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Postprint: Correlation Analysis Between Urban Size Distribution and Physical Geography in Xinjiang

Authors: Myrica rubra flower

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Abstract

How to achieve the coordination and sustainable development of population, city size, and natural geographical systems is a challenge facing human-land relationships in urbanization. Taking 91 county-level units in Xinjiang as the research object, based on three spatial dimensions—the entire study area, six major geomorphic types, and seven major water system zones—and employing the rank-size law and population Lorenz curve method, this study quantitatively analyzes the urban size system and population distribution pattern, and explores the correlation between urban size distribution and the spatial distribution of geomorphology and water systems in Xinjiang. The results show that: (1) The correlation coefficient for the size distribution of the geomorphic type zone system is 0.897, while that for the water system zone system is 0.951, indicating that the urban size pattern is more closely related to water system geographical factors. (2) The Junggar Basin and the Northern Tianshan Mountain Front River Area are two prominent population distribution agglomeration units, which are also areas with high geographical type superposition, presenting spatial polarization zones where urban size and natural geography are combined. (3) The heterogeneity of urban population distribution across natural geographical units in Xinjiang is prominent, with distinct patterns of population concentration and dispersion within geomorphic type units, relatively balanced population distribution within water system zone units, and the Northern Tianshan Mountain Front River Area showing a higher degree of population agglomeration. Overall, regional differences in urban population size in Xinjiang are significant, the urban size hierarchy exhibits gaps, the urban system is underdeveloped, and it is recommended to strengthen the development of medium-sized cities to improve the urban pattern across the entire Xinjiang region.

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Full Text

Correlation Analysis Between Urban Scale Distribution and Physical Geography in Xinjiang

YANG Meihua, CHENG Jintao, GUO Jiaxing, LI Shumin
Agricultural College, Shihezi University, Shihezi 832003, Xinjiang, China

Abstract: Achieving coordinated and sustainable development among population, urban scale, and physical geographical systems represents a critical challenge in human-environment relationships during urbanization. This study examines 91 county-level units in Xinjiang across three spatial dimensions—the entire region, six geomorphological types, and seven water system partitions—using the rank-size rule and population Lorenz curve methods to quantitatively analyze urban scale systems and population distribution patterns. The research explores correlations between urban scale distribution and the spatial distribution of landforms and water systems. Results indicate: (1) The correlation coefficient for system scale distribution in geomorphological type zones is 0.897, while for water system partitions it is 0.951, demonstrating that urban scale patterns are more closely related to water system geographical factors. (2) The Junggar Basin and the district at the northern foot of the Tianshan Mountains constitute two prominent population agglomeration units that are also highly superimposed geographical type zones, representing spatial polarization areas where urban scale and physical geography are combined. (3) The heterogeneity of urban population distribution across various physical geographical units in Xinjiang is pronounced, with distinct population concentration-dispersion patterns within geomorphological type units and relatively balanced population distribution within water system partition units, particularly high population concentration in the district at the northern foot of the Tianshan Mountains. Overall, Xinjiang exhibits significant regional differences in urban population size, a faulted hierarchical structure in urban scale grades, and an immature urban system, suggesting that development of medium-sized cities should be strengthened to improve the urban structure across Xinjiang.

Keywords: urban scale; population; physical geography; Xinjiang

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Introduction

Urbanization is the product of socio-economic and demographic development reaching a certain stage, and urban development is intimately connected with physical geography. This relationship is particularly crucial in arid regions of northwest China. Landforms and water systems, as natural environments for human survival, control urban scale by influencing population distribution, serving as both the material entities and core of human-environment relationship research in urbanization. Urban scale distribution reflects the development of urban systems. As urbanization advances, disorderly expansion of urban scale triggers problems such as "urban diseases" and "spatial mismatch." Therefore, studying the spatial distribution patterns of urban scale holds practical significance.

