

Article

Analysis of the Coordination of Built-Up Area Expansion and Population Growth in the Shandong Peninsula Urban Agglomeration

Fang Pan ¹, Yingjun Sun ^{1,*}, Na Jiang ², Zhen Jian ¹, Yuang Mei ¹ and Qinghao Liu ¹¹ College of Surveying and Mapping Geo-Informatics, Shandong Jianzhu University, Jinan 250101, China² Shandong Provincial Institute of Land Surveying and Mapping, Jinan 250102, China

* Correspondence: sunyingjungis@sdjzu.edu.cn; Tel.: +86-186-0531-7380

Abstract: Exploring the coordinated relationship between built-up area expansion and population growth in the urbanization process is important for the planning and sustainable development of cities. The article took Shandong Peninsula urban agglomeration as the study area, which was divided into the Provincial Capital Economic Circle, Jiaodong Economic Circle, and Lunan Economic Circle according to the plan named the Implementation Plan for Implementing the Opinions of the CPC Central Committee and the State Council on Establishing a New Mechanism for More Effective Regional Co-ordinated Development. The people–land coordination relationship in the region was analyzed from the perspective of spatio-temporal integration through indices such as fractal dimension, spatial autocorrelation, population sprawl, and city land expansion and population growth coordination index (CPI). The results showed that (1) the relationship between built-up area expansion and population growth in the Shandong Peninsula urban agglomeration was uncoordinated. The three economic circles mainly changed from rapid population growth to significant expansion of built-up areas. (2) The development patterns of the three economic circles were different. The Provincial Capital and Jiaodong showed a pattern with Jinan and Qingdao as the core, driving the periphery area. Lunan showed a multi-point scattered development; there was no central city, but Linyi City was developing faster. (3) Jiaodong had the biggest changes in terms of population and built-up area. This study provides a scientific reference for the urban planning and sustainable development of the Shandong Peninsula urban agglomeration.



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Keywords: built-up area expansion; population growth; coordination; people–land relationship; Shandong Peninsula urban agglomeration

1. Introduction

Urban agglomerations are highly integrated urban assemblages that have emerged as an inevitable product of the advanced stage of urbanization and industrialization of China's economy. They have driven China's economic growth and assumed responsibility as the center of economic gravity [1,2]. The continuous expansion of built-up areas and population growth in urban agglomerations brought enormous benefits to urban development, such as promoting the creation of metropolitan areas, driving economic development [3], contributing to the development of new-type urbanization, and taking urbanization to a new level [4]. However, they also inevitably led to many urban problems. The uncontrolled expansion of built-up areas affected the efficiency of construction land use as well as sustainable urban development, such as the emergence of urban sprawl or the decline of urban ecosystem services [5–8]. Population growth and migration have led to problems such as “empty cities” and serious human interference with urban ecology [5,6]. At the same time, the coordination of the growth rates of built-up areas and population numbers has an important impact on urban development [7]. Therefore, studying the coordination of built-up area expansion and population growth could provide scientific suggestions for urban planning and high-quality sustainable and coordinated development.

The coordination of built-up area expansion and population growth has previously been studied by many scholars. Brueckner argued through his study that exogenous variables such as increasing population size, income growth, and increasing transportation costs were the basic factors of the spatial expansion of towns and cities [8]. Pacione considered urban population increase as the main driver of urban expansion [9]. Zhu and others analyzed the people–land coordination in the Yellow River Delta using the coupled method of human activity intensity and ecological carrying capacity [10]. Feng and others studied the development of population and land coordination in Jiangxi province using an improved coordination index [11]. Huang and others examined the coordination of people and land in Foshan City using night-light remote sensing data and applying the urban center offset index [12]. Based on the theory of coordinated regional PRED (population, resources, environment, development) development, Li and others used methods such as geographically weighted regression models to dissect the spatial and temporal evolution of coordinated people-land quality development and its influencing factors in the Yellow River Basin from 2010 to 2019 [13]. Chen and others analyzed the anisotropic growth of urban population and urban land with the help of least squares and log-linear regression analysis techniques based on the census data of Xinyang and the information from the urban land status map [14]. In summary, fewer studies have focused their approach to people–land coherence directly on the two indices of built-up area and population and the coordination relationship between them. Even if they did focus on the above aspects, the methodology used is rather unitary. Therefore, it is worthwhile to investigate how to directly detect changes in the two and how they are coordinated or not.

The ecological protection and high-quality development of the Yellow River basin is a major national strategy [15,16], and the Shandong Peninsula urban agglomeration is located on the lower reaches of the Yellow River. The Shandong Peninsula urban agglomeration, which started earlier and developed faster, is one of the national key city clusters to be built during the 13th Five-Year Plan period [17]. The Provincial Capital, Jiaodong, and Lunan, formed by the Shandong Peninsula urban agglomeration, play important roles in the economic and urban high-quality development of the lower reaches of the Yellow River. According to the Statistical Bulletin of National Economic and Social Development of Shandong Province in 2022 and the Report on the Work of the Shandong Provincial Government in 2023, the total population of the Shandong Peninsula urban agglomeration had decreased slightly. However, the economy of the Shandong Peninsula urban agglomeration had improved steadily, with the province's gross domestic product (GDP) reaching 873.51 billion yuan and the built-up area expanding rapidly [18,19]. It can be seen that the built-up area of the study area increased while the number of the population decreased. The inconsistency between the two factors had negatively affected the planning and sustainable development of the Shandong Peninsula urban agglomeration. Current studies on the coordination of the Shandong Peninsula urban agglomeration include exploring the relationship between built-up environment quality (Qu) and environmental pressure (Pu) and seeking to establish a spatio-temporal coupled coordinated development model of the urban environment. The results showed that the coupling coordination between Qu and Pu was gradually becoming better between 2008 and 2017, and the coupling coordination degree of coastal cities was significantly better than that of inland cities [20]. Someone used a system of six environmental, social, economic, demographic, production, and living indicators to assess the coupled coordination between public demand and government supply for urban green growth (UGG). They found that the coordination between public demand for UGG and political supply was relatively qualified, but there were also differences in coordination degrees between regions [21]. Additionally, some people identified the dynamic mechanism and spatial and temporal distribution of the coupling coordination between high-quality urbanization (HQU) and ecological environmental quality (EEQ). They concluded that the coupling coordination between HQU and EEQ was increasing in 2001–2020 [22].

In summary, more studies have analyzed the coordination of the Shandong Peninsula urban agglomeration with respect to different factors and different research scales. These studies had important implications for the urbanization and urban ecology of the Shandong Peninsula urban agglomeration. However, fewer studies had analyzed the coordination of development of Shandong Peninsula urban agglomeration from the perspective of two factors: built-up area expansion and population growth. Additionally, fewer studies had been conducted at the scale of the three economic circles.

To address the above issues, this study used built-up area datasets, population density, and other data. The study analyzed the spatial and temporal changes of built-up areas and population and the coordination between built-up area expansion and population growth. The study integrated several index models and is based on newer research scales. It can provide suggestions for the high-quality and sustainable development of people–land coordination in the Shandong Peninsula urban agglomeration and for the Shandong section of the lower Yellow River urban planning and development.

2. Materials and Methods

2.1. Study Area

Shandong Peninsula is the largest peninsula in China, and the Shandong Peninsula urban agglomeration covers all cities in Shandong province. It is located on the eastern coast of China between $34^{\circ}22.9'$ and $38^{\circ}24.01'$ N and between $114^{\circ}47.5'$ and $122^{\circ}42.3'$ E; is adjacent to Beijing, Tianjin, and Hebei Province in the north; is connected to the Yangtze River Delta in the south; is east of Japan, with South Korea and North Korea across the sea; is west of the Yellow River Basin; is in China's Bohai Sea region; and is in China's front line of regional cooperation in Northeast Asia. It has a large total population, a strong industrial base, a relatively complete urban system, and a well-developed comprehensive transportation network. Under the advancement of China's economic spatial structure change and urban renewal, the development of individual cities is limited, and central cities and urban agglomerations are becoming the main spatial forms to support development. In 2020, the Shandong Provincial Party Committee and the Provincial Government issued the Implementation Plan for Implementing the Opinions of the CPC Central Committee and the State Council on Establishing a New Mechanism for More Effective Regional Coordinated Development. The document clearly put forward the implementation of the regional development strategy of the three major economic circles of the Provincial Capital, Jiaodong, and Lunan and promoted the formation of a new pattern of regional integration development in the province. The distribution of the three economic circles is shown in Figure 1. Thus, the proposal and development of the three economic circles of the Shandong Peninsula urban agglomeration is of great significance to promote its economic regional integration and high-quality development of the lower reaches of the Yellow River.

