Analysis of city centrality based on entropy weight TOPSIS and population mobility:
A case study of cities in the Yangtze River Economic Belt

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Abstract: Based on statistical data and population flow data for 2016, and using entropy weight TOPSIS and the obstacle degree model, the centrality of cities in the Yangtze River Economic Belt (YREB) together with the factors influencing centrality were measured. In addition, data for the population flow were used to analyze the relationships between cities and to verify centrality. The results showed that: (1) The pattern of centrality conforms closely to the pole-axis theory and the central geography theory. Two axes, corresponding to the Yangtze River and the Shanghai-Kunming railway line, interconnect cities of different classes. On the whole, the downstream cities have higher centrality, well-defined gradients and better development of city infrastructure compared with cities in the middle and upper reaches. (2) The economic scale and size of the population play a fundamental role in the centrality of cities, and other factors reflect differences due to different city classes. For most of the coastal cities or the capital cities in the central and western regions, factors that require long-term development such as industrial facilities, consumption, research and education provide the main competitive advantages. For cities that are lagging behind in development, transportation facilities, construction of infrastructure and fixed asset investment have become the main methods to achieve development and enhance competitiveness. (3) The mobility of city populations has a significant correlation with the centrality score, the correlation coefficients for the relationships between population mobility and centrality are all greater than 0.86 (P<0.01). The population flow is mainly between high-class cities, or high-class and low-class cities, reflecting the high centrality and huge radiating effects of high-class cities.

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Furthermore, the cities in the YREB are closely linked to Guangdong and Beijing, reflecting the dominant economic status of Guangdong with its geographical proximity to the YREB and Beijing's enormous influence as the national political and cultural center, respectively.

1   Introduction

Christaller (1933), a German economic geographer, first proposed the concept of 'centrality'. Centrality refers to the capacity of an area for providing various goods and services for local and other areas. Centrality is an index that gives a measure of the level of functions in a central region or city. Henri (2003) believes that the essence of the urban phenomenon lies in its centrality and that a city represents the best spatial arrangement for mechanization, technological transformation and economies of scale; it is a center of productive relationships and the center of 'space production' (Henri, 1968). Urban centrality reflects the ability of a city to provide services and is an important index for measuring the status of an urban center (Zhou *et al.*, 2001.)

Studies on the measurement of city centrality have been previously conducted and a single indicator has mainly been used. Christaller (1933) first used the location quotient to calculate a telephone index for measuring urban centrality; Preston (1970) used retail and service industries as a basis for measurement, and Marshall (1989) measured urban centrality using a number of central functions and functional units. Since then, indicators and methods have gradually become diversified: Phillip (1987) and Irwin (1992) measured the amount and direction of interaction between individuals in urban areas based on dynamic indicators, and Siewwuttanagul *et al.* (2016) used network analysis of a GIS platform to measure a gravity index that reflects urban centrality.

The central place theory in geography was introduced to China in the 1960s and has been widely applied and empirically researched. Research on the index system and methods for measurement of centrality has undergone developments and refinements. Ning and Yan (1993) studied central cities in China, and calculated an urban center index based on the volume of economic activity, population size and volume of postal deliveries for business. Zhou (2001) argued that central services in urban areas should include activities such as commerce, public services, transportation, information and manufacturing. An index system should be established based on five criteria: commerce and trade, service industry, spatial dimension, manufacturing industry and degree of openness to the outside world. Many subsequent studies have referred to this index system and covered provinces and regions such as Liaoning (Sun *et al.*, 2008), Shandong (Wu *et al.*, 2010) and Henan (Zhang *et al.*, 2014). The index system has also involved urban agglomerations such as the Huaihai Economic Zone (Xue *et al.*, 2009), Wuhan Metropolitan Area (Wen, 2009) and the middle reaches of the Yangtze River (Luo, 2017; Li *et al.*, 2019). The system has also covered the central cities of the country (Tian *et al.*, 2013). The main research methods used, both in China and other countries, include entropy method, location quotient method, and principal component analysis. The above-mentioned index system and research methods have laid the foundation for the study of urban centrality and the empirical studies in different areas have analyzed the urban system in various regions. Despite the above progress, few studies have been con-

conducted on the Yangtze River Economic Belt (YREB), which covers a large expanse, and the specific factors affecting the centrality of each city have rarely been examined (Jin *et al*., 2019).

The preliminary concept of the YREB was proposed in the 1980s, and has been widely accepted by the academic communities since 1994. Since 2014, the YREB has become part of the national strategic plan and a research hotspot (Zou *et al*., 2015). Many studies have examined the region as a unit, in which factors such as urban competitiveness or influence (Fang *et al*., 2015; Peng *et al*., 2016; Feng *et al*., 2017; Jin *et al*., 2017) and functional structure (Wang *et al*., 2015; Zhong *et al*., 2018; Jin *et al*., 2018) are important topics; however, few researchers have studied urban centrality. Based on the currently accepted index systems for measuring centrality, this paper used the entropy weight TOPSIS model to measure the centrality of cities in the YREB. Then the factors influencing each city's centrality are measured using the obstacle model and, further, population migration data are used to analyze the degree of connectivity between cities and to verify the centrality of cities. The overall objective of this study is to explore the laws that govern the city patterns in the YREB, to identify problems in city development, and to discuss directions for future development.

2　Study area

The Yangtze River Economic Belt (YREB) covers 9 provinces and 2 municipalities administered directly under the central government, and includes Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Sichuan, Yunnan, Guizhou, Shanghai, and Chongqing. The belt consists of 130 cities (including the 2 municipalities, 5 sub-provincial cities, 103 prefecture-level administered cities, 16 autonomous prefectures, 3 county-level cities directly under the jurisdiction of the province and 1 forested district) (Figure 1). The area of the YREB is approximately 2.05 million km², with a population and GDP for the region exceeding 40% each of
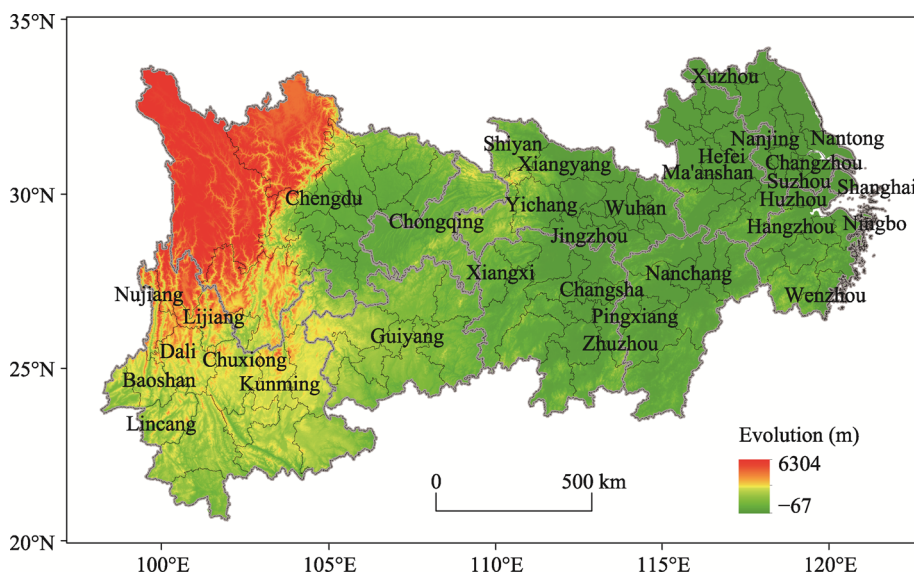

Figure 1　Location and administrative divisions of the Yangtze River Economic Belt

the total for China. The YREB spans three major regions of China from east to west. Cities in this belt are diverse in terms of their natural environment, administrative features, and economic and social development (Jin *et al*., 2018).

