Evaluation and Analysis of Urban Resilience in Districts and Counties of Inner Mongolia (Postprint)

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Abstract

Abstract: Based on a multi-dimensional perspective of economy, society, and ecology, using the entropy weight method, comprehensive index method, and global Moran' s I index, this study reveals the spatio-temporal evolution characteristics of urban resilience at the district and county level in Inner Mongolia from 2000 to 2019, and employs a geographically weighted regression model to analyze the impact of human activity intensity on changes in district and county urban resilience. The results show that: (1) Due to the continuous improvement of socio-economic development levels, the urban resilience level of districts and counties in Inner Mongolia showed continuous growth from 2000 to 2019. (2) The spatial distribution of urban resilience levels in Inner Mongolia' s districts and counties shows significant differences, with the eastern and central regions exhibiting notably higher resilience levels than districts and counties in other leagues and cities. (3) Changes in human activity intensity, including population density, construction land, and nighttime light data, have significant impacts on the variation of urban resilience levels in Inner Mongolia' s districts and counties. The research findings can provide references for the sustainable development of districts and counties in Inner Mongolia and hold important practical and theoretical significance for enriching research in the field of urban resilience in China.

Full Text

Evaluation and Analysis of Urban Resilience of Districts and Counties in Inner Mongolia

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Abstract: Based on a multidimensional perspective of economy, society, and ecology, this study investigates the spatiotemporal evolution characteristics of urban resilience in districts and counties of Inner Mongolia, China, from 2000 to 2019 using the entropy weight method, comprehensive index method, and global Moran' s I index. Furthermore, a geographically weighted regression model is employed to analyze the influence of human activity intensity on changes in urban resilience at the district and county level. The results reveal that: (1) The urban resilience level of districts and counties in Inner Mongolia showed continuous growth from 2000 to 2019, driven by ongoing improvements in socioeconomic development. (2) Spatial distribution differences in urban resilience levels were significant, with districts and counties in the eastern and central regions markedly higher than those in other leagues and cities. (3) Changes in human activity intensity, including population density, construction land area, and nighttime light data, exerted significant effects on urban resilience level changes in Inner Mongolia' s districts and counties. These findings provide a reference for sustainable development of districts and counties in Inner Mongolia and hold important practical and theoretical significance for enriching urban resilience research in China.

Keywords: district-county scale; urban resilience; human activity intensity; Inner Mongolia

1. Study Area

Inner Mongolia is located in northern China, extending in a long, narrow east-west orientation across the eastern, central, and western regions of the country (37°24 ~53°23 N, 97°12 ~126°04 E). The region represents a typical ecologically fragile area of farming-pastoral transition in northern China, as well as forest-grassland transition in the northeast and desert-oasis transition in the northwest. By 2019, the region' s urbanization rate had reached 63.4%. Inner Mongolia covers an area of 1.183 million km^2, but its total population was only 24 million by the end of 2019, making it a typical region with vast land and sparse population. According to government data, Inner Mongolia comprises 12 prefecture-level cities and 103 county-level administrative units. The Kangbashi District of Ordos City and the Zhalainuoer District of Manzhouli City in Hulunbuir were established after 2015; to ensure continuity and stability of evaluation results, these districts were excluded from the analysis. Consequently, this study evaluates the urban resilience of 101 districts and counties in Inner Mongolia from economic, social, and ecological perspectives, examining the level and evolution characteristics of urban resilience from 2000 to 2019 and analyzing the impact of human activity intensity on these changes.

2. Data and Methods

2.1 Data Sources

Socioeconomic data were obtained from the *Inner Mongolia Statistical Yearbook* (2001–2020). Afforestation area data were sourced from the *China Forestry and Grassland Statistical Yearbook* (2001–2020). Land use data for 2000, 2010, and 2019 were downloaded from the Resource and Environment Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn). PM2.5 data were obtained from Washington University in St. Louis' s data platform (https://sites.wustl.edu/acag/datasets/surface-pm2-5). Vegetation net primary productivity (NPP) data were derived from MOD17A3 products, normalized difference vegetation index (NDVI) from MOD13Q1 products, and nighttime light data from continuous DMSP/OLS NPP/VIIRS nighttime light data products (https://lpdaac.usgs.gov/, https://dataverse.harvard.edu/).

