Environment, Resource and Ecology Journal (2023)
Clausius Scientific Press, Canada
DOI: 10.23977/erej.2023.070402
ISSN 2616-3756 Vol. 7 Num. 4

Assessment of Urban Adaptability to Climate Change in the Pearl River Delta Based on the PSR Model

Yingyi Shi[1], Wenting Ye[1,2], Yueying Zhou[1,*]

[1]*School of Resources and Planning, Guangzhou Xinhua University, Guangzhou, 510520, China*
[2]*Tuolian Subdistrict Office in Jinping District, Shantou, 515021, China*
[*]*Corresponding author*

Keywords: Adaptability to climate change, climate resilient city, the Pearl River Dalta, PSR model

Abstract: This study used the nine cities in the Pearl River Delta as research objects, established an assessment indicator system based on the PSR model, and assessed the climate change adaptability of these cities from 2000 to 2020 using the multi-level grey correlation analysis method. The climate change adaptability of these cities was classified into three levels: Level I, Level II, and Level III, representing the low, medium, and high levels, respectively. From 2000 to 2020, the comprehensive climate change adaptability of the nine cities was at Level II, and has steadily improved due to investments in economic development, technological support, and risk management. Notably, cities with high-level adaptabilities at Level III include Guangzhou, Shenzhen, Zhuhai, and Foshan, whereas cities with medium-level adaptabilities at Level II include Huizhou, Dongguan, and Jiangmen. In contrast, cities with low-level adaptabilities at Level I include Zhaoqing and Zhongshan. Further, it is important to note that significant spatial differences exist in the adaptabilities of these cities, with the greatest disparities found in social development, technological support, and risk management. Finally, based on the various city levels, suggestions for constructing climate resilient cities are presented.

1. Introduction

Since the entering of the 21st century, global climate change has led to an increase in extreme weather events, which have significantly impacted the world. In June 2010, the United Nations International Strategy for Disaster Reduction (UNISDR) initiated the first “International Conference on Cities and Climate Change Adaptation” in Bonn, Germany, proposing the establishment of “resilient city”. In the following year, 35 mayors from five continents issued the *Bonn Declaration* at the “Mayors Adaptation Forum” of the second conference, urging city managers to promote local climate change adaptation and disaster risk reduction from the bottom up, enhance the adaptation and climate resilience of cities and communities, and integrate climate change adaptation into urban planning and development projects [1].

Currently, research in China on climate resilient cities is mainly focused on two aspects. Firstly, the assessment of urban climate change adaptabilities, such as the multidimensional analysis of climate change adaptability across 258 cities in China by Pei Xiaodong et al., who focused on the impacts of high temperature, low temperature, drought, and floods, utilizing spatial autocorrelation analysis and obstacle models [2]. Additionally, Zhao Chunli et al. proposed a framework for evaluating the adaptability of 286 prefectural-level cities in China, based on exposure-resilience-sensitivity analysis, using set pair analysis method [3]. Furthermore, Xie Xinlu, Cui Yan, Liu Xiafei and others assessed the climate change adaptabilities of regions and cities, such as Beijing, Chaoyang, and the western region [4-6]. Secondly, research on urban planning strategies that adapt to climate change, such as Feng Xiaoya and Zhou Quan introducing experiences in foreign countries that have planned for and adapted to climate change [7-8]. Likewise, Hong Liangping, Hua Xiang et al. proposed the "3A" method (Assessment-Application-Appraisal) for urban planning, aimed at adapting climate change, and systematically built a technical framework and critical technologies for urban planning that focuses on climate adaptation [9]. In addition, Wang Kai et al. presented a fusion strategy for adapting to climate change within the national spatial planning hierarchy in China by combining technological methods, spatial governance, and work systems from three dimensions [10].

According to the research of the IPCC (Intergovernmental Panel on Climate Change) on the vulnerable regions to global climate change, the areas most vulnerable to climate change are those located in coastal areas and river plains, regions highly connected with climate-sensitive economic resources, and areas susceptible to extreme weather events, especially those that experience rapid urbanization [11]. The Pearl River Delta region is such a climate change vulnerable region, as it has an amalgamation of several sensitive factors. Given the high population density and the evident interaction between climate change and human activities in this area, it is crucial to strengthen the adaptability of cities to climate change. This study assesses the climate adaptability of nine cities in the Pearl River Delta region from six dimensions: resource endowment, urban population, economic level, social development, technological support, and risk management. The results of this assessment can provide a valuable reference for developing scientific strategies to help these cities adapt to climate change.

