Postprint: Assessment and Characteristic Analysis of Urban Climate Change Adaptation Capacity Based on Exposure-Resilience-Sensitivity

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Abstract

Cities represent the most concentrated areas of population and socioeconomic activities. With the advancement of urbanization and climate change, climate risks and impacts faced by urban areas are becoming increasingly prominent. Enhancing urban capacity to adapt to climate change has become the most important task and pathway for cities to address climate change challenges. By reviewing and evaluating China' s urban climate change adaptation capacity and its key elements, this study aims to provide a scientific basis for the formulation and implementation of regional adaptation policies. Based on the IPCC adaptation capacity evaluation framework, we construct an urban climate change adaptation capacity assessment framework grounded in exposure-sensitivity-resilience, subsequently screening 19 indicators and categorizing them into five levels corresponding to climate change adaptation capacity, with weights assigned using the entropy weight method. Employing set pair analysis, we evaluate the climate change adaptation capacity levels of 286 prefecture-level cities in China and analyze the main limiting factors. Results indicate that the adaptation capacity in eastern China is generally higher than that in western regions; areas with lower adaptation capacity are mainly concentrated in some cities of Gansu and Shaanxi in Northwest China, cities in Hunan, Hubei, and Jiangxi in Central China, and cities in Guangxi and Yunnan in Southwest China. The limiting factors of urban adaptation capacity are primarily manifested as follows: high adaptation capacity mainly corresponds to the (low-high-low) combination of exposure-resilience-sensitivity; low adaptation capacity includes three combinations of exposure-resilience-sensitivity: (high-high-high), (low-low-low), and (high-low-low). To enhance urban climate change adaptation capacity, for cities in Gansu-Shaanxi and other cities in the western and northwestern regions, the focus should be on improving resilience to climate change, such as establishing sound post-disaster recovery and emergency response systems; for cities in Central and Southwest China, the priority should be on enhancing the capacity to

defend against climate risks.

Full Text

Preamble

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"Exposure-Resilience-Sensitivity" Based Evaluation and Characteristics Analysis of the Capacity for Urban Adaptation to Climate Change in China

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Abstract

Urban areas in China are experiencing rapid population growth and economic development while simultaneously facing aggravated climate change risks. Building capacity for urban adaptation has become one of the most critical tasks for addressing climate change challenges. This study aims to systematically evaluate the capacity for climate change adaptation in Chinese cities and identify key limiting factors to provide a scientific basis for regional adaptation policy formulation and implementation.

We established an evaluation framework based on the IPCC vulnerability assessment framework and selected 19 indicators related to exposure, sensitivity, and resilience. Using the entropy method for objective weighting, indicators were divided into five grades. We then evaluated the adaptation capacity of 286 prefecture-level cities across China using set pair analysis (SPA) and analyzed the main limiting factors.

Results show that urban adaptation capacity is generally higher in eastern regions than in western regions. Cities with low adaptation capacity are concentrated in three clusters: (1) northwestern cities in Gansu and Shaanxi provinces, (2) central Chinese cities in Hunan, Hubei, and Jiangxi provinces, and (3) southwestern cities in Guangxi and Yunnan provinces. The limiting factors affecting urban adaptation capacity in relation to "exposure-resilience-sensitivity" manifest as distinct patterns: high adaptability corresponds primarily to a "low-high-low" combination (low exposure, high resilience, low sensitivity), while low adaptability includes "high-high-high," "low-low-low," and "high-low-low" combinations.

Different countermeasures are needed to improve urban adaptation capacity across regions. For northwestern cities (Gansu-Shaanxi), the priority is enhancing resilience by establishing robust post-disaster recovery and emergency response systems. For central and southwestern cities, the focus should be on improving defense capabilities against climate risks.