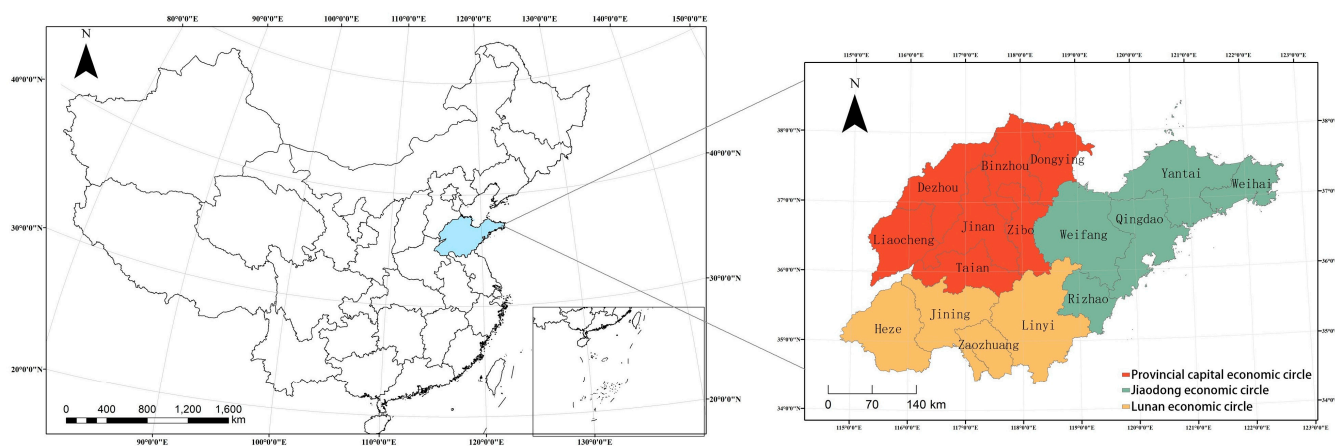


Figure 1. Geographical location of Shandong Peninsula urban agglomeration.

2.2. Data

This study was based on three periods of experimental data in 2000, 2010, and 2020. These include the Chinese built-up area dataset developed by Sun and others (<https://www.scidb.cn/detail?dataSetId=717696607260246016>) (accessed on 6 April 2023), (<https://www.scidb.cn/detail?dataSetId=5876ca6bf2064a9f9b8d4b092a7a7ba9>) (accessed on 6 April 2023). The datasets were extracted from multi-source remote sensing data, and vectorized data were provided. The spatial resolution for the 2000 and 2010 datasets is 30 m. The spatial resolution for the 2020 dataset is 10 m [23,24]. We used the 2000 and 2010 datasets and resampled the 2020 dataset to achieve the same spatial resolution (Table 1). The datasets of the three phases were selected from 600–800 validation points for accuracy assessment, and the three overall accuracies were greater than 88%, and the three Kappa coefficient were greater than 0.86. The data accuracy met the research requirements. Population density data at 100 m × 100 m spatial resolution in China (<https://hub.worldpop.org/>) (accessed on 6 April 2023), administrative division data of Shandong Province (<https://www.gscloud.cn/>) (accessed on 6 April 2023), the Statistical Yearbook of Urban Construction in China (<https://www.mohurd.gov.cn/gongkai/fdzdgnr/sjfb/index.html>) (accessed on 6 April 2023), the Statistical Yearbook of Shandong Province (<http://tjj.shandong.gov.cn/col/col6279/index.html>) (accessed on 6 April 2023), and the Statistical Yearbooks of prefecture-level cities in Shandong Province (Table 1).

Table 1. Data description.

Data	Spatial Resolution	Time Coverage	Spatial Scope	Data Types	Data Sources
Built-up area dataset (1990–2015)	30 m	1990–2015	China	vector	https://www.scidb.cn/detail?dataSetId=717696607260246016 (accessed on 6 April 2023)
Built-up area dataset of 2020	10 m	2020	China	vector	https://www.scidb.cn/detail?dataSetId=5876ca6bf2064a9f9b8d4b092a7a7ba9 (accessed on 6 April 2023)
Population counts	100 m	2000–2020	China	raster	https://hub.worldpop.org/geodata/listing?id=69 (accessed on 6 April 2023)
Administrative district boundaries	/	/	China	vector	https://www.gscloud.cn/ (accessed on 6 April 2023)
The Statistical data	/	/	China	Population size/economic data	https://www.mohurd.gov.cn/gongkai/fdzdgnr/sjfb/index.html ; http://tjj.shandong.gov.cn/col/col6279/index.html (accessed on 6 April 2023)

2.3. Methods

This study analyzed the people–land coordination of the Shandong Peninsula urban agglomeration using multi-scale and multi-perspective analysis method (Figure 2). Firstly, the built-up area part that was needed for each type of data was extracted. In the methodological approach, (1) the expansion changes of the built-up areas in the study area were analyzed using index models such as fractal dimension, compactness, and spatial autocorrelation. The fractal dimension index and the compactness index are a complete analysis of the development changes in the built-up area of the city from the morphology of the boundaries and the interior of the built-up. Spatial autocorrelation analysis can analyze the correlation between the spatial distribution of built-up areas to obtain a more detailed information about the spatial relationship of built-up area expansion. (2) The population changes in the study area were calculated using population size and population sprawl index. (3) Analysis of the people–land coordination of the Shandong Peninsula urban agglomeration used an improved people–land coordination index in combination with changes in built-up areas and population.

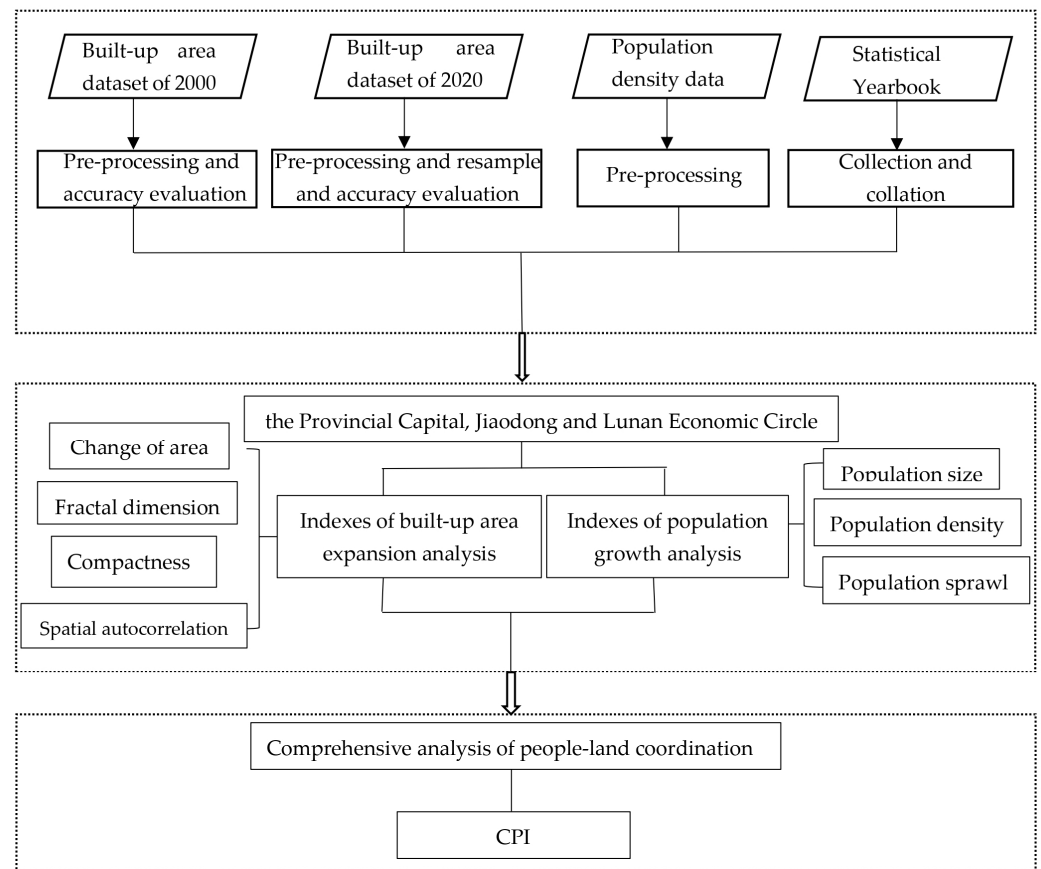


Figure 2. Method Flowchart.

2.3.1. Changes of Urban Built-Up Areas

The expansion changes to built-up areas were analyzed from the perspective of built-up area morphology and spatial distribution.

