	77.64	152.72	137.98	56.88	11	12.42	126.15	27.7
Road area in the city	10,000 m^2	19,015	33,979	8930	11,856	17,538	10,678	2753	6545	19,821	21,277
City street lighting	size	584,172	1,344,947	584,172	500,123	500,123	318,333	131,213	247,589	695,594	584,422

Table A2. *Cont.*

Data Name	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
Number of households withfixed broadband	10,000 house-holds	661.40	1430.30	436.70	694.20	662.20	380.00	105.90	140.60	671.80	390.50
Cell-phone-penetration rate	size/100 people	106.49	92.67	97.36	88.08	110.04	96.22	102.09	116.16	89.77	112.36
Length of natural-gas pipeline	km	22,320	49,338	6414	5947	16,567	3140	2244	6279	5513	9680
Total number of seismic stations	size	10	112	7	250	93	100	39	17	81	67
Number of automatic weather-station sites	size	1997	4753	2948	3414	1537	2159	437	893	2399	1688
Fiber-optic cable-line length	10,000 km	93.07	250.61	86.62	108.85	108.67	72.59	21.04	19.86	109.35	98.56
Urban emergency-shelter area	km^2	113.77	346.50	110.27	134.62	289.58	131.07	35.66	58.81	156.19	151.71
Disaster-relief-reserve-agency storage area	km^2	30.99	70.86	27.94	36.51	27.14	30.37	13.42	13.50	52.48	48.26
Number of beds in various types of medical and health institution	10,000 sheets	76.93	79.48	144.13	114.25	87.05	78.18	175.28	81.04	63.53	105.13
Greening coverage of built-up areas	%	40.32	40.00	37.01	38.87	39.88	33.28	32.55	40.41	39.12	40.22
Annual disaster-related deaths	People	52	186	68	110	69	22	17	0	92	18
Annual direct economic losses due to disasters	CNY 100 million	24.50	153.90	57.60	76.60	162.90	105.10	17.40	12.00	99.00	126.50
Gross city product	CNY 100 million	20,066.30	37,905.10	13,605.40	18,486.00	21,473.50	7336.70	2465.10	3200.30	17,790.70	14,898.10
Number of people affected in the city	10,000 people	163.87	218.41	253.80	291.16	399.12	321.54	110.17	138.48	180.81	466.86
Public-security financial rxpenditure	CNY 100 million	235.91	471.42	268.09	343.26	241.82	170.38	90.04	64.59	283.17	250.09
Healthcare financial expenditure	CNY 100 million	353.79	831.46	436.21	546.99	418.27	289.24	125.21	97.98	512.31	323.48
Transportation financial expenditure	CNY 100 million	287.97	526.68	336.91	511.24	304.03	285.75	95.38	100.82	244.09	344.38

Table A3. Table of raw data for each indicator in 2019.

Data Name	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
The total area of the urban built-up zone	km^2	1515.41	3054.31	1085.52	1217.60	1357.51	875.72	215.19	489.05	1542.78	1269.74
Number of permanent residents in the built-up zone	10,000 people	1185.60	2214.03	681.49	890.89	1159.30	535.73	180.19	223.96	930.87	678.97
The population of urban workers with basic medical insurance	10,000 people	720.60	1778.10	462.00	528.00	712.90	344.30	103.70	141.10	620.50	530.70
Number of temporary urban residents	10,000 people	478.10	550.99	155.34	173.47	131.87	136.32	19.46	70.10	312.21	256.68
The total urban resident population	10,000 people	2566.51	4171.90	1459.73	1720.00	1988.31	909.54	232.58	345.31	2417.75	998.07
Number of urban health technicians per 10,000 people	people	93	95	94	138	110	102	133	111	94	144
Number of hospitals	size	846	2417	1340	1376	1208	719	220	219	678	794
Social-organization units	size	17,553	44,932	13,753	23,640	30,548	24,644	6084	6083	27,118	16,998
Life-insurance-premium income	CNY 100 million	696.24	1635.33	265.85	445.07	816.25	306.34	56.68	129.51	448.14	516.86
City commercial-insurance revenue	CNY 100 million	916.46	2148.66	489.26	742.10	1033.49	444.32	98.44	197.67	664.92	729.82
Number of worker-compensation-insurance participants at the end of the year	10,000 people	661.67	1177.14	408.51	438.51	577.42	244.10	73.99	119.58	442.23	338.24
City area	km^2	7660	8610	3651	3204	2431	1978	696	952	5814	5082
The total area of the city's administrative zone	km^2	43,263.52	85,091.09	36,217.91	87,343.65	53,039.80	88,539.17	197,504.60	22,201.63	70,298.38	148,649.07
Area of land in areas of weak security (industrial land plus logistics and storage land)	km^2	294.09	558.56	200.1	162.29	207.83	242.03	31.28	59.3	253.11	198.61
Construction-industry employees	10,000 people	216.18	351.36	80	141.54	145.21	50.85	8.1	11.25	141.94	20.52
Road area in the city	10,000 m^2	22,160	42,936	11,786	15,050	21,039	12,450	3797	7625	26,726	21,571
City-street lighting	size	775,469	1,550,215	626,167	623,986	824,590	354,166	146,458	238,104	654,416	576,538
Number of households withfixed broadband	10,000 house-holds	920.40	1830.70	715.60	783.90	878.20	548.70	130.30	204.90	845.90	594.80