2.2 Indicator Selection

Based on the characteristics of economic, social, and ecological development in Inner Mongolia and relevant scholarly research, a total of 15 indicators were selected to evaluate urban resilience at the district and county level (Table 1). The economic resilience dimension includes GDP, total retail sales of consumer goods, grain output, meat output, oil crop output, total industrial output value of enterprises above designated size, and number of industrial enterprises above designated size. The social resilience dimension includes number of primary and secondary schools, highway mileage, number of hospital beds, medical technical personnel, employed staff and workers, public fiscal expenditure, and public fiscal revenue. The ecological resilience dimension includes afforestation area, ecosystem service value, vegetation NPP, PM2.5 concentration, and green space area.

2.3 Methods

2.3.1 Standardization As original data have different measurement units and scales, standardization was performed to eliminate dimensional and numerical differences:

For positive indicators:

$$Y_{ij} = \frac{X_{ij} - X_{\min}}{X_{\max} - X_{\min}}$$

For negative indicators:

$$Y_{ij} = \frac{X_{\max} - X_{ij}}{X_{\max} - X_{\min}}$$

where Y_{ij} is the standardized value, X_{ij} is the actual indicator value, $X_{\min}$ is the minimum value in the indicator series, and $X_{\max}$ is the maximum value.

2.3.2 Entropy Weight Method The entropy weight method was used to determine indicator weights:

$$P_{ij} = \frac{Y_{ij}}{\sum_{i=1}^{n} Y_{ij}}$$

$$E_j = -\frac{1}{\ln n} \sum_{i=1}^{n} P_{ij} \ln P_{ij}$$

$$D_j = 1 - E_j$$

$$W_j = \frac{D_j}{\sum_{j=1}^{m} D_j}$$

where P_{ij} is the proportion of the jth indicator value for the ith district/county, n is the total number of districts/counties in Inner Mongolia, E_j is the entropy value, D_j is the redundancy, W_j is the weight, and m is the number of indicators.

2.3.3 Urban Resilience Evaluation Urban resilience represents the capacity of urban economic, social, and ecological systems to respond to uncertain risks through interaction. The calculation formula is:

$$RES = \sum_{j=1}^{m} W_{jY_{ij}}$$

where RES is the urban resilience index.

2.3.4 Global Moran' s I Index Global Moran' s I index measures the overall spatial correlation of an attribute:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} \sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where x_i is the urban resilience index, $\bar{x}$ is the mean value, S^2 is the variance, and W_{ij} is the spatial weight matrix. The index ranges from -1 to 1, with values approaching 1 indicating strong positive spatial correlation, values approaching -1 indicating strong negative spatial correlation, and 0 indicating no spatial correlation.

Statistical significance was tested using the Z-value:

$$Z(I) = \frac{I - E(I)}{\sqrt{VAR(I)}}$$

where $E(I)$ is the mathematical expectation.

2.3.5 Geographically Weighted Regression Human activity intensity objectively reflects the degree of human utilization, transformation, and development of terrestrial surfaces. Following Chen et al. [27], population density, nighttime light data, and construction land area were selected as indicators of human activity intensity. A geographically weighted regression (GWR) model was used to analyze their impact on urban resilience changes:

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{k} \beta_j(u_i, v_i)x_{ij} + \varepsilon_i$$

where y_i is the dependent variable, (u_i, v_i) are the geographic coordinates, $\beta_j(u_i, v_i)$ is the local regression coefficient, and ε_i is the random error term.

3. Results

3.1 Spatio-temporal Evolution of Urban Resilience

3.1.1 Temporal Evolution Based on the evaluation indicator system and methods, urban resilience indices for 101 districts and counties were calculated for 2000, 2010, and 2019. Using ArcGIS 10.7 natural breaks classification, urban resilience levels were categorized into five classes: low ($ $0.1039), relatively low (0.1040–0.1685), moderate (0.1686–0.2573), relatively high (0.2574–0.5192), and high (>0.5192). The number of districts/counties in each class changed substantially over time. Class I (low resilience) decreased from 51 to 9, while Class V (high resilience) increased from 5 to 21. This improvement resulted from gradual optimization of economic, social, and ecological environments. Economically, GDP grew from 174.1 billion yuan to 1,686 billion yuan, and industrial output value increased from 41.32 billion to 619.2 billion yuan. As a major agricultural and pastoral region, grain and meat production improved significantly with technological advances. Socially, public fiscal expenditure rose from 10.85 billion to 300.7 billion yuan, and infrastructure including healthcare, education, and transportation improved. Ecologically, ecosystem service value and vegetation NPP increased, though afforestation area and green space decreased while PM2.5 concentrations fluctuated. The fastest-growing district was Zhungeer Banner, whose resilience level increased from 0.1458 to 0.4105. Donghe District exhibited consistently decreasing resilience, dropping from 0.2975 to 0.1812.

