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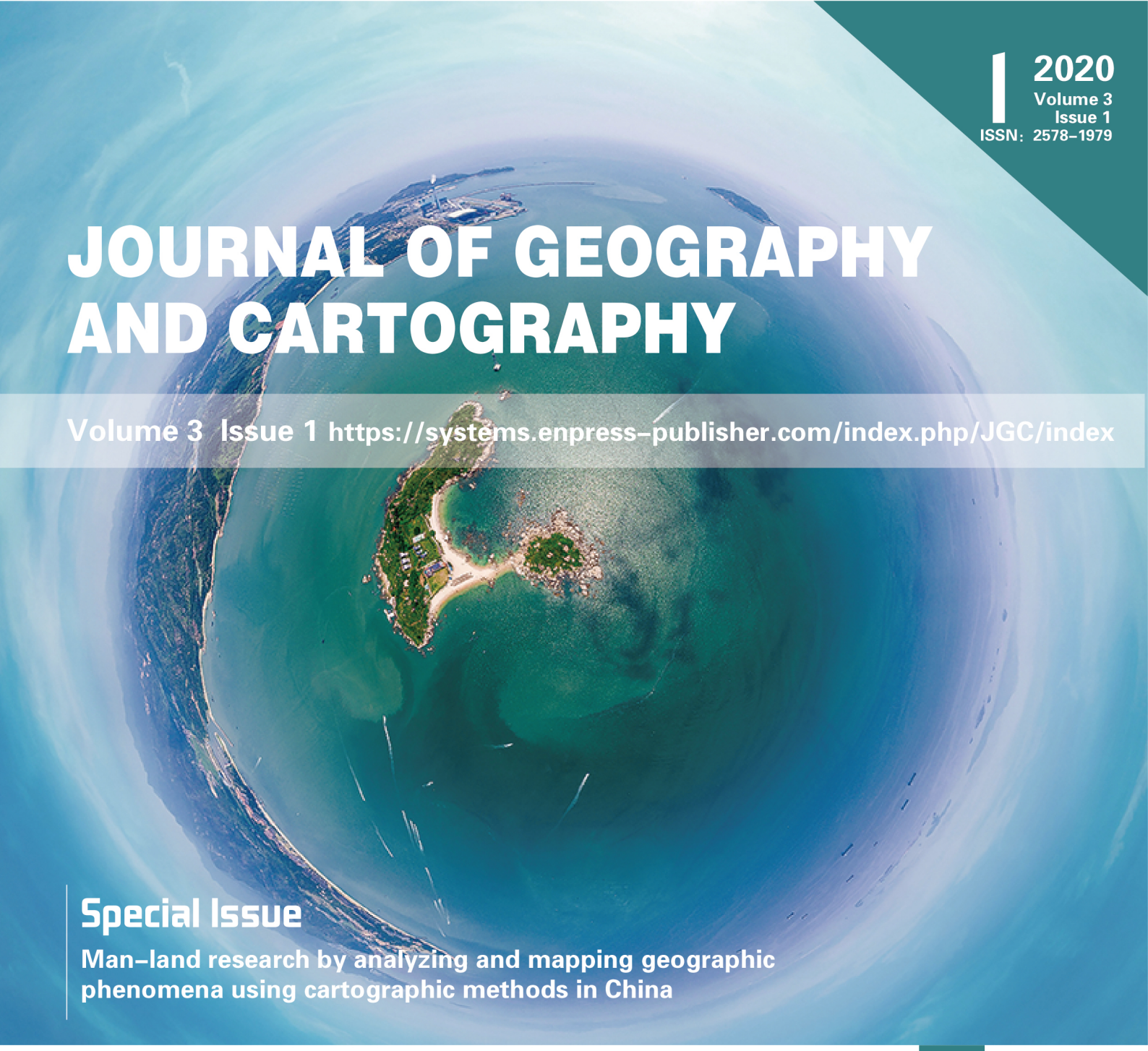

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Man–land research by analyzing and mapping geographic phenomena using cartographic methods in China

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ORIGINAL RESEARCH ARTICLE

Order, scale structure and coupling types of coastal port city system from the perspective of multi-function

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ABSTRACT

Using the rank scale rule, taking 47 major port cities in China from 2001 to 2015 as research samples, this paper discusses the rank scale characteristics and hierarchical structure of coastal port city system from a multi-functional perspective, and divides the coupling type of multi-functional development based on shipping logistics. The research shows that: 1) from 2001 to 2015, the scale-free area of manufacturing function order scale distribution in the coastal port city system appeared bifractal structure, the hierarchical segmentation characteristics appeared, and the other functions were single fractal; From the perspective of long-term evolution, only the order and scale distribution of shipping logistics function has developed from centralization to equilibrium, while the business function, manufacturing function (scale-free region I), modern service function and population distribution function are in a centralized situation. 2) The hierarchical structure of coastal port city system has gradually changed from pyramid structure to spindle structure, and generally formed five levels: national hub, regional hub, regional sub center, regional node and local node. 3) From the perspective of multi-functional coupling types, the traditional functions of port cities are generally ahead, while the high-end service functions lag behind, and the improvement speed of urban functions is slow and tends to be flat, indicating that the multi-functional development of China's coastal port cities is still at a low level, and the industrial system structure needs to be further optimized. 4) From the perspective of port cities at different levels, the functions of regional hub cities and regional sub central cities are in the stage of rapid growth; regional and local node cities are still in the growth stage of traditional functions such as industry and commerce.

Keywords: Port City System; Sequence Size Distribution; Hierarchy; Coupling Type

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Ports and cities not only organically combine production and circulation, but also develop together and promote each other. Coastal and river areas will inevitably form a series of port city systems with different sizes and characteristics, and become an organic hub system for the country to communicate domestic and foreign international trade[1]. Urban system is a hot issue in urban geography, but there has been little research on port city system for a long time. The reasons are as follows: on the one hand, due to the discontinuous distribution of ports and their cities, there are more studies on port system from the perspective of traffic geography, but less on port city system from the perspective of urban geography; on the other hand, in a long period of time, the number of regional ports is small, the functional convergence between ports and port cities, and the competition of goods supply hinder each other's economic ties, and the relevance and systematicness are not strong. Over the past 40 years of reform and opening up, the development of ports in China's coastal areas has changed with each

passing day, new ports have been emerging, and the characteristics of port regionalization are obvious. The coastal urban belt has become a port urban belt. Port cities have not only greatly increased in number, but also formed a continuous distribution in space. Especially with the strengthening of shipping network connection and logistics, the division of labor among large, medium and small ports is becoming more and more obvious, and they are more closely connected with each other. In this context, it is feasible and necessary to deeply study the port city system.