3   Data and methods

3.1   Data

3.1.1   Socio-economic statistical data

Seventeen indicators (Table 1) were selected to represent the economic and social aspects of the YREB: C1 and C2 reflect the overall scale of the city; C3, C4 and C5 reflect the basic capacity of economic development; C6, C7 and C8 reflect the level of foreign exchange activity and attractiveness; C9, C10 and C11 reflect the development and transformation ability of science and technology; C12, C13, C14 and C15 reflect the transportation capacity; C16 and C17 reflect the status of higher education.

Socio-economic statistical data were taken from the *China Urban Statistical Yearbook* (2017), the Statistical Yearbooks (2017) of the cities in the YREB, the 2016 National Economic and Social Development Statistics Bulletin of the cities in the YREB, the 12306 China Railway, and the 2016 Civil Aviation Airport Production Statistics Bulletin of China (Table 2).

Table 1   Symbol of each indicator

Indicator	Symbol	Indicator	Symbol
Total permanent residential population	C1	Number of authorized patents	C10
GDP	C2	High-tech output value	C11
Added value of secondary and tertiary industries	C3	Number of high-speed railway and express railway stations	C12
Total fixed assets investment	C4	Number of civil airports	C13
Total retail sales of consumer goods	C5	Total amount of cargo transported	C14
Actual use of foreign investment	C6	Total number of passengers transported	C15
Amount of imports and exports	C7	Number of colleges and universities	C16
Tourism income	C8	Number of students in colleges and universities	C17
R&D expenditure	C9		

Table 2   Data sources for indicators

Indicators	Data sources
C1, C2, C3, C4, C5, C6, C14, C15, C16, C17	China Urban Statistical Yearbook (2017)
C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C14, C15, C16, C17	Statistical Yearbooks (2017) of the cities in the YREB
C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C14, C15, C16, C17	2016 National Economic and Social Development Statistics Bulletin of the cities in the YREB
C12	12306 China Railway (https://www.12306.cn/mormhweb/czyd_2143/)
C13	2016 Civil Aviation Airport Production Statistics Bulletin of China (http://www.caac.gov.cn/XXGK/XXGK/TJSJ/201702/t20170224_42760.html)

Note: The above data are for 2016. The 2017 Statistical Yearbooks contain data for 2016.

3.1.2 Population flow data

When studying the degree of inter-city linkages, data from the inter-urban migration of the YREB were used. The data, which were based on the population migration number according to Tencent in 2016, reflect the relative value of desensitization and not the absolute number of migrants. The top ten cities based on population migration and emigration were selected and data were entered into ArcGIS for analysis.

3.2 Methods

3.2.1 Entropy weight TOPSIS model

City centrality was measured with the entropy weight TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) model. The TOPSIS model is a sort method (Ren *et al*., 2019). The process establishes a normalized matrix of the data after standardization to identify the positive and negative ideal solutions (Gao *et al*., 2018). The entropy weight TOPSIS model is an improvement over the traditional TOPSIS model, and optimizes the value formula of the target object as well as the positive and negative ideal solutions (Lu *et al*., 2011; Hong *et al*., 2015; Lei *et al*., 2016). The weight of the evaluation index is calculated by the entropy weight method (Table 3) and the target is sorted by the improved TOPSIS model (Ma *et al*., 2016). The improved model makes the measured result more objective and more suitable for real-world situations. The model is as follows:

Table 3 Weight of each indicator

Indicator	Weight	Indicator	Weight
C1	0.0691	C10	0.0572
C2	0.1039	C11	0.0708
C3	0.0781	C12	0.0480
C4	0.0581	C13	0.0403
C5	0.0659	C14	0.0408
C6	0.0654	C15	0.0423
C7	0.0514	C16	0.0527
C8	0.0363	C17	0.0616
C9	0.0581	—	—

(1) To standardize the original data of various indicators and adopt extreme value standardization:

$$R_{ij} = \frac{(x_{ij} - \min_j)}{(\max_j - \min_j)} \text{ (Positive indicators)} \tag{1}$$

$$R_{ij} = \frac{(\max_j - x_{ij})}{(\max_j - \min_j)} \text{ (Negative indicators)} \tag{2}$$

where R_{ij} is the standardized value of each index, $R_{ij} \in [0,1]$; x_{ij} is the evaluation index of each city; $\min_j$ is the minimum value of the index; and $\max_j$ is the maximum value of the index. Given that the indicators used in this study all have a positive effect on the final evaluation results, the standardized treatment of positive indicators is adopted.

(2) To calculate the value of entropy:

$$p_{ij} = \frac{R_{ij}}{\sum\limits_{i=1}^{m} R_{ij}} \tag{3}$$

$$E_j = -k \sum_{i}^{m} p_{ij} \ln(p_{ij}) \tag{4}$$

where E_j is the entropy value; k is the constant term, $k = 1/\ln m$; p_{ij} is the proportion of the index value of item j of i city.

(3) To calculate the index weight w_j:

$$w_j = \frac{(1 - E_j)}{\sum_{j=1}^{n}(1 - E_j)} \tag{5}$$

(4) To establish a standardized decision matrix V:

$$V = R_{ij} \times w_j = \begin{bmatrix} R_{11}w_1 & R_{12}w_2 & \cdots & R_{1j}w_n \\ R_{21}w_1 & R_{22}w_2 & \cdots & R_{2j}w_n \\ \vdots & \vdots & \ddots & \vdots \\ R_{i1}w_1 & R_{i2}w_2 & \cdots & R_{ij}w_n \end{bmatrix} \tag{6}$$

(5) To determine the positive and negative ideal solutions:

Positive indicators

Positive ideal solution: $V^+ = \left\{ \max_j V_{ij} \,\middle|\, i = 1, 2, \cdots n; j = 1, 2, \cdots m \right\}$ (7)

Negative ideal solution: $V^- = \left\{ \min_j V_{ij} \,\middle|\, i = 1, 2, \cdots m; j = 1, 2, \cdots m \right\}$ (8)

Negative indicators

Positive ideal solution: $V^- = \left\{ \min_j V_{ij} \,\middle|\, i = 1, 2, \cdots m; j = 1, 2, \cdots m \right\}$ (9)

Negative ideal solution: $V^+ = \left\{ \max_j V_{ij} \,\middle|\, i = 1, 2, \cdots n; j = 1, 2, \cdots m \right\}$ (10)

Given that the indicators used in this study all have a positive effect on the final evaluation results, the standardized treatment of positive indicators is adopted.

(6) To calculate the distance between the positive and negative ideal solutions for each city:

$$D_i^+ = \left\{ \sum_{i}^{n} (V_{ij} - V_j^+) \right\}^{1/2} \tag{11}$$

$$D_i^- = \left\{ \sum_{i}^{n} (V_{ij} - V_j^-) \right\}^{1/2} \tag{12}$$

where D_i^+ and D_i^- are the distances of the positive and negative ideal solutions, respectively.

(7) To calculate the score of comprehensive evaluation:

$$Y_i = \frac{D_i^-}{(D_i^+ + D_i^-)} \tag{13}$$

where Y_i is the closeness of the evaluated target object and the optimal solution. The larger Y_i is, the better the evaluation result.

3.2.2 Obstacle degree model

The obstacle degree model (Zhao *et al.*, 2015; Li *et al.*, 2018) was used to measure the contribution of each indicator to the centrality of each city. The model is represented as follows:

$$C_j = \frac{R_{ij}w_j}{\sum\limits_{j}^{m} R_{ij}w_j} \times 100\% \tag{14}$$

where C_j is the degree of influence of j indicators on the centrality of a city; R_{ij} is the standardized value of each index, $R_{ij} \in [0,1]$; and w_j is the weight of each index. The larger C_j is, the greater importance of this indicator for urban centrality.