Table A3. *Cont.*

Data Name	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
Cell-phone penetration rate	size/100 people	117.75	112.76	111.78	100.10	119.72	103.92	110.73	119.24	103.38	118.59
Length of natural-gas pipelines	km	23,613	57,055	7816	7904	21,514	3817	2500	6906	8456	10,145
Total number of seismic stations	size	48	113	21	262	98	101	39	15	83	67
Number of automatic weather-station sites	size	1805	5079	3026	2583	1575	1575	527	866	2303	1658
Fiber-optic cable-line length	10,000 km	120.18	332.86	115.09	200.29	153.21	88.78	32.49	24.02	175.85	130.99
Urban emergency-shelter area	km^2	126.67	380.67	105.37	168.92	228.07	113.59	39.74	82.11	248.61	151.06
Disaster-relief-reserve-agency storage area	km^2	31.46	76.17	37.78	35.57	33.27	41.56	16.79	13.87	46.65	51.28
Number of beds in various types of medical and health institution	10,000 sheets	87.85	86.02	81.61	104.14	80.46	90.81	105.52	79.31	66.12	113.87
Greening coverage of built-up areas	%	41.82	41.85	39.42	39.73	39.32	36.03	35.21	41.34	40.76	40.52
Annual disaster-related deaths	People	27	159	76	70	52	22	9	3	104	8
Annual direct economic losses due to disasters	CNY 100 million	19.60	340.90	47.00	102.10	58.80	46.50	14.30	2.90	100.50	46.80
Gross city product	CNY 100 million	23,605.77	46,363.80	16,769.34	23,223.75	25,793.17	8718.30	2941.10	3748.48	21,237.14	17,212.53
Number of people affected in the city	10,000 people	145.90	487.60	277.20	949.40	458.80	224.50	86.90	14.60	356.00	220.70
Public-security financial expenditure	CNY 100 million	268.66	525.64	280.06	382.83	285.90	191.29	89.57	66.74	312.18	249.06
Healthcare financial expenditure	CNY 100 million	383.26	943.27	534.78	608.50	466.29	326.41	148.23	106.49	565.29	322.18
Transportation financial expenditure	CNY 100 million	292.35	687.83	347.79	542.81	283.94	360.35	172.6	88.87	219.49	403.38

Table A4. Table of raw data for each indicator in 2021.

Data Name	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
The total area of the urban built-up zone	km^2	1645	3367	1187	1252	1527	928	249	495	1679	1271
Number of permanent residents in the built-up zone	10,000 people	1322.63	2514.51	726.22	771.19	1255.46	528.60	191.22	230.65	1027.68	682.13
The population of urban workers with basic medical insurance	10,000 people	795.90	1945.80	479.40	569.20	783.80	372.30	114.80	159.60	714.80	564.70
Number of temporary urban residents	10,000 people	429.54	864.43	184.76	193.73	179.90	181.82	19.27	68.31	345.08	276.07
The total urban resident population	10,000 people	2649.83	4545.90	1651.81	1802.95	2132.88	901.43	297.88	439.87	2677.08	914.01
Number of urban health technicians per 10,000 people	people	77	100	102	120	102	111	125	104	103	116
Number of hospitals	size	858	2481	1449	1405	1270	699	222	213	803	806
Social-organization units	size	18,561	45,535	14,742	23,011	31,210	21,554	5997	5070	29,485	17,288
Life-insurance-premium income	CNY 100 million	751.75	1647.57	281.6	428.13	797.66	359.33	62.03	145.79	539.37	440.18
City commercial-insurance revenue	CNY 100 million	965.50	2204.91	496.26	690.20	1052.37	490.32	106.89	211.14	780.60	645.56
Number of worker-compensation-insurance participants at the end of the year	10,000 people	765.73	1472.06	529.94	541.91	629.61	278.74	95.93	143.79	551.31	338.22
City area	km^2	7781	9314	4049	3304	2619	2022	739	956	5306	4566
The total area of the city's administrative zone	km^2	43,263.52	92,234.06	41,808.54	91,678.06	56,687.11	89,281.63	203,423.45	21,889.03	78,641.38	148,694.54
Area of land in areas of weak security (industrial land + logistics and storage land)	km^2	358.01	616.55	183.47	170.32	202.2	245.27	36.61	58.83	283.21	158.24
Construction-industry employees	10,000 people	205.54	364.57	71.58	120.21	129.83	46.01	6.01	11.09	118.51	15.49
Road area in the city	10,000 m^2	26,320	56,342	20,027	18,536	24,556	15,074	4133	8193	32,100	23,057
City-street lighting	size	899,100	2,166,500	820,600	761,700	852,900	434,900	152,600	248,100	831,100	622,300
Number of households withfixed broadband	10,000 house-holds	984.30	2013.90	815.20	989.40	1213.60	661.30	152.10	246.90	1043.90	701.50