The research on urban system mainly focuses on the theoretical content of "three structures and one network", namely regional spatial structure, hierarchical scale structure, and functional type structure and network system organization[2]. Among them, the research objects involved in the study of functional type structure are relatively rich, such as national prefecture level cities, central plains urban agglomeration, Yangtze River economic belt urban agglomeration, central Liaoning urban agglomeration, etc. [3–7]; in terms of research methods, urban functions are classified and identified by general description method, statistical analysis method, factor analysis, location entropy and other methods. As a special type of city, the port function of port city is the basic function. With the development of port industry system, more and more other port industries and even non port industries are gradually attracted, so as to promote the multi-functional development of port city. However, at present, domestic research on port cities mostly focuses on port city relations, port city spatial structure, port city competitiveness and sustainable development capacity[8–13]. The deficiencies are as follows:

1) From the perspective of urban system, most of them focus on a single port city or port city port and shipping logistics, trade and other aspects, and there are few studies on exploring the hierarchical structure and relationship of port city system from the perspective of urban system. 2) In terms of methodology, the rank scale rule is mostly used in the study of hierarchical scale structure of urban system, but there are few attempts in the study of port city system[14]; this rule is also widely used in the fields of floating population, tourism flow, oil flow, traffic flow and so on[15–19]. However, most of them measure the scale distribution with a single index, and the comparative research on the rank scale from the multi-functional perspective has not been carried out.

In view of this, based on the theory of port function evolution and the characteristics of urban development, this paper selects five representative functions of port cities, uses the rank scale rule to describe the multi-functional scale distribution characteristics of port city system from multi-dimensional indicators, and constructs the coupling relationship between basic port and shipping functions and other functional scales based on the rank scale rule, This paper discusses the multi-functional differentiation and development of China's port city system[20].

1. Research methods and data sources

1.1 Rank scale rule of port city system

The rank–scale model of urban distribution starts from the whole urban system, reflects the relationship between the size of different cities and their rank in the whole system, and can evaluate the distribution of urban system in a country or region[14]. In 1913, the law was proposed by German scholars. In 1935, American linguistics professor obtained Ziff's law through statistical analysis. The basic formula of Lotka model now widely used is:

$$P_i = \frac{P_i}{P_i^q} \text{ or } P_i = P_1 \times R_i^{-q} \quad (1)$$

In the formula, *Pi* is the city scale at *i* level and P_1 is the first city scale; q is Zipf index; R_i is the order of city *i*. Based on different functions and referring to Formula (1), it is concluded that the basic form and logarithmic form of the calculation formula of port city system rank scale in this paper are as follows:

$$F_i = \frac{F_1}{R_i^q} \text{ or } F_i = F_1 \times R_i^{-q} \quad (2)$$

$$1\mathrm{n}\, F_i = 1\mathrm{n}\, F_1 - q1\mathrm{n}R_i \quad (3)$$

In the formula, F_i is the functional scale of the port city at i level, and F_1 is the functional scale of the first port city. Zipf index (q value) has the following properties: when $q = 1$, the ratio of the first city to the smallest city in the urban system is the number of cities in the whole urban system; when $q < 1$, the scale of high-level sub cities is not very prominent, and there are more and dominant cities in the middle order; when $q > 1$, the urban scale distribution is relatively concentrated, the urban scale distribution is quite different, and the urban primacy is high. If q becomes larger, the concentrated force is greater than the dispersed force; if q becomes smaller, and the scattered force is greater than the concentrated force. When $q \to \infty$, there will be only one city in the system; when $q = 0$, the size of cities in the urban system is equal.

1.2 Multi-functional coupling type division based on bit order scale rule

1.2.1 Construction of multi-functional index system of port city

The intergenerational division of ports is not based on time period. Different ports in China have different development levels, intergenerational differences and functional characteristics. In 1999, the United Nations Conference on Trade and Development (UNCTAD) proposed: so far, the international developed ports have entered the fourth generation[21]. Many scholars have explained the evolution theory of port function: the main functional characteristics of the first generation port are transportation transfer function; the second generation of port functions are characterized by industry, commerce and value-added services; the third generation port features logistics and cargo information flow services; the fourth generation ports are characterized by resource allocation and global hub functions. The multi-functional development of the port also drives the diversification of the functions of the city where the port is located. Therefore, we regard shipping logistics, commercial trade, modern manufacturing and modern service as the four functions of port cities. In addition, in order to reflect the economic vitality and attraction of modern port cities, we have especially increased the function of population distribution. Based on this, the multi-functional scale evaluation index system of port city system (**Table 1**) is constructed to further characterize the function of port city.

Table 1. The multi-functional scale evaluation index system of port city system

Functional type index	
Shipping logistics function	Total freight volume, water freight volume, port cargo throughput, port container throughput and port foreign trade throughput.
Commercial trade function	Total retail sales of social consumer goods, total sales of wholesale and retail goods above the quota, employees of wholesale and retail units, total amount of foreign capital actually utilized in the current year, and number of wholesale and retail enterprises above the quota.
Manufacturing function	The indexes above designated size include total output value of industries, total profits of industrial enterprises, current assets of industrial enterprises, number of industrial enterprises, and employees of manufacturing units.
Modern service function	Various loan balances of financial institutions, various deposit balances of financial institutions, employees of financial institutions, number of inbound international tourists, employees of information transmission, computer service industry and software industry.
Population distribution function	Total passenger volume, railway passenger volume, highway passenger volume, water passenger volume and civil aviation passenger volume.

1.2.2 Classification of multi-functional coupling types

Ideally, the function scale of high-grade port cities is larger and the level is higher, accounting for a greater proportion in different function sequences, while that of low-grade cities is the opposite; under the multi-functional coordination and interaction mechanism of port city, the development levels of different functions are unified. In the double logarithmic curve of rank order scale, it shows that the rank order of each functional scale of high-grade port city is higher, while that of low-grade city is on the contrary. The double logarithmic curves of different

functional scales of any port city coincide. In reality, the curves are misaligned.

According to the double comparison relationship between different functional scale and the proportion of functional scale, the development differences between port city functions can be measured from two aspects and the port city can be explored based on the coupling type characteristics of multi-functional development level in the city. The specific calculation formula is as follows:

$$\Delta F_i = \ln(F_{bi}/F_{ai}) = \ln F_{bi} - \ln F_{ai} \quad (4)$$

$$\Delta S_i = \ln\left(\frac{F_{bi}}{\sum_{i=1}^{n} F_{bi}} / \frac{F_{ai}}{\sum_{i=1}^{n} F_{ai}}\right) = \ln\frac{F_{bi}}{\sum_{i=1}^{n} F_{bi}} - \ln\frac{F_{ai}}{\sum_{i=1}^{n} F_{ai}} \quad (5)$$

In the formula, F_{ai} is the port function scale (shipping logistics function), F_{bi} is the urban function scale (commercial trade function, manufacturing function, modern service function and population distribution function), and n is the number of cities. The ΔF_i obtained from the above formula reflects the comparison relationship between the functional scale of the port city, and ΔS_i reflects the comparison relationship between the functional status of the port city. Based on this, four coupling types can be divided (**Table 2**).

