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Validating the usefulness and calibration of a two-dimensional situation model of urgency-adaptability for cities responding to climate change — Taking Shenzhen as case study

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Abstract. Climate change is a major challenge for human sustainable and urban governance mode. A Two-Dimensional Urgency-Adaptability Situation Model for Cities Responding to Climate Change was constructed in this study to evaluate cities adaptation capacity to climate change. The model evaluated city adaptability in five aspects: social and economic development, disaster response, urban planning adaptation, science and technology and policy management. To verify the effectiveness of the model, Shenzhen was chosen as a case, which had a start in climate change adaptation as a developed coastal city in China. The result shows that Shenzhen should further focus on enhancing its urban planning adaptability in the aspects including green construction, planning and design, as well as city renovation and regeneration. The Urgency-Adaptability Situation Model helps to make policy suggestions aiming at enhancing the climate adaptability of cities.

1. Introduction

Recent studies have highlighted the possible impact caused by large global warming, including the study of climate change-induced disaster models [1,2], climate change impact assessment on agriculture with a focus on grain production [3], impact assessments on industrial structure change, population shift [4] and the environment including impacts on species, landscapes and water resources [5]. Climate change prediction models are used in numerous papers as well (Nordhaus & Boyer 2003), such as climate change models' sensitivity analysis, green-house gas emission targets for limiting global warming to 2 °C [6], probabilistic models to recast for 21st century climate based on uncertainties in emissions and climate parameters [7], modelling and interpreting the economics of catastrophic climate change [8] or climate change impact on nations, cities and regions [9-11].

Climate change adaptation “includes actions undertaken in natural or human systems in response to actual or expected climatic stimuli or their effects in order to reduce harm or exploits benefits” [12]. The long-term objective of adaptation is to construct a climate-smart economy and climate-adaptation society, which is also an important element for urban sustainable development [13,14]. Possible adaptation strategies involve several aspects, including thermal balance, urban greening, roof greening,



flood risk management, sustainable drainage systems, management of water resources, waste and polluted soil and others [15].

Adaptation to climate change has historically received less attention than mitigation [16]. However, for some of the added greenhouse gases (GHGs) will remain in the atmosphere for centuries and some parts of the climate system respond in a gradual manner, awareness that some climate changes are inevitable is growing. Adaptation strategies have been increasingly promoted in the literature and in policies [17-20]. The recent scientific literature has shown a growing interest in assessing climate adaptation plans at the urban level [21]. Studies also increasingly link vulnerability, adaptation, and resilience science for practice: taking into account possible pathways, relevant players, and necessary partnerships [22]; identifying a range of factors, such as scientific uncertainty, the current state of technology, the availability of financial resources and the importance of adequate time horizons [10,23-25].

For urban climate adaptability research in developed countries, qualitative analysis of cause and effect correlation and logical argumentation are usually used and arrive at relevant strategic directions and action measures on climate change adaptation through reviewing the weaknesses or areas with improvement potentials [19] but lack diversity. In less developed countries resources and technical expertise are often limited, thus adaptation measures to protect cities need to be planned and prioritized carefully to reduce vulnerability while simultaneously considering risk reduction and local constraints [26,27]. Though there have been several guidelines for adaptation assessment set up by IPCC, UNDP or UNFCCC, situations vary from case to case. As a significant representative of developing countries, the overall carbon emission of China is considerably high (the highest in the world according to the World Bank) and China also expects and already experiences a severe influence of global climate change on its population. China's economic growth rate (2015: 6.4%) is still high but slowing down compared to previous years, which means the transformation of economic structure is urgently needed. Thus it is necessary to set up a climate change adaptability evaluation system tailored to Chinese conditions. In recent years, some Chinese cities gradually started to conduct research on the evaluation of climate change adaptation in cities such as Shanghai, Dalian and Xianyang. These studies mainly make use of development coupling models and conduct relatively comprehensive and deep analysis of urban climate change and relevant adaptabilities from the perspective of historical development [28-30]. However, such models usually take only the change in temperature as indicator for climate change and lack risk summarization and evaluation which take into account characteristics of urban climate. Thus, measuring the coupling adaptation relations between urban development and the process rate of climate change cannot comprehensively reflect the adaptability to climate risks at the existing development level [31].

Available studies using IPCC climate risk indicators, due to the asymmetry in the indicator data, remain mostly at the macro and semi-qualitative analysis levels and are mostly at the level of countries. Thus this study constructs a Two-dimensional Model of Urgency-adaptability for Responding to Climate Change at the city level to evaluate the city's capacity to adapt to climate change. This paper selects Shenzhen as a case study for the model, since it has witnessed more pronounced effects of climate change as a developed coastal city of China, and has already started some government response measures in terms of climate risk adaptation. Based on the evaluation model results, policy measures and technology paths to improve the capacity to climate change adaptation are discussed.

