Chapter

Climate Resilience, Megalopolis Vulnerability and Spatial Distribution

Tao Ma, Nairong Tan, Xiaolei Wang, Hao Wang and Mingxi Zhou

Abstract

This chapter takes three megalopolises including Guangdong-Hong Kong-Macao, Yangtze River Delta and Beijing-Tianjin-Hebei as research objects, firstly analyzes the connection relationship and megalopolis vulnerability among core cities in the context of regional integration. Secondly, we calculate there megalopolises to obtain the vulnerability of each city in 2018 Sex index. The results show that the central cities and economically underdeveloped cities of the three megalopolises are relatively vulnerable areas in the urban agglomerations, and areas have low sensitivity and high response. Finally, policy suggestions for megalopolis are given to improve the adaptive capacity of tackling climate change. The innovation of this chapter is to use spatial data to comprehensively evaluate and analyze the vulnerability, and to realize visualization in the map, which better reflects the distribution law and proposes a response to megalopolis vulnerability.

Keywords: climate change, megalopolis, vulnerability, connectivity

1. Introduction (The identification of megalopolis vulnerability to climate change)

1.1 The concepts of vulnerability to climate change

Climate change mainly includes temperature, precipitation, solar radiation, wind speed, humidity, and air pressure. It represents a typical multi-scale global change problem, characterized by the infinite diversity, multiple pressures and time scales [1]. There is much research on vulnerability caused by climate change, and also has gradually become a forward position field of global environmental change and sustainable development. Vulnerability includes the fields of disasters research (delineated into human ecology, hazards, and the 'Pressure and Release' model) [2], which is the core of climate change. It can include the vulnerability of natural systems, such as the impact of floods and hurricanes caused by climate change on agricultural production and human life; it also includes economic and social vulnerability [3], emphasizing risks and uncertainties come from economic and social environment change. In social vulnerability, it is often measured as a function of the socioeconomic conditions of the communities [4].

1.2 The identification of megalopolis vulnerability

A city is a complex giant system, and urban systems have been growing exponentially in size and complexity [5]. While a megalopolis is a complex coupled giant system. Spatial scales about connection relationships and measurement indicators in quite different ways. The energy use of industry, infrastructure (water, electricity, gas), land and buildings in cities are the importance of factors in climate change [6]. Megalopolis is core to cities, which the highly integrated connectivity networks formed by developed infrastructure networks such as transportation, information and communications. With the industrial division, factor flow, and the integration of cross-regional infrastructure in megalopolis, there are more connectedness in cities, while the more vulnerability increased due to the effects of climate change.

The concept of urban vulnerability evolved from vulnerability and refers to the ability affecting by adverse events. It was first proposed by the United Nations Development Program in 1999, and specifically includes sensitivity and capacity of response [7]. The reasons for urban vulnerability include the natural environment and external shocks related to trade and diplomacy. At present, the research on urban vulnerability in China mainly focuses on the resource-based cities (such as mining cities and ocean cities).

There are more than 660 cities in China, including 7 megalopolises with urban populations of more than 10 million, 9 megacities with populations of 5-10 million, and 124 large cities with populations of 1 to 5 million. The five major urban agglomerations (the Pearl River Delta, the Yangtze River Delta, the Beijing-Tianjin-Hebei, the middle reaches of the Yangtze River, and Chengdu-Chongqing) gather 55% of the country's total economic output and 40% of the total population. In 2018, the domestic product of the Yangtze Delta megalopolis reached about 2.7 trillion US dollars, and the economic scale surpassed that of Italy, which is the eighth largest economy in the world, and the Pearl River Delta megalopolis was about 1.2 trillion US dollars, which is equivalent to Mexico. However, in general, the internal links are not connected between China's megalopolises and cities, it should consolidate cooperation in different sizes of cities. The urban commuter railway mileage in central cities such as Beijing and Shanghai is less than other international metropolises. Core cities, surrounding areas, and peripheral cities were of inferior spatial connectivity, and even some core cities have "fault zones" with surrounding areas.