Keywords: set pair analysis; urban; adaptation to climate change

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1. Methods and Data

1.1 Evaluation Framework and Indicator System

This study constructs an evaluation framework and indicator system for urban climate change adaptation capacity based on the IPCC vulnerability assessment framework. The IPCC Third Assessment Report defines vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change. Climate change risk comprises hazard, vulnerability, and exposure, influenced by socio-economic pathways, mitigation pathways, and governance.

We conceptualize climate change adaptation as a function of three components: exposure (climate risks faced by cities), sensitivity (vulnerability to climate impacts), and resilience (capacity to reduce climate impacts and recover quickly). Based on this framework, we developed an indicator system for evaluating urban climate change adaptation capacity in China.

The indicator system comprises 19 metrics across three dimensions . Exposure indicators include temperature change intensity, precipitation change intensity, continuous dry index, extreme rainfall, heat persistence index, and annual disaster index. Sensitivity indicators encompass air quality days, low-income population, registered unemployed persons, population density, energy consumption level, per capita fossil fuel consumption, and water consumption. Resilience indicators include medical rescue capacity (number of doctors), disaster reduction research capacity, natural ecosystems, drainage network length, per capita urban road area, GDP, employment numbers, and built-up area green coverage.

We applied the entropy method for objective weighting. Indicators were first normalized: for cost-type indicators (where lower values are better), the normalization formula transforms them into positive indicators where higher values indicate better performance. For benefit-type indicators, the original values were retained. After normalization, the entropy method assigned weights and indicators were classified into five grades .

1.2 Set Pair Analysis Method

This study employs Set Pair Analysis (SPA), a systems analysis method proposed by Zhao Keqin for analyzing uncertainty through connection number operations. SPA is particularly effective for evaluating non-traditional security issues. The core concept treats certainty and uncertainty as a unified system, studying their interconnections and transformations.

For a given problem , set pair H consists of two sets with N characteristics: S shared characteristics, P opposing characteristics, and F = N - S - P characteristics that are neither shared nor opposing. The connection degree is defined as:

= S/N + (F/N)i + (P/N)j

where i is the discrepancy coefficient and j is the opposition coefficient, with a + b + c = 1 for = a + bi + cj.

For urban adaptation capacity evaluation, we use a five-element connection degree that expands the discrepancy degree into multiple levels:

= a + b i + b i + ⋯+ b i + cj

The discrepancy coefficients i , i , ⋯, i represent different levels of discrepancy (e.g., mild, moderate, severe). In this evaluation, these parameters can be understood as the degree to which a sample belongs to a particular standard grade.

The closeness degree r , which indicates how close city sample k is to the optimal solution, is calculated as:

r = a - c

Higher r values indicate stronger adaptation capacity. For each sample value x and indicator standard s, the connection degree is determined based on whether the indicator is cost-type (smaller values better) or benefit-type (larger values better), using piecewise functions that compare x against standard thresholds s , s , ⋯, s .

1.3 Data Sources

Meteorological data were obtained from the China Meteorological Data Network (http://data.cma.cn/site/index.html) using the China Surface Climate Standard Value Dataset, based on changes between 1981-2010. Climate disaster data were sourced from the *2014 Natural Disaster Atlas*. Air quality data came from the 2014 China Environmental Status Bulletin. Other data were primarily collected from 2014 statistical yearbooks, urban construction statistical yearbooks, and socio-economic development bulletins. Due to data limitations, some missing values were substituted with 2013 data.

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2. Results and Analysis

2.1 Spatial Distribution of Adaptation Capacity Grades

Based on the above data and weights, the 286 evaluated cities were classified into five adaptation capacity grades: 105 cities in grade 1 (highest), 51 in grade 2, 7 in grade 3, 6 in grade 4, and 117 in grade 5 (lowest) [Figure 1: see original paper].

Cities with high adaptation capacity are relatively dispersed, mostly located in eastern China. Cities with low adaptation capacity are concentrated in: (1) northwestern Gansu and Shaanxi provinces, (2) central Hunan, Hubei, and Henan provinces, and (3) southern Guangxi and Yunnan provinces. The predominance of grades 1 and 5 may reflect the influence of the indicator grading system.