Table 2. The basis and characteristics of coupling type classification of port city system

Type	ΔF_i	ΔS_i	Characteristics
Absolute leading type	>0	>0	The urban functional scale and status in the urban system are higher than the port functional scale.
Relatively advanced type	>0	<0	The urban functional scale is higher than the port functional scale, and its position in the urban system is lower than the port functional scale.
Relative lag type	<0	>0	The urban functional scale is lower than the port functional scale, and its position in the urban system is higher than the port functional scale.
Absolute lag type	<0	<0	The urban functional scale and status in the urban system are lower than the port functional scale.

1.3 Overview of the study area and data sources

Taking the coastal port cities as the research sample, this paper selects 47 major port cities based on the historical evolution and importance of ports and the development status of port cities, of which only cities below Nanjing are selected along the Yangtze River; according to the division of port groups and the availability and continuity of index data in the national coastal port layout plan issued by the Ministry of Communications in 2006, the port city samples are finally determined as: port city groups around the Bohai Sea (Tianjin, Dandong, Dalian, Yingkou, Jinzhou, Tangshan, Cangzhou, Qinhuangdao, Yantai, Weihai, Qingdao and Rizhao); Yangtze River Delta port urban agglomeration (Shanghai, Suzhou, Ningbo, Lianyungang, Zhoushan, Nanjing, Nantong, Wenzhou, Changzhou, Wuxi, Jiaxing, Taizhou, Taizhou, Yangzhou and Zhenjiang); Pearl River Delta port urban agglomeration (Guangzhou, Shenzhen, Zhuhai, Shantou, Shanwei, Huizhou, Dongguan, Zhongshan, Yangjiang, Jiangmen and Maoming); southeast coastal port urban agglomeration (Fuzhou, Putian, Quanzhou and Xiamen); southwest coastal port urban agglomeration (Zhanjiang, Beihai, Qinzhou, Fangcheng and Haikou).

In view of the availability of port data, the time series is determined as 2001–2015. The urban index data is from China Urban Statistical Yearbook (2002–2016), the port index data is from China port Yearbook (2002–2016), and the tourism index data is from China Regional Economic Development Yearbook (2002–2014)[22–24]. Some missing data come from provincial and municipal yearbooks and Statistical Bulletins, and individual data are fitted by mathematical methods. Because the data units of each index are not unified, the data are standardized, and the five indexes under each function are weighted and summed by entropy method to obtain the

scale of each function.

2. Rank scale distribution of coastal port city system from a multi-functional perspective

2.1 Comparative analysis of size distribution of different functional bit sequences

Since the 21st century, Chinese cities, especially the eastern port cities, have developed well. Due to its unique location advantages and the support and guidance of national policies, the port city belt has gradually evolved into a port city system with high urbanization level, strong economic development speed and close international trade exchanges in eastern China. All cities have also become port cities with multi-functional characteristics. Using Formula (3) for 2001–2015, simulated regression analysis was carried out for each functional scale of the port city system, and the goodness of fit of the curve was as high as 90%, which proved that the rank scale rule can be used to explain the scale distribution characteristics of the port city system. The scatter diagram of various functions of the port city system and the double logarithm fitting curve of bit order scale (**Figure 1**) are as follows.

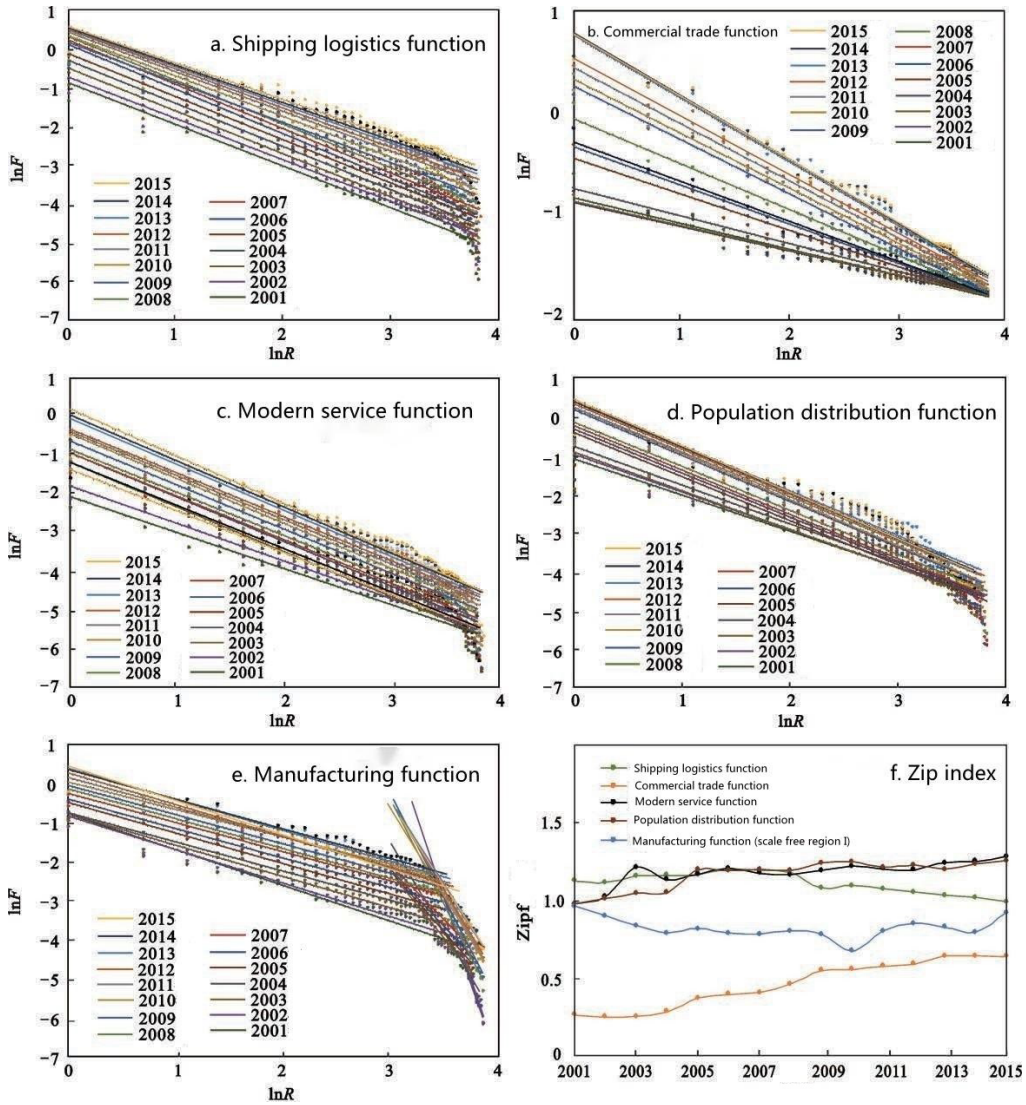

Figure 1. The multifunctional rank-size double logarithm fitting curve and Zipf exponential curve of port city system.