China's megalopolises are the spatial carriers that form economies of scale and scope, they are also a crucial support for improving economic efficiency, resilience, and resistance to external uncertain risks. In particular, as the construction of new infrastructure will enter a stage of rapid growth, which represented by 5G technology, artificial intelligence and data centers. It will be beneficial to the sustainability of megalopolises and the adaptability to vulnerabilities and risks, for enhancing the connectivity, the flexible layout adjustment of cities's internal structure.

This chapter firstly identifies the vulnerabilities of Guangdong-Hong Kong-Macao, Yangtze River Delta and Beijing-Tianjin-Hebei, and establishes the sensitivity index and capacity of response index for the three megalopolises under the effects of climate change. Secondly, it assesses the impact of urban vulnerability, and finally put forward response the measures for China's megalopolises that are climate-adaptive.

2. Analysis of the vulnerability of Chinese urban agglomerations and urban continuous belts

2.1 Theoretical model

According to the concept of urban vulnerability, relevant indicators are selected to establish an urban vulnerability evaluation index system, as shown in **Table 1**.

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Target layer	Criterion layer	Code	Indicator layer	Positive and negative	Weight
Urban vulnerability index(V)	Sensitivity index(S)	x_1	Industrial dust emissions	Positive	0.0857
		x_2	Industrial sulfur dioxide emissions	Positive	0.0577
		x_3	Industrial wastewater emissions	Positive	0.0575
		x_4	Fiscal deficit	Positive	0.0097
		x_5	Urban registered unemployment rate	Positive	0.0325
		x_6	Financial institution loan balance	Positive	0.1631
	Coping Ability Index(R)	x_7	Urban green coverage rate	Negative	0.0070
		x_8	Per capita disposable income of urban residents	Negative	0.0423
		x_9	Actual use of foreign capital	Negative	0.1217
		x_{10}	Freight volume	Negative	0.0754
		x_{11}	Passenger volume	Negative	0.1162
		x_{12}	Urban road area	Negative	0.0836
		x_{13}	Domestic and foreign currency household deposits of financial institutions	Negative	0.0904
		x_{14}	The proportion of science and education expenditure in fiscal expenditure	Negative	0.0572

Table 1.
Urban vulnerability evaluation index system.

Urban vulnerability refers to the sensitivity it exhibits when faced with the influence of multiple factors inside and outside the urban system and the strength of its coping ability to adapt to this sensitivity. The higher the sensitivity of the urban system, the stronger the urban vulnerability. The higher the response capacity of the urban system, the smaller the urban vulnerability. Therefore, urban vulnerability is a function of the sensitivity and coping ability of the urban system when faced with internal and external factors [8].

$$V = f(S,R) = \frac{S}{R} \quad (1)$$

In the formula, V represents the urban vulnerability index. S represents the urban sensitivity index and R represents the urban response capability index. Urban vulnerability is directly proportional to sensitivity and inversely proportional to coping ability.

According to the calculation method of the urban vulnerability evaluation index system [7], the acquired data is processed first. Due to the diversity of data types in the evaluation index system, the dimensions and magnitudes of different index data have certain differences [9]. Therefore, it is necessary to further non-dimensionalize the acquired data to eliminate its impact on urban vulnerability evaluation indicators. In this evaluation indicator system, all indicators have a positive correlation with the sub-target level [10]. The standardization method of deviation of the data is selected to process the original data without dimension. The standardization of the dispersion of the data is a linear transformation of the original data, so that the result falls into the interval [0,1]. The conversion function is as follows:

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

Second, the entropy method is used to determine the weight of each index in the urban vulnerability evaluation index system. The specific process is as follows:

1. Quantify all indicators with the same measurement. Calculate the proportion of the j-th index value of the i-th evaluation object, the calculation method is as follows:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{3}$$

2. Calculate the information entropy e_j:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\left(p_{ij}\ln p_{ij}\right) \tag{4}$$

In the formula, $0 \le e_j \le 1$; when $p_{ij} = 0$, $e_j = 0$.

3. Calculate the difference coefficient g_i:

$$g_i = 1 - e_j \tag{5}$$

The smaller the entropy value, the greater the difference between indicators.

4. Calculate the index weight w_j:

$$w_j = \frac{g_j}{\sum_{i=1}^{n} g_j} \tag{6}$$

2.2 The indicator system

According to the concept of urban vulnerability [11], relevant indicators are selected to establish an urban vulnerability evaluation index system, as shown in **Table 1**.