3.2.3 ArcGIS XY To Line tool

The ArcGIS XY To Line tool was used to analyze inter-city population migration and study inter-city linkages. The XY To Line tool in the Arc Toolbox generates straight lines based on the starting and ending coordinates in the input table. The cities in the YREB are set as the starting and ending points, and population migration between cities is regarded as the attribute of the connection between two points, which is used for analysis.

4   Results

4.1   Analysis of centrality

Using the natural breakpoint method, the score is divided into five classes and the overall ranking of cities from east to west gradually decreases until it runs backward (Figure 2).
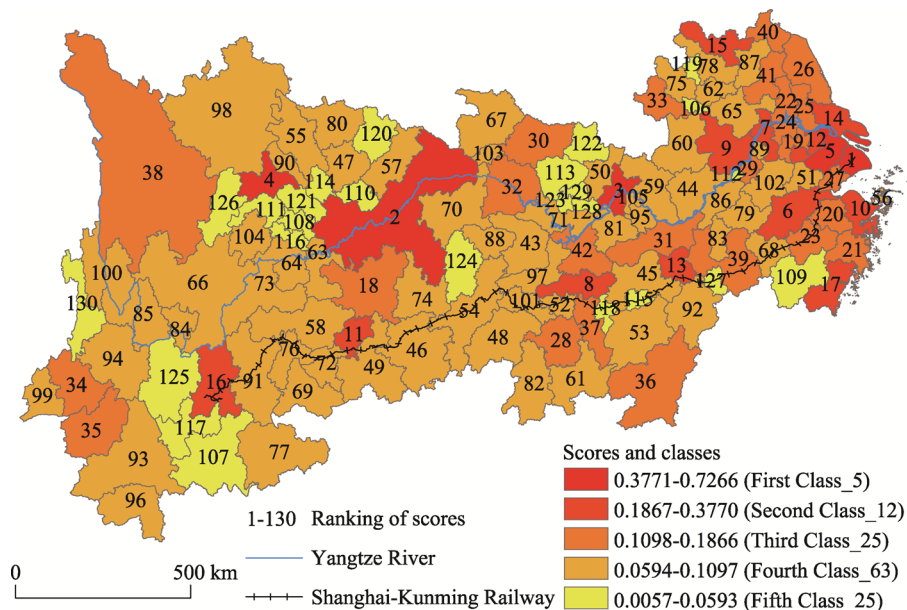

Figure 2   Scores and classes of city centrality in the Yangtze River Economic Belt

The first-class cities are Shanghai, Chongqing, Wuhan, Chengdu, and Suzhou. Two regions are in the lower and the upper reaches of the Yangtze River, and one region is in the middle reaches of the river. Two cities (Shanghai and Chongqing) are directly under the central government and two (Wuhan and Chengdu) are sub-provincial cities. Suzhou is an important central city in the Yangtze River Delta urban agglomeration. These cities are im-

portant node cities of the YREB and play a role in promoting the overall development of the YREB. Shanghai and Chongqing are national central cities in accord with the National Urban System Planning (2010–2020). Shanghai is the leading city in the whole of the YREB, and Chongqing is the leading city in the upper reaches of the YREB. In 2016, Chengdu was given the support of the National Development and Reform Commission and the Ministry of Housing and Construction to establish a national central city. Together with Chongqing, this city promotes the development of the Chengdu-Chongqing urban agglomeration. Wuhan is the central city in the middle reaches of the Yangtze River. In 2016, Wuhan was positioned as one of the three core cities of the YREB in the Outline of the YREB Development Plan. In 2018, it was given the support of the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development to establish a national central city. Suzhou is a national high-tech industrial base undergoing rapid economic and social development.

There are 12 second-class cities: Hangzhou, Nanjing, Changsha, Hefei, Guiyang, Nanchang, and Kunming, as well as Ningbo, Changzhou, Nantong, Xuzhou, and Wenzhou. In this category, there are 8 cities in the lower reaches of the Yangtze River, 2 in the middle reaches, and 2 in the upper reaches. Seven of the cities are provincial capitals and five are cities in Jiangsu and Zhejiang provinces. These results show that the provincial capitals are located in the upper and middle reaches of the Yangtze River and the cities in Jiangsu and Zhejiang provinces have strong centrality.

There are 25 cities in the third-class category, mainly in the lower and middle reaches of the Yangtze River, and a few in the upper reaches. The number of cities in the lower, middle and upper reaches of the Yangtze River is 13, 8 and 4, respectively; these represent the most important node cities in the region.

The fourth-class category contains 63 cities, mainly in the middle and upper reaches of the Yangtze River with a few in the lower reaches. There are 14 cities in the lower reaches, 21 in the middle reaches, and 28 in the upper reaches of the Yangtze River. The fifth-class cities number 25, most of which are located in the upper reaches of the Yangtze River with a few in the middle and lower reaches. The number of cities in the lower, middle and upper reaches of the Yangtze River is 4, 9 and 12, respectively. The centrality of the fourth- and fifth-class cities has gradually weakened, and the number of distributions has increased from downstream to upstream, indicating that the cities in the upper reaches of the Yangtze River are weaker than those in the middle and lower reaches.

The results of spatial autocorrelation analysis show that the Yangtze River Delta is a high-high agglomeration area with high significance; parts of southern Sichuan and western Yunnan, as well as Shiyan and Jingzhou, are low-low agglomeration areas; Huzhou and Ma'anshan are low-high agglomeration areas; Wuhan, Xiangyang, Yichang, Chengdu, Kunming, Baoshan, and Lincang are high-low agglomeration areas (Figure 3). The analysis reveals that hotspots are concentrated in the lower reaches of the Yangtze River and gradually increase from inland to coastal areas, forming a clear gradient; cold-spots are mainly distributed in the upper reaches of the Yangtze River in Yunnan and western Sichuan, examples being Dali, Lijiang, Chuxiong, and Nujiang; these spread to the north and south, forming a well-defined urban centrality gradient; Zhuzhou, Pingxiang, and Xiangxi also form a cold-point center (Figure 4). Overall, this result shows that the cities in the lower reaches of

the Yangtze River (especially in the Yangtze River Delta) exhibit improved development and high centrality; the cities in southern Sichuan and western Yunnan in the upper reaches of the Yangtze River are relatively backward and have a low degree of centrality; Wuhan, Xiangyang, Yichang, Chengdu, Kunming, Baoshan, and Lincang also display a far higher development level than the surrounding areas.
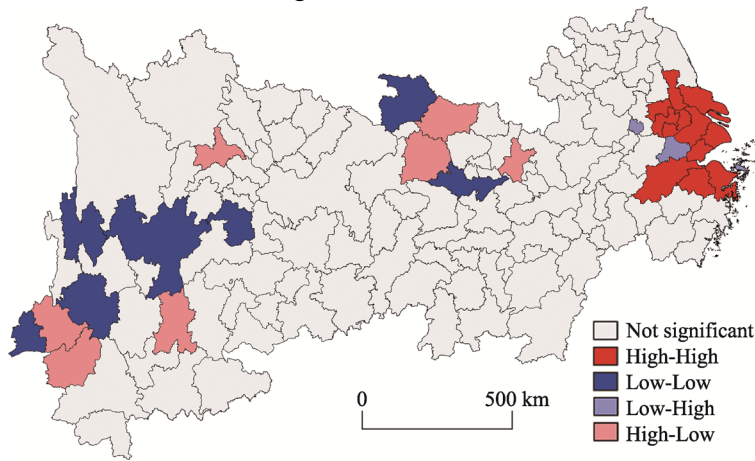