2.2 Closeness Degree Analysis

Cities were ranked by adaptation capacity using the closeness degree r [Figure 2: see original paper]. Eastern regions generally show better performance, while low-capacity areas cluster in Gansu, Shaanxi, Henan, Ningxia, southwestern Yunnan and Guangxi, and central Hunan. The closeness degree analysis yields results consistent with the capacity grading but provides better differentiation between cities.

2.3 Analysis of Key Limiting Factors

This section examines limiting factors from three dimensions: exposure, sensitivity, and resilience.

Exposure Analysis: High-exposure cities (marked in red) are concentrated in central China, particularly in parts of Hunan, Hubei, and Jiangxi. Cities surrounding high-exposure areas also face elevated climate risks. Key influencing factors include the annual disaster index (weight: 0.1287), continuous dry index (0.0969), precipitation change intensity (0.0967), and extreme rainfall, with the annual disaster index having the highest weight.

Sensitivity Analysis: The spatial distribution of sensitivity aligns closely with the Hu Huanyong Line (Heihe-Tengchong Line). Northwest China has low population density and thus low sensitivity to climate change, while the southeast, with higher economic development and over 95% of national population, shows higher sensitivity. The sensitivity pattern maintains strong consistency with the Hu Huanyong Line.

Resilience Analysis: Resilience exhibits a gradual transition from east to west, with highest levels in eastern coastal cities, moderate levels in central cities, and lowest levels in western cities. Resilience is strongly influenced by regional economic development; better economic foundations enable more complete adaptation infrastructure, personnel, and rapid mobilization for recovery and emergency response.

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3. Discussion

Further analysis of factor interactions was conducted using contour plots of exposure-sensitivity-resilience [Figure 6: see original paper]. The limiting factor combinations manifest as distinct patterns:

- **High adaptability** primarily corresponds to "low exposure-high resilience-low sensitivity" combinations (upper-left region of plot), representing cities with low climate risk, low vulnerability, and strong recovery capacity, mainly in northeastern China.
- **Low adaptability** includes three combinations:
  1. **"High-high-high"** (lower-right blue region): High exposure, high sensitivity, high resilience. These cities face high climate risks and have high sensitivity but possess relatively strong recovery capacity, corresponding to central China' s Hunan-Hubei-Jiangxi region.
  2. **"Low-low-low"** (deep yellow region): Low exposure, low sensitivity, low resilience. These cities have relatively low climate risk and sensitivity but weak recovery capacity, mainly in Gansu and Ningxia.
  3. **"High-low-low"** (lower-left region): High exposure, low sensitivity, low resilience. These cities face high climate risk but have low sensitivity and weak recovery capacity, primarily in Guangxi and Yunnan.

Cities in the upper-right region show low exposure and low sensitivity, representing another high-adaptability type, mainly distributed in northeastern China.

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4. Conclusions and Recommendations

This study yields the following conclusions:

1. Urban climate change adaptation capacity in China is relatively better in eastern regions and poorer in western regions. Low-capacity cities are concentrated in northwestern Gansu-Shaanxi, southwestern Guangxi, and central Hunan-Jiangxi.
2. The limiting factors for low-adaptation city clusters differ by region:
    - **Central China cities** (Hunan-Hubei-Jiangxi) face high climate risks and disasters with high sensitivity; despite relatively strong resilience, high exposure and sensitivity remain primary constraints.
    - **Northwestern cities** (Gansu-Shaanxi) have high climate exposure but low sensitivity; their low adaptation capacity stems primarily from weak resilience.
    - **Southwestern cities** (Guangxi-Yunnan) have low sensitivity but high climate risk and low resilience.
3. Regional strategies should prioritize different aspects:
    - **Northwestern cities** should focus on improving resilience through establishing robust post-disaster recovery and emergency systems.
    - **Central and southwestern cities** should prioritize enhancing defense capabilities against climate risks.

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Note: Figure translations are in progress. See original paper for figures.