2.3 Research scope and data sources

The research scope includes the Beijing-Tianjin-Hebei urban agglomeration, the Yangtze River Delta urban agglomeration and the Guangdong-Hong Kong-Macao

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City group	Cities
Beijing-Tianjin-Hebei City Group	Beijing; Tianjin; Baoding, Tangshan, Langfang, Shijiazhuang, Qinhuangdao, Zhangjiakou, Chengde, Cangzhou, Hengshui, Xingtai, Handan, Dingzhou, Xinji in Hebei Province; Anyang in Henan Province
Yangtze River Delta City Group	Shanghai; Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Zhenjiang, Taizhou in Jiangsu Province; Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Jinhua, Zhoushan and Taizhou in Zhejiang Province; Hefei, Bengbu, Wuhu in Anhui Province, Ma'anshan, Tongling, Anqing, Chuzhou, Chizhou, Xuancheng
Guangdong-Hong Kong-Macao Greater Bay Area	Hong Kong; Macau; Guangzhou, Shenzhen, Zhuhai, Foshan, Zhongshan, Dongguan, Zhaoqing, Jiangmen, Huizhou in Guangdong Province

Table 2.
Definition of the study area.

Greater Bay Area. The relevant indicator data comes from the 2019 data China City Statistical Yearbook, the 2019 provincial and municipal statistical yearbooks and statistical bulletins. Due to the availability of data, the calculation does not include Hong Kong, Macau Special Administrative Region, Dingzhou and Xinji county-level cities. For individual missing values, replace with the mean value of the city group where the city is located (**Table 2**).

2.4 Result analysis

Combining the relevant index data of the studied cities and using the urban system vulnerability evaluation index model, the 2018 Beijing-Tianjin-Hebei urban agglomeration, the Yangtze River Delta urban agglomeration, and the Guangdong-Hong Kong-Macao Greater Bay Area are calculated to obtain the vulnerability index of each city in 2018. As shown in **Figure 1**.

The central cities and economically underdeveloped cities of the three major urban agglomerations are relatively vulnerable areas in the urban agglomerations, and are low-sensitive and high-response areas. The vulnerability of the urban system is divided into 4 levels according to the clustering results. Among the Guangdong-Hong Kong-Macao Greater Bay Area, Guangzhou is a very vulnerable area with a vulnerability index of 0.45, a sensitivity index of 0.1, and a coping capacity index of 0.34; Shenzhen is a low-vulnerability area; other areas are not vulnerable. Among the Yangtze River Delta urban agglomerations, Shanghai and Suzhou are vulnerable areas with a vulnerability index of 0.57 and 0.43, of which Shanghai's vulnerability index and sensitivity index are 0.18 and 0.39, respectively. Hangzhou and Nanjing are vulnerable areas. Other areas are not fragile areas. In the Beijing-Tianjin-Hebei urban agglomeration, Beijing is a very vulnerable area, with the vulnerability index and sensitivity index being 0.18 and 0.44, respectively. Tianjin and Tangshan are low-vulnerability areas. Other areas are not vulnerable areas. The vulnerability structure of the central cities of China's three major urban agglomerations is obvious. Their economic development is in a leading position in the urban agglomerations and the country, and from the perspective of urban infrastructure, cities have a strong ability to deal with vulnerability. Therefore, these cities are vulnerable. Therefore, urban sensitivity can be reduced through environmental protection policies (**Table 3**) [12].

3. Measures to improve the climate adaptability of megacities

According to the results of the second section, the fragility structure of the central cities of the three major urban agglomerations is obvious. Their economic