Scholars have long focused on the spatial distribution characteristics of urban scale and their causes. Mandelbrot applied fractal geometry to analyze urban scale distribution features, while Arlinghaus used fractal theory to demonstrate the fractal properties of urban central place hierarchical systems. Domestic scholars have also explored relevant fractal theoretical discussions regarding urban system spatial structures. Chen Yanguang et al. proposed the fractal similarity between cities and rivers, while Tang Zhiqiang et al. and Liao Jinzhong et al. applied fractal methods to study the impacts of land and water resources on urban development. Fractal theory has also been used in empirical analyses of urban system fractal characteristics in Changchun, Anhui, Shanxi, and Henan. Urban scale can be represented by population size, and population density is a key parameter for Lorenz curves, which quantitatively express the multifractal patterns of population across different scales on geomorphological and hydrological elements. Han Jiafu et al. established methods for creating population density distribution maps using Lorenz curves, Bai Zhongqiang et al. analyzed population distribution characteristics across China's provinces using Lorenz curves, and Lin Aiwen studied the relationship between population and land elements in Hubei Province.

Existing research has analyzed the relationship between urbanization and water-land resource benefits in some regions of Xinjiang. However, quantitative studies on Xinjiang's urban scale distribution characteristics from the perspective of human-environment relationships in physical geography remain scarce. This paper examines 91 county-level units in Xinjiang across three spatial dimensions—the entire region, six geomorphological type zones, and seven water system partitions—using the rank-size rule and population Lorenz curve method to quantitatively analyze Xinjiang's urban scale and population spatial distribution characteristics, aiming to provide a quantitative basis for optimizing Xinjiang's urban scale structure and rational population development.

Study Area Overview

Xinjiang Uygur Autonomous Region (hereinafter referred to as Xinjiang) is located in northwestern China, in the hinterland of the Eurasian continent, with geographical coordinates of 73°40 ~96°18 E and 34°25 ~48°10 N. It borders eight countries and serves as an important transportation hub connecting Central Asia to Europe, as well as a core area of China's Silk Road Economic Belt. Xinjiang covers an area of approximately 1.66$\times10^{6}$ km^2, accounting for one-sixth of China's total land area, making it the largest provincial administrative unit. Mountains and basins are the primary landform types, forming the geographical environment characteristic of "three mountains sandwiching two basins." Mountain landforms are distributed in an east-west orientation, following the mountain shape in zonal patterns, with the Tianshan and Kunlun Mountains intersecting in a "Y" shape. Most rivers originate directly or indirectly from the three major mountain ranges, with water supply primarily from mountain precipitation and snow/glacial meltwater from the three mountain systems, exhibiting obvious seasonal characteristics. Xinjiang has a typical temperate continental climate with large diurnal temperature variations, arid conditions with little rainfall, sparse vegetation, and extremely fragile ecological environments. The distribution pattern of ecological environments is closely related to the sustainability of urban development.

In 2020, Xinjiang's urbanization rate reached 51.87%. The acceleration of urbanization exerts varying degrees of pressure on the ecological environment. Regional urban scale distribution contains substantial information, and exploring the characteristics of urban scale distribution and its correlation with physical geography provides scientific decision-making references for optimizing Xinjiang's urban system hierarchical structure and achieving coordinated, sustainable development among population, urban scale, and physical geographical systems.

Data Sources

This study uses the urban system from the State Council-approved "Xinjiang Urban System Plan (2012-2020)" as the research scope, merging Xinjiang's 106 county-level cities and districts into 91 county-level units, each containing a county-level or higher city (town). Tianshan District and seven other municipal districts plus Urumqi County are counted as one county-level unit corresponding to Urumqi City. The same unit delineation standard applies to Karamay City. Additionally, due to significant natural geographical environment differences among the county-level cities within Hami City and Turpan City, Hami City is divided into Yizhou District, Barkol Kazakh Autonomous County, and Yiwu County, while Turpan City is divided into Gaochang District, Shanshan County, and Toksun County. Apart from these areas, other county-level units basically correspond to county-level administrative divisions.