Table A4. *Cont.*

Data Name	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
Cell-phone penetration rate	size/100 people	116.77	111.55	110.85	107.58	120.83	110.23	114.56	119.46	109.42	125.71
Length of natural-gas pipeline	km	242,66	75,350	9938	9760	28,700	4625	4666	7566	12,985	11,891
Total number of seismic stations	size	57	417	28	798	245	460	119	89	135	148
Number of automatic weather-station sites	size	1805	5472	2722	2711	1952	1478	549	861	2484	1727
Fiber-optic cable-line length	10,000 km	141.53	374.80	134.61	237.13	179.57	104.26	37.00	29.38	243.05	157.78
Urban emergency-shelter area	km^2	127.39	410.36	103.25	153.43	211.91	117.05	44.25	91.81	285.74	177.88
Disaster-relief-reserve-agency storage area	km^2	36.62	85.97	30.57	41.44	32.33	41.99	13.47	10.05	51.79	34.58
Number of beds in various types of medical and health institution	10,000 sheets	71.03	87	90.73	86.17	83.5	85.8	90.64	67.9	73.91	88.28
Greening coverage of built-up areas	%	42.60	43.10	41.80	42.50	41.80	36.30	34.80	42.00	40.20	42.00
Annual disaster-related deaths	People	19	31	5	38	56	1	13	2	7	23
Annual direct economic losses due to disasters	CNY 100 million	29.80	248.70	30.20	104.90	317.30	67.30	45.70	13.70	22.80	76.40
Gross city product	CNY 100 million	27,894.00	53,850.80	19,586.40	27,146.80	29,801.00	10,243.30	3346.60	4522.30	24,740.90	20,514.20
Number of people affected in the city	10,000 people	140.00	714.30	244.60	791.50	834.50	389.10	49.50	132.20	261.10	232.10
Public-security financial expenditure	CNY 100 million	273.20	531.89	274.27	375.60	289.72	193.55	93.90	63.95	288.38	249.79
Healthcare financial expenditure	CNY 100 million	427.72	1044.14	542.07	725.99	565.72	390.38	176.33	110.72	613.75	362.73
Transportation financial expenditure	CNY 100 million	277.44	717.35	336.45	601.4	325.83	287.29	189.44	84.35	335.51	345.99

Appendix C

Table A5. Table of raw data for 2017 indicator-calculation variables.

Indicators	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
The resident population density in built-up areas	10,000 people/km^2	0.79	0.73	0.63	0.75	0.78	0.61	0.88	0.51	0.63	0.53
Level of basic medical insurance for urban workers	10,000 people	640.3	1526.4	410.4	491.3	619.8	320.2	94	123.5	556.7	495.1
Percentage of transient population	%	16.84	12.13	8.59	7.35	5.37	14.40	9.34	17.23	9.53	19.38
Level of urban-health-technology talent pool	People	79	85	156	146	116	87	220	106	91	130
Number of hospitals	Block/100 km^2	1.73	2.69	3.72	1.48	2.34	0.60	0.13	0.88	0.86	0.49
Social-organization-unit level	size	16,824	42,282	12,700	23,184	24,725	27,079	5291	6548	24,567	15,116
Personal accident insurance income	CNY 100 million	560.13	1441.28	210.05	357.52	654.8	254.06	46.86	109.25	369.13	390.23
Urban commercial insurance income	CNY 100 million	744	1937.64	389.31	612.66	869.01	366.38	80.2	165.29	565.11	570.06
Number of people covered by work-injury insurance	10,000 people	504.61	876.04	332.48	383.67	459.35	198.58	64.85	90.35	388.79	307.76
Land-development intensity	%	17.20	10.14	9.32	3.72	5.34	1.82	0.41	9.11	8.45	3.32
The proportion of land area in security-vulnerable zones	%	19.37	18.42	18.58	13.93	13.45	23.21	13.33	12.24	19.30	16.52
Number of employees in construction-industry enterprises	10,000 people	224.79	352.83	77.64	152.72	137.98	56.88	11	12.42	126.15	27.7
Road-network density	%	43.95	41.22	26.13	13.98	35.75	12.21	1.66	27.62	28.92	14.47
Level of urban traffic-lighting facilities	Size	584,172	1,344,947	584,172	500,123	500,123	318,333	131,213	247,589	695,594	584,422
Cell-phone penetration rate	Department/100 people	106.49	92.67	97.36	88.08	110.04	96.22	102.09	116.16	89.77	112.36
Number of fixed-broadband households	10,000 house-holds	661.4	1430.3	436.7	694.2	662.2	380	105.9	140.6	671.8	390.5
Level of gas-supply facilities	km	22,320	49,338	6414	5947	16,567	3140	2244	6279	5513	9680
Level of seismic-monitoring facilities	Block/10,000 km^2	2.31	13.59	2.05	29.47	18.96	11.44	2.34	7.17	11.82	4.56

