

Analysis of Infrastructure and Population Distribution - Taking Xiangtan as an Example

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Abstract:

This study systematically analyzes the characteristics and interrelationship between infrastructure and population distribution in Xiangtan. Utilizing Moran's I analysis and geographically weighted regression (GWR) methods, combined with multi-source data, the study reveals the spatial autocorrelation of infrastructure distribution and its impact on population distribution in Xiangtan. The results indicate a certain degree of spatial clustering of infrastructure, particularly in healthcare and commercial infrastructures, while the distribution of elderly care infrastructures is relatively dispersed. The GWR results show significant regional differences in the impact of infrastructure on population distribution, with a higher degree of matching in the eastern region compared to the western region. Based on these findings, the paper proposes policy recommendations to optimize infrastructure layout, enhance regional balanced development, and improve public service accessibility, all aimed at promoting the sustainable development of Xiangtan.

Keywords:

Infrastructure Layout, Population Distribution, Spatial Autocorrelation Analysis

1. Introduction

The term “infrastructure” primarily refers to the fundamental infrastructures and systems serving a country, city, or area, encompassing transportation, bridges, water resources, and other essential services [1]. As the foundation of urban development, infrastructure is crucial for the functioning and growth of cities. It includes transportation infrastructures like roads and bridges, utilities such as water, electricity, gas, and telecommunications, as well as public service infrastructures like healthcare, education, and cultural services. The development level and layout of infrastructure directly affect the quality of life for urban residents and significantly determine the city's attractiveness and competitiveness. Therefore, studying the relationship between infrastructure and population distribution holds both theoretical and practical significance.

Xiangtan, located in the central part of Hunan Province, China, is an important member of the Chang-Zhu-Tan urban agglomeration. With rapid economic development and ongoing urbanization, Xiangtan's infrastructure construction has achieved remarkable progress. Simultaneously, rapid population growth and migration have profoundly altered the city's population distribution patterns. How to scientifically and rationally plan and layout infrastructure to adapt to and guide population distribution is a crucial issue for Xiangtan's urban development.

Although substantial research has explored the impact of infrastructure on urban development, the specific interactions between infrastructure and population distribution in Xiangtan require further study. On the one hand, Xiangtan's geographical location, economic structure, and socio-cultural characteristics are unique, potentially leading to significant differences in its infrastructure development patterns and population distribution compared to other cities. On the other hand, the advancement of information technology and data science offers new possibilities for in-depth research through emerging data sources and analytical methods.

This paper aims to systematically analyze the characteristics and interrelationship between infrastructure and population distribution, using Xiangtan as a case study. Specifically, this study employs Moran's I analysis and geographically weighted regression (GWR) methods, integrated with multi-source data, to conduct a comprehensive empirical study of Xiangtan's infrastructure and population distribution. First, comprehensive infrastructure and population distribution data are collected from the Xiangtan Statistical Yearbook, urban planning bureau data, and remote sensing imagery combined with geographic information system (GIS) data. Next, cluster analysis identifies patterns of infrastructure and population distribution across different regions of Xiangtan. Finally, the GWR model is utilized to analyze the impact of infrastructure on population distribution and its spatial heterogeneity.

Through this research, the paper aims to uncover the intrinsic relationship between infrastructure and population distribution in Xiangtan, providing a scientific basis for urban planning and infrastructure development in the city. Additionally, it is hoped that this study will serve as a reference for similar research in other cities. Ultimately, the paper enriches the theoretical understanding of the relationship between infrastructure and population distribution while offering valuable policy recommendations for urban development.

2. Materials and Methods

2.1. Data Sources

To ascertain the current status of infrastructure and population distribution in Xiangtan, this study utilizes Points of Interest (POI) data and population data from 2020. The POI data is sourced from Guihuayun (<http://guihuayun.com/poi/>) [2], and the population data is from the Resource and Environmental Science Data Platform (<https://www.resdc.cn/DOI/DOI.aspx?DOIID=32>). The details of the data sources are shown in the table. The population and infrastructure data were aggregated to Xiangtan's administrative regions to facilitate subsequent spatial autocorrelation analysis and GWR. (Table 1)

Table 1. Data sources.

Data Name	Data Content	Data Precision	Data Source
POI	Parks, Healthcare Infrastructures, Commerce Infrastructures, Elderly Care Infrastructures	- -	http://guihuayun.com/poi/
Population	Population Count	1km	https://www.resdc.cn/DOI/DOI.aspx?DOIID=32

2.2. Moran's I Analysis

To determine the characteristics of infrastructure distribution and explore spatial autocorrelation [3], this study employs global Moran's I to analyze the clustering of infrastructure. Global Moran's I is used to explore the spatial clustering of infrastructure, while local Moran's I is utilized to identify localized spatial clusters or dispersions within the study area.