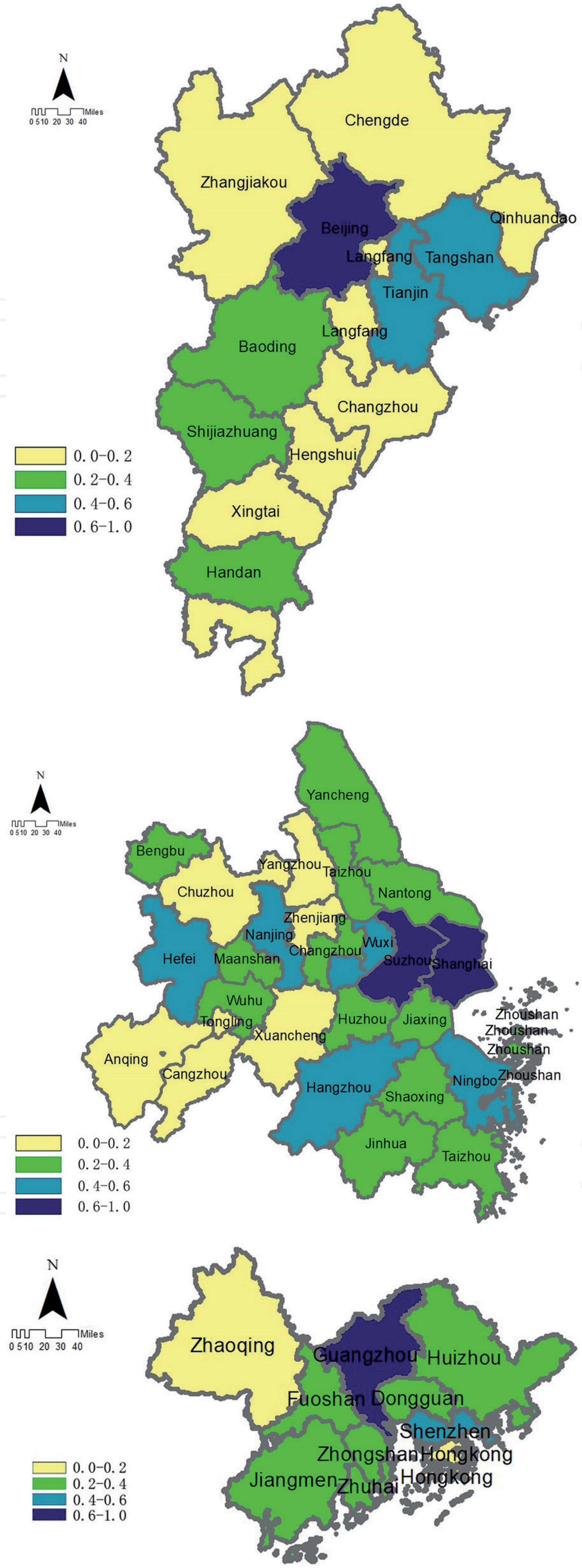

Figure 1.
Sketch map of vulnerability of Beijing-Tianjin-Hebei urban agglomeration, Yangtze River Delta urban agglomeration and Guangdong-Hong Kong-Macao Greater Bay Area.

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Vulnerability value	0 ≤ V < 0.2	0.2 ≤ V < 0.4	0.4 ≤ V < 0.6	0.6 ≤ V < 1
Classification	Not vulnerable	Low vulnerable	Vulnerable	Very vulnerable

Table 3.
Criteria for the classification of urban vulnerability levels.

development is in a leading position in the urban agglomerations and the whole country, and from the perspective of urban infrastructure, cities have a strong ability to deal with fragility. The central cities and economically underdeveloped cities of the three major urban agglomerations are all relatively vulnerable areas in the urban agglomerations, and are areas with low sensitivity and high response capacity. For such cities, the focus is to improve their comprehensive carrying capacity. In addition, a series of pan-smart city technologies that emerged under the background of the fourth industrial revolution are playing an increasingly important role in the development and operation of cities. Scientifically and rationally cognizing the relationship between technology and urban multi-agents, and guiding the coordinated development of future technological development and urban planning, design, construction, and governance is crucial for building a resilient system of climate-adaptive large urban agglomerations.

3.1 Improve the comprehensive carrying capacity of central cities and urban agglomerations

Optimize the layout of population functions to enhance the city's carrying capacity. Urban agglomerations must form a reasonable allocation of population and industrial layout within the city, and form a "city-region" organizational model in terms of modern economic cultivation. Optimizing the population distribution within urban agglomerations can not only alleviate the "urban disease" caused by the excessive concentration of population in megacities, but it is also a necessary means to realize the high-level population function of world-class urban agglomerations and enhance the overall participation of the urban agglomeration in global competition. To optimize the layout of population functions with a global perspective, it is necessary to consider the differentiated needs of the diverse population structure of world-class urban agglomerations for urban space and urban functions, and improve the comprehensive carrying capacity of the urban agglomeration.