Urban population data primarily come from the "2020 Xinjiang Statistical Yearbook" published by the Xinjiang Uygur Autonomous Region Bureau of Statistics. Water system partition data are from the "Xinjiang Water Resources Bulletin." Geomorphological type data are based on geographical grid data from the new geomorphological zoning of Xinjiang, divided into six geomorphological types: Altai Mountains and Beita Mountain, Junggar Western Mountains, Junggar Basin, Tianshan Mountains, Tarim Basin, and Kunlun Mountains and Altun Mountains. Water system partition data are from Xinjiang water resources zoning, including seven river water systems: the Turpan-Hami Basin Small Rivers District, Altai Mountains Southern Foothills Rivers District, Central Asian Inland Rivers District, Tianshan Mountains Northern Foothills Rivers District, Tarim River Source District, Tarim River Mainstream District, and Kunlun Mountains Northern Foothills Small Rivers District.

Research Methods

Rank-Size Rule: The rank-size rule effectively reflects urban system scale hierarchy and fractal characteristics, serving as the basis for urban system scale structure optimization. This study employs the rank-size rule to analyze urban scale distribution characteristics. The relevant calculation formulas are as follows:

Zipf's formula: MATH_{FORMULA}1

Pareto formula: MATH_{FORMULA}2

Where: Pi is the population of the ith city (persons), with i being an integer between 1 and n; P_1 is the population of the primate city (persons); q is the number of cities larger than the threshold population size; p is urban population scale; A is a coefficient; R^2 is the determination coefficient of the rank-size curve fitting equation; and D is the fractal dimension value.

Lorenz Curve: The Lorenz curve can quantitatively describe population distribution characteristics and patterns. Population density is a key parameter for drawing Lorenz curves and represents the main indicator of regional population distribution differences. Based on data from the Xinjiang Statistical Yearbook, this study calculates the population density of each county-level city in the research area using the formula: MATH_{FORMULA}3

Where: is population density (persons·km^{-2}); P is urban population (persons); and S is the area of the urban unit (km^2).

The process involves first sorting population per unit area in descending order by district and county, then calculating cumulative population proportions (Y-axis) and cumulative area proportions (X-axis) for each district and county, and finally plotting the population density Lorenz curve.

Four-City Index: The four-city index is a quantitative indicator of population agglomeration degree in the primate city within a region, calculated as: MATH_{FORMULA}4

Where: S is the four-city index; and Pi is the population of the ith city (persons).

Results

3.1 Spatial Structure Characteristics of Urban Scale in Xinjiang

The urban scale distribution in Xinjiang exhibits obvious fractal characteristics, with a faulted hierarchical structure showing missing middle layers, indicating an immature urban system. The correlation coefficient from the double logarithmic regression is 0.995, with good fit between the regression line and scatter points, where actual values closely match model predictions [Figure 1: see original paper]. Adjacent rank levels show small differences in urban scale. The first discrete point on the coordinate graph fits well with the regression line, with a fractal dimension value of 0.754, indicating strong monopolization by the primate city. The double logarithmic scatter plot shows obvious subsidence of the second-rank city, with a four-city index value of $S_4 = 2, 3, 4 = 0.57$, indicating that upper-rank cities (urban rank i = 2, 3, 4) have relatively small scales. In terms of urban quantity structure, the extremely small number and low proportion of large cities represent a prominent problem in Xinjiang's urban scale structure, with only 2 cities accounting for 2.2% of the urban agglomeration. Medium-sized cities number 10, while small cities account for 86.8% of the total.

Urban scale distribution heterogeneity in Xinjiang is prominent from the perspective of urban population agglomeration. Cities with population density below 50 persons $\cdot$ km^{-2} number 79, covering 83.52% of the research area but accounting for only 48.45% of the total population, indicating generally low urban population density in Xinjiang. Only 7 cities have population density above 500 persons $\cdot$ km^{-2}, representing 0.07% of the area but 12.15% of the population, reflecting high population concentration in individual cities .