The global Moran's I statistic mainly represents the spatial autocorrelation of objects and can reveal the degree of correlation and spatial distribution characteristics within a study area [4]. The formula is as follows:

$$I = \frac{1}{D^2} \times \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (y_i - \bar{y})(y_j - \bar{y})}{\sum_{i=1}^n \sum_{j=1}^n W_{ij}} \quad (1)$$

Where y_i and y_j are the values of the attribute at locations i and j , $\bar{y}$ is the mean of the y_i ($i = 1, 2, \dots, n$) values, D^2 is the variance of y_i , W_{ij} is the spatial weight matrix. The global Moran's I value ranges from -1 to 1; higher absolute values indicate stronger clustering, with $I > 0$ indicating positive spatial correlation, $I < 0$ indicating negative spatial correlation, and $I = 0$ indicating no spatial autocorrelation (random distribution).

This study also uses the local indicator of spatial association (LISA) to analyze the spatial clustering patterns of infrastructure. LISA combines local Moran's I values with standardized test statistics to determine the autocorrelation level of infrastructure in each village. The calculation method for the standardized test statistic is as follows:

$$Z(I_i) = \frac{I_i - E(I_i)}{S(I_i)} \quad (2)$$

Where I_i is the local Moran's I value, $Z(I_i)$ is the standardized test statistic, $E(I_i)$ is the expected value, and $S(I_i)$ is the variance of I_i .

2.3. Geographically Weighted Regression (GWR)

Geographically weighted regression (GWR) is a regression method used to address spatial heterogeneity, effectively capturing local variation and heterogeneity in geographic space[5]. This study employs the GWR method to explore the impact of infrastructure on population distribution and spatial heterogeneity in Xiangtan. The calculation method is as follows:

$$Y_i = \alpha_0(u_i, v_i) + \sum_{k=1}^m \alpha_k(u_i, v_i) X_{ik} + \beta_i \quad (3)$$

Where Y_i is the i th infrastructure, $\alpha_0(u_i, v_i)$ is the intercept, X_{ik} is the k th explanatory variable in the i th infrastructure, (u_i, v_i) is the spatial coordinates of the infrastructure in the i th, $\alpha_k(u_i, v_i)$ is the regression coefficient of the k th explanatory variable in the i th infrastructure, m is the total number of explanatory variables, k is the ordinal number of the explanatory variables, and β_i is the random error. The

spatial weight matrix directly determines its regression coefficients in GWR use, while broadband strongly affects the spatial weight matrix.

3. Results and Discussion

3.1. Moran's I Analysis Results

To explore the spatial distribution characteristics of four types of infrastructure in Xiangtan, the number of infrastructures within each village boundary was counted, and Moran's I index was used for analysis. The global Moran's I values for parks, healthcare, commercial, and elderly care infrastructures were 0.04, 0.08, 0.11, and 0.03, respectively. Among the four types of infrastructure, healthcare and commercial infrastructures had a probability of random distribution of less than 1%, while elderly care infrastructures had a probability of random distribution of less than 10%, likely due to the relatively low overall number of elderly care infrastructures in Xiangtan. The LISA analysis results indicated that the northeast region of Xiangtan showed the most instances of high-high clustering, with other clustering patterns sparsely distributed across the region. Overall, these four types of infrastructure in Xiangtan exhibit slight clustering effects, with healthcare and commercial infrastructures being the most significantly clustered, and elderly care infrastructures the least. (Figure 1)

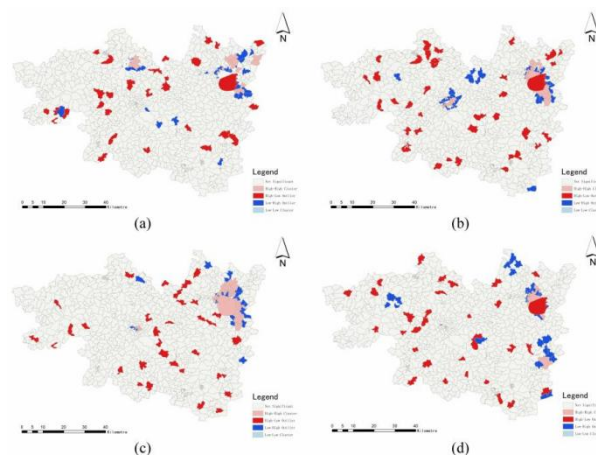


Figure 1. (a) Results of LISA analysis for parks; (b) Results of LISA analysis for healthcare infrastructures; (c) Results of LISA analysis for commercial infrastructures; (d) Results of LISA analysis for elderly care infrastructures.

3.2. Geographically Weighted Regression Results

This study used GWR with parks, healthcare infrastructures, commercial infrastructures, and elderly care infrastructures as independent variables and population as the dependent variable to explore the impact of infrastructure on population distribution. The resulting R^2 was 0.80. The closer R^2 is to 1, the better the model fit, indicating that these four types of infrastructure provide a good explanation for population distribution. In the GWR results (Figure 2), the local R^2 values are shown for each area, with redder areas indicating stronger explanatory power of the regression model, and bluer areas indicating weaker explanatory power. In the eastern region of Xiangtan, the R^2 value is higher and the fitting effect is good, while the western region shows the opposite trend. This is due to the fact that the overall development of the eastern part of Xiangtan is greater than that of the western part, and the amount as well as distribution of infrastructure is much greater than that of the western part, so the eastern region is better explained.