(1) The urban land fractal dimension index indicates the curvature and complexity of urban contour and reflects the degree of variation in the shape of urban built-up area boundaries [25]. The fractal dimension can be used to calculate the degree of urban spread (fragmentation and complexity), and the index refers to the proportional relationship between perimeter and area [26]. Its mathematical expression is as follows:

$$F_t = \frac{2\ln\left(\frac{L_t}{4}\right)}{\ln(A_t)}, \quad (1)$$

where F_t is the fractal dimension index of the built-up area, L_t is the perimeter of the built-up area boundaries, and A_t is the area of the built-up area. In the study, the fractal dimension index was calculated and analyzed for the built-up areas in the three economic circles of Shandong Peninsula to reflect the development of urban expansion. The theoretical value of the fractal index was between 1 and 2, and the larger the value, the more complicated the boundary of the city, and the more chaotic the urban form. When $F_t < 1.5$, the boundaries of the city are simple and planned, and the urban land is compact. When $F_t = 1.5$, the boundary of the city was in random motion, and when $F_t > 1.5$, the boundary of the city tended to be complicated and less stable.

(2) The urban compactness index can reflect the integrity and aggregation of urban built-up areas and can be used in the analysis of the internal patches of an urban area [27].

The index is a proportional relationship between the area of a patch and its perimeter. Its mathematical expression is as follows:

$$CI_t = \frac{2\sqrt{\pi A_t}}{P_t}, \quad (2)$$

where CI_t is the compactness index, A_t is the area of built-up area patch, and P_t is the perimeter of built-up area patch. The value of the compactness index was between 0 and 1. A more circular shape had a larger value and reflected a more compact city, while when the value tended towards 0, the city was more scattered.

(3) Spatial autocorrelation is a spatial statistical analysis method that can be used to measure the correlation of a certain geographical phenomenon at a location or the value of an attribute with the same phenomenon or attribute value in a nearby location. Its spatial distribution characteristics can be measured by the global and local metrics of spatial autocorrelation [28]. The global autocorrelation coefficient is used to verify the spatial pattern and to measure the distribution or concentration of attribute values across the study area. The autocorrelation coefficient chosen for this study was Moran's I index. Its mathematical expression is as follows:

$$\text{Moran's I} = \frac{N \sum_{i=1}^N \sum_{j=1}^N W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\left(\sum_{i=1}^N \sum_{j=1}^N W_{ij} \right) (X_i - \bar{X})^2}. \quad (3)$$

In the study, a 1 km × 1 km fishnet was created for the built-up area of each of the three economic circles, and each grid cell was used as a sub-area to calculate the proportion of built-up land in that sub-area. GeoDa (<http://geodacenter.github.io/index-cn.html>) (accessed on 10 April 2023) was used for correlation analysis to reflect the distribution of urban built-up area. The values of Moran's I index ranged from −1 to 1, and features greater than 0 showed a positive correlation.

2.3.2. Changes of Urban Population

The population change of the Shandong Peninsula urban agglomeration was analyzed from two aspects: population size and population sprawl index. The population sprawl index integrated the changes of both urban population and urban land and considered the density distribution structure within the city [29], which reflected the balance between population and land. The index used the value of the functional relationship between the respective land area occupied by the high-density population and the low-density population. Its mathematical expression is as follows:

$$SA_i = 0.5 \times (LA_i - HA_i) + 0.5, \quad (4)$$

where SA_i is the urban population sprawl index in period i , and LA_i is the ratio of the area of low-density population to the total built-up area of the city in period i . HA_i is the ratio of the area of high-density population to the total built-up area of the city in period i . The low-density population area in a city in period i refers to an area where the population density is lower than the national urban average, and the opposite is true for the high-density population area. A higher value of the sprawl index indicates a more severe population sprawl.

2.3.3. Analysis of People–Land Coordination

The coordination of people–land was analyzed comprehensively by combining the expansion of built-up areas and the change of urban population. The traditional elasticity index is used to reflect the coordination relationship between people and land. It refers to the proportional relationship between the rate of expansion of built-up areas and the rate of population growth [30]. However, it does not clearly reflect the amount of built-up area

per capita in a city, nor does it objectively reflect the coordination between built-up areas expansion and population growth. Thus, CPI was introduced [31]. In the calculation of CPI, the area of built-up area was used for the experimental data mentioned above, and the population of the main city was used for this study. Population data were obtained from the *China Statistical Yearbook of Urban Construction*, the *Shandong Statistical Yearbook*, and the Statistical Yearbooks of each city in Shandong Peninsula urban agglomeration. Its mathematical expression is as follows:

$$CPI = \frac{CR_I}{PR_I} \times R \quad (5)$$

$$R = \frac{LP_t}{LPI_t} / \frac{LP_0}{LPI_0} \quad (6)$$

where CPI is the index of coordination between built-up area expansion and population growth, CR_I and PR_I are the average annual growth rates of built-up area and population, respectively, R is the per capita built-up area constraint coefficient, and LP_0 and LP_t are the per capita built-up area of a city in the base year and the target year, respectively. LPI_0 and LPI_t are the ideal built-up area per capita of the category of cities to which the city belongs in the base year and the target year, respectively. According to the document *Building Climate Zoning Standards* (GB50178-93) [32] (<https://max.book118.com/html/2019/1210/5301000240002210.shtm>) (accessed on 10 April 2023), Shandong Province was sub-district II. The population and per capita built-up area of the three economic circles exceeded the highest values in the standard by consulting *Urban Land Classification and Planning Construction Land Standard* (GB50137-2011) [33] (<https://max.book118.com/html/2016/0228/36307681.shtm>) (accessed on 10 April 2023). According to the official documents issued by *General Office of the State Council of the People's Republic of China*, such as the *Regulations on Urban Planning* and the *Notice on Adjusting the Criteria of Urban Scale Classification*, the prefecture-level cities in Shandong Peninsula urban agglomeration were divided into different urban scales between 2000 and 2020. Combined with the results of other studies, this study selected 95, 100, and 105 m², respectively, as ideal built-up area per capita for mega-cities, large cities, and medium cities between 2000 and 2020. Table 2 shows the grading criteria of coordination between built-up area expansion and population growth [30].

Table 2. Grading criteria for coordination between built-up area expansion and population growth.

Type	Level	Standard	Features
Rapid land expansion	Significant land expansion	$CPI > 1.7$	Land expansion in built-up areas is much higher than population growth rate, resulting in a significant increase in per capita land use.
	Obvious land expansion	$1.3 < CPI \leq 1.7$	The land expansion in built-up areas is higher than the population growth rate, resulting in an obvious increasing trend of per capita land use.
Basic coordination between man and land	Basic coordination between man and land	$0.9 < CPI \leq 1.3$	Land expansion and population growth in built-up areas are basically the same speed, and the relationship between them is basically coordinated, with little change in per capita land use
Rapid population growth	Significant population growth	$0 \leq CPI \leq 0.5$	The land expansion in built-up areas is far lower than the population growth rate, resulting in a significant trend of decreasing per capita land use.
	Obvious population growth	$0.5 < CPI \leq 0.9$	The land expansion in built-up areas is lower than the population growth rate, resulting in an obvious trend of decreasing per capita land use.
Population and land shrink	Population and land shrink	$CPI < 0$ or $CPI > 0$ $CRI < 0$ & $PR_I < 0$	The number of land and population in built-up areas decreases at the same time or one of them decreases; the population emigration is greater than the population emigration, and the scale of land use or population in built-up areas decreases.

3. Results

3.1. Expansion of Urban Built-Up Area

Between 2000 and 2020, the built-up area of the Shandong Peninsula urban agglomeration increased significantly. The boundaries of the built-up area are gradually becoming more complex but are still relatively regular. The built-up area patches within the boundaries were more dispersed, with the Provincial Capital and Jiaodong becoming more dispersed and Lunan becoming more compact. From the spatial perspective, the aggregation of built-up areas with the same attributes in the three economic circles was not high, and they were still at the stage of urban agglomeration of development.

According to the statistical results for the built-up area, the size of the built-up areas in the three major economic zones increased year by year. The morphology of the built-up areas showed that outward expansion and internal filling of built-up areas were being carried out simultaneously (Figure 3). The specific values of the built-up area in the three major economic circles were obtained using spatial statistics for each year (Table 3). Jiaodong had the largest increase in area of 1902.835 km² between 2000 and 2020, and it also had the largest built-up area among the three economic circles. The Provincial Capital had the second largest built-up area and the second largest growth area, with an increase of 1242.447 km². Lunan had the smallest increase of 950.911 km². Among the three economic circles, Jinan City, Qingdao City, and Linyi City experienced the greatest increase in built-up area.