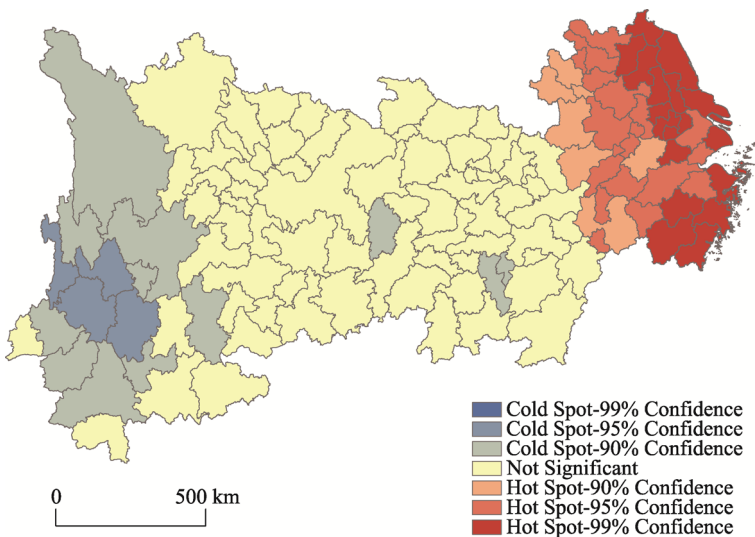**Figure 3**   Clustering of city centrality of the Yangtze River Economic Belt

Figure 4   Hotspot analysis of city centrality of the Yangtze River Economic Belt

4.2   Analysis of factors influencing centrality

After analysis of the cumulative contribution of the top 5 indicators in terms of the size of the contribution (Figures 5 and 6), it was found that for the first- and second-class cities, the cumulative contribution of the GDP is the largest indicator, and the impact of GDP is significantly greater than other indicators. This result shows that the economies of the first- and second-class cities are very large, which clearly confers considerable advantages to these cities. The cumulative contribution of the number of students in colleges and universities ranks

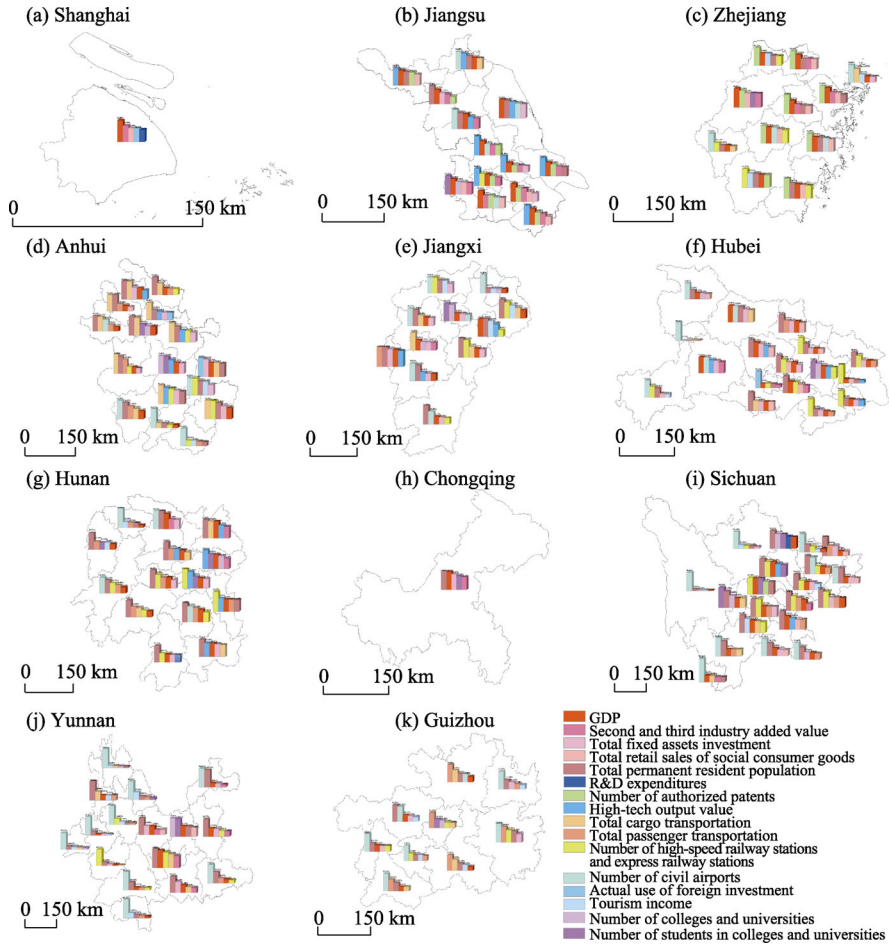**Figure 5**   The top 5 factors influencing city centrality in the Yangtze River Economic Belt
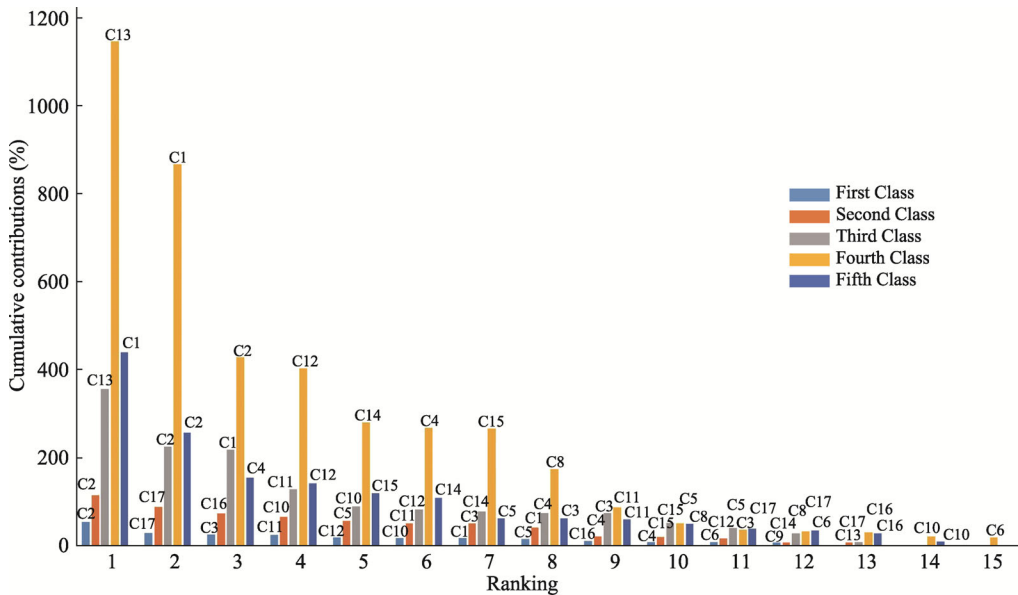

Figure 6   Ranking of cumulative contributions of the top 5 indicators in the ranking of cities of different classes in the Yangtze River Economic Belt

second, indicating that the first- and second-class cities play an extremely important role in higher education. In the first- and second-class cities, the cumulative contribution of the secondary and tertiary industries equates to high added value, and together with the total retail sales for consumer goods, the high-tech output value, the number of colleges and universities, and the total permanent population is very large. This finding confirms that industry, consumption, scientific research, higher education, and the size of the population are the main competitive features of the first- and second-class cities.

For the third-class cities, the cumulative contribution of the number of civil airports has rapidly become the largest indicator, followed by the cumulative contribution of GDP, then the total permanent residential population. The high-tech output value and the number of authorized patents also have a significant contribution. The relative importance of the number of high-speed and express railway stations and total cargo transported has increased. The latter shows that in the third-class cities, the impact of transportation has improved significantly.