Give full play to comparative advantages and build a multi-level power system for regional development. To improve the carrying capacity of central cities, it is necessary to strengthen regional integration and build a multi-level dynamic system for regional development. According to the differences in the location conditions of the economy, society and resource environment, division of labor, coordination, and organic configuration form an overall process of synergy. The idea of planning and formulating the main functional zone can be followed. Some areas do the division of ecological products, and some areas do the division of industrial products. The main function is different, the area type will be different. Different regions have different development levels and advantages, so the focus of division of labor is also different. By improving regional policies and spatial layout, mechanisms for counterpart cooperation, cross-regional cooperative governance, transfer payments, and ecological compensation should be established between advantageous regions and underdeveloped regions.

Improve the efficiency of agglomeration and tilt the allocation of construction land to advantageous areas. In order to improve the efficiency of agglomeration and give full play to comparative advantages, it is necessary to strengthen the flexibility of construction land management. For areas with serious population loss, land use indicators can be appropriately reduced, and land use efficiency can be improved on existing land, so as to avoid idle land waste. For those areas with long-term population growth and rapid growth, and areas with tight land use, urban space can be developed by increasing land use indicators. Or expand the scope of cities through the integrated development of urban agglomerations or metropolitan areas, and use the scale of urban agglomerations or metropolitan areas to expand market space. Peripheral cities in metropolitan areas have the greatest potential and focus for enhancing their carrying capacity. In the future, apart from adjusting administrative divisions, they can also integrate the economy of metropolitan areas or urban agglomerations for integrated development, which can also promote the development of peripheral cities in metropolitan areas.

Promote green development and build a livable environment for ecological city clusters. Ecological environment is the key element and bottom line of comprehensive carrying capacity. How to achieve a win-win situation for ecology and economy, first, adjust the industrial structure and energy structure, develop green industries and use new energy, reduce energy consumption, and reduce environmental pollution. Strengthen the protection of the common ecological space, strengthen the coordinated treatment of environmental pollution such as water, gas, and soil, comprehensively treat the ecosystem of large rivers and lakes, and improve the ecological benefits and environmental carrying capacity of central cities and urban agglomerations. Determine the development goals and scale of the city based on the carrying capacity of resources and environment, delineate ecological red lines, avoid the development of urban pie, and reduce the number of healthy urban garden cities. Improve the ecological and environmental protection legal system, and improve the ecological compensation mechanism and environmental compensation mechanism.

3.2 Improve urban resilience with pan-smart city technology

Use pan-smart city technology to obtain public data. Public data acquisition is the first step in rapid and intelligent decision-making and coordinated prevention and control of urban vulnerability emergencies. Information channels and data acquisition sources mainly include urban IoT systems, communication networks and online information. When urban vulnerability events occur, the use of big data technology can realize the identification and supervision of risk areas and specific groups of people, fully clarify the flow of various types of people, and provide a large amount of data support and early warning and decision-making for the coordinated prevention and control of emergencies; In the communication network, the biological signs and infrared data recorded by the RFID sensor, the user's comprehensive life, work, entertainment and usage habits information stored by the wireless smart phone, and the voice, text, image, and video information recorded by the base station communication system are all Precise prevention and control and the coordinated prevention and control of various functional departments provide effective support; online public opinion information and Internet browsing records on the Internet can effectively reflect the media and people's public opinion, and can eliminate rumors and guide through timely and effective data information management and guidance. Avoid panic, carry out active information dissemination at the same time, and strengthen coordination in all aspects.