Lorenz curve analysis reveals significant curvature, indicating severe unevenness in Xinjiang's urban population distribution. Combined with analysis of cities with population density greater than 500 persons $\cdot$ km^{-2}, 11 county-level units show significant population agglomeration, representing only 1.10% of the area but 38.30% of the population, forming the urban core area of Xinjiang. When the cumulative population percentage reaches 80%, the cumulative area percentage is 35.45%, conforming to the "80-20 rule," with the corresponding urban population density being 100 persons $\cdot$ km^{-2}. When urban population density cumulative percentage reaches 50%, the cumulative area percentage is 17.76%, meaning only 17.76% of the area accommodates 64.55% of the population with density below 100 persons $\cdot$ km^{-2} [Figure 2: see original paper].

3.2 Correlation Analysis Between Urban Scale Distribution and Geomorphological Elements

Urban scale distribution in all six geomorphological type zones exhibits fractal characteristics [Figure 3: see original paper]. The double logarithmic model fit is relatively low for the Tianshan Mountains region, with a correlation coefficient of 0.582. Correlation coefficients for other geomorphological type zones range from 0.897 to 0.993, with fractal dimension values between 0.735 and 0.829 . All fractal dimension values are less than 1, indicating unbalanced distribution patterns across all zones except the Tarim Basin, which shows a weak dispersion pattern. The Tarim Basin has a fractal dimension value of 0.829, closest to 1, indicating its urban distribution basically conforms to Zipf's law with a relatively balanced urban scale distribution pattern, though its primate city is not prominent. The other five geomorphological type zones have fractal dimension values less than 0.8, showing significant fractal differences from the Tarim Basin urban agglomeration.

The Tianshan Mountains region shows the strongest primate city monopolization, with the starting discrete point far from the regression line in its double logarithmic plot, reflecting large differences in urban scale within the region and dispersed urban hierarchies. The number of cities distributed across geomorphological type zones varies considerably. The Tianshan Mountains region contains the most cities (36.26% of the total), while the Altai Mountains and Beita Mountain region contains only 4.40%. The Junggar Basin has the largest four-city index (0.88), indicating prominent dominance and strong monopolization by the primate city, Urumqi. The Junggar Basin also ranks first in primate city scale among all geomorphological types, showing obvious urban polarization effects.

Population distribution heterogeneity is pronounced across Xinjiang's geomorphological zones, with large inter-unit differences . Lorenz curve analysis for each geomorphological type zone reveals distinct population concentration-dispersion patterns, with two geographical units showing high population concentration [Figure 4: see original paper]. The Lorenz curves for the Tarim Basin and Junggar Basin show greater curvature than Xinjiang's overall population distribution Lorenz curve. When cumulative urban area percentage reaches 20%, the cumulative population percentage in these two geomorphological units exceeds 60%, highlighting prominent population agglomeration. Other geomorphological types show relatively gentle Lorenz curve curvature, closer to the central diagonal, reflecting more dispersed population distribution.

The Junggar Basin has the highest population density (247.62 persons $\cdot$ km^{-2}), serving as a population agglomeration center, while the Kunlun Mountains and Altun Mountains have the lowest (3.29 persons $\cdot$ km^{-2}), representing a sparse population distribution area. Based on population density, geomorphological type zones can be classified into three types: (1) High-density zones (>100 persons $\cdot$ km^{-2}) include the Junggar Basin, covering only 15.31% of the research area but containing 34.80% of Xinjiang's population, reflecting close coupling between natural geography and cities. (2) Medium-density zones (25-100 persons $\cdot$ km^{-2}) include the Junggar Western Mountains and Tianshan Mountains, accounting for 33.07% of the area but 36.64% of the population, showing relatively coordinated human-environment relationships. (3) Low-density zones (<25 persons $\cdot$ km^{-2}) include the Tarim Basin, Altai Mountains and Beita Mountain, and Kunlun Mountains and Altun Mountains, where urban scales are generally small.