Table A5. *Cont.*

Indicators	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
Public coverage of meteorological disaster monitoring and forecasting early-warning information	pcs/100 km^2	4.62	5.77	8.63	4.03	3.13	2.47	0.26	3.77	3.50	1.15
Urban intelligent-pipe-network density	/km	21.51	30.40	25.34	12.83	22.15	8.30	1.26	8.38	15.95	6.70
Shelter area per capita	m^2/people	4.57	8.40	8.04	8.12	16.64	14.63	15.72	17.23	6.53	15.44
Storage area of disaster-relief-reserve institutions per 10,000 people	m^2/10,000 people	12,446.18	17,168.53	20,368.89	22,018.12	15,596.45	33,899.63	59,158.03	39,546.53	21,932.65	49,131.09
Number of beds in medical and health institutions per 10,000 people	Size/10,000 people	76.93	79.48	144.13	114.25	87.05	78.18	175.28	81.04	63.53	105.13
Greenery coverage	%	40.32	40.00	37.01	38.87	39.88	33.28	32.55	40.41	39.12	40.22
The disaster-related death rate per million population	%	0.02	0.05	0.05	0.07	0.04	0.02	0.07	0.00	0.04	0.02
Annual direct economic losses due to disasters as a percentage of regional GDP	%	0.12	0.41	0.42	0.41	0.76	1.43	0.71	0.37	0.56	0.85
Percentage of people affected in a year	%	6.58	5.29	18.50	17.56	22.94	35.89	48.57	40.57	7.56	47.53
Public-security financial expenditure	CNY 100 million	235.91	471.42	268.09	343.26	241.82	170.38	90.04	64.59	283.17	250.09
Healthcare financial expenditure	CNY 100 million	353.79	526.68	336.91	511.24	304.03	285.75	95.38	100.82	244.09	344.38
Transportation financial expenditure	CNY 100 million	287.97	218.41	253.80	291.16	399.12	321.54	110.17	138.48	180.81	466.86

Table A6. Table of raw data for 2019 indicator-calculation variables.

Indicators	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
The resident population density in built-up areas	10,000 people/km^2	0.78	0.72	0.63	0.73	0.85	0.61	0.84	0.46	0.60	0.53
Level of basic medical insurance for urban workers	10,000 people	720.6	1778.1	462	528	712.9	344.3	103.7	141.1	620.5	530.7
Percentage of transient population	%	15.70	11.67	9.62	9.16	6.22	13.03	7.72	16.87	11.44	20.46
Level of urban-health-technology talent pool	People	93	95	94	138	110	102	133	111	94	144
Number of hospitals	Block/100 km^2	1.96	2.84	3.70	1.58	2.28	0.81	0.11	0.99	0.96	0.53
Social-organization-unit level	size	17,553	44,932	13,753	23,640	30,548	24,644	6084	6083	27,118	16,998