3.1.2 Spatial Evolution The spatial distribution of urban resilience differed markedly across regions. High-resilience districts/counties were concentrated in eastern Inner Mongolia (Tongliao, Chifeng, Hinggan League, and Hulunbuir) and central Inner Mongolia (Hohhot, Baotou, and Ordos). Other regions showed improvements but lagged behind these areas (Figure 2). This pattern reflects policy preferences and ecological foundations. Eastern leagues were included in the "Northeast Revitalization" strategy, with Hulunbuir' s resilience particularly influenced by its vast grasslands and forest ecosystems. Central cities form the core of the Hohhot-Baotou-Ordos-Yulin urban agglomeration, serving as key economic anchors. The global Moran' s I index was positive and significant ($p \leq 0.01$) for all three years (Table 2), indicating strong spatial clustering. The index declined from 2000 to 2010 but increased from 2010 to 2019, suggesting that spatial clustering intensified over time.

3.2 Impact of Human Activity Intensity on Urban Resilience

GWR model results showed adjusted R^2 values of 0.65–0.85, indicating the model explained 65–85% of the variation in urban resilience (Table 3). Human activity intensity significantly influenced resilience changes.

3.2.1 Population Density Population density impacts were higher in western regions in 2000, where low population density hindered urban development due to large areas and poor transportation. By 2019, high-impact areas shifted to central regions, where increased population density enhanced human capital and labor productivity, promoting coordinated economic, social, and ecological development.

3.2.2 Nighttime Light Index Nighttime light index had weaker effects than population density and construction land. In 2000, it negatively affected western regions, where limited human activity constrained resilience. By 2019, effects became positive across all regions, with strongest impacts in Tongliao and Chifeng in eastern Inner Mongolia, indicating that expanded human activity ranges enhanced resilience.

3.2.3 Construction Land Area Construction land area positively promoted urban resilience. Over time, the affected area shrank but impact intensity increased. In 2000, large impacts occurred in eastern regions with low development intensity. By 2019, impacts were concentrated in areas with relatively low resilience, as high-resilience areas had saturated construction expansion while developing areas still benefited significantly from urban construction.

4. Discussion

Overall, urban resilience in Inner Mongolia' s districts and counties showed clear improvement from 2000 to 2019. To avoid impacts from the COVID-19 pandemic, the study period ended in 2019; future research should examine post-pandemic resilience. Due to data limitations, the indicator system could be expanded to include organizational and institutional resilience dimensions.

The study demonstrates that human activity intensity significantly influences resilience changes, providing important insights for sustainable urban development.

5. Conclusions and Recommendations

5.1 Conclusions

This study evaluated spatiotemporal evolution of urban resilience in 101 Inner Mongolia districts/counties and analyzed human activity intensity impacts using statistical and remote sensing data. Key findings include:

1) **Temporal trends**: Urban resilience improved continuously from 2000–2019. Class I districts/counties decreased from 51 to 9, while Class V increased from 5 to 21. Economic resilience improved most dramatically, followed by social and ecological resilience. However, leapfrog transitions were uncommon, indicating threshold characteristics and suggesting that steady accumulation is the optimal path for resilience development.

2) **Spatial patterns**: Significant positive spatial correlation demonstrated regional radiation effects. Eastern regions (Tongliao, Chifeng, Hinggan, Hulunbuir) and central regions (Hohhot, Baotou, Ordos) maintained higher resilience, showing core-periphery patterns. Economic resilience was more determinative than social or ecological resilience.

3) **Human activity intensity**: Population density, nighttime light index, and construction land area all significantly affected resilience changes, with population density and construction land having greater impacts than nighttime light.

5.2 Recommendations

1) Given Inner Mongolia’ s vast east-west span and limited inter-county development linkages, infrastructure construction should be strengthened to improve transportation networks and county service capacity. Enhancing industrial systems and radiation effects will promote integrated economic, social, and ecological development.

2) As an important ethnic minority region with complex population composition and diverse languages, urban development should respect cultural differences and formulate targeted policies aligned with local characteristics.

3) Since human activity intensity significantly affects resilience, future urban resilience building should account for human activity changes to promote sustainable development.

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