2. Study area

2.1. Background

We selected Shenzhen as the case study for thorough research, for some success has been achieved through its early start on climate adaptation and mitigation practice. Shenzhen is the first special economic zone and is one of the four first-tier cities in China, which is located on the southern coast of China in the south of Guangdong Province (Figure 1). It is located between 113°46'E and 114°37'E longitude and between 22°27'N and 22°52'N latitude, with a subtropical, oceanic climate, deeply

influenced by monsoon. It is a region prone to weather disasters. Drought, cold wave, extreme heat, thunderstorm, torrential rain and typhoon occur from time to time. Its prevailing wind direction throughout the year is southeast by east and its average annual temperature is 22.4°C. In summer, the southeaster prevails and it is hot and humid due to the influence of the subtropical high. In other seasons, the northeaster prevails and it is warm and dry. It has rich precipitation throughout the year, but the precipitation is unevenly distributed within a year. Its annual precipitation is around 2,000 mm which mainly concentrates in the rainy season from April to September. In autumn and winter, it is usually dry with little rain. At present, the city does not have the ability to protect itself under the influence of a series of destructive factors caused by climate change. At the end of 2015, the permanent population of the whole city was 11.4 million, the local GDP for the whole year was RMB 1750.3 billion and the per capita GDP was renminbi (RMB) 158,000. As a huge, developed coastal city, Shenzhen urgently needs to evaluate its adaptability to climate change and formulate climate change adaptation strategies.

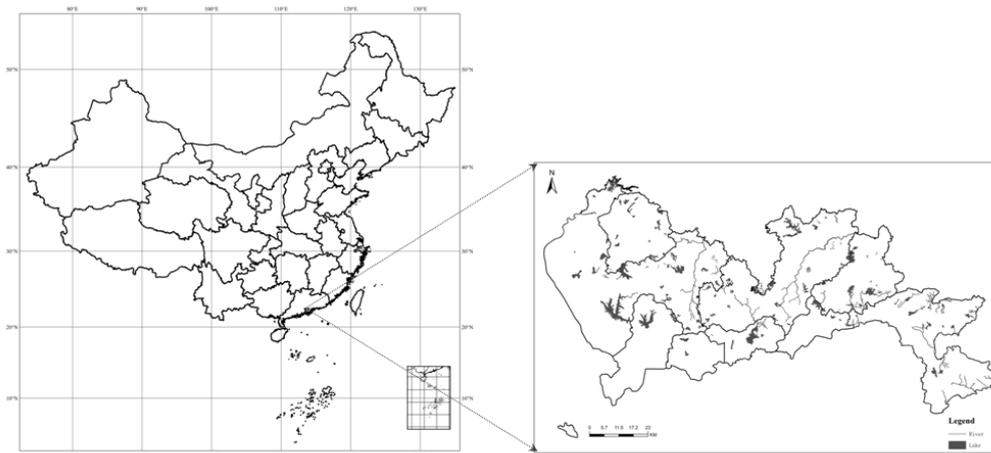


Figure 1. Location of Shenzhen municipality in China.

2.2. Major characteristics for the climate change risk in Shenzhen

Shenzhen is undergoing continuous climate change. Since the 20th century, as is shown in the continuous meteorological monitoring data analysis in the past 50 years, the temperature of Shenzhen has risen by 1.6°C, which is more than twice as high as the temperature rise of the world in the past century (0.74°C). The temperature has risen, the relative humidity has decreased, the atmospheric visibility has dropped, the sunshine duration has gone down and the number of extreme weather events has increased. However, risks resulting in climate change mainly focus on two aspects of impact, including impact on the natural environment and on the urban construction. They mainly include extreme precipitation, meteorological drought, high temperature, warm winter and abrupt changes in temperature, dust-haze and thunder and lightning; impact on the urban construction includes energy utilization, coastal belt construction, water resources, human health and transportation, etc. (Figure 2).