2. Data and Methods

2.1. Assessment Model of Urban Adaptability to Climate Change

2.1.1. Establishment of Indicator System

Based on the climate vulnerability and risk factors present in the Pearl River Delta region, and guided by the Environmental Indicator Model's "Pressure-State-Response" (PSR) framework, this study identified three criteria layers, six elemental layers, and twenty-three indicator layers for the assessment of urban climate adaptability, while taking into account the principles of indicator accessibility, quantifiability, and representativeness.

Of the twenty-three indicators identified, nineteen are positively correlated with climate change adaptability, while the remaining four - namely, annual average temperature, population natural growth rate, population density, and water consumption per 10,000 yuan of GDP - are negatively related to the same metric, indicating reduced adaptability when their values are higher.

2.1.2. Indicator Weight Assignment

This study employed a combination of the analytic hierarchy process (AHP) and expert scoring method. Based on the scores given by multiple experts and calculated using the weight average method, the final weight values of the indicators were obtained (Table 1).

Table 1: The assessment indicator system of urban adaptability to climate change

Criteria layer (A)	Elemental layer (B)	Indicator layer (C)		Weight	Direction
Pressure index (A1=0.384)	Resource endowment (B1=0.308)	C1	Green coverage rate in built-up areas (%)	0.073	+
		C2	Per capital area of parks and green land (m^2)	0.058	+
		C3	Air quality compliance rate (%)	0.067	+
		C4	Annual average precipitation (mm)	0.069	+
		C5	Annual average temperature (℃)	0.041	-
	Urban population (B2=0.076)	C6	Population natural growth rate (‰)	0.031	-
		C7	Population density (person/km^2)	0.045	-
State index (A2=0.294)	Economic level (B3=0.144)	C8	Per capita gross domestic product (10000 yuan)	0.044	+
		C9	Per capita disposable income (yuan)	0.053	+
		C10	Gross domestic product (100 million yuan)	0.047	+
	Social development (B4=0.15)	C11	Proportion of health care expenditure (%)	0.039	+
		C12	Number of beds in health institutions per 10000 population (bed)	0.039	+
		C13	Number of physicians per 10000 population (person)	0.033	+
		C14	Per capita urban road and street land area (m^2)	0.039	+
Response index (A3=0.322)	Technological support (B5=0.163)	C15	Rate of municipal sewage disposal (%)	0.033	+
		C16	Per capita water storage capacity (m^3)	0.036	+
		C17	Rate of harmless disposal of urban domestic (%)	0.032	+
		C18	Water consumption per 10000 yuan of GDP (m^3/10000 yuan)	0.036	-
		C19	Comprehensive utilization rate of general industrial solid wastes (%)	0.026	+
	Risk management (B6=0.159)	C20	Number of comprehensive disaster reduction demonstration community per 10000 population (unit)	0.043	+
		C21	Drainage pipeline density in built-up areas (km/km^2)	0.053	+
		C22	Number of fully employed staff and workers in management of water conservancy, environment and public facilities (person)	0.026	+
		C23	Number of centers for disease control and prevention (unit)	0.037	+

2.2. Data Sources

The study focused on nine cities in the Pearl River Delta region, with population, economic, social, environmental, energy, and urban construction-related indicator data mostly derived from the *Guangdong Statistical Yearbook* between 2001 and 2021. Other sources of data included the statistical yearbooks and reports, the urban construction status reports, the environmental quality status reports, and the water resources reports of each city. The number of comprehensive disaster reduction demonstration community was obtained from the official website of the Ministry of Emergency Management of the People's Republic of China.

In order to reflect the dynamic changes in urban adaptability to climate change over the past two decades, data from every two years between 2000 and 2020 were selected, taking into account data availability. To ensure the consistency of this study, some relative indicator values were transformed using absolute indicators, which did not affect the comprehensive assessment results.

2.3. Multi-level Grey Correlation Analysis Method

Assessment of urban adaptability to climate change is based on various aspects such as social, natural, and economic factors that arise from urban responses to climate change, which can cause subjective biases and errors in the assessment process, resulting in the introduction of grey areas of uncertainty. Therefore, in order to address the errors inherent in the assessment process, this study employed a multi-level grey correlation analysis method.