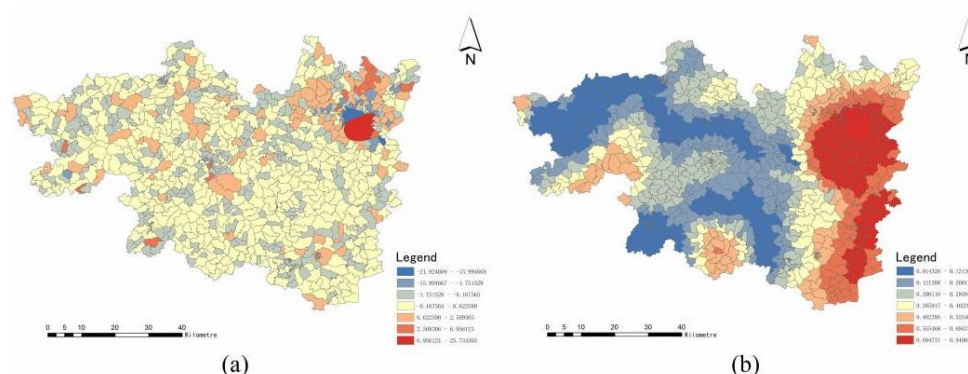


Figure 2. (a) *StdResid* results in GWR analysis; (b) R^2 results in GWR analysis.

3.3. Recommendations for Future Development in Xiangtan

(1) Optimize Infrastructure Layout to Enhance Regional Balance

To balance development between the eastern and western regions of Xiangtan, it is evident from the study that the infrastructure in the eastern region is better aligned with population distribution compared to the western region. This suggests that infrastructure development in the east has generally met the population needs, whereas the west still faces significant deficiencies. To promote balanced city-wide development, it is recommended to strengthen infrastructure construction in the western region, particularly in medical, commercial, and elderly care infrastructures, to improve its attractiveness and capacity.

Additionally, expanding the coverage of elderly care infrastructures and optimizing their spatial distribution is crucial [6]. The current distribution of these infrastructures in Xiangtan is relatively dispersed, with minimal clustering effects. This indicates that the number and distribution of elderly care infrastructures are insufficient to meet the needs of the aging population. Therefore, it is advisable for the government and planning departments to increase the construction of elderly care infrastructures in areas with a high elderly population but inadequate services, ensuring that the demands of an aging society are fully addressed.

(2) Refine Urban Planning to Improve Accessibility to Public Services

Enhancing the transportation network to improve access to public infrastructures is necessary. Although parks and medical infrastructures in Xiangtan exhibit some degree of clustering, some areas still face difficulties in accessing these services. Therefore, it is recommended to further develop and expand the urban transportation network, particularly public transportation systems, to enhance residents' access to these infrastructures. Additionally, constructing more regional parks and community medical centers could help alleviate the high concentration of existing infrastructures.

(3) Promote Integration of Industry and City to Drive Regional Coordination

Strengthening the functional layout of commercial infrastructures is essential. While commercial infrastructures in Xiangtan are notably concentrated, which reflects active commercial activities, this may lead to issues such as traffic congestion and uneven resource distribution. Hence, in planning commercial infrastructures, it is important to consider not only their economic benefits but also their coordination with surrounding areas to avoid problems related to over-concentration. Developing emerging commercial districts or multifunctional complexes that integrate

commercial, cultural, and recreational functions could facilitate industry-city integration and promote coordinated regional economic development.

(4) Guide Rational Population Movement to Promote Sustainable Urban Development

Tailoring infrastructure development to local conditions is crucial. The GWR analysis shows significant spatial variation in the impact of infrastructure on population distribution in Xiangtan. Therefore, it is recommended to consider the actual population distribution and development potential of different regions when planning and constructing infrastructure. For areas with high population density but insufficient infrastructure, increased investment is needed to improve residents' quality of life. Conversely, for sparsely populated areas, infrastructure investment should be moderated to guide population concentration towards central or more developed areas, thus preventing resource waste.

4. Conclusions

This study reveals the interrelationship between infrastructure and population distribution in Xiangtan and their spatial heterogeneity through the characterization of the two. The results show that the eastern region of Xiangtan has a better match between infrastructure and population distribution, and its development trend is better than that of the western region, which is deficient in medical, commercial and elderly infrastructures. The distribution of senior care infrastructures is relatively decentralized, failing to adequately meet the needs of the aging population. Although parks and medical infrastructures show some agglomeration, the accessibility of public services in some areas still needs to be improved. In addition, the over-concentration of commercial infrastructures may lead to traffic congestion and uneven distribution of resources. Therefore, it is recommended that Xiangtan should optimize its infrastructure layout in the future to enhance the development of the western region, improve public service accessibility, and promote coordinated regional economic development in order to achieve sustainable urban development.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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