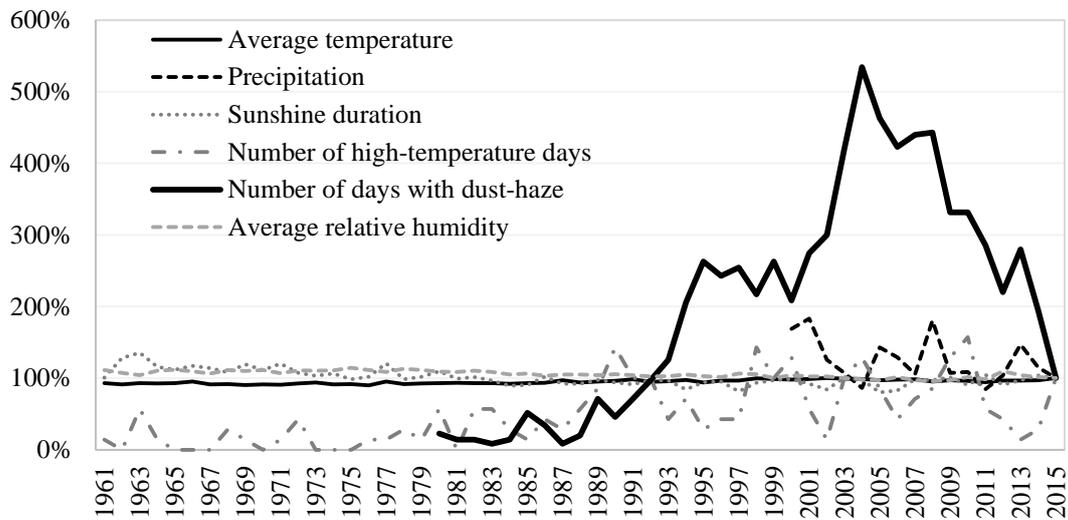


Figure 2. Characteristics for the Climate Change Risks in Shenzhen City in the Past 50 Years. (Note: The value in 2015 is the benchmark (100%))

Note: As for the impact of climate change on Shenzhen City, we mainly consider infrastructure construction, energy utilization, water resource utilization and transportation while putting less emphasis on agriculture and tourism.

3. Research methods and data source

The evaluation of a city’s climate adaptability is suggested to follow steps as shown in Figure 3.

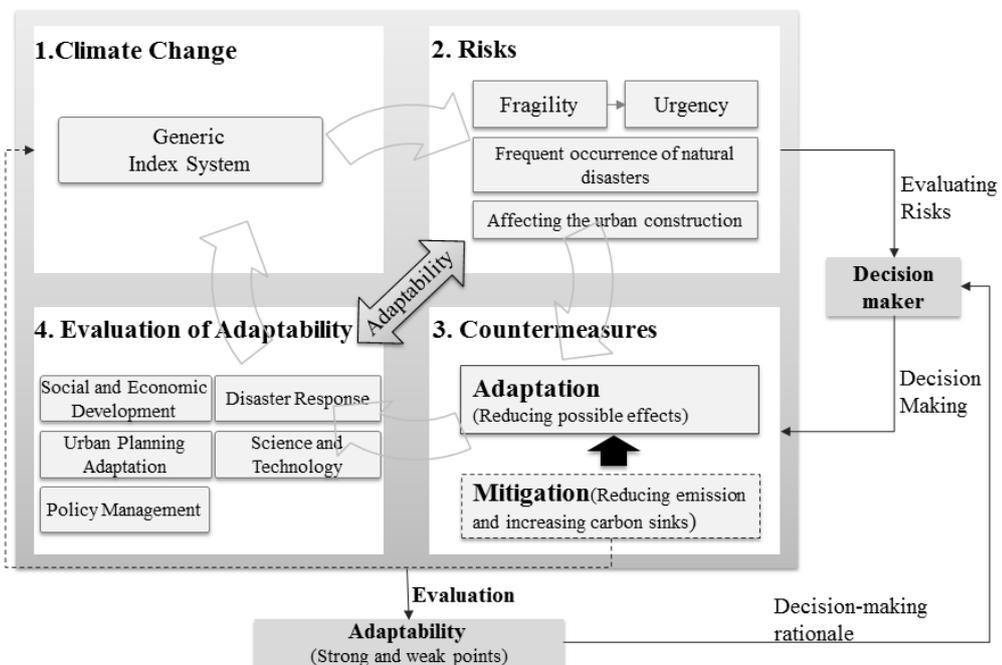


Figure 3. Evaluation Framework for the Adaptability of Climate Change.

3.1. Identifying climate change risks

The direct risks of urban climate change mainly include human thermal stress, crop production, and pressure from water resources, drought, flood, sea level rise and extreme weather. The identification of

a certain city's risk to climate change should be based on its location and characteristics, so that distinctive risks screened by experience and expertise are combined to build the evaluation indicator system (Table 1).

Based on the climate characteristics of the research objects against the background of global warming and their impact on urban construction, six categories of climate risks can be summarized with corresponding indicators including average annual temperature rise (warming risks), total annual precipitation decline (drought risks), increase in the number of days of dust-haze (air quality risks), increase in the number of high-temperature days (extreme temperature risks), increase in the number of heavy precipitation in a short period (waterlogging risks) and increase in the number of typhoon (disaster risks).