2.1.1 Change track of bit order scale distribution

The distribution structure, trend and growth characteristics of each functional scale of coastal port city system have different characteristics. 1) In terms of fractal structure, there are two regions with

high fitting in the manufacturing function rank scale curve, which is a significant bifractal structure, with obvious hierarchical segmentation characteristics. The number of cities in scale-free region I is much higher than that in scale-free region II, while the other functions are single fractal structure. From the perspective of Zipf index, the Zipf index of business function and manufacturing function (scale-free region I) is less than 1, and its rank scale distribution is currently in the stage of equalization; In contrast, the Zipf index of shipping logistics, modern services and population distribution functions is more than 1, and the rank scale distribution is in the centralized stage. 2) From the curve characteristics and long-term evolution characteristics of scale distribution, the growth characteristics of each function are different while realizing scale expansion. The scale of Commerce and trade functions shows a significant "funnel-shaped" divergent growth. The growth rate of large-scale port cities is significantly faster than that of small and medium-sized cities. The scale distribution tends to be unbalanced, and the concentrated force is greater than the decentralized force. The scale of other functions is generally characterized by parallel growth: for example, the scale of modern service and population distribution functions is parallel and divergent growth, which means that the growth rate of large-scale port cities is relatively fast, and the scale distribution still tends to centralization; in the bifractal structure of functional scale of manufacturing industry, the distribution of urban scale in scale-free area tends to be centralized; only the scale of shipping logistics function tends to be parallel and convergent, that is, small and medium-sized cities continue to develop and catch up with large cities, and the scale distribution is gradually balanced. 3) Compared with the development characteristics of shipping logistics function, the business function is quite different. As a traditional function of port, this function is integrated into the evolution of urban function earlier in the process of continuous refinement of social division of labor, and can develop independently to a certain extent; modern services, population distribution and other high-end service industries are easier to land in high-level port cities and give full play to their derivative potential. At present, the main body with stronger economic vitality and population distribution capacity is still a few high-level port cities, which is highlighted by the centralized distribution of modern service and population distribution functions of high-level port cities, and the scale is significantly higher than that of low-level port cities.

2.1.2 Comparison of changes in urban order

Comparing and calculating the urban order of various functions in 2001 and 2015 (**Table 3**), the results show that: 1) from the perspective of total change, the adjustment and change range of urban order in shipping logistics and population distribution function is obvious. Among them, cities with more than 10 shipping logistics functions are Rizhao, Yingkou, Tangshan, Cangzhou, Taizhou, Huizhou,

Table 3. The changes in port city order adjustment in 2001–2015

Function type	Regional port city system	Bohai Rim (12 ports)		Yangtze River Delta (15 ports)		Pearl River Delta (11 ports)	
	Total variation	Total variation	Unit variation	Total variation	Unit variation	Total variation	Unit variation
Shipping logistics function	300	24	2	30	2	12	1.09
Commercial trade function	192	10	0.83	14	0.93	20	1.82
Manufacturing function	166	10	0.83	18	1.20	8	0.73
Modern service function	170	10	0.83	4	0.27	12	1.09
Population distribution function	292	22	1.83	24	1.60	18	1.64

Note: the value is the absolute value of urban rank change in 2001 and 2015.

Qinzhou and Dandong; cities with a ranking of more than 10 are Qinhuangdao, Zhuhai, Maoming, Jiaxing, Zhongshan and Wenzhou. During this period, the in-depth adjustment of the port system and the reorganization and integration of the port area made the urban order change greatly, and a stable pattern has not yet been formed. Cities with more than 10 cities in the population distribution function are Zhanjiang, Nantong, Weihai and Beihai; more than 10 cities with a decline in rank are Dongguan, Shantou, Maoming, Dalian, Wenzhou and Cangzhou. The change of urban order in this function mostly reflects the strength of urban attraction. Regional economic level differences, traffic accessibility and industrial capital flow have become important factors affecting urban population agglomeration. 2) The order of manufacturing functional cities has changed steadily and developed mature. As the core function of the second generation port, the adjustment range of urban order in the manufacturing function is the smallest, which shows that most coastal port cities in China are still in the transformation stage from the second generation port to the third generation port, and the port industry is the leading industry of many port cities.

2.2 Difference of multi-functional rank scale distribution among the three coastal port urban agglomerations

2.2.1 Change track of bit order scale distribution

The study uses Formula (3) to conduct simulated regression analysis on the functional scale of the three port city clusters from 2001 to 2015, and proves that the rank scale rule can be used to explain the scale distribution characteristics of regional port city system. The function scatter diagram and bit order scale double logarithm fitting curve (**Figure 2**) are as follows. There are both similarities and differences in the change trajectories of the order scale distribution of various functions in the Bohai rim, Yangtze River Delta and Pearl River Delta. 1) The change track of the rank scale distribution of the three regional trade and modern service functions is highly consistent. On the one hand, the change track of the rank scale distribution of trade functions presents a "funnel shape" in the three regions, and the degree of centralization is more obvious. With the evolution of time, the growth range of trade functions in port cities becomes larger, and the distribution of trade functions in port city system shows an obvious Matthew effect. On the other hand, the change track of the rank scale distribution of modern service functions represented by finance, computer and information services shows a weak decentralized trend in the three regions. 2) There are great differences in the functional order scale distribution trajectories of shipping logistics, manufacturing and population distribution in the three regions. The scale-free area of the functional order scale distribution of shipping logistics and population distribution around the Bohai Sea changed from single fractal to double fractal in 2007 and 2008, respectively; the bifractal structure of manufacturing function in the Pearl River Delta changed to single fractal in 2013, and the overall bit order scale distribution structure tends to be stable. In contrast, with the function of single fractal structure, the change trajectories of bit order scale distribution show a roughly parallel trend, and the difference of scale distribution changes little. 3) From the overall situation of the three regions, the five functions of cities in the Yangtze River Delta have obvious sequence and scale distribution characteristics, and the port city system structure is relatively stable. The order scale distribution characteristics of the four functions in the Pearl River Delta are obvious, while the order scale characteristics of manufacturing functions have strong volatility, and many years do not have the overall order scale distribution characteristics. In the Bohai Rim region, there are two functions: shipping logistics and population distribution. The rank scale distribution shows strong volatility, and many years do not have the characteristics of rank scale distribution. From a multi-functional perspective, the regional order scale distribution characteristics of Bohai rim, Yangtze River Delta and Pearl River Delta are relatively obvious, and the development degree of regional port city system still needs to be strengthened.