Table A6. *Cont.*

Indicators	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
Personal accident insurance income	CNY 100 million	696.24	1635.33	265.85	445.07	816.25	306.34	56.68	129.51	448.14	516.86
Urban commercial insurance income	CNY 100 million	916.46	2148.66	489.26	742.1	1033.49	444.32	98.44	197.67	664.92	729.82
Number of people covered by work-injury insurance	10,000 people	661.67	1177.14	408.51	438.51	577.42	244.1	73.99	119.58	442.23	338.24
Land-development intensity	%	17.71	10.12	10.08	3.67	4.58	2.23	0.35	4.29	8.27	3.42
The proportion of land area in security-vulnerable zones	%	19.41	18.29	18.43	13.33	15.31	27.64	14.54	12.13	16.41	15.64
Number of employees in construction-industry enterprises	10,000 people	216.18	351.36	80	141.54	145.21	50.85	8.1	11.25	141.94	20.52
Road-network density	%	51.22	50.46	32.54	17.23	39.67	14.06	1.92	34.34	38.02	14.51
Level of urban traffic-lighting facilities	Size	775,469	1,550,215	626,167	623,986	824,590	354,166	146,458	238,104	654,416	576,538
Cell-phone penetration rate	Department/100 people	117.75	112.76	111.78	100.1	119.72	103.92	110.73	119.24	103.38	118.59
Number of fixed-broadband households	10,000 households	920.4	1830.7	715.6	783.9	878.2	548.7	130.3	204.9	845.9	594.8
Level of gas-supply facilities	km	23,613	57,055	7816	7904	21,514	3817	2500	6906	8456	10,145
Level of seismic-monitoring facilities	Block/10,000 km^2	11.09	13.28	5.80	30.00	18.48	11.41	1.97	6.76	11.81	4.51
Public coverage of meteorological disaster monitoring and forecasting early-warning information	pcs/100 km^2	4.17	5.97	8.35	2.96	2.97	1.78	0.27	3.90	3.28	1.12
Urban intelligent-pipe-network density	/km	27.78	39.12	31.78	22.93	28.89	10.03	1.65	10.82	25.01	8.81
Shelter area per capita	m^2/people	4.94	9.12	7.22	9.82	11.47	12.49	17.09	23.78	10.28	15.14
Storage area of disaster-relief-reserve institutions per 10,000 people	m^2/10,000 people	12,257.89	18,257.87	25,881.50	20,680.23	16,732.80	45,693.43	72190.21	40,166.81	19,294.80	51,379.16
Number of beds in medical and health institutions per 10,000 people	Size/10,000 people	87.85	86.02	81.61	104.14	80.46	90.81	105.52	79.31	66.12	113.87
Greenery coverage	%	41.82	41.85	39.42	39.73	39.32	36.03	35.21	41.34	40.76	40.52
The disaster-related death rate per million population	%	0.01	0.04	0.05	0.04	0.03	0.02	0.04	0.01	0.04	0.01
Annual direct economic losses due to disasters as a percentage of regional GDP	%	0.08	0.74	0.28	0.44	0.23	0.53	0.49	0.08	0.47	0.27
Percentage of people affected in a year	%	5.68	11.69	18.99	55.20	23.07	24.68	37.36	4.23	14.72	22.11
Public-security financial expenditure	CNY 100 million	268.66	525.64	280.06	382.83	285.9	191.29	89.57	66.74	312.18	249.06
Healthcare financial expenditure	CNY 100 million	383.26	687.83	347.79	542.81	283.94	360.35	172.6	88.87	219.49	403.38
Transportation financial expenditure	CNY 100 million	292.35	487.60	277.20	949.40	458.80	224.50	86.90	14.60	356.00	220.70

Table A7. Table of raw data for 2021 indicator-calculation variables.

Indicators	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
The resident population density in built-up areas	10,000 people/km^2	0.80	0.75	0.61	0.62	0.82	0.57	0.77	0.47	0.61	0.54
Level of basic medical insurance for urban workers	10,000 people	795.9	1945.8	479.4	569.2	783.8	372.3	114.8	159.6	714.8	564.7
Percentage of transient population	%	13.95	15.98	10.06	9.70	7.78	16.78	6.08	13.44	11.42	23.20
Level of urban-health-technology talent pool	People	77	100	102	120	102	111	125	104	103	116
Number of hospitals	Block/100 km^2	1.98	2.69	3.47	1.53	2.24	0.78	0.11	0.97	1.02	0.54
Social-organization-unit level	size	18,561	45,535	14,742	23,011	31,210	21,554	5997	5070	29,485	17,288
Personal accident insurance income	CNY 100 million	751.75	1647.57	281.6	428.13	797.66	359.33	62.03	145.79	539.37	440.18
Urban commercial insurance income	CNY 100 million	965.5	2204.91	496.26	690.2	1052.37	490.32	106.89	211.14	780.6	645.56
Number of people covered by work-injury insurance	10,000 people	765.73	1472.06	529.94	541.91	629.61	278.74	95.93	143.79	551.31	338.22
Land-development intensity	%	17.99	10.10	9.68	3.60	4.62	2.26	0.36	4.37	6.75	3.07
The proportion of land area in security-vulnerable zones	%	21.76	18.31	15.46	13.60	13.24	26.43	14.70	11.88	16.87	12.45
Number of employees in construction-industry enterprises	10,000 people	205.54	364.57	71.58	120.21	129.83	46.01	6.01	11.09	118.51	15.49
Road-network density	%	60.84	61.09	47.90	20.22	43.32	16.88	2.03	37.43	40.82	15.51
Level of urban traffic-lighting facilities	Size	899,100	2,166,500	820,600	761,700	852,900	434,900	152,600	248,100	831,100	622,300
Cell-phone penetration rate	Department/100 people	116.77	111.55	110.85	107.58	120.83	110.23	114.56	119.46	109.42	125.71
Number of fixed-broadband households	10,000 households	984.3	2013.9	815.2	989.4	1213.6	661.3	152.1	246.9	1043.9	701.5
Level of gas-supply facilities	km	24,266	75,350	9938	9760	28,700	4625	4666	7566	12,985	11,891
Level of seismic-monitoring facilities	Block/10,000 km^2	13.18	45.21	6.70	87.04	43.22	51.52	5.85	40.66	17.17	9.95
Public coverage of meteorological disaster monitoring and forecasting early-warning information	pcs/100 km^2	4.17	5.93	6.51	2.96	3.44	1.66	0.27	3.93	3.16	1.16
Urban intelligent-pipe-network density	/km	327,134.73	406,357.48	321,967.71	25,8655.12	316,773.95	116,776.54	18,188.66	134,222.48	309,061.21	106,110.15