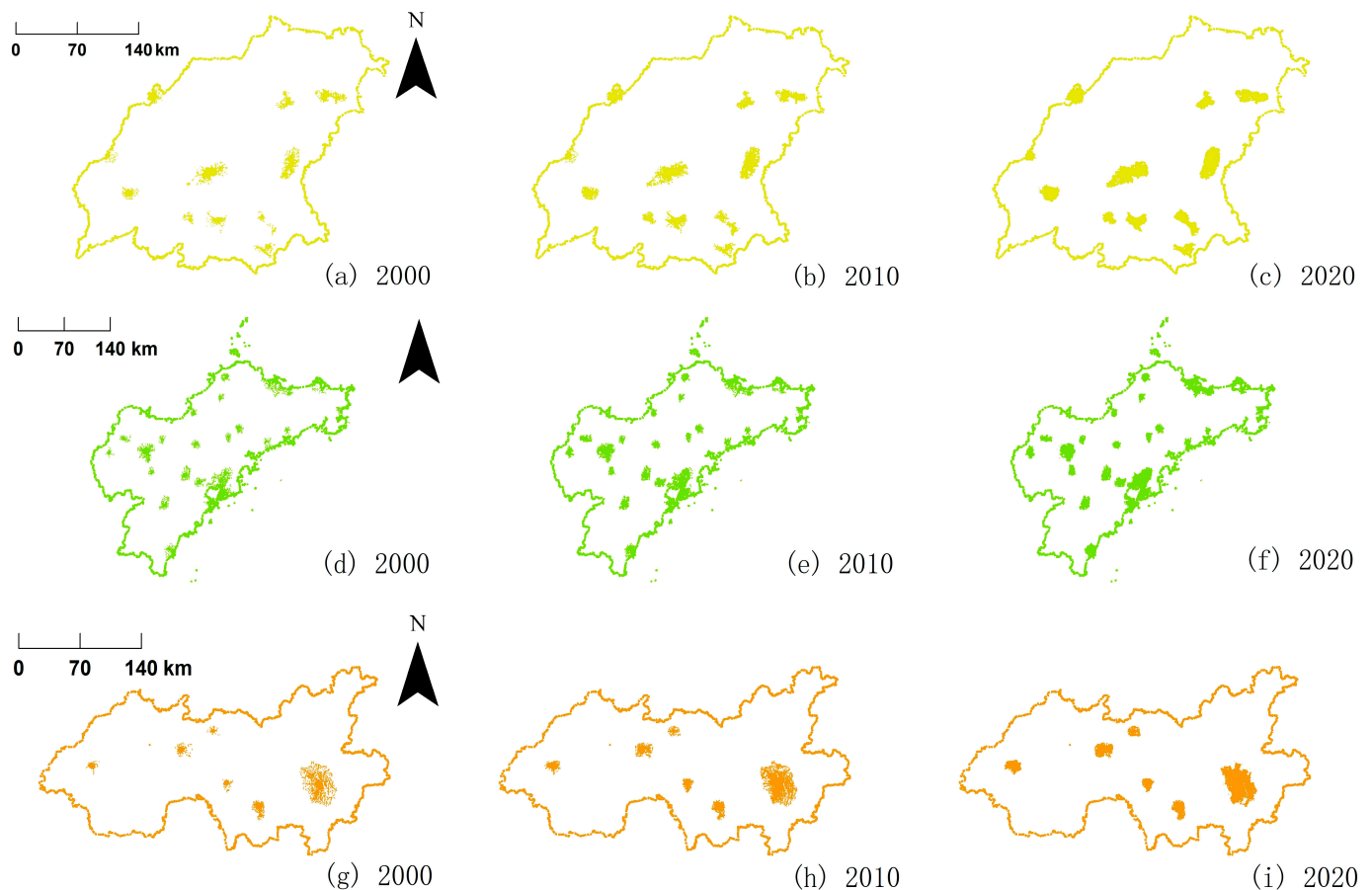


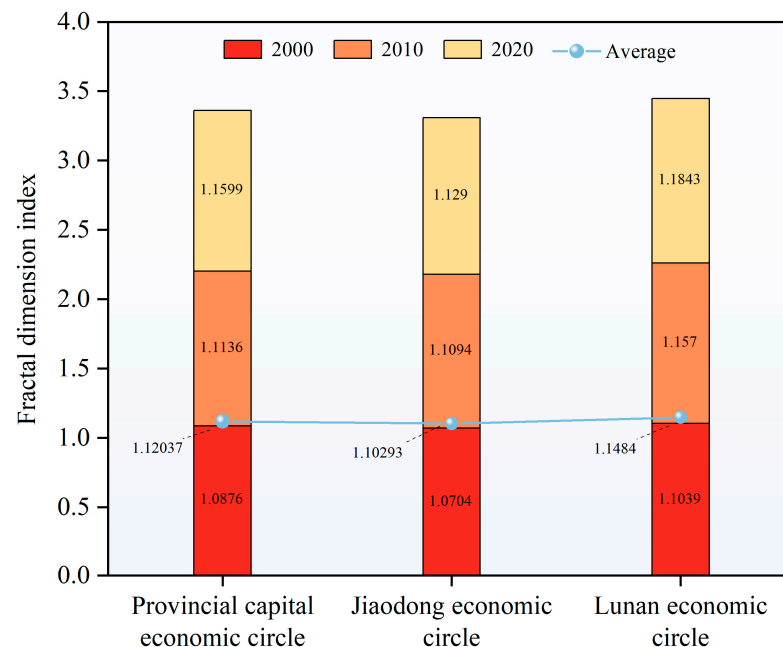
Figure 3. Distribution of built-up areas in Shandong Peninsula urban agglomeration from 2000 to 2020: (a–c) are the built-up areas in the Provincial Capital Economic Circle; (d–f) are the built-up areas in Jiaodong Economic Circle, and (g–i) are the built-up areas in Lunan Economic Circle.

Table 3. Built-up area of Shandong Peninsula urban agglomeration from 2000 to 2020 (km²).

Year	Provincial Capital Economic Circle (km ²)	Jiaodong Economic Circle (km ²)	Lunan Economic Circle (km ²)
2000	668.6313	980.790928	410.771198
2010	1241.063449	1791.60682	861.722589
2020	1911.077777	2883.62583	1361.682461

3.1.1. Fractal Dimensional Analysis of the Built-Up Area

The fractal dimension was used to explore the changes in the boundaries of built-up areas. From Figure 4, it can be seen that the values of the fractal dimension index of all three economic circles increased between 2000 and 2020, which indicated that the boundaries of built-up areas all became more complex. Lunan had the largest value increase, and Jiaodong had the smallest, indicating that Jiaodong was more planned in the development of built-up areas. The values of fractal dimension index in three economic circles were less than 1.5, which indicated that the economic circles were still in the development stage and the boundaries were relatively simple and well-planned.

**Figure 4.** Change of fractal dimension index of Shandong Peninsula urban agglomeration.

3.1.2. Compactness Analysis of the Built-Up Area

The results of the fractal dimension index showed that the built-up area boundaries of the three economic circles gradually become more complex. The compactness index could provide a better understanding of the compactness of the built-up area patches and their variation. Figure 5 showed that the compactness of built-up areas patches in the three economic circles was low. Jiaodong had the lowest compactness index, while the built-up area patches in Lunan were the most compact. The Provincial Capital and Jiaodong were still developing toward dispersion year by year, while Lunan was gradually becoming more compact. However, the value of the compactness index in Lunan did not change particularly much, which was related to the poor economy and the uncoordinated regional development of Lunan, while there was faster development in some regions. The other two economic circles were gradually becoming more dispersed, which was related to their better regional economy, multi-city co-development, and greater expansion of built-up areas.

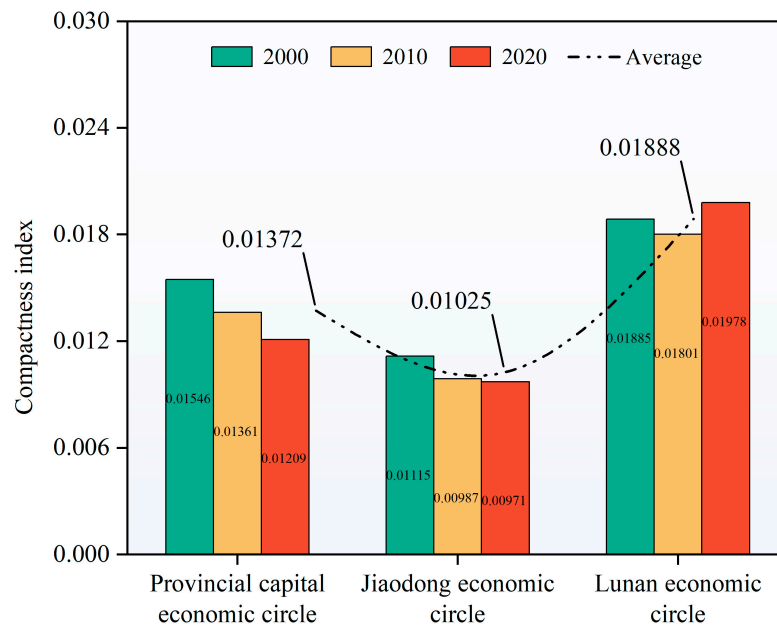


Figure 5. Change of compactness index of Shandong Peninsula urban agglomeration.