Table 1. Climate Change Risk Indicators System for Chinese Cities.

Rule layer	No.	Indicator layer
Temperature	1	Average annual temperature
Precipitation	2	Average annual precipitation
Visibility	3	Number of days with the air quality index above grade II
Disaster, extreme weather	4	Number of high-temperature days
	5	Frequency of heavy precipitation
	6	Frequency of typhoon

Note: The effect of the indicators, positive effect or negative effect, should be considered. The significance of the positive effect (+) is that increasing the indicator value can help reduce the climate change risks; the significance of the negative effect (-) is that increasing the indicator value can exacerbate the climate change risks. Meanwhile, the frequency of typhoon is added as the indicator with regional features based on the characteristics of the urban climate in Shenzhen City.

3.2. Two-dimensional Situation Model of Urgency-adaptability

3.2.1. Climate risk adaptability model. The adaptability comprehensively reflects the strengths and weaknesses of adaptability to different climate change impacts and evaluates the coupling coordination degree between climate change and urban planning in the process of development through building the indicator system and calculating the coupling coordination degree based on the urban climate change and the historical process and future expectation for the building of its adaptability to reflect its present and future potential to climate change of cities.

The urban climate adaptability is mainly reflected in the following five aspects: social and economic development, disaster response, urban planning adaptation, science and technology, and policy analysis & management [14,32] (see Table 2).

- Indicators of social and economic development. They mainly start from the economic characteristics, structure, efficiency and social income levels to measure the material ability and social foundation for adapting to climate change in Shenzhen City and reflect its decision-making and execution ability to adapt to climate change and the supportive attitude and ability of the society and citizens.
- Indicators of disaster response. They mainly start from such factors as the ability for the natural ecosystem to adapt to disasters and human-constructed infrastructure and comprehensively measure the early warning and handle the city's adaptability. Among them, the human factors, which include indicators such as water resource quantity per capita and forest coverage rate (bio-diversity), reflect the short-term response capacity for cities to cope with sudden-onset disasters caused by climate change.
- Indicators of urban planning adaptation. They mainly measure the influence factors of climate change in the urban planning from multiple dimensions such as capital input, energy, resources, transportation, greening and coastline security and from the perspective of urban planning. The

indicators include proportion of investment in environmental protection in GDP (%), energy consumption per unit floor area, water consumption per 10,000 Yuan of output value, proportion of sidewalk area in the area of all roads, per capita public green area and proportion of houses constructed in regions with a high risk of seawater inundation, mainly covering areas of influence on cities by climate change risks and reflecting the long-term adaptability of cities to climate change.

- Indicators of science and technology. They reflect the scientific and technological input and current city level in climate change adaptation. The indicators include proportion of research and development (R&D) expenditure in GDP, new energy output and utilization rate of industrial solid waste.
- Indicators of policy management. They reflect the government competence and execution ability of the city in coping with climate change. The indicators include urban operation and management level, proportion of employees related to climate change, and conducting green and low-carbon advertisement publicity through media or non-media forms.

Table 2. Climate Risk Adaptability Indicators.

Rule layer	No.	Indicator layer	Effect
Social and economic development	1	Per capita GDP	+
	2	Proportion of the tertiary industry	+
	3	Energy consumption per unit of GDP	-
	4	Per capita disposable income	+
	5	Rate of minimum living standard for urban residents	-
Disaster response (man-made or natural)	6	Number of beds per 10,000 people	+
	7	Comprehensive utilization ratio for industrial solid waste	+
	8	Firefighting coverage rate	+
	9	Drainage network density	+
	10	Per capita water resource quantity	+
Urban planning adaptation	11	Qualified rate of drinking water source and biodiversity (forest coverage rate)	+
	12	Proportion of investment in environmental protection in GDP (%)	+
	13	Energy consumption per unit of floor area	-
	14	Water consumption per 10,000 yuan of output value	-
	15	Proportion of sidewalk area in the area of all roads	+
	16	Per capita public green area and per capita refuge area	+
Science and technology	17	Proportion of houses constructed in regions with a high risk of seawater inundation	-
	17	Proportion of R&D expenditure in GDP	+
	18	Whether or not the early warning system has been built/release rate of natural disaster early warning	+
Policy management	19	Clean energy utilization rate, new energy output	+
	20	Urban operation and management level	+
	21	Proportion of employees related to climate change	+
	22	Conducting green and low-carbon advertisement publicity through media or non-media forms	+

(Note:

1. The effect of the indicators, positive effect or negative effect, should be considered. The significance of the positive effect (+) is that increasing the indicator value can help reduce the climate change risks; the significance of the negative effect (-) is that increasing the indicator value can exacerbate the climate change risks.