The multi-level grey correlation analysis method measures the degree of similarity or dissimilarity in the development trends among various factors to determine the level of correlation between them. Essentially, it compares the geometric shape of the curve formed by several data series with that of the ideal (standard) data series. The correlation reflects the order in which each evaluation object approaches the ideal (standard), and the higher the correlation, the stronger the adaptability. The evaluation object with the highest grey correlation is considered to be in the best state [12]. The analysis steps are as follows:

Step 1: Establish the optimal indicator set (F^*):

$$F^* = [j_1^*,\ j_2^*,\ \cdots,\ j_n^*] \tag{1}$$

Where, j_k^* (k=1,2,3, ..., n) is the optimal value of the k-th indicator.

Step 2: Define the compared sequence in the correlation analysis as D:

$$D = \left[j_1^i,\ j_2^i,\ \cdots,\ j_n^i\right] \tag{2}$$

Where, j_k^i is the original numerical value of the k-th indicator in the i-th assessment object.

Step 3: Normalize the indicators. Since the selected data are not on the same order of magnitude or dimension, they need to be dimensionless so that subsequent calculations and analysis can be made.

For positive indicators:

$$c_k^i = \frac{j_k^i - j_{k1}}{j_{k2} - j_{k1}} \tag{3}$$

For negative indicators:

$$c_k^i = \frac{j_{k2} - j_k^i}{j_{k2} - j_{k1}} \tag{4}$$

Where j_{k1} and j_{k2} are the minimum and maximum values of the k-th indicator among all assessment objects. The standardized comparison sequence is denoted as: $c = \left[c_1^i, c_2^i, \cdots, c_n^i\right]$. The standardized optimal values of each city from 2000 to 2020 are taken as the reference sequence, denoted as: $c^* = [c_1^*, c_2^*, \cdots, c_n^*]$.

Step 4: Calculate the correlation coefficient:

$$\varepsilon_i(k) = \frac{min_i\, min_k\left|c_k^* - c_k^i\right| + \rho\, max_i\, max_k\left|c_k^* - c_k^i\right|}{\left|c_k^* - c_k^i\right| + \rho\, max_i\, max_k\left|c_k^* - c_k^i\right|} \tag{5}$$

Where, $\varepsilon_i(k)$ is the correlation coefficient of the i-th assessment object on the k-th indicator, and ρ is the resolution coefficient, $\rho \in [0, 1]$, which is used to reduce the impact of extreme values on the calculation, and is generally set to $\rho \leq 0.5$.

Step 5: Calculate the correlation degree R_i. If the weight coefficient of the k-th assessment indicator is $W(k)$, $\sum_1^n W(k) = 1$, then:

$$R_i = \sum_{k=1}^{n} W(k) \times \varepsilon_i(k) \tag{6}$$

The higher the correlation degree R_i, the stronger the adaptability of the i-th assessment object. The maximum value (positive indicator) or minimum value (negative indicator) of indicators in 9 cities from 2000 to 2020 were taken as the optimal sets, and the resolution coefficient ρ was set to 0.5.

3. Results and Analysis

3.1. Assessment Results of Climate Change Adaptability for Each City

In this study, the assessment results of the climate change adaptability were classified into three levels: Level I with low adaptability ($R_i \in [0, 0.510)$), Level II with medium adaptability ($R_i \in [0.510, 0.590)$), and Level III with high adaptability ($R_i \in [0.590, 1)$). A higher level indicates that the city has a higher correlation in its adaptability to climate change, and therefore has a stronger adaptability.

Upon analysis of the comprehensive correlation degree results and the annual trend, it is discovered that the climate change adaptability of cities located in the Pearl River Delta has undergone a continuous strengthening process over the span of 20 years. Among them, Guangzhou, Zhuhai, Foshan, and Shenzhen exhibit significantly higher adaptabilities when compared to other cities, categorizing them under Level III with high adaptability and displaying an overall increasing trend in their adaptabilities. In contrast, the adaptabilities of Jiangmen, Huizhou, and Dongguan are more moderate, locating them under Level II with medium adaptability, experiencing some instability in annual trends while maintaining a certain degree of equilibrium. On the other hand, the adaptabilities of cities such as Zhaoqing and Zhongshan are the lowest, categorizing them under Level I with low adaptability, and showing evidence of a consistent level of stationary adaptability (as presented in Table 2 and Figure 1).