2.2.2 Comparison of changes in urban order

From the perspective of the three regions, the change of the order of multi-functional development of port cities. On the whole, the change of the order of cities in the Pearl River Delta region is the largest, and the order distribution in the Yangtze River Delta region is the most stable (**Table 3**), but the specific conditions of each function are different. 1) In terms of functions, the Pearl River Delta region in shipping logistics and manufacturing functions, the Bohai

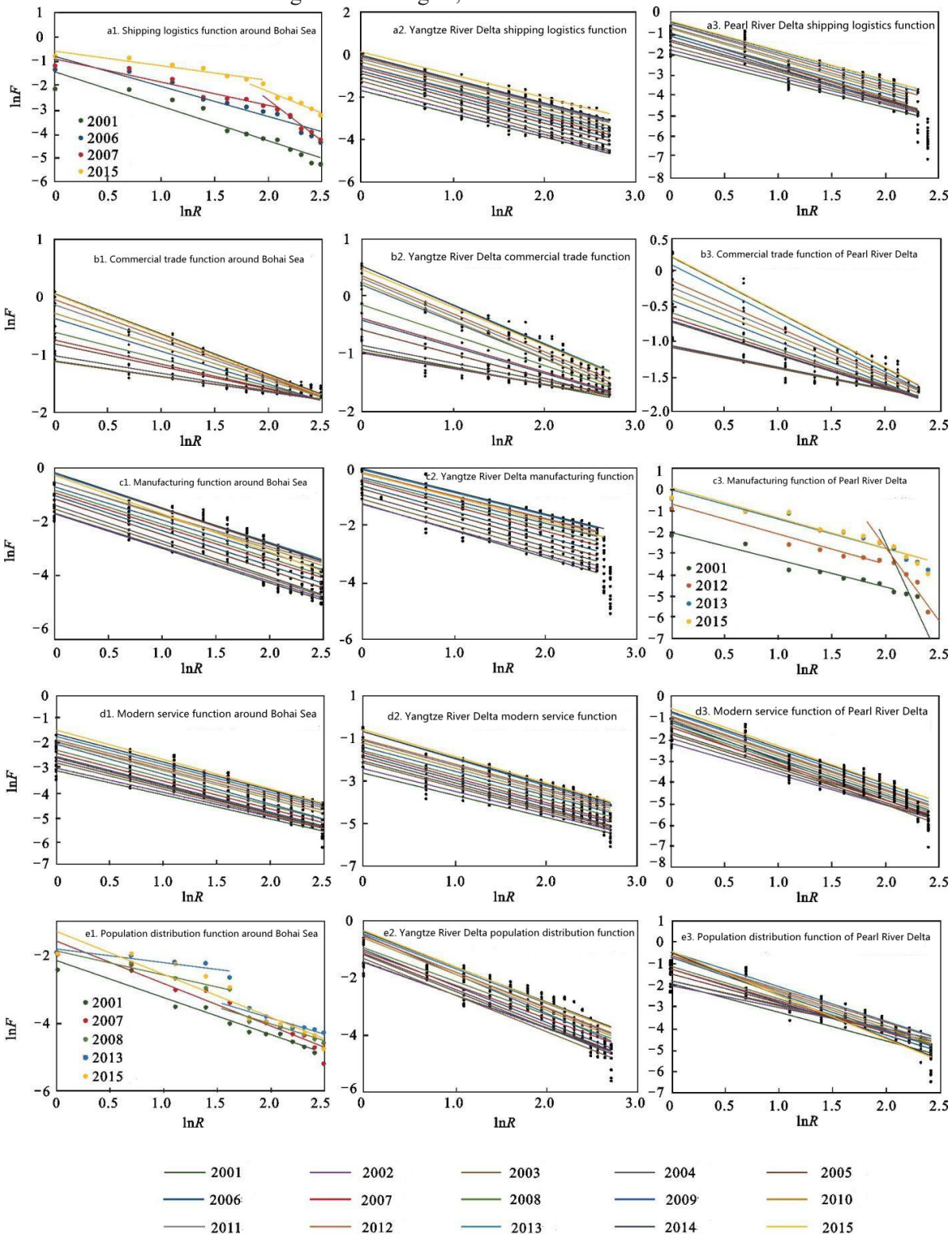

Figure 2. The multi-functional rank-size logarithm fitting curve of three major port urban agglomerations.

Rim region in commerce and trade functions, and the Yangtze River Delta region in modern service and population distribution functions have small adjustment range and stable development. 2) There are cities with large adjustment range in each region. For example, in the Bohai Rim region, the ranking of Qinhuangdao decreased by 5 in the shipping logistics function; population distribution work in Cangzhou fell by 5 places and Weihai rose by 4 places; Rizhao ranked fourth in the manufacturing function. Yangtze River Delta: Jiaxing dropped 8 places and Taizhou rose 5 places in shipping logistics function; in the function of population distribution, Wenzhou dropped by 5, Zhenjiang dropped by 5 and Taizhou increased by 5. Pearl River Delta region: Maoming dropped 4 places and Huizhou increased 5 places in shipping logistics function; Huizhou dropped 6 places in trade function; in the modern service function, Zhuhai rose 4 places and Dongguan fell 5 places in the population distribution function.

3. Hierarchical structure, coupling type and multi-functional development level of port city system

3.1 Hierarchical structure characteristics of port city system

The hierarchical structure of urban scale is a comprehensive reflection of the status and role of cities in the urban system, and it is an important basis for detecting the internal distribution pattern of the urban system. Traditionally, urban hierarchy is often reflected by population and land scale indicators, but its scale cannot be completely equal to the hierarchical level. The grade of cities with large population or wide land area may not be high, and the population or land scale of cities with the same grade may not be equal. Therefore, the classification of port city scale hierarchical structure by using multi-functional scale index system can better illustrate the strength of urban comprehensive strength. The rank scale method can also reflect the hierarchical structure characteristics of urban system based on scale-free area, but the hierarchical division is not detailed enough and has certain subjectivity in the determination of hierarchical boundary. The principle of fuzzy clustering analysis is to divide different categories according to the membership degree of each data point to the clustering center and obtain the clustering grade results. The most commonly used fuzzy mean algorithm (i.e. fuzzy c-means algorithm, referred to as FCM) is a data clustering method based on the optimization of the objective function and different from the traditional hard clustering algorithm, It can describe the urban system level more accurately. Based on MATLAB-lab9.0 software platform, this paper takes the size of five major functions as the data source for cluster analysis of port city system, and obtains the hierarchical division results of port city system scale in 2001 and 2015 (**Table 4**).

3.1.1 Time evolution of hierarchy

From 2001 to 2015, the hierarchy of port city system gradually changed from pyramid structure to spindle structure. 1) In 2001, the level of the coastal port city system showed a pyramid structure. There are 38 regional and local port cities, accounting for 80.85% of the port city system; there are 6 regional sub central port cities, accounting for 12.77%; there are only two regional hub port cities, accounting for 4.26%, Guangzhou and Tianjin respectively; Shanghai's comprehensive strength is second to none. It has developed into an important material import and export channel, and the annual port throughput has exceeded 200 million tons, gradually establishing its position as a national hub. 2) In 2015, with the reduction of the number of low-level port cities, the number of middle and high-level port cities increased, and the level of port city system gradually transitioned to spindle structure. The number of regional and local nodes decreased to 31, and the proportion decreased to 65.96%. Zhanjiang, Huizhou and other port cities are upgraded to regional nodes; Wuxi, Wenzhou, Fuzhou, Nantong, Dongguan, Quanzhou and Xiamen rose by one level; the number of middle and high-level regional hubs and regional sub centers has increased significantly, an increase of 7 compared with 2001. Among them, Shenzhen, Suzhou and Ningbo have risen from the third level regional sub centers to the ranks of regional hubs.