2. Mutual exclusivity and acceptability of experts is up to 50%.)

The significance of the positive effect (+) and the negative effect (-) are the same as Table 1. The coupling coordination algorithm can be expressed as follows (Liu et al., 2005):

$$D = (C \times T)^\theta \quad (1)$$

$$C = 2 \left(\frac{U_i V_i}{(U_i + V_i)^2} \right)^{\frac{1}{2}} \quad (2)$$

$$T = aU_i + bV_i \quad (3)$$

D is the adaptability (or the coupling adaptability, $D \in [0,1]$), C is the coupling degree, U_i and V_i are adaptability and comprehensive climate risks, T is the harmonized index of adaptability and comprehensive climate risks and θ , a , and b are undetermined parameters. The three parameters are adjusted according to the urbanization level of Shenzhen City in 2004 and the coupling coordination degree of the urban ecological system (Liu, 2005) and general experience and are finally determined as 0.57, 0.5 and 0.5.

Among them,

$$U_i = \sum_{j=1}^m \lambda_{ij} u_{ij} \quad (4)$$

$$V_i = \sum_{j=1}^n \mu_{ij} v_{ij} \quad (5)$$

u_{ij} and v_{ij} are the No. j indicator (after standardization) in the adaptability of the No. i category of climate, m and n are respectively the indicator number for adaptability and climate risks, and λ_{ij} and μ_{ij} are the weights. According to the ideas of experts, $\sum_{j=1}^m \lambda_{ij} = 1$, $\sum_{j=1}^n \mu_{ij} = 1$.

$$u_{ij}, v_{ij} = \begin{cases} \frac{x_{ij} - \beta_{ij}}{\alpha_{ij} - \beta_{ij}}, \text{ positive effect} \\ \frac{\alpha_{ij} - x_{ij}}{\alpha_{ij} - \beta_{ij}}, \text{ negative effect} \end{cases} \quad (6)$$

α_{ij} and β_{ij} are the upper and lower limits for the order parameter on the critical point of the system. The upper limit is usually the planned objective or internationally advanced urban level and the lower limit is usually the level of the base year. The effect of the indicators (positive effect/negative effect is marked +/−) is given based on its contribution to easing climate change risks and adapting to climate change.

3.2.2. Climate risk urgency model. Urgency is the reflection of climate risk in the building of adaptability, showing the urgency of improving the adaptive capacity. A relational matrix is constructed for the correlation between those risks and the climate adaptability building (action process) with the Delphi method based on the evaluation of urgency for different climate risks (action result) in cities by experts who are familiar with the city's climate change or engineering management work [33] to arrive at the urgency to improve adaptability through mapping calculation. Such correlation is reflected in the contribution of adaptability building to ease climate risks, or in other words, the degree of urgent demand caused by climate risks on adaptability building. The weight is determined in order to comprehensively evaluate the urgency of urban climate risks.

Based on the mapping relationship between climate risks and adaptability, the relational matrix is utilized to calculate the urgency to improve adaptability to different climate change impacts.

$$X = [\mu_1 RP_1, \mu_2 RP_2, \dots, \mu_3 RP_m] \quad (7)$$

$$Y = [P_1, P_2, \dots, P_n] \quad (8)$$

$$Y = X * R \quad (9)$$

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \quad (10)$$

R is the relational matrix, subject to $\sum_{i=1}^m r_{ij} = 1$, $0 \leq r_{ij} \leq 1$.

P_i is the urgency to improve adaptability (standardized), RP_j is the urgency for risks (standardized), μ is the subordinate degree for different risk factors, and m and n represent climate risk dimensions and represent adaptability respectively.

Through expert assessment, the city is scored in six aspects of climate change risk (score ranges from 1-5, a higher value indicates higher degree of urgency) and calculations via the relational matrix result in the level of urgency in enhancing the five aspects of climate adaptability.

3.2.3. Climate risk urgency-adaptability: two-dimensional indicator system and evaluation model. From the two dimensions of climate change extent and climate change adaptability, relevant indicators can be selected based on the representativeness and availability of the indicator for the climate change risks. Subjective (Semi-structured questionnaire survey and Delphi Method) and objective (Drawing upon the experience of advanced overseas cities in building the climate change adaptation evaluation indicator system) methods are combined in an analytical hierarchy process to summarize the evaluation indicators for climate change and adaptability, determine the effect of the indicator and build the indicator system consisting of 28 indicators (See Tables 1 and 2).