3.2. Assessment Results of Climate Change Adaptability in Different Dimensions

3.2.1. Dimension of Resource Endowment

There exist significant differences in the resource endowment dimension across various cities, with Shenzhen and Dongguan ranking higher than their counterparts. Shenzhen’s construction of parks and green land has created a certain degree of value for its natural resource endowment, maintaining a balance between human beings and nature in a harmonious coexistence. In contrast, Guangzhou’s lower air quality compliance rate has emerged as a critical factor constraining its resource endowment dimension's correlation degree (Figure 2).

Table 2: The correlation degree values of urban adaptability to climate change in the PRD

City / Year	Guangzhou	Shenzhen	Zhuhai	Foshan	Dongguan	Huizhou	Zhaoqing	Zhongshan	Jiangmen
2000	0.636	0.657	0.595	0.582	0.445	0.557	0.506	0.454	0.560
2002	0.632	0.566	0.639	0.630	0.480	0.546	0.513	0.490	0.563
2004	0.602	0.570	0.587	0.601	0.515	0.526	0.536	0.518	0.539
2006	0.612	0.583	0.560	0.594	0.512	0.564	0.493	0.462	0.500
2008	0.645	0.642	0.619	0.605	0.534	0.560	0.496	0.496	0.502
2010	0.674	0.557	0.616	0.606	0.545	0.538	0.469	0.508	0.569
2012	0.644	0.597	0.625	0.587	0.513	0.537	0.475	0.476	0.571
2014	0.645	0.590	0.639	0.613	0.510	0.573	0.502	0.459	0.487
2016	0.600	0.610	0.640	0.555	0.578	0.530	0.506	0.513	0.477
2018	0.621	0.595	0.594	0.574	0.551	0.553	0.545	0.504	0.569
2020	0.721	0.589	0.642	0.593	0.501	0.529	0.566	0.419	0.583
Comprehensive adaptability	0.639	0.596	0.614	0.595	0.517	0.547	0.509	0.482	0.538

3.2.2. Dimension of Urban Population

The cities ranking high in the urban population dimension are Zhaoqing, Huizhou, and Jiangmen, while those ranking lower are Shenzhen, Dongguan, and Zhongshan. The reason behind this lies in the fact that population density serves as a negative indicator, and the industrial attractiveness of Shenzhen and Dongguan has resulted in an influx of external labor force, thereby leading to higher population density. In contrast, the relatively weaker economic conditions of Zhaoqing, Huizhou, and Jiangmen have spurred a considerable outflow of labor force, thereby mitigating the current state of population pressure in these cities to some extent (Figure 3).

3.2.3. Dimension of Economic Level

Coping with the disasters caused by climate change necessitates a certain level of economic. The 9 cities in the Pearl River Delta exhibit temporal and spatial unevenness in terms of their economic level, with Shenzhen and Guangzhou providing strong basic support for adapting to climate change due to their advanced economic development. However, the weaker economic foundations of Huizhou, Zhaoqing, and Jiangmen have resulted in the lowest correlation degree of their adaptability to climate change (Figure 4).

3.2.4. Dimension of Social Development

The cities with the highest correlation degree in the social development dimension are Guangzhou and Jiangmen, while those with the lowest correlation degree are Shenzhen, Dongguan, and Zhongshan. Guangzhou’s sound social medical system has enhanced its adaptability to climate change, with the most notable indicators being the number of beds and physicians per 10000 population. Although Jiangmen has fewer beds and physicians than other cities, its lower population has increased per capita resources. In contrast, despite having the highest economic level, Shenzhen’s proportion of health care expenditure is relatively low, leading to a severe shortage of medical and health care resources per 10000 population (Figure. 5).