Table 4. The classification of port city system based on fuzzy clustering

Levels	2001		2005	
	Proportion	**City**	**Proportion**	**City**
National hub	2.13%	Shanghai	2.13%	Shanghai
Regional hub	4.26%	Guangzhou, Tianjin	10.64%	Guangzhou, Tianjin Shenzhen, Suzhou, Ningbo
Regional sub center	12.77%	Qingdao, Shenzhen, Suzhou, Dalian, Ningbo, Nanjing	21.28%	Qingdao, Dalian,Nanjing, Xiamen, Wuxi, Wenzhou, Fuzhou, Dongguan, Nantong, Quanzhou
Regional node	42.55%	Zhoushan, Wenzhou, Xiamen, Wuxi, Fuzhou, Yantai, Dongguan, Quanzhou, Zhuhai, Haikou, Changzhou, Tangshan, Nantong, Taizhou, Jiaxing, Zhenjiang, Qinhuangdao, Maoming, Zhongshan, Jiangmen	34.04%	Tangshan, Yantai, Lianyungang, Jiaxing, Zhoushan, Weihai, Taizhou, Huizhou, Zhongshan, Changzhou, Zhuhai, Jiangmen, Zhanjiang, Zhenjiang, Yangzhou and Taizhou
Local node	38.30%	Zhanjiang, Huizhou, Taizhou, Yangzhou, Weihai, Cangzhou, Lianyungang, Jinzhou, Yingkou, Putian, Dandong, Rizhao, Yangjiang, Beihai, Shanwei, Fangcheng, Qinzhou, Shantou	31.91%	Haikou, Yingkou, Dandong, Jinzhou, Qinhuangdao, Cangzhou, Rizhao, Putian, Shantou, Shanwei, Yangjiang, Maoming, Beihai, Qinzhou, Fangcheng

3.1.2 Spatial distribution of hierarchical structure

1) Bohai rim, Yangtze River Delta and Pearl River Delta are high-level port city agglomeration areas. The top three port cities Tianjin, Shanghai and Guangzhou in 2001 and the top six port cities in 2015 are mostly distributed in the Bohai rim, Yangtze River Delta and Pearl River Delta. Among them, the number of regional hub port cities in Yangtze River Delta is more than that in other two places. Its unique geographical location makes it develop multi-layer and high-level cities. From the perspective of urban multi-functional development, the level of port cities in the southeast coast has been improved, with strong multi-functional development potential. In contrast, the underdevelopment of high-level port cities along the southwest coast is significant. Zhanjiang has replaced Haikou as the regional node of multi-functional development in the region. 2) Based on the hierarchical division, the development hubs, sub centers and important nodes of the three main regions can be preliminarily defined. In the Bohai Rim region, Tianjin is the regional hub, Qingdao and Dalian are the sub centers, and Tangshan and Yantai are important nodes; in the Yangtze River Delta region, Shanghai, Suzhou and Ningbo are regional hubs, Nanjing, Wuxi, Wenzhou and Nantong are sub centers, and Lianyungang and Jiaxing are important nodes; in the Pearl River Delta region, Guangzhou and Shenzhen are regional hubs, Dongguan is the sub center, Huizhou and Zhuhai are important nodes.

3.2 Urban multi-functional development level based on coupling classification

3.2.1 Lag of high-end service functions

Based on the classification of coupling types (**Table 5**), on the basis of port and shipping development, the functional development levels from high to low are business function, manufacturing function, population distribution function and modern service function, indicating that the traditional functions of port cities are generally ahead of development, while the high-end service functions lag behind. 1) From the development track of the basic functions of shipping logistics, driven by the upgrading of ports and container multimodal transport, the scale of shipping logistics in the port city system has accelerated. From 2001 to 2015, the overall container throughput increased from 25.545 million TEU to 19.958 million TEU; the overall port cargo throughput increased from 1.55 billion t to 9.243 billion t; the overall foreign trade throughput increased from 626 million t to 4.56 billion t. The elements of traditional business functions were first integrated into the process of urban development and became the beginning of

multi-functional development of port cities. Subsequently, while the port land agglomeration, the port industry has gradually become a strong driving force for the rapid development of the port city. At present, in addition to national and regional central and sub central cities, more port cities are still in the stage of industrialization, and the function of industry and trade is still the main function of cities. 2) Among the high-end functions, modern service functions involve various high value-added industries such as finance, information and tourism, with intellectual support, capital guarantee and information transmission as the important support. In particular, modern port cities pay more attention to crossing space constraints through multimodal transport and communication technology to realize the interconnection of functional networks, Therefore, such functions are only well developed in a few high-level port cities. The lag of population distribution function reflects that there is still much room to improve the economic activity of port cities at all levels. Whether the socio-economic benefits of people flow, cargo flow and other factor flows brought by shipping logistics have realized the maximum efficiency transformation has become the main problem affecting the vitality of port cities. The multi-functional development of the whole port city system is still at a low level, and the industrial system structure needs to be further optimized. 3) The development speed of urban functions is generally lower than that of port functions, but it cannot be ignored that port functions have become an important support for urban development. The probability of their direct effect on urban functions is gradually decreasing, but the indirect effect cannot be underestimated. Once port functions disappear in the environment of urbanization development, the port city system is bound to face major adjustments.

3.2.2 There are obvious regional differences in multi-functional development of port cities

1) On the basis of the development of port and shipping functions, the business functions are well developed in the south of the Yangtze River Estuary. The opening period of the region is early. With the in-depth development of marketization, it drives trade circulation, and has outstanding advantages in business and economic integration; The Pearl River Delta region has mature manufacturing functions, of which more than 90% of the cities are advanced in manufacturing functions; cities with well-developed modern service functions are mostly distributed in the Yangtze River Delta and southeast coastal areas. Due to the dense container routes and wide influence range in this area, a modern logistics industry platform integrating trade information, financial capital and other elements has been formed earlier, which has driven the improvement of the modern service function level of the whole city. In contrast, the function of modern service industry in southwest coastal area lags behind obviously; in terms of population distribution function, the number of lagging cities in each region has increased, especially in the Bohai Rim region. 2) Looking at all regions (**Figure 3**), the multi-functional development level of cities around the Bohai Sea is different, especially the multi-functional development level of port cities in Liaoning province is low; the multi-functional development level of the Pearl River Delta region is the most balanced. The high-end service function development of the Yangtze River Delta region has an absolute advantage. The multi-functional development potential of the southeast coastal region is the largest, while the functional level of the southwest coastal region is not high.