3.1.3. Spatial Autocorrelation Analysis of the Built-Up Area

In order to study the spatial characteristics of the dispersed or concentrated built-up areas of the three economic circles for subsequent analysis of people–land coordination, the spatial autocorrelation Moran’s I and LISA clustering were introduced. A 1 km × 1 km fishnet was created for the built-up area data of the three economic circles, and the proportion of built-up areas within the cell grid was used for spatial autocorrelation analysis.

As can be seen from the Moran’s I index changes (Figure 6), the spatial aggregation of fast developing regions or slow developing regions in the expansion of the built-up areas of the three economic circles is not obvious. The Provincial Capital and Jiaodong were more clustered, while Lunan was the most scattered. The Provincial Capital had a higher degree of aggregation than Jiaodong. Aggregation in The Provincial Capital was more obvious between 2010 and 2020 than between 2000 and 2010. Jiaodong showed little change in the dispersion of built-up areas over those 20 years.

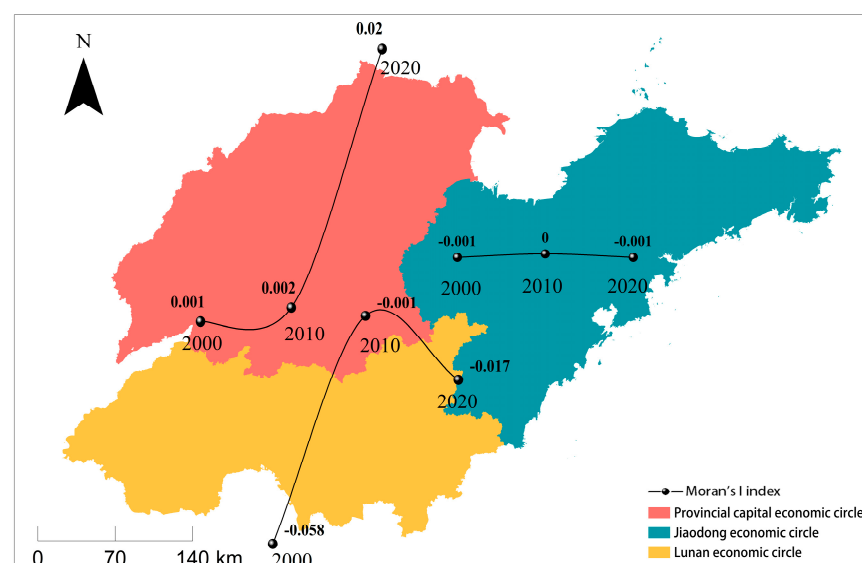


Figure 6. Change of Moran’s I index in Shandong Peninsula urban agglomeration from 2000 to 2020.

In order to further measure the local spatial structure characteristics of and changes in the built-up areas in each economic circle, the LISA analysis was used (Figure 7). Through the LISA clustering map, it was found that the three economic circles had different development changes. The spatial distribution of the built-up areas of the Provincial Capital gradually changed from slow-developing close to each other to fast-developing close to each other, but there was no direct connection between the spatial development of most areas. It was noteworthy that Dongying City developed faster, and the development pattern with Jinan as the core gradually changed to Jinan-Zibo-Tai'an showing spatial clustering. The fast-developing regions in Jiaodong showed clustering in 2000, but this clustering disappeared in the later development. The clustering in the slow-developing regions also diminished. However, there was a spatial agglomeration around Qingdao city and the coastal area, but it played a very weak role in the agglomeration of Jiaodong. Overall, Jiaodong showed a more dispersed state. Lunan was the most dispersed economic circle, and the inter-regional correlation was not obvious. There was a certain spatial clustering of fast-developing regions in 2000, but it changed to slow-developing regions close to each other in 2010, and fast-developing regions and slow-developing regions were closed to each other in 2020, and the spatial correlation became low. Linyi City had a relatively high aggregation. Among the three economic circles, Jinan City and Qingdao City played important roles as they approached the goal of becoming the “Central City of the Yellow River Basin” and the “Ocean City Now”, respectively, while the development of Linyi City was more prominent in Lunan.

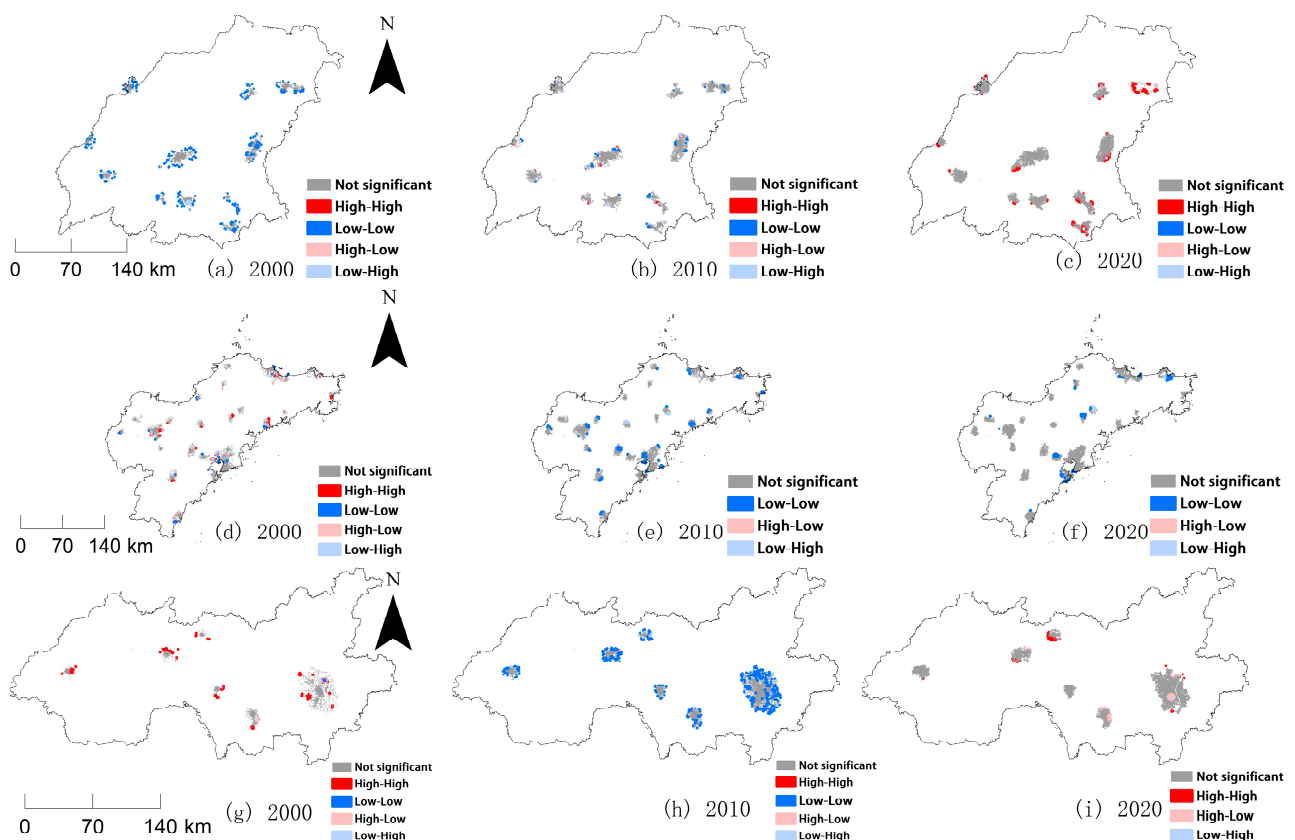


Figure 7. LISA cluster map of Shandong Peninsula urban agglomeration 2000–2020: (a–c) are the LISA cluster map of the Provincial Capital Economic Circle; (d–f) are the LISA cluster map of Jiaodong Economic Circle, and (g–i) are the LISA cluster map of Lunan Economic Circle.

3.2. Changes in the Urban Population

Between 2000 and 2020, the urban population of each city in the Shandong Peninsula urban agglomeration increased by at least two times and even three times, with increasing population density.

3.2.1. Analysis of the Urban Population Size

The spatial distribution of the population of the main city changes in cities of Shandong Peninsula urban agglomeration between 2000 and 2020 was obtained from *The Statistical Yearbook of Urban Construction of China* and *The Statistical Yearbook of Shandong Province* (Figure 8). From Figure 9, we can see the specific numbers of the population of the main city in the three major economic circles between 2000 and 2020. In 2000, 2010, and 2020, the population of the main city of the Provincial Capital was 6,264,400, 8,938,900, and 12,997,700, respectively; the population of the main city of Jiaodong was 7,239,200, 11,751,900, and 14,580,000, respectively, and the population of the main city of Lunan was 3,102,800, 4,662,400, and 6,385,200, respectively. The difference in the number of the population of the main city between the Provincial Capital and Jiaodong was not large, and the population of the main city of Lunan was the smallest. Jiaodong has the largest increase in the population of the main city, in which Qingdao played an important role. The Provincial Capital increased the second largest number of the population of the main city, with Jinan increasing the most. Lunan increased the least in terms of the population of the main city, and Linyi City had the largest population growth of the four cities. Thus, Jinan, Qingdao, and Linyi play important roles in the population growth of the three economic circles. In addition, Liaocheng City, Tai'an City, Dezhou City, Weifang City, and Jining City also had more significant population growth.