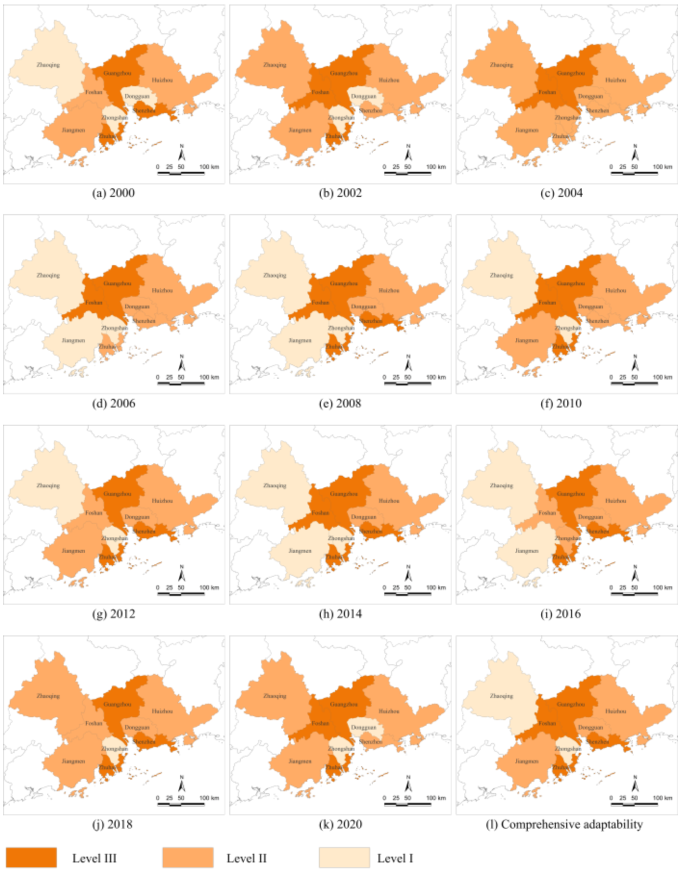

Figure 1: The correlation degree levels of urban adaptability to climate change in the PRD

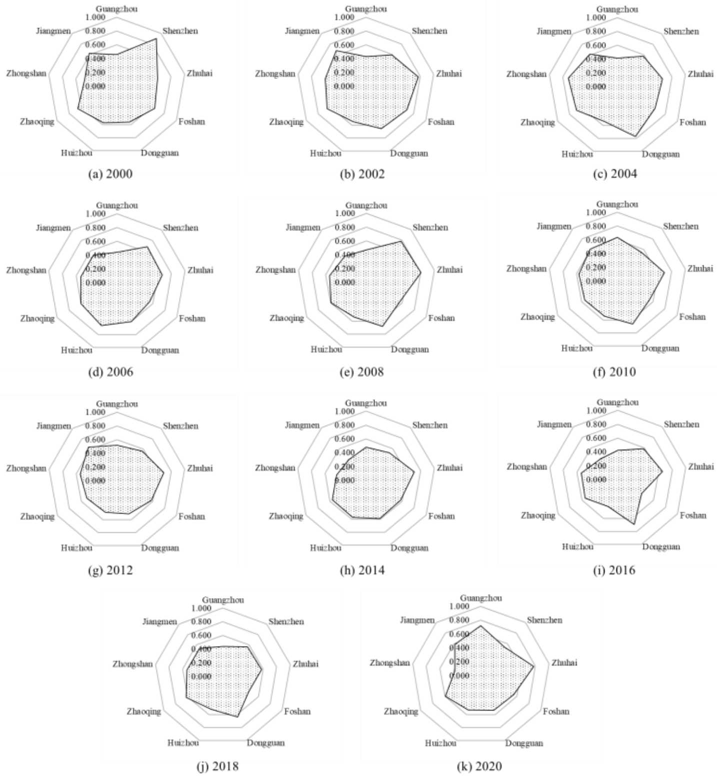

Figure 2: The correlation degree on resource endowment dimension of 9 cities in the PRD

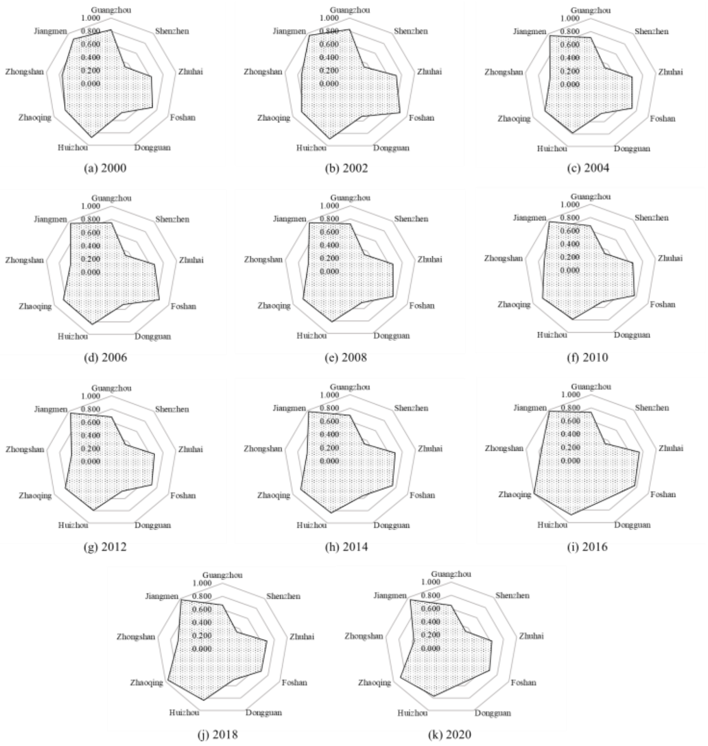

Figure 3: The correlation degree on urban population dimension of 9 cities in the PRD

