Research on the Relationship Between Population and Urban Development in Jinan Based on Statistical Modeling

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Abstract. This study aims to explore the intrinsic relationship between population characteristics and urban development in Jinan. Based on census data, methods such as multiple linear regression, time series modeling, and spatial correlation analysis were employed to construct models for predicting total population, aging trends, and the relationship between population and economic public service spatial distribution. The findings reveal that Jinan's total population is growing steadily but at a slow pace, with the aging rate projected to reach 22.3% by 2030. The spatial distribution of the population shows significant correlations with economic development and public resource allocation. The research provides quantitative evidence for optimizing population management strategies and improving urban planning in Jinan, demonstrating the application value of statistical modeling in urban population and development studies.

Keywords: Census Data, Statistical Modeling, Aging, Urban Development Correlation.

1. Introduction

In the development of any city, population factors always play a central role. As the capital of Shandong Province and a core city in the Bohai Rim Economic Zone, Jinan is experiencing dual opportunities from new urbanization and regional coordinated development. The complex evolution of population dynamics poses multidimensional challenges to urban governance. In terms of resource allocation, the population density in the central urban area has reached 14,000 people per square kilometer, leading to an imbalance in the distribution of educational and medical resources, characterized by "overload in the center and scarcity in the periphery." In infrastructure, the daily passenger flow of rail transit has exceeded 600,000, highlighting issues with commuting efficiency and spatial layout. Public services face the dual challenge of surging "silver-haired demands" and the developmental needs of the younger population. Under the "Strong Provincial Capital" strategy, Jinan bears the strategic mission of building a central city in the Yellow River Basin and creating a regional talent hub, necessitating accurate population development prediction models to support urban planning.

In studies on the relationship between population aging and economic development, Zhang Wei used a panel data model to indicate that aging has a "U-shaped curve" effect on regional economic growth, but the unique geographical characteristics of Jinan as a central city in the Yellow River Basin were not fully considered [1]. Regarding urban planning and age-friendly facility design, Green proposed that urban planners should fully account for the characteristics of the elderly and rationally allocate public facilities [2]. In terms of the construction of elderly-friendly communities, Li et al. established an evaluation index system covering medical care, transportation, and cultural services through a combination of Delphi method and analytic hierarchy process, and verified its applicability in eastern coastal cities [3]. However, this system rarely involves the adaptation of evaluation indicators to the industrial structure characteristics of inland central cities like Jinan, making it difficult to directly reflect the specific needs of the elderly groups in such regions in the process of urban development. At the same time, existing research lacks quantitative assessments of the impact of universal cultural advancement on various indicators of elderly-friendly city construction.

In summary, this study aims to analyze Jinan's census data, using statistical modeling to examine trends in total population, age structure, and gender composition, and to quantify the interactive relationship between population and economic development, public service allocation, and urban spatial layout. The findings will provide data support and decision-making basis for Jinan's population policies and urban planning optimization.

2. Materials and Methods

2.1. Data Collection and Processing

The data for this study were sourced from the Jinan municipal government portal, civil affairs bureau, and statistical bureau, including census reports, statistical yearbooks, and elderly care service development reports from 2020 to 2024. The data covered total population, structure, GDP, natural population growth rate, and other indicators. Methods such as literature review, interviews, and field observations were also used to collect data. The Jinan municipal government portal data was retrieved from (http://www.jinan.gov.cn/), where various official announcements and data releases are available.

Data cleaning and standardization were performed to improve quality. For anomalies in time-series data like total population and GDP, adjustments were made based on social-economic events (e.g., policy changes or public health emergencies) [4-7]. Inexplicable outliers were removed to avoid distorting model results. For missing age data in census records, the KNN algorithm was used for imputation, with gender, household registration type, and education level as feature variables [8]. The imputed age structure deviated by less than 2% from official statistics, meeting analysis requirements. Data with over 40% missing values (e.g., quarterly population mobility for certain townships) were excluded as they could not be reasonably estimated, without affecting overall regional trends.

2.2. Methodology

This study employed a variety of statistical analysis and modeling techniques, following a logical framework of "data processing → descriptive analysis → inferential modeling → spatial correlation mining." Methods were selected based on research objectives (e.g., total population prediction, aging trend analysis, and population-economy correlation validation) to form a complete analytical system. Multiple linear regression was used to explore linear relationships between one dependent variable (e.g., total population) and multiple independent variables (e.g., GDP growth rate, natural population growth rate, and migration). Spatial correlation models were applied to examine relationships between population distribution and public service resources (e.g., education and medical facilities). For example, public service accessibility was modeled as the dependent variable, with population density, aging rate, and distance from the city center as independent variables.