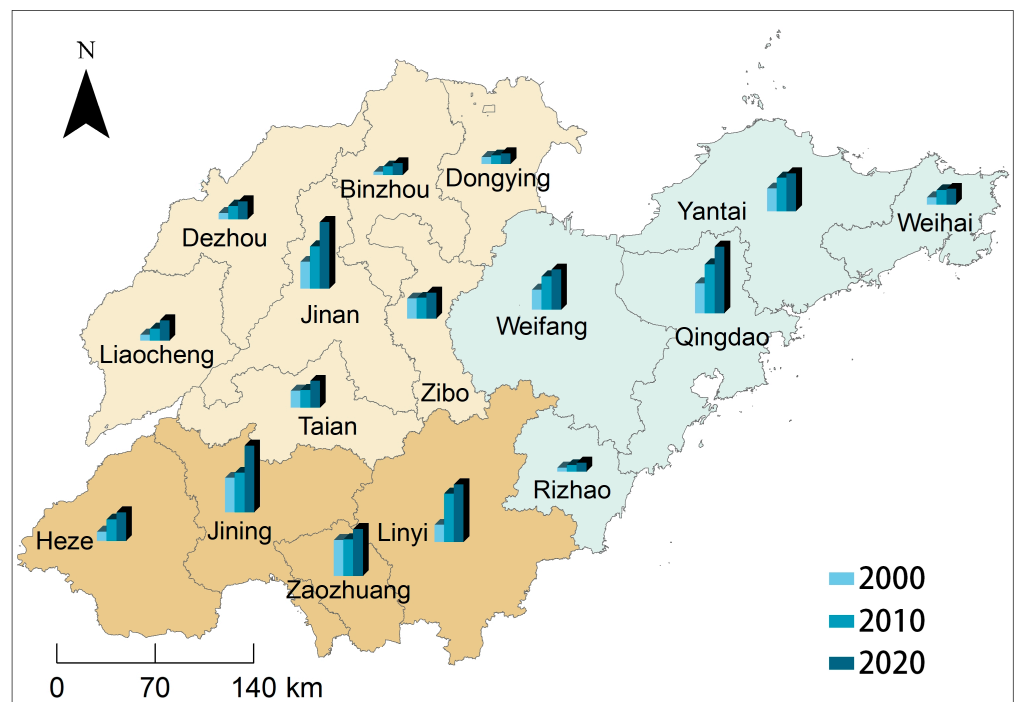


Figure 8. Spatial distribution of the population of the main city in Shandong Peninsula urban agglomeration, 2000–2020.

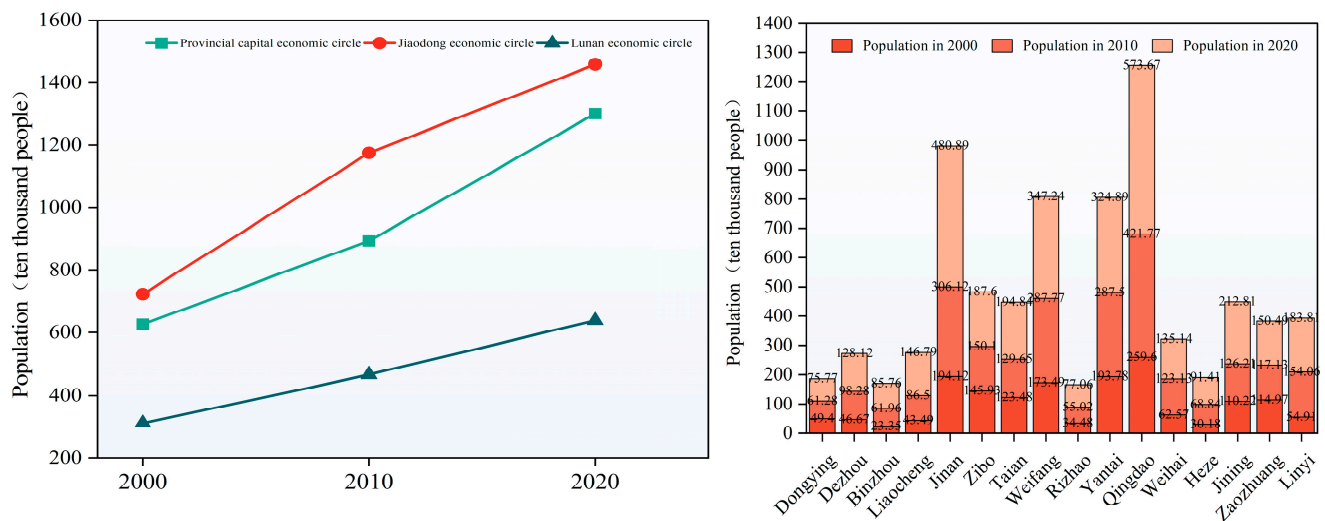


Figure 9. Change in the number of the population of the main city in Shandong Peninsula urban agglomeration from 2000 to 2020.

3.2.2. Analysis of Urban Population Sprawl

According to the population sprawl formula, a larger value of population sprawl represents a larger area of built-up area occupied by low-density population, indicating that the allocation of land is irrational. The data used in the calculation of population sprawl index were the Chinese 100 m \times 100 m population density data. The population densities of the three major economic circles were obtained through spatial analysis (Figure 10). The population density map showed that the values of the highest population densities of Jiaodong and Lunan both increased between 2000 and 2020. Lunan increased the most, indicating that population is highly concentrated in certain areas. In contrast, the values of the highest population density in the Provincial Capital slightly decreased.

Combining the population density data for China and the three economic circles, we calculated the changes in the population sprawl index of the three economic circles (Figure 11). From the figures, it can be seen that the population sprawl in the three economic circles was not serious. The growth rate of the area occupied by the low-density population in the Provincial Capital and Jiaodong was higher than the growth rate of the area occupied by the high-density population, while the opposite was true for Lunan. The Provincial Capital was the area with the most obvious degree of population sprawl, followed by Jiaodong, while Lunan had the least serious sprawl among the three economic circles. The built-up area occupied by the low-density population of the Provincial Capital had been the larger of the three economic circles. The Provincial Capital had the largest value-added in population sprawl between 2000 and 2020, indicating that the population of the Provincial Capitals was more dispersed and no longer developing with one city as the center. This was consistent with the previous conclusion that built-up areas were dispersed and central cities drove multiple cities to develop. The value of population sprawl in Jiaodong became smaller between 2000 and 2010, which was caused by the concentration of population in high-density areas as the area occupied by low-density population became smaller. However, between 2010 and 2020, the population distribution changed, with multi-city population becoming more, and the economic circle showed polycentric development. Unlike the other two circles, Lunan experienced a significant decrease in the area occupied by low-density population between 2000 and 2010, leading to a smaller value of population sprawl. This result was inseparable from the significant increase in population in Linyi City. However, there was a very slight dispersion of the population between 2010 and 2020.