3.2.3 The diversification of urban functions is closely related to the multi-functional development of ports

Due to the intergenerational differences of ports, the influence of port functions on the functional evolution of the city is different, which also leads to the hierarchical differences of port city development to a certain extent. 1) In addition to loading, unloading, warehousing and land and water transfer, the second generation port mainly adds value through commercial and industrial activities, so commerce and manufacturing are its core functions. It is not difficult to see that most of the four and five level port cities only have the leading advantages in trade and manufacturing functions, and the other functions

Table 5. The number and proportion of coupling cities based on different levels of scale

Function type	2001					2005				
	Level (quantity)	Absolute advance	Relative advance	Relative lag	Absolute lag	Level (quantity)	Absolute advance	Relative advance	Relative lag	Absolute lag
Commercial trade function	First class (1)	0	1 (100%)	0	0	First class (1)	0	1 (100%)	0	0
	Second class (2)	0	2 (100%)	0	0	Second class (5)	1 (20%)	4 (80%)	0	0
	Third class (6)	1 (17%)	5 (83%)	0	0	Third class (10)	7 (70%)	3 (30%)	0	0
	Fourth class (20)	20 (100%)		0	0	Fourth class (16)	11 (69%)	5 (31%)	0	0
	Fifth class (18)	17 (94%)	1 (6%)	0	0	Fifth class (15)	12 (80%)	3 (205)	0	0
	Total	38 (81%)	9 (19%)	0	0	Total	31 (66%)	16 (34%)	0	0
Manufacturing function	First class (1)	1 (100%)	0	0	0	First class (1)	0	0	0	1 (100%)
	Second class (2)	0	2 (100%)	0	0	Second class (5)	3 (60%)	0	0	2 (40%)
	Third class (6)	2 (33%)	1 (17%)	0	3 (50%)	Third class (10)	4 (40%)	0	0	6 (60%)
	Fourth class (20)	16 (80%)	2 (10%)	0	2 (10%)	Fourth class (16)	10 (63%)	0	1 (6%)	5 (31%)
	Fifth class (18)	8 (44%)	2 (11%)	0	8 (44%)	Fifth class (15)	6 (40%)	0	0	9 (60%)
	Total	27 (57%)	7 (15%)	0	13 (28%)	Total	23 (49%)	0	1 (2%)	23 (49%)
Modern service function	First class (1)	0	0	0	1 (100%)	First class (1)	0	0	1 (100%)	0
	Second class (2)	0	0	1 (50%)	1 (50%)	Second class (5)	0	0	3 (60%)	2 (40%)
	Third class (6)	0	0	3 (50%)	3 (50%)	Third class (10)	1 (10%)	0	4 (40%)	5 (50%)
	Fourth class (20)	0	0	16 (80%)	4 (20%)	Fourth class (16)	0	0	7 (44%)	9 (56%)
	Fifth class (18)	4 (22%)	0	6 (33%)	8 (44%)	Fifth class (15)	0	0	5 (33%)	10 (67%)
	Total	4 (9%)	0	26 (55%)	17 (36%)	Total	1 (2%)	0	20 (43%)	26 (55%)
Population distribution function	First class (1)	0	0	0	1 (100%)	First class (1)	0	0	1 (100%)	0
	Second class (2)	0	0	0	2 (100%)	Second class (5)	1 (20%)	0	1 (20%)	3 (60%)
	Third class (6)	2 (33%)	0	0	4 (67%)	Third class (10)	1 (10%)	0	3 (30%)	6 (60%)
	Fourth class (20)	14 (70%)	0	0	6 (30%)	Fourth class (16)	4 (25%)	0	2 (13%)	10 (63%)
	Fifth class (18)	12 (67%)	0	0	6 (33%)	Fifth class (15)	3 (20%)	0	1 (7%)	11 (73%)
	Total	28 (60%)	0	0	19 (40%)	Total	9 (19%)	0	8 (17%)	30 (64%)

Note: 1. The data of coupling type is: number of cities (accounting for% of the same level). 2. The hierarchy standard is: first class, equivalent to the national hub of this year; second class is equivalent to a regional hub; third class is equivalent to a regional sub center; fourth class is equivalent to a regional node; fifth class is equivalent to a local node.

lag significantly, indicating that port industrialization and trade liberalization are still the essence of their development. The advantages of trade logistics brought by ports cannot form high-quality transformation and docking, and the development of high-end service functions is insufficient. Regional and local node port cities are in a relatively independent stage of industrial and trade development, and most of their ports are in the second generation. 2) The third generation port focuses on the improvement of commerciality and comprehensive service capacity. While building into a trade logistics center, it also has the distribution functions of goods, information, talents, capital and technology. The integration of advantageous functions of regional hub and regional sub center port cities has made the modern port cities take shape. Combined with their port and shipping conditions, urban comprehensive strength and better

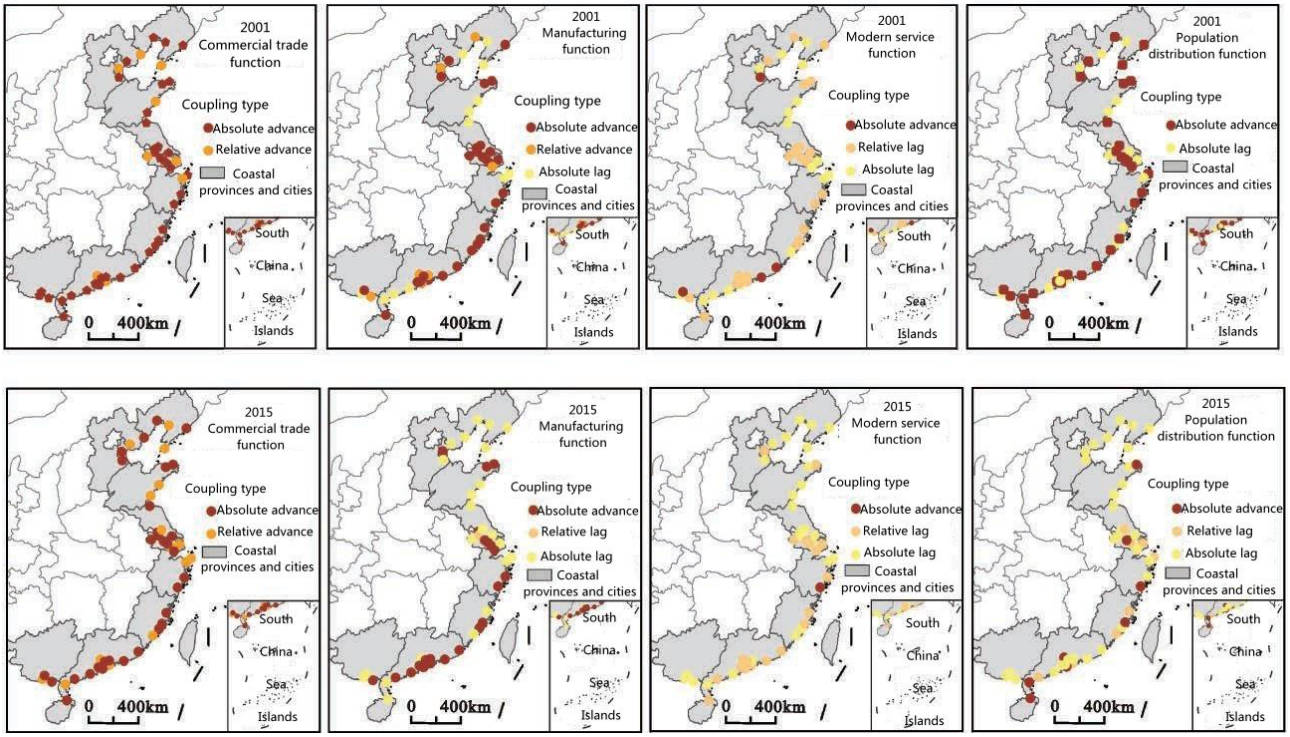

Figure 3. The spatial distribution pattern of functional coupling types in port cities.