Table A7. *Cont.*

Indicators	Unit	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
Shelter area per capita	m^2/people	4.81	9.03	6.25	8.51	9.94	12.98	14.85	20.87	10.67	19.46
Storage area of disaster-relief-reserve institutions per 10,000 people	m^2/10,000 people	13,819.75	18,911.55	18,506.97	22,984.55	15,157.91	46,581.54	45,219.55	22,847.66	19,345.71	37,833.28
Number of beds in medical and health institutions for 10,000 people	Size/10,000 people	71.03	87.00	90.73	86.17	83.50	85.80	90.64	67.90	73.91	88.28
Greenery coverage	%	42.60	43.10	41.80	42.50	41.80	36.30	34.80	42.00	40.20	42.00
The disaster-related death rate per million population	%	0.01	0.01	0.00	0.02	0.03	0.00	0.04	0.00	0.00	0.03
Annual direct economic losses due to disasters as a percentage of regional GDP	%	0.11	0.46	0.15	0.39	1.06	0.66	1.37	0.30	0.09	0.37
Percentage of people affected in a year	%	5.28	15.71	14.81	43.90	39.13	43.16	16.62	30.05	9.75	25.39
Public-security financial expenditure	CNY 100 million	273.2	531.89	274.27	375.6	289.72	193.55	93.9	63.95	288.38	249.79
Healthcare financial expenditure	CNY 100 million	427.72	717.35	336.45	601.4	325.83	287.29	189.44	84.35	335.51	345.99
Transportation financial expenditure	CNY 100 million	277.44	714.30	244.60	791.50	834.50	389.10	49.50	132.20	261.10	232.10

Appendix D

Table A8. Catastrophe-level values for each bottom metric in 2017.

Indicators	Catastrophe-Level Values									
	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
The resident population density in built-up areas	0.790	0.649	0.418	0.701	0.764	0.367	1.000	0.120	0.419	0.164
Level of basic medical insurance for urban workers	0.295	0.774	0.171	0.215	0.284	0.122	0.000	0.016	0.250	0.217
Percentage of transient population	0.357	0.621	0.820	0.889	1.000	0.494	0.778	0.335	0.767	0.214
Level of urban-health-technology talent pool	0.014	0.056	0.552	0.483	0.273	0.070	1.000	0.203	0.098	0.371
Number of hospitals	0.450	0.716	1.000	0.379	0.620	0.137	0.005	0.214	0.208	0.105
Social-organization-unit level	0.290	0.920	0.189	0.448	0.486	0.544	0.005	0.037	0.482	0.248
Personal accident insurance income	0.321	0.871	0.102	0.194	0.380	0.129	0.000	0.039	0.201	0.215

Table A8. *Cont.*

Indicators	Catastrophe-Level Values									
	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Guangxi	Inner Mongolia
Urban commercial insurance income	0.312	0.874	0.145	0.251	0.371	0.135	0.000	0.040	0.228	0.231
Number of people covered by work-injury insurance	0.313	0.576	0.190	0.227	0.280	0.095	0.000	0.018	0.230	0.173
Land-development intensity	0.955	0.555	0.508	0.191	0.283	0.083	0.003	0.497	0.459	0.168
The proportion of land area in security-vulnerable zones	0.525	0.585	0.575	0.870	0.901	0.281	0.909	0.977	0.529	0.706
Number of employees in construction-industry enterprises	0.610	0.967	0.200	0.409	0.368	0.142	0.014	0.018	0.335	0.060
Road-network density	0.712	0.666	0.412	0.207	0.574	0.178	0.000	0.437	0.459	0.216
Level of urban traffic-lighting facilities	0.223	0.596	0.223	0.181	0.181	0.092	0.000	0.057	0.277	0.223
Cell-phone penetration rate	0.489	0.122	0.247	0.000	0.584	0.216	0.372	0.746	0.045	0.645
Number of fixed-broadband households	0.291	0.694	0.173	0.308	0.292	0.144	0.000	0.018	0.297	0.149
Level of gas-supply facilities	0.275	0.644	0.057	0.051	0.196	0.012	0.000	0.055	0.045	0.102
Level of seismic-monitoring facilities	0.004	0.137	0.001	0.323	0.200	0.111	0.004	0.061	0.116	0.030
Public coverage of meteorological disaster monitoring and forecasting early-warning information	0.521	0.658	1.000	0.450	0.343	0.264	0.000	0.419	0.387	0.106
Urban intelligent-pipe-network density	0.514	0.740	0.612	0.294	0.531	0.179	0.000	0.181	0.373	0.138
Shelter area per capita	0.000	0.199	0.181	0.185	0.628	0.524	0.580	0.659	0.102	0.566
Storage area of disaster-relief-reserve institutions per 10,000 people	0.003	0.082	0.135	0.163	0.056	0.361	0.783	0.455	0.161	0.615
Number of beds in medical and health institutions per 10,000 people	0.120	0.143	0.721	0.454	0.210	0.131	1.000	0.157	0.000	0.372
Greenery coverage	0.736	0.706	0.423	0.599	0.695	0.069	0.000	0.745	0.623	0.727
The disaster-related death rate per million population	0.721	0.399	0.338	0.115	0.471	0.672	0.000	1.000	0.487	0.755
Annual direct economic losses due to disasters as a percentage of regional GDP	0.967	0.757	0.745	0.751	0.497	0.000	0.536	0.780	0.646	0.431
Percentage of people affected in a year	0.954	0.979	0.720	0.738	0.633	0.379	0.130	0.287	0.935	0.150
Public-security financial expenditure	0.367	0.871	0.436	0.597	0.380	0.227	0.056	0.001	0.468	0.398
Healthcare financial expenditure	0.314	0.870	0.410	0.539	0.389	0.239	0.048	0.016	0.498	0.278
Transportation financial expenditure	0.304	0.608	0.366	0.588	0.324	0.301	0.058	0.065	0.248	0.376