3. Model Construction and Solutions

3.1. Correlation Analysis of Rural Residents' Living Conditions

Using Jinan's statistical yearbook data, a correlation coefficient matrix heatmap (Figure 1) was generated. It revealed a strong positive correlation between rural residents' per capita disposable income and housing area (Pearson coefficient close to 1), providing insights into living standards and policy formulation. Figure 1 virtually presents the correlation between two variables: rural residents' per capita disposable income and per capita housing area, using data from Jinan's statistical yearbook. The heatmap shows a strong positive correlation (with a Pearson coefficient of 0.87) between these two variables, indicating that as one increases, the other tends to increase as well. The color - coding (from dark red for a correlation of 1 to blue for lower correlations) helps to easily identify the strength of the correlation, providing insights into living standards and policy formulation.

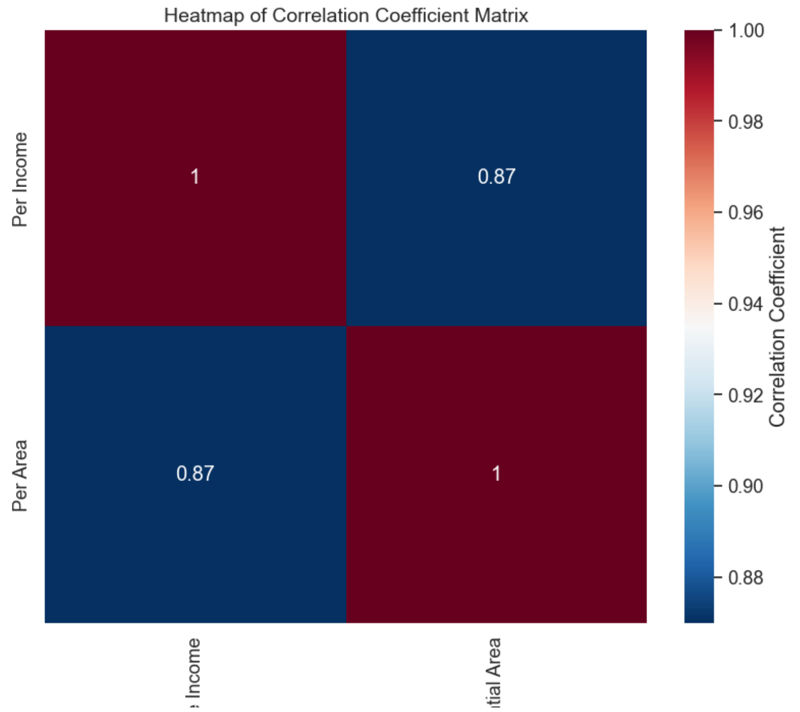

Figure 1. Correlation coefficient matrix heatmap.

3.2. Population Analysis and Model Predictions

3.2.1. Total Population Prediction Model

A multiple linear regression model was used to predict Jinan's total population, accounting for economic, social, and policy factors [9]. Time series analysis was applied to enhance prediction accuracy. Figure 2 shows the growth trends of different industries, with the secondary industry exhibition higher growth rates in certain value-added intervals.

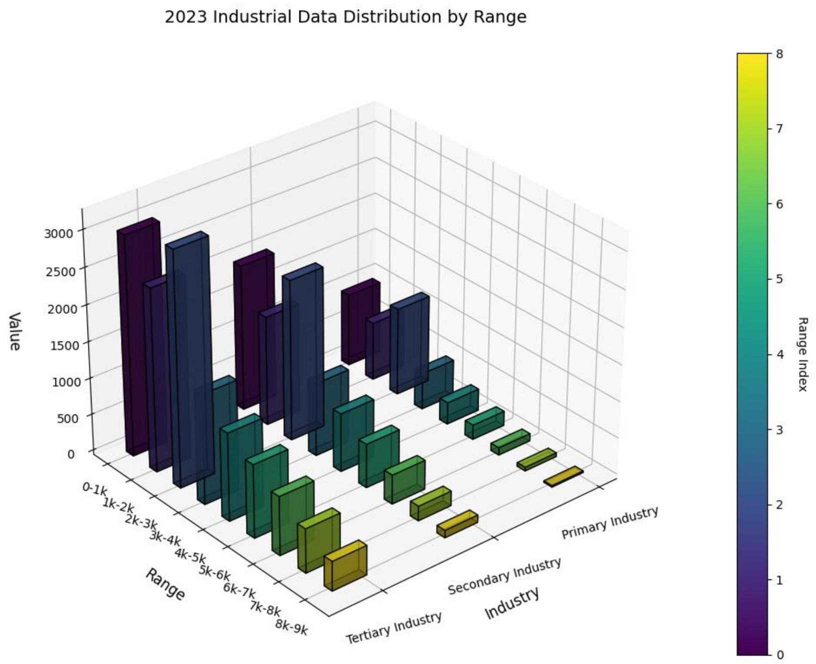

Figure 2. 3D spatial graph of industry value-added and growth rates.