The urgency and adaptability two-dimensional situation model can be constructed based on the above indicator system to make comprehensive judgment, prioritize relatively urgent areas that are not adaptive to climate change risks and maintain relatively less urgent areas adaptive to climate change risks so that the strategic directions for climate adaptation strategies can be identified and the priorities ranked to provide support for urban planning construction.

A compilation of the key climate change risks and response measures of cities in all of China's climate zone were taken into consideration when selecting the indicators for the two-dimensional situation model. When applied to specific cases, indicators suitable to the city can be selected for use in evaluation (guaranteeing at least two indicators for each type of adaptability) based on the city's climate, geological characteristics and expert opinions.

4. Results

4.1. Survey

A survey of experts familiar with the city's climate change or engineering management work was carried out on evaluation of climate change risk and adaptability from July 21 to 28, 2016. 118 questionnaires were recovered, 115 (97.4%) of which were valid (Table 3).

Questionnaires analysis shows that respondents covered a variety of professional backgrounds, including carbon emission assessment, energy and resource management, industrial development, eco-city planning, transportation, urban management, architecture, water system, landscape, risk management, finance, and others. The male to female ratio of all respondents is about 6:4 and average age is 38 years. Around 86% of the experts have a master's or higher degree, 79.7% have worked more than 6 years in their field, mostly 6-10 years. Overall, the level of knowledge of the respondents is representative and their judgments are credible.

Table 3. Interviewees' basic information.

Basic Situation	Group	Percentage (%)	Basic Situation	Group	Percentage (%)
Gender	Male	59.3	Knowledge Background	Carbon Emission Assessment	37.3
	Female	40.7		Energy and Resource Management	28.8
Working Years/year	> 15	19.5		Industry Development	19.5
	11-15	16.1		Eco-city Planning	16.1
	6-10	44.1		Transportation	14.4
	1-5	18.6		Urban Management	12.7
Education	0	1.7		Architecture	12.7
	Bachelor	14.1		Water System	10.2
	Master	37.0		Landscape	7.6
	Doctor	48.9		others	10.1

4.2. Urgency analysis

Through the analysis of the data on climate change in Shenzhen City in the past 50 years, we can identify the characteristics of climate change risks including six factors: average annual temperature change, average annual precipitation change, decreasing air quality, increasing number of high-temperature days, increasing frequency of heavy precipitation and increasing typhoon frequency. A mapping matrix can be constructed between these six factors and the five categories including social and economic development, disaster response, urban planning adaptation, science and technology input and policy management to form the urgency incidence relations.

The mapping matrix can be constructed through the analysis of the scoring on the correlation between climate adaptability and climate risks identified with the expert survey to obtain the priorities for climate adaptability through calculation. The result is shown as follows (Table 4).

The research result shows that the ranking of climate risk characteristics in Shenzhen can be described as follows: decreasing air quality and the number of high-temperature days are the most urgent characteristics for climate risk changes, the average temperature change (climate warming) is relatively urgent, precipitation change, extreme weather and typhoon risks are in the medium level in terms of urgency. At present, the five dimensions of climate adaptability can be ranked as follows: urban planning adaptation and improving the disaster response capacity (urgency>4), science and technology input, policy and human resource support and strengthening economic and social support.

Table 4. Matrix Table on the Urgency for Climate Risk Changes in Shenzhen (standardized).

		Characteristics for climate change risks						Average
		Average annual temperature	Average annual precipitation	Decreasing air quality	Increasing number of high-temperature days	Increase in the number of heavy precipitation	Increasing frequency of typhoon	
Dimensions for climate change adaptability	Increasing economic and social support	3.68	3.22	4.53	2.77	3.40	2.54	3.35
	Improving disaster response capacity	3.30	4.02	2.74	5.07	4.94	5.81	4.31
	Urban planning adaptation	4.70	4.56	4.95	4.30	3.71	3.81	4.34
	Level of science and technology input	4.06	3.49	5.68	3.84	3.71	3.63	4.07

Policy and human resource support	4.06	3.62	4.21	4.92	3.55	2.90	3.88
Average	3.96	3.78	4.42	4.18	3.86	3.74	

(Note: For the given climate risk factors, a one to five Likert scale was used. Five points, four points, three points, two points, one point represent very urgent, urgent, neutral, not urgent and totally not urgent respectively; the mean is calculated based on the scores given by the experts. The mapping matrix on the urgency from risks to adaptability can be constructed after the weights are determined based on the normalization of the difference in the correlation between indicators and based on the result of evaluation by experts on the correlation between six categories of climate risk factors and five categories of climate adaptability.)