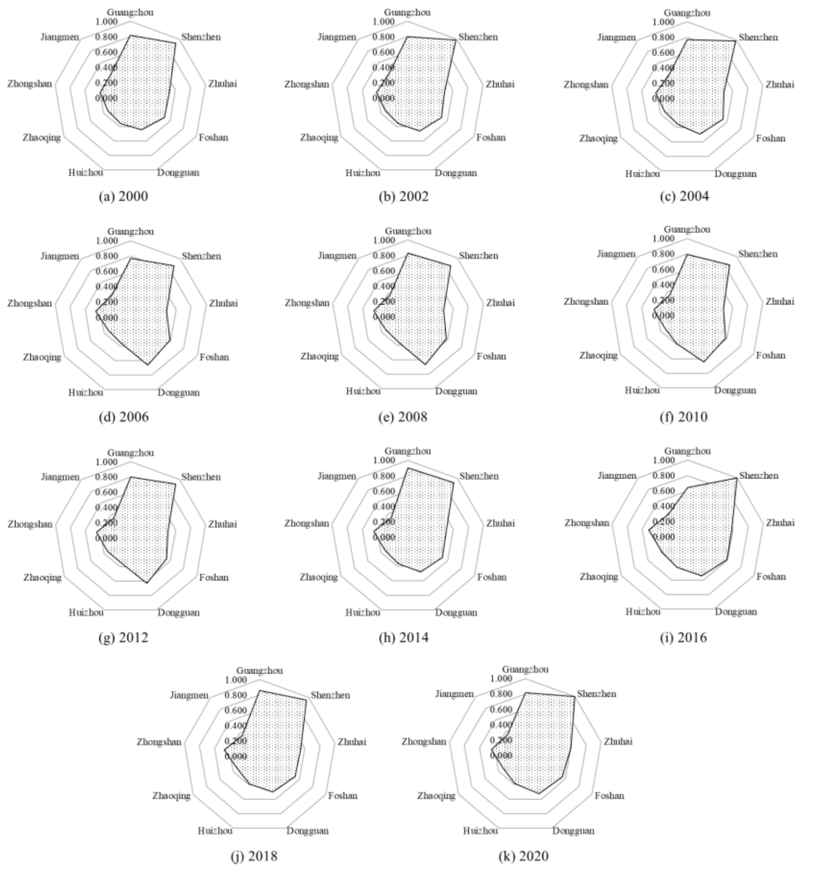

Figure 4: The correlation degree on economic level dimension of 9 cities in the PRD

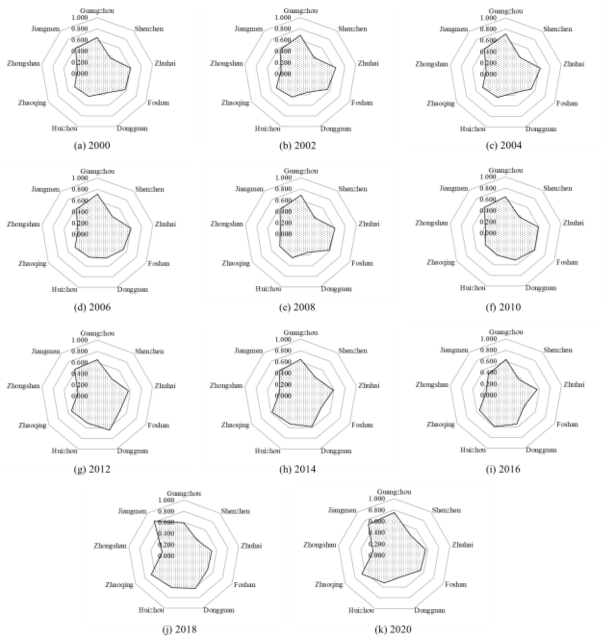

Figure 5: The correlation degree on social development dimension of 9 cities in the PRD