3.2.2. Age Structure and Aging Trend Prediction

Shanghe County had the highest aging rate (21.3%), significantly exceeding the central urban areas (e.g., Lixia District at 15.2%) and the citywide average (16.7%). Figures 3 and 4 illustrate the aging rate comparisons and population age pyramid for Jinan in 2020. Figure 3 is a bar chart titled “Comparison of Aging Rates in Districts of Jinan (2020)”. It visually compares the aging rates (percentage of elderly population) across different districts in Jinan. Each blue bar represents a district's aging rate, while Shanghe County stands out with a red bar, having the highest aging rate of 21.3%. Other districts, like Lixia District (15.2%) and others shown, have relatively lower rates, clearly illustrating the significant difference in aging levels among Jinan's districts. Figure 4 is a population age pyramid of Jinan in 2020. It shows the population proportion (%) distribution across different age groups for males (blue) and females (orange). The pyramid shape reflects the population structure, with younger age groups (e.g., 0-4, 5-9) having certain proportions, and older age groups (e.g., 80-84, 85+) showing their respective population shares, helping to visualize Jinan's demographic composition by age and gender in that year.

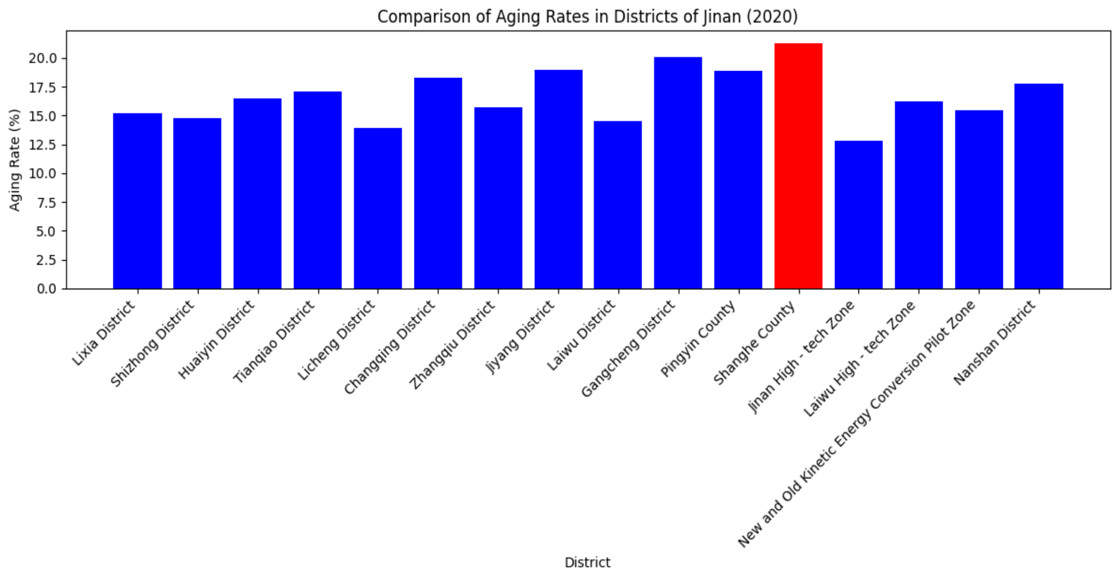

Figure 3. Comparison of aging rates across Jinan's districts.