3.3 Correlation Analysis Between Urban Scale Distribution and Water System Elements

Urban scale distribution across all seven water system partitions exhibits fractal characteristics, with good model fit [Figure 5: see original paper]. The Kunlun Mountains Northern Foothills Small Rivers District shows the best fit with a determination coefficient of 0.993, though its fractal dimension value of 0.829 indicates the primate city is not prominent. The Tarim River Source District contains the most cities (30.77% of the total), while the Central Asian Inland Rivers District and Tarim River Source District have low four-city indices (0.43 and 0.47 respectively), indicating small primate city scales and weak monopolization. The Tianshan Mountains Northern Foothills Rivers District has the largest four-city index (1.71), reflecting strong monopolization by its primate city.

Fractal dimension values vary significantly across water system partitions, showing obvious heterogeneity in urban system scale distribution among different regions. The Turpan-Hami Basin Small Rivers District and Tianshan Mountains Northern Foothills Rivers District show particularly prominent imbalance, with fractal dimension values of 0.735 and 0.741 respectively, indicating loose urban agglomeration hierarchical structures and large differences in city numbers across water system units. The Tianshan Mountains Northern Foothills Rivers District has a primate city scale far exceeding other partitions, with its double logarithmic plot showing the starting point far from the regression line. The Altai Mountains Southern Foothills Rivers District shows subsidence of the second-rank city, indicating a weak middle layer in its urban system.

Population density varies considerably among water system geographical units . The Tianshan Mountains Northern Foothills Rivers District has the highest population density (277.27 persons $\cdot$ km^{-2}), serving as a population agglomeration center, while the Kunlun Mountains Northern Foothills Small Rivers District has the lowest (3.29 persons $\cdot$ km^{-2}), representing a sparse population distribution area. Based on population density, water system partitions can be classified into three types: (1) High-density zones (>100 persons $\cdot$ km^{-2}) include the Central Asian Inland Rivers District and Tianshan Mountains Northern Foothills Rivers District, covering 15.31% of the research area but containing 55.49% of the population, reflecting abundant water resources suitable for human habitation. (2) Medium-density zones (25-100 persons $\cdot$ km^{-2}) include the Tarim River Mainstream District and Tarim River Source District, covering 34.43% of the area but 35.96% of the population, showing relatively balanced human-environment relationships. (3) Low-density zones (<25 persons $\cdot$ km^{-2}) include the Altai Mountains Southern Foothills Rivers District, Turpan-Hami Basin Small Rivers District, and Kunlun Mountains Northern Foothills Small Rivers District, covering 50.26% of the area but only 8.55% of the population, indicating sparse population distribution.

Lorenz curve analysis shows that water system partition units have relatively balanced population distribution patterns [Figure 6: see original paper]. The Tianshan Mountains Northern Foothills Rivers District's Lorenz curve most closely resembles Xinjiang's overall population distribution, with 50% of the area containing 80% of the population, indicating strong inter-city population distribution imbalance within the region. Other water system partitions show Lorenz curves closer to the central diagonal, reflecting more dispersed population distribution. Particularly, the Turpan-Hami Basin Small Rivers District's Lorenz curve is nearly parallel to the central diagonal, indicating relatively uniform inter-city population distribution.

Conclusions

4.1 Main Findings

(1) Urban scale distribution in Xinjiang exhibits fractal characteristics. The correlation coefficient for system scale distribution in geomorphological type zones is 0.897, while for water system partitions it is 0.951, indicating that urban scale patterns are more closely related to water system geographical factors. The Tarim Basin urban system shows a weak dispersion pattern, while fractal dimension values vary significantly across the seven water system partitions, showing obvious heterogeneity in urban system scale distribution, with particularly prominent imbalance in the Turpan-Hami Basin Small Rivers District and Tianshan Mountains Northern Foothills Rivers District.