For the fourth-class cities, the cumulative contribution of the number of civil airports is still the highest indicator, and the advantages here are quite clear. The cumulative contribution of the total permanent population is the second highest, followed by the cumulative contribution of GDP, but the value is less than half of that for the total permanent population. For the fifth-class cities, the first and second largest indicators of cumulative contribution are the total permanent population and GDP, respectively. For both the fourth- and fifth-class cities, the cumulative contribution of the number of high-speed and express railway stations, total cargo transported, the total fixed assets investment, and the total number of passengers transported are clearly highly ranked. However, the cumulative contribution of the total retail sales of consumer goods, the added value for secondary and tertiary industries, the number of students in colleges and universities, the high-tech output value, and the number of authorized patents is low. This result indicates that for the fourth- and fifth-class cities, the impact of traffic on centrality is dominant; also population still plays a significant role and its impact on centrality is clearly higher than that of the economy. Fixed asset investment is an important measure to promote urban development, and the influence of consumption, industry, education and scientific research remains insufficient.

Based on the above analysis, it is evident that economic activity and the size of the population play a fundamental role in the centrality of a city. The cumulative contribution of other factors reflects the differences in the development of cities at different levels. The first- and second-class cities are basically located on the coast or are regional capital cities in the central and western regions of China, where all aspects of development are being sustained. The factors that control the long-term development of industry, consumption, research, education, etc., provide the main competitive advantages for these cities. In the third-class cities, the impact of industry, consumption, scientific research and education are relatively weak, however, the relative importance of transportation has increased significantly. Most of the fourth- and fifth-class cities are located in the central and western regions of the YREB, and the overall development is lagging behind that of the upper-tier cities. Factors such as construction of transportation facilities and fixed asset investment have become the main methods to promote the development of these cities and enhance their competitiveness. However, it is considered difficult for these cities to exploit industry, consumption, scientific research, and education and to secure competitive advantage in the near term.

4.3 Analysis of inter-city linkages

The mobility of city populations in the YREB has a significant correlation with the centrality score. The correlation coefficient between population inflows and outflows in the YREB and the centrality scores of cities is 0.9030 and 0.9257, respectively. The population entering the YREB from other cities in China is related to the centrality scores of cities in the YREB and the coefficient is 0.9508. The correlation coefficient between the population flowing out of the YREB to other cities in China and the centrality scores of cities in the YREB is 0.8613. The P values, 8.56E-49, 6.66E-56, 5.48E-67 and 1.84E-39, respectively, are all less than 0.01 (Table 4).

Table 4 The correlation coefficient between population flows and the centrality scores of cities in the Yangtze River Economic Belt

Classification	Correlation coefficient	P
The correlation coefficient between population inflows and the centrality scores of cities in the YREB	0.9030	8.56E-49
The correlation coefficient between population outflows and the centrality scores of cities in the YREB	0.9257	6.66E-56
The correlation coefficient between population entering the YREB from other cities in China and the centrality scores of cities in the YREB	0.9508	5.48E-67
The correlation coefficient between population flowing out of the YREB to other cities in China and the centrality scores of cities in the YREB	0.8613	1.84E-39

The inflow and outflow of population between cities decreases as the city class decreases. The population flow is mainly between high-class cities and between high-class and low-class cities, whereas the population flow is low between low-class cities (Figure 7, Table 5; Figure 8, Table 6), reflecting the high centrality and dominant radiating effects of the high-class cities. The first- and second-class cities are the main sources of population inflows to all classes of cities and the main destinations for population outflows, reflecting the enormous radiating effects of these cities in the YREB. Among them, the first-class cities are the most important sources of population inflows for the first-, second- and fifth-class cities, and the most important destinations for population outflows, reflecting the high centrality position of the first-class cities in the YREB. The second-class cities are the most important sources of population inflows to the third- and fourth-class cities and the most important destinations for the population outflows of these cities, reflecting the central position of the second-class cities in the sub-regions.

The flow of urban population also reflects the strength of relationships between cities. With respect to the population flows between the upstream, midstream and downstream regions of the YREB, the proportion between the cities in the downstream regions was 35.52%, for the upstream regions 24.95% and the midstream regions 18.31%. The proportion from the upstream to the downstream cities was 7.83%, from the downstream to the upstream cities 7.28%, from the upstream to the midstream cities 2.29%, from the downstream to the midstream cities 1.82%, from the midstream to the upstream cities 1.66%, and from the midstream to the downstream cities 0.34%. These results reflect that the fact that the connections between the downstream cities are the closest, followed by the connections between the upstream cities; the connections between the midstream cities are weak and the connections between the midstream and the upstream or the downstream cities are weaker than the connections between the upstream and the downstream cities.
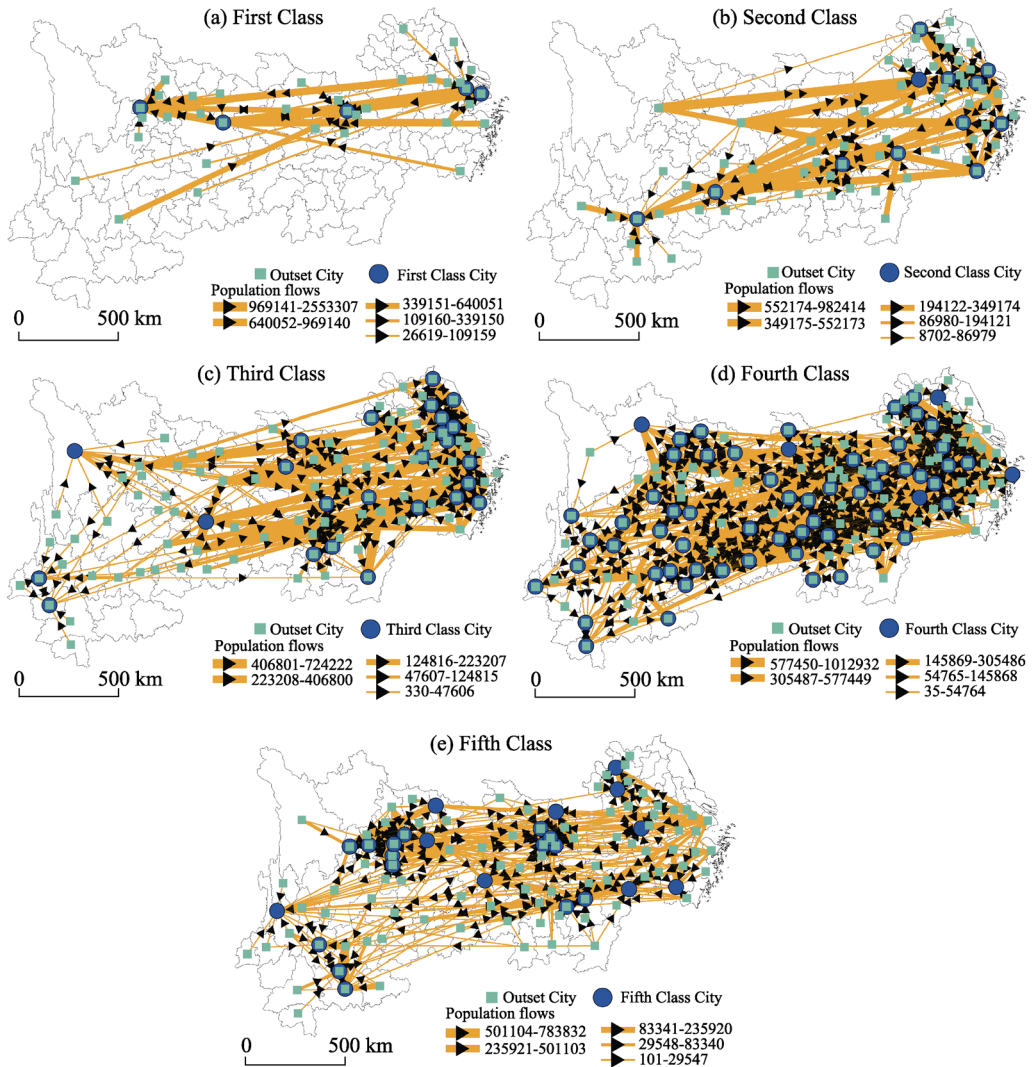
Figure 7   Population inflows between cities in the Yangtze River Economic Belt (The above data are for 2016)