4.3. Adaptability analysis

The data on the climate change adaptability indicators in Shenzhen since 1961 have been collected. The corresponding weight of correlation matrix and expertise judgment are comprehensively considered to use the coupling coordination degree model for the calculation of the adaptability of various types of abilities to climate risk changes from the five aspects of economic and social development, disaster response, urban planning adaptation, science and technology level and policy management. Weighted calculation is conducted on the total correlation (expertise judgment) between various types of climate adaptability and climate change risks to get the comprehensive adaptability and concrete result (See Figure 4). The result is that during nearly 10 years from 2004 to 2014, the comprehensive adaptability to climate risks in Shenzhen has increased from 0.53 to 0.73, from slightly adaptive to medium adaptive.

Generally speaking, the adaptability rises with some fluctuations show that with economic development, the disaster response, urban planning adaptation, science and technology level, policy and management and input in science and technology and human resources have all been improved to varying degrees in terms of the adaptability to climate risk changes.

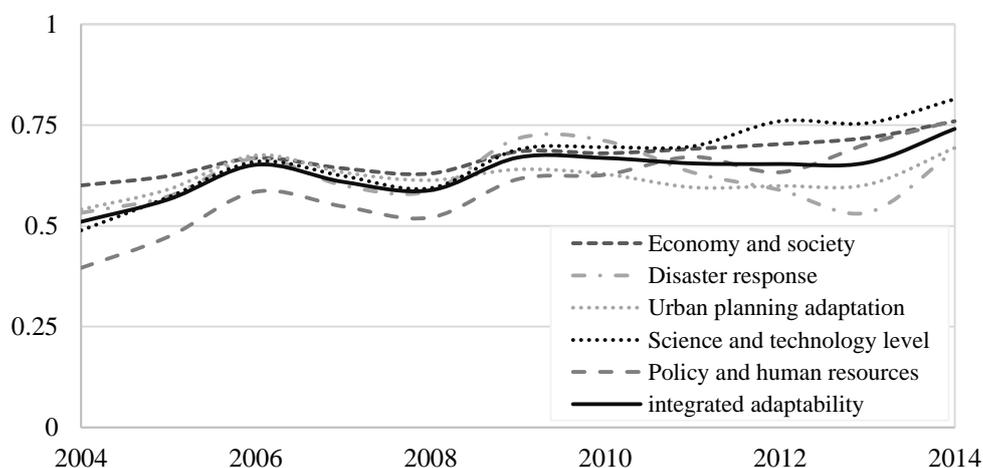


Figure 4. Climate Change Risk Adaptive Value of Shenzhen from 2004 to 2014.

(Note: The comprehensive adaptability is the adaptability result through the comprehensive weighting and summation of social and economic development, disaster response, urban planning adaptation and science and technology level and policy management. As for the connotation of the other indicators, please refer to the Climate Risk Adaptability Evaluation Indicator System (Table 1). In the calculation of the total recognition degree, different weights should be given to the ideas of experts with different years of work experience. The weight of 3 should be given to the idea of experts with one to five years of work experience; the weight of 8 should be given to the idea of experts with six to ten years of work experience; the weight of 13 should be given to the idea of experts with 11 to 15 years of work experience; the weight of 15 should be given to the idea of experts with above 15 years of work experience.)

4.4. Urgency-adaptability-based two-dimensional evaluation model

To examine the adaptability to climate change risks in Shenzhen from the two dimensions of urgency and adaptability model based on Climate Risk Adaptability Indicators and the survey of experts, we should consider not only the urgency to face climate change characteristics but also the adaptability. Only by comprehensively considering the two dimensions we can evaluate the adaptability of a certain effort. Meanwhile, we can add the extent of increase for adaptability from 2004 to 2014 as the supplementary dimension (Figure 5). We can take the science and technology level as example. Its urgency is 4.07 (urgent), its adaptability is 0.81 (medium and high-level adaptive) and the extent of increase for the adaptability is 0.28; however, the urgency for the urban planning adaptation is 4.33, the adaptability is 0.69 (medium-level adaptive), but the extent of increase is only 0.11. Through analysis, it can be concluded that the factor of urban planning adaptation is relatively lower than the science and technology level in terms of climate adaptability and the extent of increase in the past ten years is relatively small (with great difference), but it also has a high degree of urgency and should be prioritized in relevant actions.