3.2.5. Dimension of Technological Support

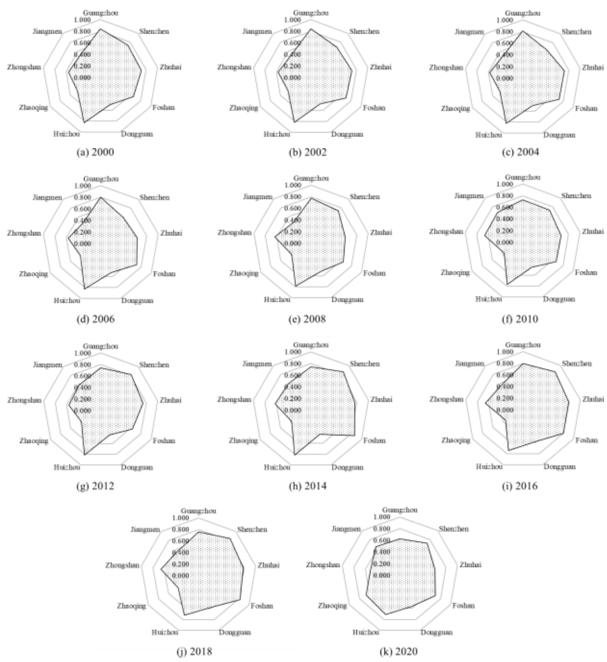

Figure 6: The correlation degree on technological support dimension of 9 cities in the PRD

Guangzhou, Zhuhai, Foshan, and Huizhou are four cities with relatively high technological adaptabilities. They have achieved good results in water and energy conservation as well as in the circular use of resources and energy, providing strong support for reducing greenhouse gas emissions. However, the weaker per capita water storage capacity in Zhaoqing and Dongguan, as well as the lower comprehensive utilization rate of industrial solid wastes, have resulted in their lower ranking in the technological support dimension. Overall, the differences in technological adaptabilities among various cities are still considerable (Figure. 6).

3.2.6. Dimension of Risk Management

Foshan ranks high in the risk management dimension, which is related to its emphasis on increasing the drainage pipeline density in built-up areas, effectively preventing losses caused by meteorological disasters such as storm surges and urban waterlogging. The correlation degree of the risk management dimension in Shenzhen, Huizhou, Zhaoqing, and Zhongshan is relatively low, mainly due to the lack of comprehensive disaster reduction demonstration communities (Figure. 7).

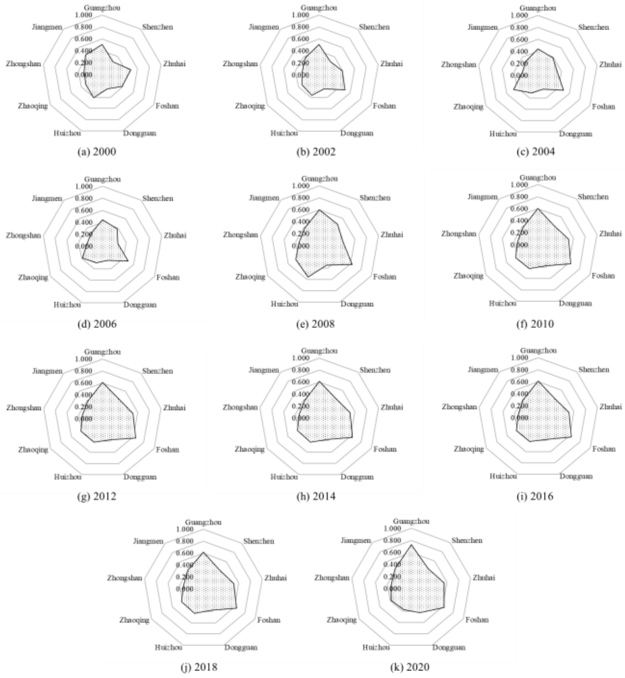

Figure 7: The correlation degree on risk management dimension of 9 cities in the PRD

4. Conclusions and Suggestions

4.1. Conclusions

Therefore, the following conclusions can be drawn:

(1) The comprehensive adaptability to climate change in the Pearl River Delta region is at a medium level of level II.

(2) Between 2000 and 2020, with the investment in economic development, technological support and risk management, the comprehensive adaptability to climate change of the 9 cities has improved to some extent.

(3) Based on the low, medium, and high levels of adaptability, they are classified into level I, II, and III, with level III representing high levels including Guangzhou, Shenzhen, Zhuhai, and Foshan, level II representing medium levels including Huizhou, Dongguan and Jiangmen, and level I representing low levels including Zhaoqing and Zhongshan. Guangzhou has the highest adaptability, while Zhongshan has the lowest.