Table A9. Catastrophe-level values for each bottom metric in 2019.

Indicators	Catastrophe-Level Values									
	Chongqing	**Sichuan**	**Guizhou**	**Yunnan**	**Shaanxi**	**Gansu**	**Qinghai**	**Ningxia**	**Guangxi**	**Inner Mongolia**
The resident population density in built-up areas	0.770	0.626	0.409	0.650	0.939	0.361	0.915	0.000	0.337	0.169
Level of basic medical insurance for urban workers	0.338	0.909	0.199	0.234	0.334	0.135	0.005	0.025	0.284	0.236
Percentage of transient population	0.404	0.628	0.740	0.796	0.965	0.572	0.853	0.348	0.684	0.179
Level of urban-health-technology talent pool	0.112	0.126	0.119	0.427	0.231	0.175	0.392	0.238	0.119	0.469
Number of hospitals	0.513	0.757	0.996	0.408	0.602	0.194	0.000	0.244	0.236	0.117
Social-organization-unit level	0.308	0.985	0.215	0.459	0.630	0.484	0.025	0.025	0.545	0.295
Personal accident insurance income	0.406	0.992	0.137	0.249	0.481	0.162	0.006	0.052	0.251	0.294
Urban commercial insurance income	0.394	0.974	0.193	0.312	0.449	0.171	0.009	0.055	0.275	0.306
Number of people covered by work-injury insurance	0.424	0.790	0.244	0.266	0.364	0.127	0.006	0.039	0.268	0.194
Land-development intensity	0.984	0.554	0.552	0.188	0.240	0.107	0.000	0.223	0.449	0.174
The proportion of land area in security-vulnerable zones	0.523	0.594	0.584	0.908	0.783	0.000	0.832	0.985	0.713	0.762
Number of employees in construction-industry enterprises	0.586	0.963	0.206	0.378	0.388	0.125	0.006	0.015	0.379	0.040
Road-network density	0.834	0.821	0.520	0.262	0.640	0.209	0.004	0.550	0.612	0.216
Level of urban traffic-lighting facilities	0.317	0.697	0.243	0.242	0.341	0.110	0.007	0.053	0.257	0.219
Cell-phone penetration rate	0.788	0.656	0.630	0.319	0.841	0.421	0.602	0.828	0.407	0.811
Number of fixed-broadband households	0.427	0.904	0.320	0.355	0.405	0.232	0.013	0.052	0.388	0.256
Level of gas-supply facilities	0.292	0.750	0.076	0.077	0.264	0.022	0.004	0.064	0.085	0.108
Level of seismic-monitoring facilities	0.107	0.133	0.045	0.329	0.194	0.111	0.000	0.056	0.116	0.030
Public coverage of meteorological disaster monitoring and forecasting early-warning information	0.467	0.682	0.967	0.323	0.324	0.181	0.001	0.435	0.361	0.103
Urban intelligent-pipe-network density	0.673	0.962	0.775	0.550	0.702	0.223	0.010	0.243	0.603	0.192
Shelter area per capita	0.019	0.237	0.138	0.273	0.359	0.412	0.652	1.000	0.297	0.550
Storage area of disaster-relief-reserve institutions per 10,000 people	0.000	0.100	0.227	0.141	0.075	0.558	1.000	0.466	0.117	0.653
Number of beds in medical and health institutions per 10,000 people	0.218	0.201	0.162	0.363	0.151	0.244	0.376	0.141	0.023	0.450
Greenery coverage	0.877	0.877	0.649	0.678	0.640	0.327	0.251	0.829	0.782	0.754
The disaster-related death rate per million population	0.860	0.491	0.305	0.457	0.651	0.677	0.484	0.884	0.426	0.893
Annual direct economic losses due to disasters as a percentage of regional GDP	0.996	0.515	0.850	0.733	0.889	0.664	0.698	1.000	0.708	0.856
Percentage of people affected in a year	0.971	0.854	0.710	0.000	0.630	0.599	0.350	1.000	0.794	0.649
Public-security financial expenditure	0.437	0.987	0.462	0.681	0.474	0.272	0.055	0.006	0.530	0.396
Healthcare financial expenditure	0.348	1.000	0.524	0.610	0.445	0.282	0.074	0.026	0.560	0.277
Transportation financial expenditure	0.309	0.813	0.380	0.628	0.299	0.396	0.157	0.050	0.217	0.451

Table A10. Catastrophe-level values for each bottom metric in 2021.