Use pan-smart city technology for data interaction and intelligent decision-making. There are many problems and difficulties in urban resource management, such as the personal user privacy and security needs of ordinary people, the

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security of business management confidential data of enterprises and institutions, and the security of confidential information of national government agencies. The distributed storage technology and consensus mechanism of the blockchain can provide reasonable and effective solutions to the above problems, and "upload" public decisions such as management and emergency to the blockchain, and arrange corresponding credit incentives, honor incentives, and material incentives In accordance with the constraints of laws and regulations, the use of artificial intelligence technology for in-depth mining of big data. On the basis of blockchain-based collaborative prevention and control, we propose a public chain for ordinary people, alliance chains for national government agencies and enterprises and institutions, and blockchain network scenarios for private chains for confidential systems. At the same time, the national policy guidelines Under the supervision of relevant supervisory agencies, formulate effective incentive mechanisms and relevant laws and regulations to promote data interaction and intelligent decision-making capabilities, and realize the efficient, safe, intelligent, reliable and authoritative of large-scale accident prevention and control of big data Reliable processing level.

Build an intelligent platform around the lifeline of the city. The urban emergency information platform is the neural network and nerve center of the emergency management system. It plays an important role in cross-departmental emergency data management, information sharing, business collaboration and comprehensive services. It is to improve the information, scientific, intelligent and integrated service of urban public crisis management. An important means of synergy. The urban emergency information platform is an open and complex giant system. Its construction is a complex social project involving many factors and problems. It is necessary to use cloud computing technology to further improve the basic structure and functions of the platform itself, and it also needs to learn from the information resource system., Emergency data standards, data technology applications, and talent team construction are fully prepared for the construction of emergency information platforms.

4. Conclusions

Combining the relevant index data of the research cities, and using the urban system vulnerability evaluation index model, we calculate the 2018 Beijing-Tianjin-Hebei urban agglomeration, the Yangtze River Delta urban agglomeration and the Guangdong-Hong Kong-Macao Greater Bay Area to obtain the vulnerability of each city in 2018 Sex index. The results show that the central cities and economically underdeveloped cities of the three major urban agglomerations are relatively vulnerable areas in the urban agglomerations, and are areas with low sensitivity and high response. According to the clustering results, the vulnerability of the urban system can be divided into four levels. In the Guangdong-Hong Kong-Macao Greater Bay Area, Guangzhou is a very vulnerable area, and Shenzhen is a vulnerable area. Among the city clusters in the Yangtze River Delta, Shanghai and Suzhou are vulnerable areas; Hangzhou and Nanjing are vulnerable areas. In the Beijing-Tianjin-Hebei urban agglomeration, Beijing is a very vulnerable area, and Tianjin and Tangshan are low-vulnerability areas. The vulnerability structure of the central cities of China's three major urban agglomerations is obvious. Their economic development is in a leading position in urban agglomerations and countries. From the perspective of urban infrastructure, cities have a strong ability to deal with vulnerabilities. To this end, this paper proposes measures to respond to climate-adaptive large urban agglomerations in terms of enhancing the carrying capacity of central cities and strengthening the application of pan-smart city technologies.

5. Discussion

This chapter is to use spatial data to comprehensively evaluate and analyze the vulnerability of major megalopolise, and to realize visualization in the map, which better reflects the distribution law of urban vulnerability, and proposes a response to urban vulnerability. In this chapter, the three megalopolise vulnerability show that the more developed the urban economy, the higher the vulnerability index. This is an interesting and very thought-provoking discovery. We think this research is valuable because we have seen the urban vulnerability in the most economically developed regions of China, where the core cities are connected to other cities by elements, industries and infrastructure. And the results show that the more developed the city is, the higher the vulnerability will be. Therefore, in the medium and long term development of China in the future, how to overcome the vulnerability and continuously enhance the resilience of megalopolise should be further put forward countermeasures. In fact, as infrastructure integration and city-to-city connectivity grow, so does vulnerability. From the perspectives of government, industrial layout, elements flow, wage and welfare, etc., it is also a question that needs further thinking about how to deal with the increasing risks in the future megalopolise in the form of layout, industrial (employment) structure and welfare growth.

Due to the limitation of data access, some descriptive indicators of urban vulnerability have not been introduced into the evaluation system, which limits the research conclusions. In the follow-up, multi-source heterogeneous data should be collected to strive for more accurate and comprehensive evaluation results.

The follow-up research needs to use regional climate simulation or statistical downscaling methods to predict regional climate change, and comprehensive simulation results provide suggestions for each city group.

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