(2) Xinjiang's urban scale system suffers from too few large cities and missing middle layers, indicating an immature urban system. The Junggar Basin and Tianshan Mountains Northern Foothills Rivers District are two prominent population agglomeration units that are also highly superimposed geographical type zones, representing spatial polarization areas combining urban scale and physical geography. Within geomorphological units, the Tianshan Mountains region shows relatively low double logarithmic model fit and weak primate city monopolization, while the Tarim Basin urban system has excessive lower hierarchies causing insufficient agglomeration support function. Within water system partitions, the Central Asian Inland Rivers District, Tarim River Mainstream District, and Kunlun Mountains Northern Foothills Small Rivers District show good double logarithmic model fit, while the Altai Mountains Southern Foothills Rivers District exhibits middle layer deficiency.

(3) The heterogeneity of urban population distribution across Xinjiang's physical geographical units is pronounced. The overall Lorenz curve shows severe curvature, substantially deviating from the central diagonal. Geomorphological type units display distinct population concentration-dispersion patterns, with high population agglomeration in the Tarim Basin and Junggar Basin. Water system partition units show relatively balanced pop-

ulation distribution, with high concentration in the Tianshan Mountains Northern Foothills Rivers District. Population density varies significantly between different natural geographical units.

4.2 Recommendations

The overall structural imbalance between urban scale and population distribution in Xinjiang represents a prominent problem in its urban scale system. Within natural geographical units, factors such as unbalanced regional industrial layout and uneven economic development have led to a widespread phenomenon of missing medium-sized cities and relative shrinkage of small cities. Additionally, the fractal dimension value of 0.754 for the seven water system partitions is smaller than Xinjiang's overall urban system fractal dimension value of 0.754, reflecting water resource shortages in the urban system. Addressing these issues, this study proposes the following optimization recommendations:

(1) Coordinate natural geographical regional system development during urbanization and improve urban scale hierarchical structures within natural geographical units. For example, support development of border areas such as Bole City, Wenquan County, and Alashankou City through policy measures, strengthen port economies, cultivate regional urban industrial structure advantages, and further optimize the urban hierarchical pattern of the Tianshan Mountains Northern Foothills Rivers District to achieve coordinated regional development.

(2) Actively cultivate medium-sized cities by selecting cities with good natural resource environments but lower rankings for development into medium-sized cities to enhance urban agglomeration support functions. For cities with low population density distributed in the Altai Mountains and Beita Mountain region, such as Fuyun County, Habahe County, and Qinghe County, strengthen support through innovative assistance models in education, technology, and talent, introduce population and industrial resources to promote economic improvement, and advance urban infrastructure construction to narrow the scale gap with medium-sized cities.

(3) Conduct heterogeneous research on urban scale and population distribution to achieve measurement and coordination of urban scale with urban development stages and patterns, thereby optimizing the combination of various "human" and "land" elements in cities. For instance, the Turpan-Hami Basin Small Rivers District should utilize geographical conditions to optimize regional spatial industrial structures, establish multiple small clusters within peripheral urban agglomerations according to their endowments to alleviate regional imbalances, promote economic exchanges between regions, and drive coordinated development of cities at all scales within the region.

The rationality of urban scale hierarchical structure directly affects urban agglomeration function and competitiveness. Influenced by multiple factors including geomorphological types and water system resources, urban scale development generally follows physical geographical structures. This analysis may have limitations in indicator selection for factors influencing Xinjiang's urban scale and population distribution. Future research could incorporate transportation networks, regional economies, and ecological resources to enhance heterogeneous studies of urban scale and population distribution, promoting overall optimization of the coordinated development between urban scale and physical geography and the human-environment system.

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