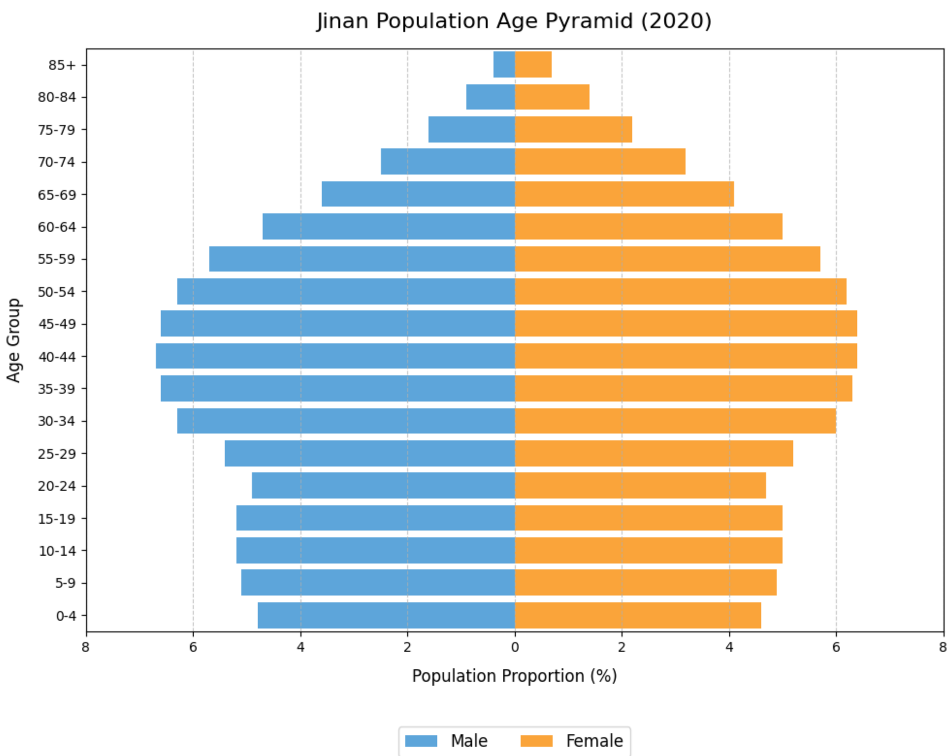

Figure 4. Population age pyramid of Jinan (2020).

3.3. Population and Jinan's Development

3.3.1. Population and Economic Development

(1) Population and GDP Growth

Multiple linear regression showed a significant positive correlation between population size and GDP growth. By 2023, Jinan's permanent population exceeded 9.2 million, with the tertiary sector contributing 62.8% to GDP (801.59 billion CNY), highlighting population-driven economic growth.

(2) Aging Population

By 2030, Jinan's elderly population (65+) will exceed 22%, with a dependency ratio of 38.6%. This trend will spur growth in elderly care industries but may cause labor shortages in manufacturing. Strategies like "smart transformation + elderly workforce development" (e.g., a pilot program in Laiwu District) are recommended to mitigate these challenges [10, 11].

3.3.2. Population and Public Services

(1) Education Resources

Spatial auto correlation analysis (Moran’s I = 0.34, p = 0.02) revealed that central districts (e.g., Lixia and Shizhong) had overlapping high population density and education resources, while peripheral areas (e.g., Jiyang and Shanghe) had only 60% of central resources per student. A "prestigious school trusteeship" model was proposed to bridge this gap.

(2) Healthcare Resources

By 2030, Jinan's elderly chronic disease patients will increase to 890,000, requiring 12,000 additional geriatric beds (95% CI).

$$A_i = \sum_{j=1}^{n} \frac{S_j}{\sum_{k=1}^{m} P_k \cdot f(d_{kj})} \cdot f(d_{ij}) \tag{1}$$

Explanation: A_i represents the accessibility of region i, S_j represents the capacity of medical facilities, P_k represents the demand population, and $f(d_{kj})$ represents the distance decay function. d_{ij} represents the index of the "distance" or "interaction resistance" between the i-th object and the j-th object. This formula can help evaluate the spatial accessibility of public service facilities (such as hospitals, schools, etc.) and can convert the abstract concept of “service equity” into a quantifiable indicator. Spatial accessibility calculations showed that elderly residents in Pingyin County faced 3.5 times longer travel times to the nearest hospital compared to Lixia District (52 vs. 15 minutes). Solutions included adding nursing beds in high-aging areas and promoting remote monitoring systems.

(3) Population and Urban Spatial Layout

Jinan's monocentric spatial layout (e.g., Lixia and Shizhong Districts hosting 38% of jobs but only 9% of land area) led to severe commuting pressures (e.g., 120% subway capacity during rush hours). A spatial decay model (Equation 2) indicated a low-density gradient coefficient (β = 0.15 vs. Beijing’s 0.21), suggesting the need for TOD (Transit-Oriented Development) strategies. Proposed measures included:

(1) Adding a "smart manufacturing industrial park" in Zhangqiu District to increase local employment to 70% by 2030.

(2) Planning the S3 rail line (Zhangqiu-CBD) to reduce cross-district commuting by 15%.

(3) Developing a "Silver Navigation" app to prioritize barrier-free routes for the elderly.

4. Conclusions

This study used statistical modeling to reveal multidimensional relationships between population and urban development in Jinan. Key findings include steady but slow population growth, a projected 22.3% aging rate by 2030, significant spatial disparities in public resource allocation, and a strong positive correlation between population size and economic growth. Recommendations include optimizing population policies, promoting smart transformation, developing elderly workforce potential, and adjusting public service layouts based on population forecasts. Limitations include the model's reliance on static census data, which may not fully capture real-time population mobility (e.g., short-term migration, seasonal labor flows). Future research could integrate dynamic datasets such as mobile phone signaling or transportation card records to refine spatial-temporal analyses of population distribution. Additionally, qualitative studies (e.g., in-depth interviews with elderly residents in high-aging districts) could complement quantitative findings, providing richer insights into the practical needs behind the data.

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