Table 5   The source city for population inflow from different classes of city in the Yangtze River Economic Belt

| The source city for population inflow from first-class cities		The source city for population inflow from second-class cities		The source city for population inflow from third-class cities		The source city for population inflow from fourth-class cities		The source city for population inflow for fifth-class cities	
Class	Proportion (%)	Class	Proportion (%)	Class	Proportion (%)	Class	Proportion (%)	Class	Proportion (%)
First	55.01	First	35.85	Second	43.09	Second	33.81	First	43.15
Second	23.65	Third	23.43	First	28.25	First	31.06	Fourth	22.34
Fourth	13.78	Second	19.91	Third	14.86	Fourth	18.83	Second	19.76
Fifth	4.96	Fourth	17.71	Fourth	12.20	Third	11.58	Fifth	8.38
Third	2.59	Fifth	3.10	Fifth	1.60	Fifth	4.73	Third	6.38

The above data are for 2016.
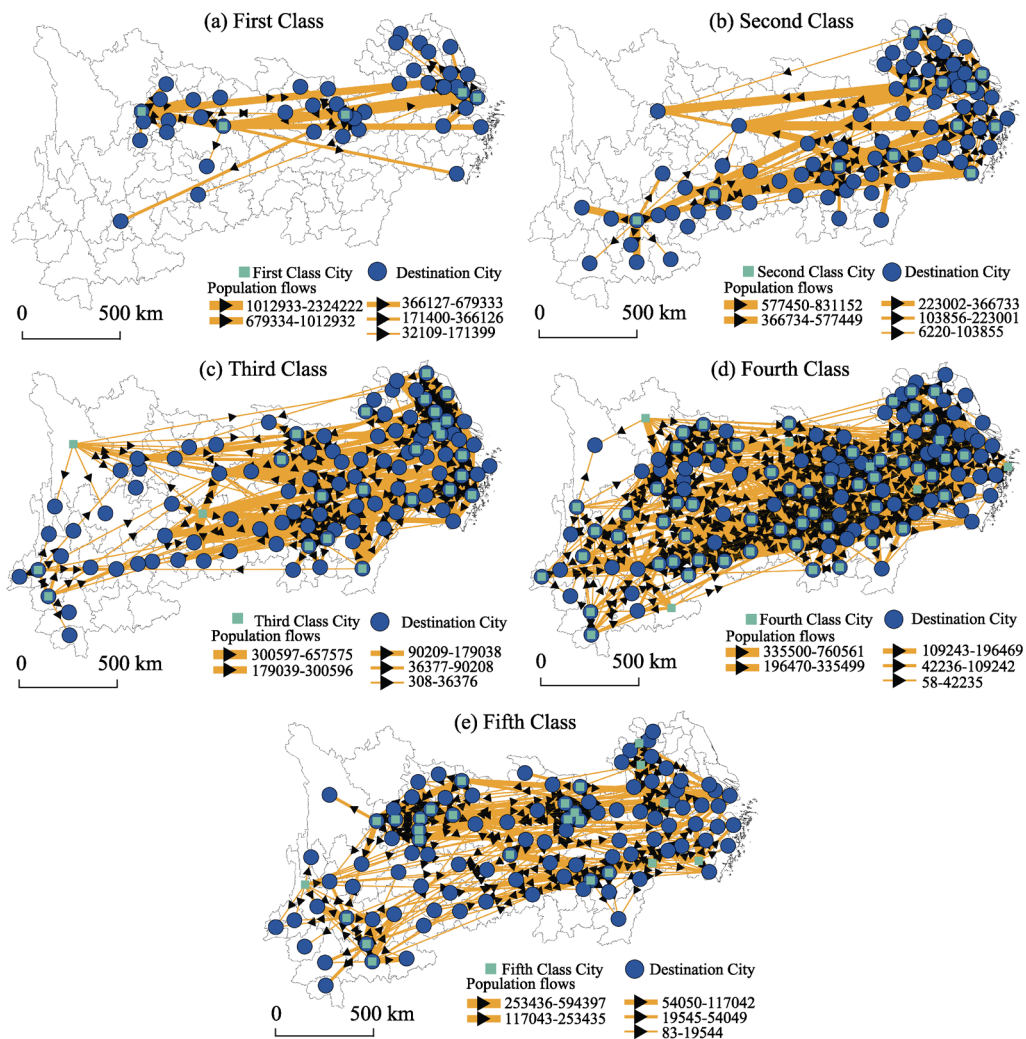
Figure 8   Population outflows between cities in the Yangtze River Economic Belt (the above data are for 2016)

Table 6   The destination city for the population outflow from different classes of city in the Yangtze River Economic Belt

The destination city for the population outflow from first-class cities		The destination city for the population outflow from second-class cities		The destination city for the population outflow from third-class cities		The destination city for the population outflow from fourth-class cities		The destination city for the population outflow from fifth-class cities	
Class	Proportion (%)	Class	Proportion (%)	Class	Proportion (%)	Class	Proportion (%)	Class	Proportion (%)
First	42.39	First	42.39	Second	38.11	Second	28.49	First	36.00
Second	22.47	Second	22.47	First	23.55	First	26.60	Fourth	28.46
Fourth	21.68	Fourth	21.68	Fourth	18.50	Fourth	25.50	Second	17.40
Fifth	7.91	Fifth	7.91	Third	17.85	Third	13.27	Fifth	10.48
Third	5.55	Third	5.55	Fifth	2.00	Fifth	6.15	Third	7.66

The above data are for 2016.