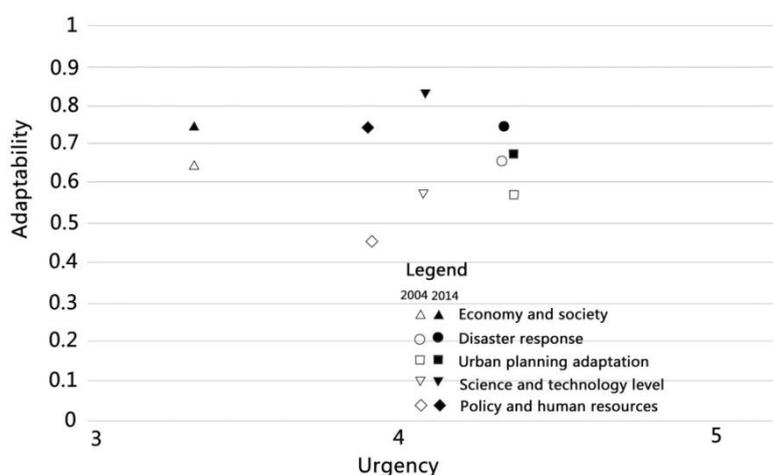


Figure 5. Analysis Result for the Urgency-adaptability Situation on the Climate Risk Changes in Shenzhen from 2004 to 2014. (Note: Adopting the research analysis of the climate risk changes in the decade from 2004 to 2014 in the Statistical Yearbook of Shenzhen.)

The overall research result shows that in the next stage, Shenzhen should prioritize the building of climate change adaptability in terms of urban planning adaptation and disaster response in its efforts. In particular, it should put emphasis on improving the capacity of urban planning adaptation from the proportion of investment in environmental protection in GDP (%), the architecture energy consumption, green transportation and per capita public green space area. There is room for further improvement in other areas of adaptability building, e.g. regarding the science and technology level and policy management.

5. Discussion

This research constructed an urgency-adaptability two-dimensional model for coping with climate changes risk and examines the climate change adaptability in the case study of Shenzhen. The research conclusions are as follows:

- The two-dimensional model of Urgency-adaptability for responding to climate change at the city level built in this study helps to evaluate the five aspects of adaptability and the urgency in promoting them. The evaluation gives policy suggestions for Shenzhen on prioritizing the adaptation measures to reduce its fragility.

- Shenzhen is further undergoing climate change. In the past 50 years, the temperature has risen by 1.6°C, which is more than twice as high as the average temperature rise of the world in the past century (0.74°C). The urgency of climate change risks is ranked in descending order as follows: decreasing air quality, increase in the number of high-temperature days, average temperature change (climate warming), precipitation change, extreme weather and typhoon risks, in which air quality and high temperature are the most serious problems.

- Though Shenzhen has maintained rapid economic growth and its per capita disposable income has increased by 50% (compared to which year 2010), the urban planning and infrastructure construction still deserve greater attention. In terms of improving Shenzhen's climate adaptability, the most urgent need is to improve its urban planning adaptation capacity, its disaster response capacity and its scientific and technological capacity. After comprehensive consideration of the characteristics urgency and adaptability, it can be concluded that the major drive for the improvement of climate adaptability originates from the steady improvement in social and economic development, science and technology and policy management. Therefore, it is of great importance for Shenzhen to enhance the adaptability in urban planning and design, with emphasis on infrastructure construction, especially green infrastructure including green transportation, green building and sponge cities in order to improve the adaptability of ecologically sensitive areas. Particularly, climate change adaptability measures ought to be taken into account at the stage of green architectural design, district planning, city renovation and regeneration in order to strengthen climate adaptability of new-builds as well as old districts.

- Based on our analysis of climate change risks in Shenzhen, its adaptability and major factors, it is important to put forward strategic objectives, major tasks and key projects and guarantee measures for climate change adaptation. Climate change adaptation should be incorporated into existing and future guiding documents for city development. Pilot and demonstration projects on climate change adaptation should be established, institutional development should be strengthened and public awareness should be enhanced, funding and investment should be increased and international cooperation should be carried out.

- Our study is city-specific. As there is no unified fitness evaluation criterion at present, it is difficult to verify our model and its results. Therefore, background information about urban development, mainly about climatic risks, as well as the comprehensiveness and the mutual exclusivity of indicators should be considered when making selections. For research in the future, it is difficult to unify the evaluation criterion when dealing with different cities, for it needs to be classified according to the climatic risks of different cities (e.g. coastal cities, inland cities) and evaluated by experts, reversed verification and indicators reselection should also be done according to ample analytical results.

The present model and analysis of urban planning and climate adaptability employs historical data, which reflects Shenzhen's current climate adaptability characteristics and the aspects needing further attention. However, since future climate changes are uncertain, it is necessary to incorporate certain climate change risk projections and urban construction scenario analysis, to enable the city to develop new adaptability measures when facing future climate change risks and challenges. Analysis of urban planning scenarios under different economic and population conditions can identify primary drivers and obstacles to improving climate adaptability, which may enable comprehensive, reasonable and effective solutions in the long-run.

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