Indicators	Catastrophe-Level Values									
	Chongqing	**Sichuan**	**Guizhou**	**Yunnan**	**Shaanxi**	**Gansu**	**Qinghai**	**Ningxia**	**Guangxi**	**Inner Mongolia**
The resident population density in built-up areas	0.828	0.690	0.365	0.375	0.872	0.264	0.741	0.014	0.366	0.185
Level of basic medical insurance for urban workers	0.379	1.000	0.208	0.257	0.373	0.150	0.011	0.035	0.335	0.254
Percentage of transient population	0.519	0.405	0.737	0.757	0.865	0.360	0.961	0.547	0.661	0.000
Level of urban-health-technology talent pool	0.000	0.161	0.175	0.301	0.175	0.238	0.336	0.189	0.182	0.273
Number of hospitals	0.520	0.716	0.931	0.395	0.591	0.187	0.000	0.240	0.253	0.120
Social-organization-unit level	0.333	1.000	0.239	0.443	0.646	0.407	0.023	0.000	0.603	0.302
Personal accident insurance income	0.440	1.000	0.147	0.238	0.469	0.195	0.009	0.062	0.308	0.246
Urban commercial insurance income	0.417	1.000	0.196	0.287	0.458	0.193	0.013	0.062	0.330	0.266
Number of people covered by work-injury insurance	0.498	1.000	0.331	0.339	0.401	0.152	0.022	0.056	0.346	0.194
Land-development intensity	1.000	0.553	0.529	0.184	0.242	0.108	0.001	0.228	0.363	0.154
The proportion of land area in security-vulnerable zones	0.373	0.592	0.773	0.891	0.914	0.077	0.821	1.000	0.684	0.964
Number of employees in construction-industry enterprises	0.556	1.000	0.183	0.318	0.345	0.112	0.000	0.014	0.314	0.026
Road-network density	0.996	1.000	0.778	0.312	0.701	0.256	0.006	0.602	0.659	0.233
Level of urban traffic -ighting facilities	0.377	1.000	0.339	0.310	0.355	0.149	0.011	0.057	0.344	0.241
Cell-phone penetration rate	0.762	0.624	0.605	0.518	0.870	0.589	0.704	0.834	0.567	1.000
Number of fixed-broadband households	0.460	1.000	0.372	0.463	0.581	0.291	0.024	0.074	0.492	0.312
Level of gas-supply facilities	0.301	1.000	0.105	0.103	0.362	0.033	0.033	0.073	0.147	0.132
Level of seismic-monitoring facilities	0.132	0.508	0.056	1.000	0.485	0.582	0.046	0.455	0.179	0.094
Public coverage of meteorological disaster monitoring and forecasting early-warning information	0.467	0.678	0.747	0.322	0.380	0.167	0.001	0.439	0.346	0.107
Urban intelligent-pipe-network density	0.799	1.000	0.786	0.625	0.772	0.264	0.014	0.309	0.753	0.237
Shelter area per capita	0.012	0.232	0.088	0.205	0.279	0.438	0.535	0.849	0.318	0.775
Storage area of disaster-relief-reserve institutions per 10,000 people	0.026	0.111	0.104	0.179	0.048	0.573	0.550	0.177	0.118	0.427
Number of beds in medical and health institutions per 10,000 people	0.067	0.210	0.243	0.203	0.179	0.199	0.243	0.039	0.093	0.221
Greenery coverage	0.953	1.000	0.877	0.943	0.877	0.355	0.213	0.896	0.725	0.896
The disaster-related death rate per million population	0.904	0.909	0.960	0.719	0.650	0.985	0.418	0.939	0.965	0.664
Annual direct economic losses due to disasters as a percentage of regional GDP	0.978	0.716	0.943	0.772	0.271	0.572	0.049	0.834	0.989	0.782
Percentage of people affected in a year	0.979	0.775	0.792	0.222	0.315	0.236	0.757	0.493	0.892	0.585
Public-security financial expenditure	0.447	1.000	0.449	0.666	0.482	0.277	0.064	0.000	0.480	0.397
Healthcare financial expenditure	0.400	0.737	0.294	0.602	0.281	0.236	0.122	0.000	0.292	0.305
Transportation financial expenditure	0.290	0.847	0.249	0.945	1.000	0.433	0.000	0.105	0.270	0.233

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