In general, Guangdong contributed the most in terms of having the largest population inflow to the YREB and being the largest population outflow destination from the YREB, followed by Beijing and the sum of the two accounted for 84.15% (inflow) and 78.76% (outflow) of the total population flow. For the first-, third-, fourth- and fifth-class cities, Guangdong and Beijing were also the top two cities for population inflow and outflow, both of which accounted for more than 70%. In the case of the second-class cities, Beijing and Guangdong occupied the first and second places for population inflow and population outflow, and the sum of the two accounted for 84.41% and 81.90%, respectively. Among the population outflow destinations, the proportion going to Beijing was significantly higher than that to Guangdong (Figure 9, Table 7; Table 8, Figure 10).
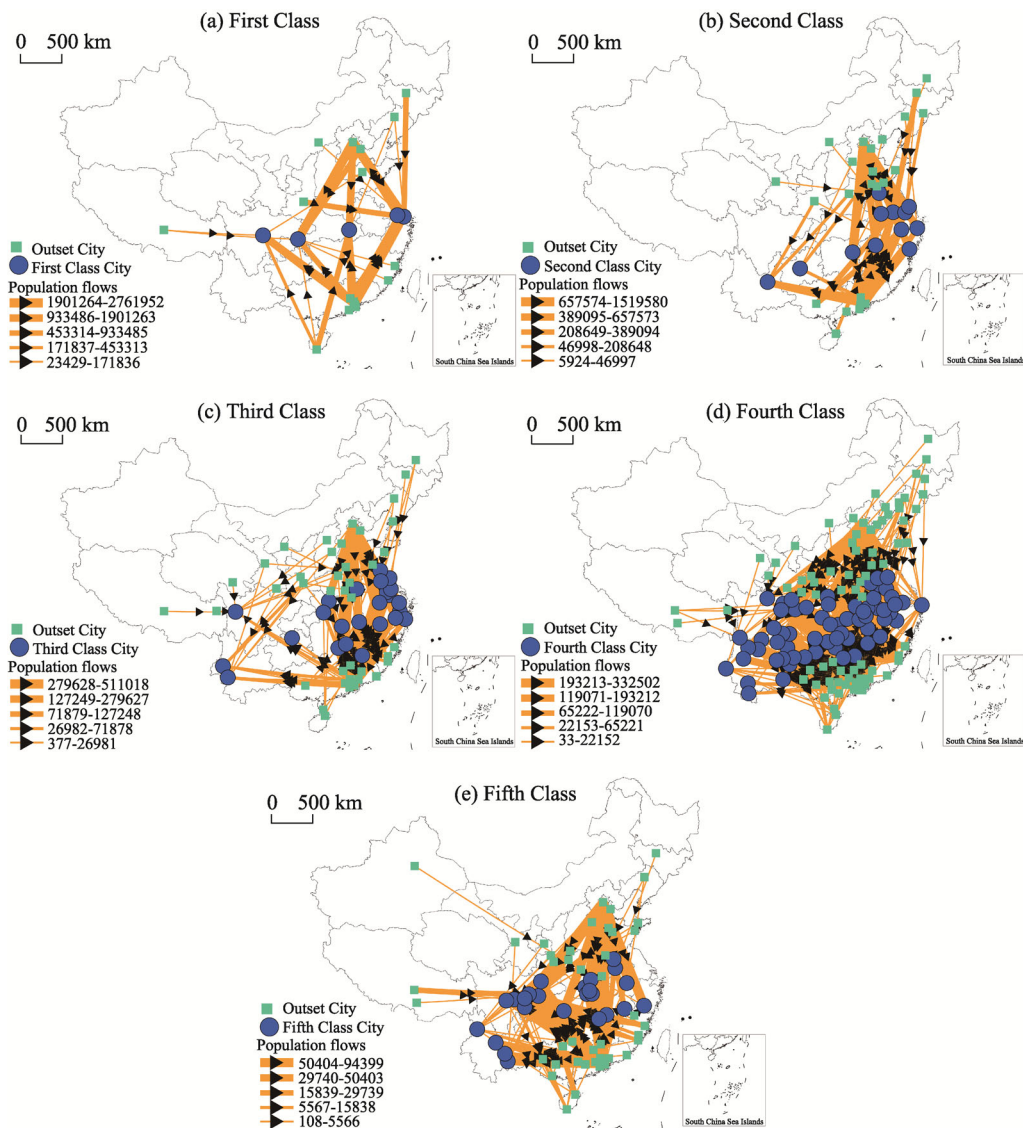

Figure 9 The population flows into the Yangtze River Economic Belt from other parts of China (the above data are for 2016)

Table 7 Source areas (outside the YREB) for population inflow for different classes of city in the Yangtze River Economic Belt

Source area of the population inflow for first-class cities		Source area for the population inflow for second-class cities		Source area for the population inflow for third-class cities		Source area for the population inflow for fourth-class cities		Source area for the population inflow for fifth-class cities	
Area	Proportion (%)	Area	Proportion (%)	Area	Proportion (%)	Area	Proportion (%)	Area	Proportion (%)
Guangdong	45.32	Beijing	44.73	Guangdong	61.27	Guangdong	59.70	Guangdong	55.08%
Beijing	34.38	Guangdong	39.68	Beijing	29.68	Beijing	25.77	Beijing	33.12
Jilin	4.50	Guangxi	4.51	Henan	3.11	Fujian	5.43	Fujian	3.45
Hainan	4.45	Jilin	3.62	Fujian	1.77	Guangxi	2.63	Henan	2.49
Shaanxi	3.45	Shandong	2.00	Shandong	1.25	Henan	2.06	Tibet	1.46
Tianjin	3.06	Henan	1.36	Shaanxi	0.68	Shaanxi	0.98	Hainan	1.43
Liaoning	1.54	Tianjin	1.21	Heilongjiang	0.38	Hainan	0.93	Guangxi	0.77
Hong Kong	1.54	Shaanxi	1.12	Guangxi	0.38	Tianjin	0.91	Shandong	0.75
Fujian	0.79	Hainan	0.87	Liaoning	0.38	Hebei	0.42	Shaanxi	0.59
Tibet	0.72	Hebei	0.32	Tianjin	0.34	Liaoning	0.41	Tianjin	0.23
Shandong	0.14	Heilongjiang	0.26	Jilin	0.19	Tibet	0.23	Hebei	0.22
Inner Mongolia	0.11	Inner Mongolia	0.14	Hainan	0.14	Shandong	0.19	Liaoning	0.14
—	—	Gansu	0.11	Gansu	0.14	Jilin	0.13	Jilin	0.12
—	—	Liaoning	0.07	Tibet	0.14	Gansu	0.10	Gansu	0.08
—	—	—	—	Ningxia	0.10	Shanxi	0.03	Xinjiang	0.04
—	—	—	—	Hebei	0.04	Heilongjiang	0.03	Shanxi	0.04
—	—	—	—	Shanxi	0.01	Inner Mongolia	0.03	—	—
—	—	—	—	Qinghai	0.01	Macao	0.03	—	—

The above data are for 2016.

Table 8 Destination areas (outside the YREB) for population outflow for different classes of city in the Yangtze River Economic Belt

Destination area for the first-class city outflow population		Destination area for the second-class city outflow population		Destination area for the third-class city outflow population		Destination area for the fourth-class city outflow population		Destination area for the fifth-class city outflow population	
Area	proportion (%)	Area	proportion (%)	Area	proportion (%)	Area	proportion (%)	Area	proportion (%)
Guangdong	37.59	Beijing	49.46	Guangdong	43.24	Guangdong	47.26	Guangdong	46.21
Beijing	37.18	Guangdong	32.44	Beijing	40.21	Beijing	31.46	Beijing	38.21
Hainan	5.16	Guangxi	3.59	Henan	7.17	Fujian	5.57	Fujian	4.13
Jilin	3.94	Henan	3.52	Shandong	2.09	Henan	4.89	Henan	4.09
Tianjin	3.91	Shandong	3.28	Shaanxi	1.22	Guangxi	3.51	Shandong	1.65
Shaanxi	3.33	Jilin	3.12	Fujian	1.20	Shaanxi	2.17	Tibet	1.61
Hong Kong	2.33	Shaanxi	1.07	Jilin	0.96	Tianjin	1.39	Hainan	1.13
Shandong	2.30	Tianjin	0.89	Heilongjiang	0.82	Hainan	1.04	Shaanxi	1.10
Liaoning	1.79	Fujian	0.79	Guangxi	0.81	Shandong	0.71	Guangxi	0.99
Tibet	1.48	Hebei	0.49	Liaoning	0.63	Liaoning	0.67	Tianjin	0.49
Fujian	0.85	Hainan	0.48	Tianjin	0.60	Hebei	0.54	Shanxi	0.18
Inner Mongolia	0.14	Heilongjiang	0.45	Tibet	0.31	Tibet	0.34	Hebei	0.10
—	—	Inner Mongolia	0.24	Gansu	0.24	Gansu	0.22	Gansu	0.07
—	—	Liaoning	0.17	Hebei	0.21	Jilin	0.11	Liaoning	0.04
—	—	—	—	Hainan	0.19	Inner Mongolia	0.05	Ningxia	0.01
—	—	—	—	Hong Kong	0.10	Heilongjiang	0.05	—	—
—	—	—	—	Shanxi	0.01	Macao	0.03	—	—
—	—	—	—	—	—	Shanxi	0.02	—	—