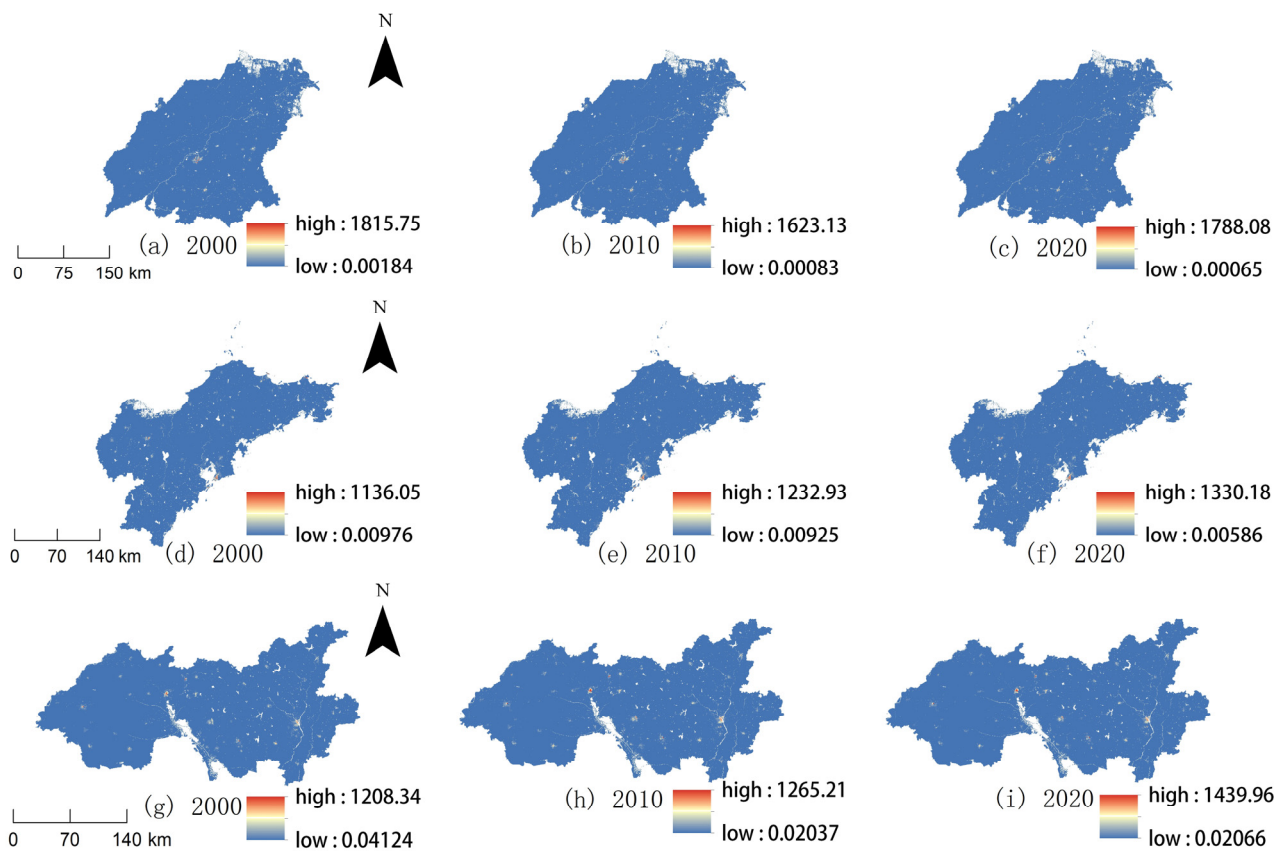


Figure 10. Population density of 100 m × 100 m in Shandong Peninsula urban agglomeration from 2000 to 2020: (a–c) show the population density of the Provincial Capital Economic Circle; (d–f) show the population density of Jiaodong Economic Circle, and (g–i) show the population density of Lunan Economic Circle.

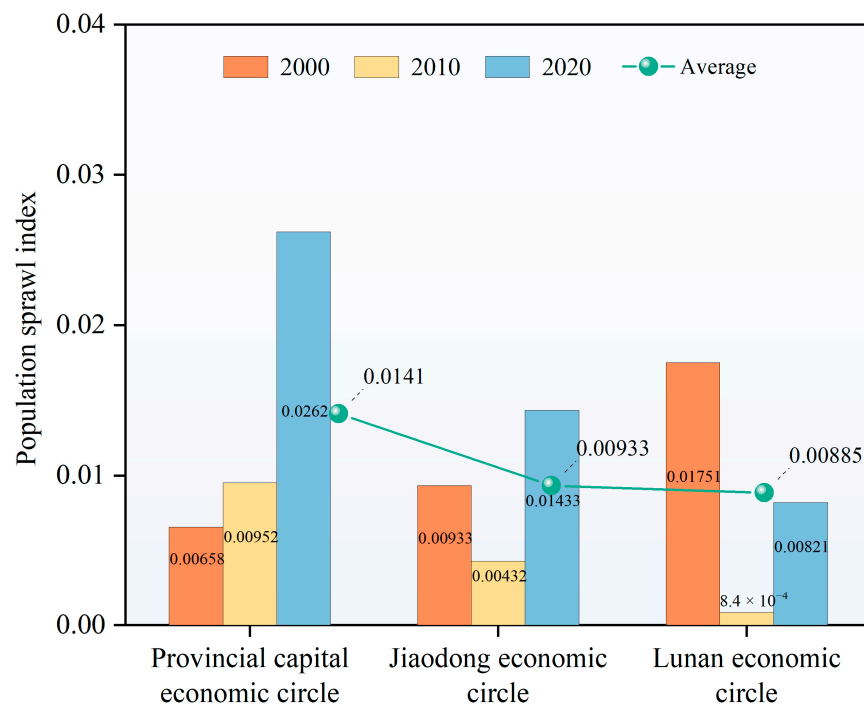


Figure 11. Change of population sprawl index in Shandong Peninsula urban agglomeration, 2000–2020.

In summary, the population size in the three economic circles increased, and the population in the high-density or low-density areas increased accordingly. From a spatial perspective, the population had not sprawled significantly and was concentrated in the fast-growing areas.

3.3. People–Land Coordination Analysis

With the CPI model, this paper obtained the people–land coordination of each prefecture-level city (Figure 12). The Shandong Peninsula urban agglomeration had weak people–land coordination between 2000 and 2020. Among the 16 prefecture-level cities, 12 of them had CPI values greater than 1.7, showing significant growth in built-up areas; Qingdao City belonged to the standard of obvious expansion of built-up areas, Binzhou City belonged to the standard of significant population growth, and Liaocheng City and Linyi City had a more coordinated development in the 20-year period. Most of the prefecture-level cities in the Shandong peninsula urban agglomeration demonstrated the problem that the rate of built-up areas expansion was faster than the population growth rate. In the Provincial Capital, Liaocheng City and Dezhou City’s people–land development was coordinated, while Zibo City was less coordinated. In Jiaodong, the people–land development of Weihai City and Qingdao City were better coordinated, while Yantai City was less coordinated. In Lunan, Linyi City was better coordinated, and Zaozhuang City was less coordinated. In terms of the calculated value of CPI, there were no cities with people–land coordination in Jiaodong, which showed the worst situation among the three economic circles.

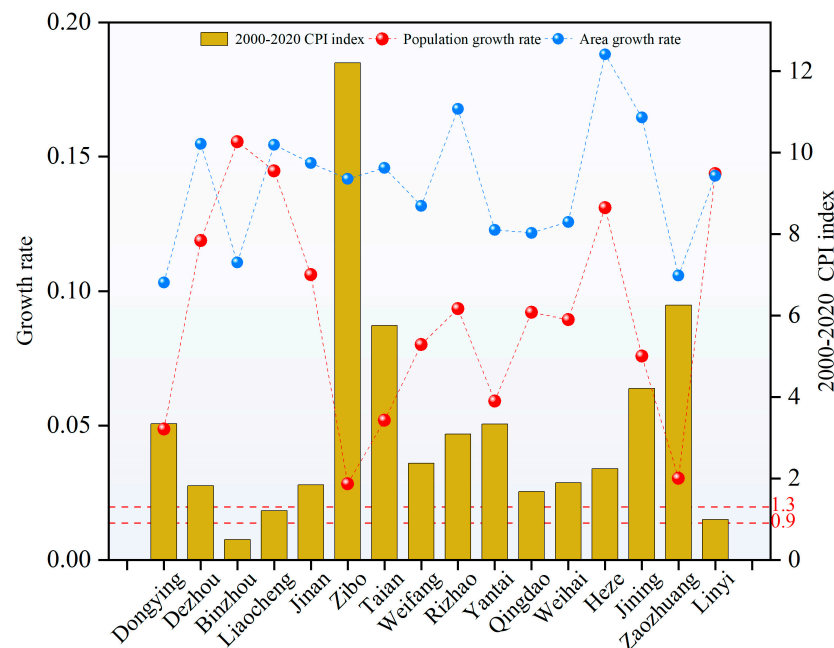


Figure 12. Growth rate of population and built-up areas of Shandong Peninsula urban agglomeration, 2000–2020.

The change of CPI index from 2000 to 2010 and from 2010 to 2020 (Figure 13) showed that most of the cities in the three economic circles had transformed from obvious population growth to significant expansion of built-up area. This also indicated the weak coordination of people–land in the Shandong Peninsula urban agglomeration. It is noteworthy that the CPI was high in Zibo, Tai’an, Jining, and Zaozhuang between 2000 and 2010. The reason for this was the low population growth of the four prefecture-level cities during this time. In contrast, from having two cities with coordinated development, Yantai and Qingdao, Jiaodong had transformed into five cities all with significant built-up areas growth.