(4) There are significant spatial differences in the adaptability of the 9 cities, with the most significant differences being in the dimensions of social development, technological support, and risk management.

(5) There is a certain degree of complementarity among the various cities in terms of resource endowment, economic level, social development, technological support, urban population, and risk management dimensions.

4.2. Suggestions on the Construction of Climate Resilient Cities in the Pearl River Delta Region

Due to different positioning and development capabilities, various cities face common but differentiated climate risks. Therefore, different construction strategies should be adopted in the construction of climate-adaptive cities.

(1) Level III high-level cities: While they have overall commendable climate change adaptabilities, ecological resources and economic and social development are uneven in some instances. Therefore, a scientific and rational approach must be taken with respect to territorial space planning, reinforced protection and judicious utilization of natural resources, intensified urban greening, and development of an environmentally sustainable society.

(2) Level II medium-level cities: Although the risk pressure has decreased, these cities still face challenges in terms of inadequate responses and underdevelopment against climate risks. It is necessary to promote industrial transformation and structural upgrading, improve the ecological functions of natural resources within urban areas, and enhance the city's capacity to manage meteorological disasters.

(3) Level I low-level cities: Currently, they face relatively lower climate change adaptabilities, and strive for comprehensive economic and social development. Raising the level of technological support for meteorological warning, health care, disaster prevention and reduction, disease prevention and control, and other relevant sectors must be promoted. This will help them to tackle and mitigate the negative impacts arising from climate change.

Acknowledgement

This study was supported by the Scientific Research Project approved by the Department of Education of Guangdong Province (No. 2020KQNCX125) and the Scientific Research Foundation of Guangzhou Xinhua University (No. 2019KYZD04, No. 2019KYYB08).

References

[1] Zheng Y. Resilient City: Mainstreaming Climate Risk Management and Adaptation to Climate Change into Urban Planning. Urban Development Studies, 2012, 19 (1): 47-51. (In Chinese)

[2] Pei X. D., Wu J., Xue J. B., Zhao J. C., Liu C. X., Tian Y. Assessment on Cities' Adaptation to Climate Change in China. Urban Development Studies, 2022, 29 (03): 39-46+52+2. (In Chinese)

[3] Zhao C. L., Yan Y., Lu Y. Q., Ding D., Song Y., Wu G. "Exposure-resilience-sensitivity" based evaluation and characteristics analysis of the capacity for urban adaptation to climate change in China. Acta Ecologica Sinica, 2018, 38 (09): 3238-3247. (In Chinese)

[4] Xie X. L., Zheng Y. Assessment Indicators for Measuring Climate Resilient City: A Case Study of Beijing. Urban and Environmental Studies, 2016 (04): 50-66. (In Chinese)

[5] Cui Y., Ao X., Zhou X. Y., Wang T., Lin R., Zhao C. Y., Liu M. Y., Yi X. Assessment of urban comprehensive adaptability to climate change: a case study of Chaoyang. Journal of Meteorology and Environment, 2020, 36 (06): 122-129. (In Chinese)

[6] Liu X. F., Qu J. S., Liu L. N., Li H. J., Pei H. J., Zeng J. J. Research on the Assessment of Urban Climate Change Adaptation Capability in Western China. Ecological Economy, 2019, 35 (04): 104-110. (In Chinese)

[7] Feng X. Y., Li H. M., Yang X. International Experience of Climate Change Adaption Actions at City Level and Its Implications. Ecological Economy, 2016, 32 (11): 120-124+135. (In Chinese)

[8] Zhou Q., Chen Y., Kang J. J., Jin M. Y. The Study of Urban Planning Adaptation to Climate Change in the Foreign City and Its Implications for China. Chinese & Overseas Architecture, 2016 (07): 73-75. (In Chinese)

[9] Hong L. P., Hua X. Urban planning for climate change. China Architecture & Building Press, 2015: 56-78. (In Chinese)

[10] Wang K., Jiang G. X., Luo Y., Bing Q. L. Territorial Space Planning Response to Climate Change. Planners, 2023, 39 (02): 5-10. (In Chinese)

[11] IPCC. Climate Change 2001. Cambridge University Press, 2001: 3.

[12] Du D., Wu Y. From "Combination Evaluation" to "One-One Integrating" of Evaluation Method. Statistics & Information Forum, 2008 (05): 5-8. (In Chinese)