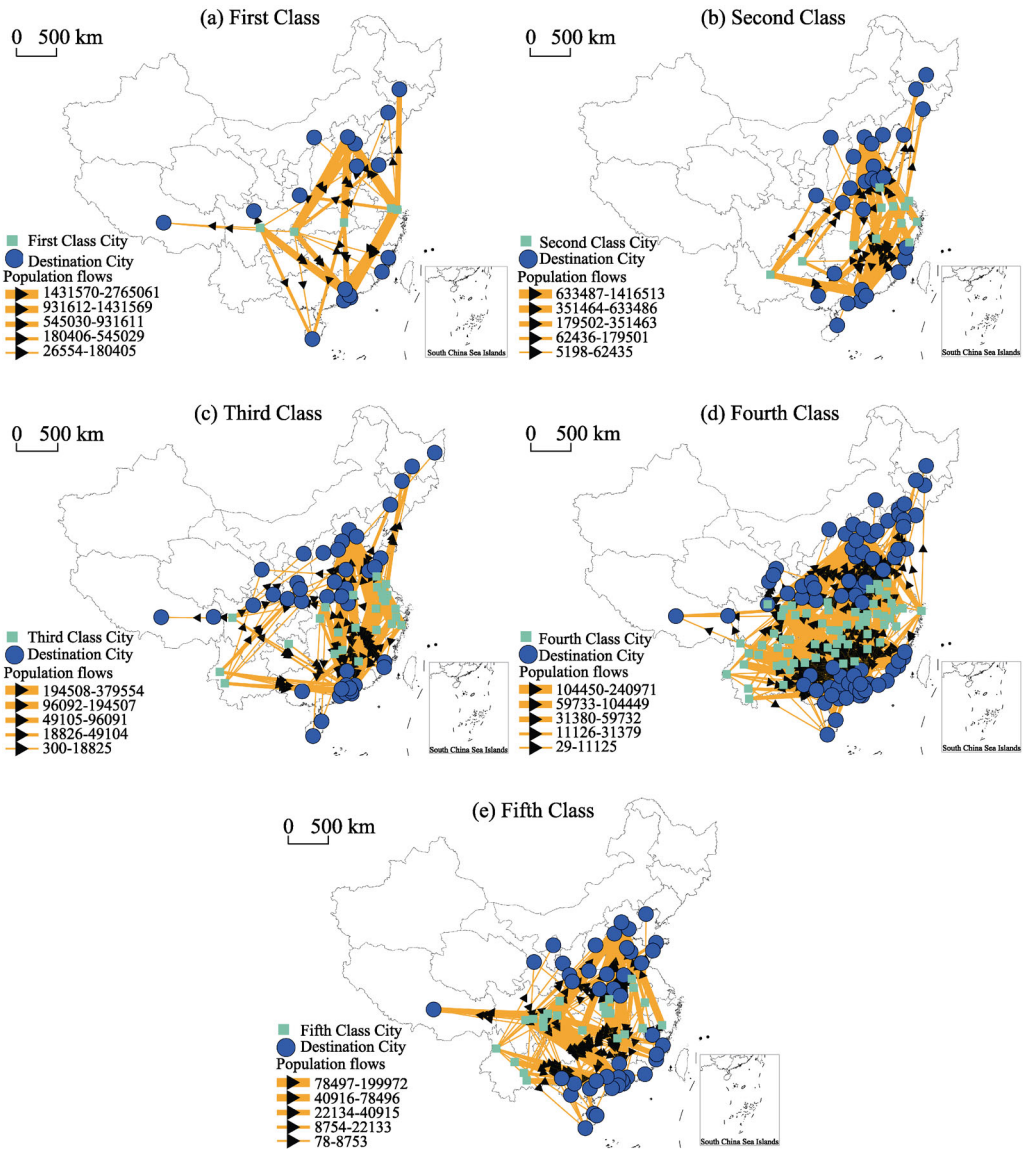The above data are for 2016.

Figure 10   Population outflow from the Yangtze River Economic Belt to other parts of China (the above data are for 2016)

Overall, the YREB is more connected to Guangdong than to Beijing because Guangdong is closer to the YREB and has a larger population than Beijing. The second-class cities are more connected to Beijing than Guangdong, mainly because the second-class cities are mostly provincial capital cities having excellent transportation hubs, such that exchanges with Beijing are more extensive. The cities in the YREB are closely linked to Guangdong and Beijing, reflecting Guangdong's strong economic status and its geographic proximity to the YREB. The results are also a reflection of Beijing's enormous influence as the national political and cultural center.

5   Conclusions and discussion

5.1   Conclusions

(1) The basic characteristics of cities in the YREB largely conform to the point axis theory and central geography theory. Two axes are connected in series with the cities of the YREB: one axis is the Yangtze River with Shanghai, Suzhou, Wuhan, Chongqing, and Chengdu acting as key nodes along the connecting line; the other is the Shanghai-Kunming railway route, which links Shanghai, Hangzhou, Nanchang, Changsha, and Guiyang, with the cities acting as important nodes. With the above cities positioned centrally, a city hierarchy for the region has been developed. The level of urban centrality for the downstream area is more extensive than that for the middle and upper reaches. The downstream gradient positioned around Shanghai and Suzhou is relatively gentle, and the urban system is more mature. The gradient in the middle and upper reaches is steeper and even transits directly from the highest centrality level to the lowest level where the urban system is underdeveloped.

(2) The factors influencing urban centrality in the YREB largely conform to comparative and late-developing advantage theories. Although the GDP and the total permanent residential population are basic factors in cities of different classes, other factors have different impacts on cities of different classes and on the regions. For the first- and second-class cities and for the lower reaches of the Yangtze River, higher education, R&D and high-tech industries, social consumption, and transportation are the main influencing factors. In the third-, fourth- and fifth-class cities and in the middle and upper reaches of the Yangtze River, fixed asset investment and tourism income are the main influencing factors, reflecting the comparative advantages of cities with different development levels. However, in the third-, fourth- and fifth-class cities and for the middle and upper reaches of the Yangtze River, the impact of transportation is particularly significant. In particular, with the development of aviation and high-speed or express railways, the impact of external traffic on the previously underdeveloped areas has been substantial and transformative in terms of developing a recent competitive advantage.

(3) The mobility of populations is significantly correlated with centrality of cities. The degree of connectivity of cities in the YREB is positively correlated with city class. As stated earlier, there are two axes that align in the east-west direction, namely, the Yangtze River and the Shanghai-Kunming railway line. Moreover, the complexities of the connectivities between cities are positively correlated with the degree of economic development. Shanghai, Chongqing, Suzhou, Chengdu, Wuhan, and other provincial capitals have higher migration and stronger links. However, fewer cities are connected with similar cities of the same class. Also, the connectivities between the midstream cities and the upstream or downstream cities are weaker than those between the upstream cities and downstream cities. For areas outside the YREB, Guangdong and Beijing are the two regions most closely linked.

5.2   Discussion

(1) Analysis of social and economic data can yield insights into the economic development of the city in a general way; however, a sustainable ecological environment is also an important direction for urban development in the future. As one of the most dynamic factors in society, the migration of people reflects the connectivity between cities; furthermore, lo-

gistics and information flow are important factors for establishing connectivity between cities. To maintain the integrity of the study area, the indexes of ecological environment, logistics, and information flow were not included in the present analysis because of the difficulty of securing data in some areas. The study of the ecological value of the area and the human settlement environment, as well as logistics and information flow, will be important elements to address in follow-up studies on urban centrality and linkages.

(2) Cities with high levels of centrality can exert a strong agglomeration effect, take advantage of the economies of scale, and improve resource utilization efficiency. However, these impacts may result in drastic changes to population, industry, and resources of the surrounding cities. Within these cities there may also be problems due to overcrowding, housing shortages, and traffic congestion. A city with low centrality faces the opposite challenges. Starting from a low level of centrality, the scientific analysis of strategies to control a city's centrality, rationally lay out cities with different levels of centrality, and effectively oversee the development of cities and adjoining regions deserves further study.

(3) At present, research on city centrality is under similar methods, but the development background of each city differs by region. The population represents the core and main body of the city in new urbanizations, and because people differ in their needs and aspirations, the development background of different cities varies. Questions that need to be posed include: can the development of the future city be 'decentralized' and take the form of an open, flat, and equal urban network, and can we create a unique urban pattern?

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