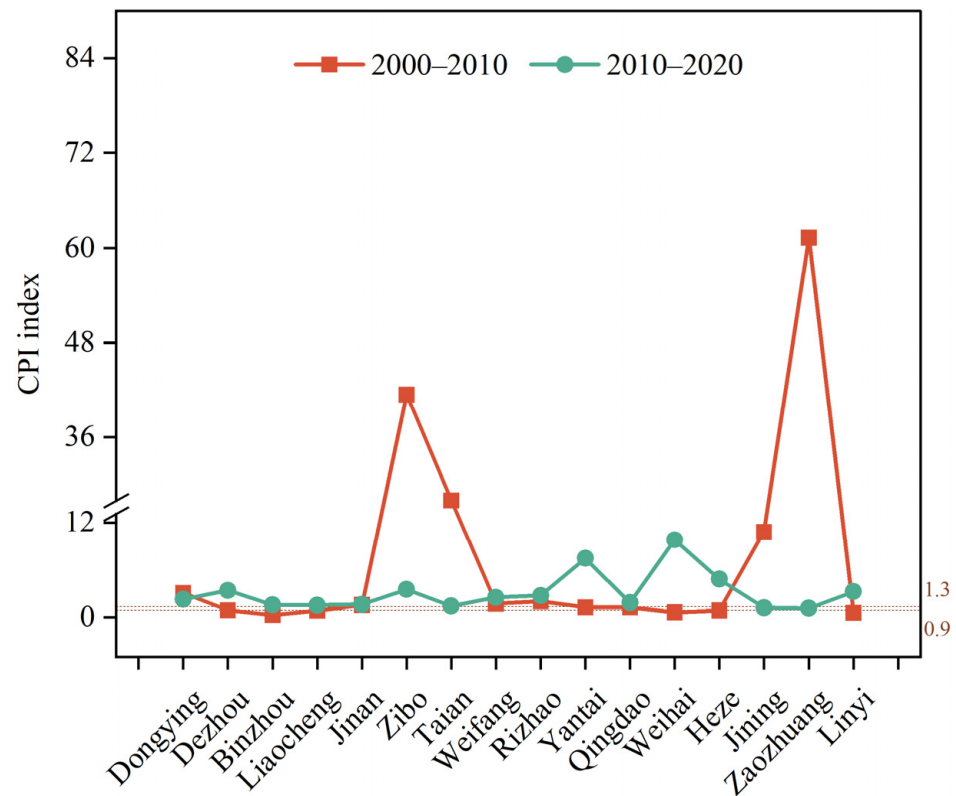


Figure 13. Change in CPI index of Shandong Peninsula urban agglomeration, 2000–2020.

4. Discussion

4.1. Policy Recommendations

Currently, China's economy is in a period of rapid development, and it is predicted that urbanization will be faster in the future and urban agglomerations will play important roles in this process. Shandong Peninsula urban agglomeration is a key region for the development of Shandong Province. It is one of the important intensive urban areas in East China. It is also the outlet to the sea for the vast hinterland of the middle and lower reaches of the Yellow River in China and is the only urban agglomeration in a mature stage among the seven major urban agglomerations along the Yellow River. *The Shandong Peninsula Urban Agglomeration Development Plan (2021–2035)* issued by Shandong Provincial People's Government contained even more expectations and planning for the development of Shandong Peninsula. Therefore, it is important to study the coordination of built-up area expansion and population growth in the Shandong Peninsula urban agglomeration, for reasons of urban planning as well as sustainable and high-quality urban development.

According to previous studies, the urban land expansion provides development space for cities; however, the disorderly expansion of urban land also results in a significant waste of land resources [34]. In recent years, the quick urbanization of Shandong Peninsula urban agglomeration resulted in large amount of expansion of built-up area [35]. At the same time, the significant increase in population density also put pressure on urban land. Among them, Jinan City and Qingdao City are growing at a faster pace. Thus, the government should adopt an intensive land use policy. Good planning is the basic condition for ensuring the smooth development of the city. The government should implement policy measures to promote regional urban development [36].

In the future, the following issues should be noticed in the development of the Shandong Peninsula urban agglomeration: (1) pay attention to the dynamic changes of land, make full use of land resources, improve the use rate of developed land, and not irrationally exploit land leading to the disorderly expansion of built-up areas; (2) comprehend the direction of the leading development role of the dominant cities in each economic circle;

for example, Jinan City in the Provincial Capital and Qingdao City in Jiaodong should continue to play an important role, while the cities in Lunan can strengthen their ties with each other to jointly promote regional development; (3) strengthen the industrial structure of the built-up areas so that the high-density areas of residents have opportunities to work and live better.

4.2. Contributions and Limitations

In this study, several index models were used to construct the research indicators of people–land coordination in the Shandong Peninsula urban agglomeration. (1) This study analyzed multiple scales, from cities to economic circles to urban agglomerations. (2) The spatial scales selected in this study are the three latest planning units of the Shandong Peninsula urban agglomeration—the Provincial Capital, Jiaodong, and Lunan—and there are fewer people–land studies using this as the scope of study. (3) Because the Shandong Peninsula urban agglomeration has no obvious development characteristics that differ from other urban agglomerations, the method can be applied to the study of others in China. (4) Most studies on urban land had focused on the relationship between urban sprawl and ecology, and fewer focused on the coordination of people and land. This study linked urban sprawl with urban population and provided suggestions for planning and sustainable coordinated urban development.

However, there are two points in this study that can be improved in subsequent studies: (1) more indices can be selected to analyze people–land coordination, and the people–land coordination model can be improved (e.g., coupling analysis of changes to further reflect the problem, etc.). (2) Drivers such as socio-economic factors can be added to the analysis of people–land coordination. Therefore, the future article will improve and add aspects such as the people–land coordination of urban agglomerations and its influencing factors.

5. Conclusions

This study analyzed the built-up area expansion and population growth as well as the coordination of people and land in the Shandong Peninsula urban agglomeration from multiple scales using a combination of temporal and spatial data such as built-up area datasets, population density, and socio-economic data. In recent years, China has proposed a national strategy for ecological protection and high-quality development of the Yellow River Basin. The Shandong Peninsula urban agglomeration is located in the lower reaches of the Yellow River. It was emphasized that the leading role of Shandong Peninsula urban agglomeration should be played to promote the high-quality development of the central cities and urban agglomerations along the Yellow River area. With the implication of the policy, the built-up area of the Shandong Peninsula urban agglomeration expanded significantly, mainly by internal expansion. There is high population growth and relatively concentrated spatial distribution of population. The coordination between people and land in Shandong Peninsula urban agglomeration was poor over the last 20 years. Therefore, in the future, attention should be paid to the expansion of urban land to better serve people in order to achieve the coordination of people–land and sustainable development. The study would provide scientific references for land use planning and regional economic development of Shandong Peninsula urban agglomeration, as well as for population allocation and sustainable urban development. Specific conclusions are as follows.

(1) Between 2000 and 2020, there was an imbalance in the coordination of built-up area expansion and population growth in the Shandong Peninsula urban agglomeration. Most of the cities showed a much faster rate of built-up area expansion than population growth, and there was a significant shift from population growth in 2000–2010 to significant land expansion in 2010–2020. In terms of the urban development pattern, the Provincial Capital and Jiaodong had Jinan City and Qingdao City as the core cities, respectively, leading to the synergistic development of the surrounding cities in a group. In Lunan, Linyi City

was the fastest growing city, with multi-city decentralized development. In the past two decades, only two cities in the three economic circles had coordinated people and land development, namely Liaocheng City in the Provincial Capital and Linyi City in Lunan, with poor coordination in Jiaodong.

(2) The built-up area expansion of the Shandong Peninsula urban agglomeration between 2000 and 2020 had distinct characteristics. The built-up area of Jiaodong increased the most, followed by the Provincial Capital and finally Lunan. The built-up area of Jiaodong increased twice as much as the built-up area of Lunan. However, from the viewpoint of the boundary of the built-up area, the boundary of the three economic circles did not change much, indicating that the built-up area mainly expanded internally. From the internal view of the built-up areas, the compactness of the built-up areas of the Provincial Capital and Jiaodong decreased, which indicated that the aggregation of the built-up areas of the two was slightly lower, although they were filled internally. The compactness of Lunan slightly increased, although the change was not significant. Spatially, the insignificance of the spatial autocorrelation of the three was high. However, the difference was that the Provincial Capital changed from slow-developing regions close to each other to fast-developing regions attracting each other. Jiaodong showed the opposite pattern to the Provincial Capital. Lunan had no obvious change characteristics and maintained a more dispersed state.

(3) The population of urban areas in the Shandong Peninsula urban agglomeration increased rapidly in the past two decades. The population of Jiaodong increased the most, by 7,340,800 people; followed by the Provincial Capital by 6,733,300 people, while the population of Lunan only increased by 3,282,400 people. The increase in population brought an increase in the area occupied by the high-density population areas or low-density population areas of each economic circle. The population distribution of the three economic circles was still relatively concentrated, and there was no obvious population sprawl. In terms of the center of gravity of population distribution, Jinan City in the Provincial Capital, Qingdao City and coastal areas in the Jiaodong, and Linyi City and Jining City in Lunan play important roles.

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