development of most functions, it shows that the port cities at two levels are in the stage of diversified growth, and most of their ports are in the third generation, and continue to promote the multi-functional transformation and upgrading of port cities under the in-depth development of ports. 3) The fourth generation port is the main direction of port evolution in the world. Taking port containers as the main cargo and based on technology, capital and information, it has developed multi-dimensional core functions such as port logistics, modern service and population distribution, which has become an important link in the international supply chain. As one of the top ten ports in the global container throughput, Shanghai port has become a growth node of international economic activities. It can quickly respond to the international economic situation and provide differentiated services. It plays an absolute role in promoting the development of regional economic integration and is gradually moving towards the ranks of the Fourth Generation Ports. Taking this advantage, Shanghai is now a modern metropolis driven by the integration and radiation of various functional elements. It is a veritable national hub port city with leading functions.

4. Conclusion and discussion

Taking 47 major coastal port cities as research samples, this paper describes the distribution characteristics of multi-functional scale of port city system by using the ordinal scale rule of urban geography, analyzes and compares the regional differences of multi-functional scale structure of the three major port city clusters, and constructs the coupling relationship between basic port and shipping functions and other functional scales based on the ordinal scale rule. This paper discusses the multi-functional differentiation and development of port city system. The main conclusions are as follows: 1) the distribution structure, trend and scale growth characteristics of each functional scale have different characteristics. From 2001 to 2015, only the scale-free area of the scale distribution of the functional order of the manufacturing industry was a bifractal structure with hierarchical characteristics, and the other functions were a single fractal structure; the scale distribution of shipping logistics function has gradually developed from centralization to equilibrium, the scale distribution of business function and manufacturing function (scale-free region I) has transitioned from equilib-

rium to centralization, and the scale distribution of modern service function and population distribution function has always been in a centralized situation. Modern services and other high-end service industries are easier to land in high-level port cities and give full play to their derivative potential. At present, the main body with stronger economic vitality and population distribution capacity is still a few high-level port cities. 2) By comparing the regional differences in the scale of functional order, the distribution and change trajectory of the scale of business function and modern service function order of port cities in the three regions are highly consistent; there are great differences in the functional order distribution trajectories of shipping logistics, manufacturing and population distribution. From the perspective of multi-function, the sequence scale distribution characteristics of the three port city clusters around the Bohai Sea, the Pearl River Delta and the Yangtze River Delta are relatively significant, but a few of the functional scale distribution show bifractal characteristics, and the development degree of the regional port city system still needs to be enhanced. 3) From 2001 to 2015, with the reduction of the number of low-level port cities and the increase of the number of middle and high-level port cities, the pyramid structure of port city system will gradually transition to spindle structure; based on the hierarchical division, it can be preliminarily defined that in the Bohai Rim region, Tianjin is the regional hub, Qingdao and Dalian are the sub centers, and Tangshan and Yantai are important nodes; the Yangtze River Delta region Shanghai, Suzhou and Ningbo are regional hubs, Nanjing, Wuxi, Wenzhou and Nantong are sub centers, and Lianyungang and Jiaxing are important nodes; in the Pearl River Delta region, Guangzhou and Shenzhen are regional hubs, Dongguan is the sub center, Huizhou and Zhuhai are important nodes. 4) From the perspective of multi-functional coupling types, the traditional functions of port cities are generally ahead of the development, while the high-end service functions lag behind, and the improvement speed of urban functions is generally slow and tends to be flat. The multi-function of port cities is closely related to the multi-function evolution of ports. Based on the development of the second generation of ports, regional and local node port cities are still in the growth stage of traditional functions such as industry and trade; while the regional hub and sub central port cities realize the deepening development of the third generation ports, the urban functions show the characteristics of diversification and integration; in the process of moving towards the fourth generation of ports, Shanghai has become an important growth node of international economic activities and a truly national hub port city.

On the whole, the sequence scale structure and functional coupling type characteristics of the port city system can comprehensively reflect the development of each function. The division of leading and lagging types takes the basic shipping logistics function of port cities as the comparison object, which reveals the internal correlation between port upgrading and the transformation of urban function scale. The expansion of port city functional scale promotes the formation of intercity functional network. In the future, we should focus on the networking characteristics of port cities to comprehensively judge the internal relationship of the port city system.

Conflict of interest

The authors declare that they have no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Population distribution characteristics and its relationship with natural factors in karst mountainous areas of Northwest Guangxi

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ABSTRACT

The smallest administrative unit of the sixth national census-township (town) is selected as the basic unit, the population spatial distribution characteristics at the township (town) level in karst mountainous areas of northwest Guangxi are analyzed by using Lorenz curve and spatial correlation analysis method, and the influence intensity of natural factors on regional population spatial distribution is detected by using geographic detector method. The results show that: 1. the spatial distribution of population at the township (town) level has the characteristics of imbalance, showing generally significant positive correlation and certain aggregation; 2. There are significant differences in the impact of the spatial distribution of various natural factors on the population distribution. For the towns without karst distribution in the northwest and central south of the study area, the population density increases with the increase of factors conducive to human residence, but the average population density is only 79 people/km^2. In the towns with karst distribution in the East and south, the spatial distribution of population density and natural factors is not a simple increase or decrease relationship, but fluctuates with the change of karst distribution area. 3. The factor detection results of the geographic detector show that the altitude has the greatest impact on the spatial distribution of population. The interactive detection results show that the impact intensity of any two natural factors after superposition and interaction presents nonlinear enhancement and two factor enhancement. It can be seen that the karst mountain area in northwest Guangxi is similar to other areas. Altitude is one of the main factors affecting the spatial distribution of population, but the river network density and unique geological landform of karst mountain area have a strong catalytic effect on the spatial distribution of population. The superposition and interaction with other factors can further strengthen the impact on population distribution.

Keywords: Karst Mountain Area; Population Distribution Characteristics; Geographic Detectors; Northwest Guangxi; Guangxi

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1.Introduction

Population, resources, environment and development are the most important global issues[1]. The number of population and its spatial distribution characteristics reflect the difference of natural conditions and the level of economic development in a region to a certain extent. Therefore, it is of great significance to reveal the regional characteristics of population spatial distribution[2]. The number and distribution of population are mainly affected by the level of social and economic development, but no matter what degree of social and economic development, human survival and development are inseparable from the

natural environment. Its process and combination type are affected by various natural environmental factors, showing distinct regional differences[3]. China's diversified natural environment leads to regional differences in population distribution. Clarifying the relationship between population spatial distribution pattern and natural environment plays an important role in improving the understanding of man land relationship and realizing the sustainable management of population, resources and environment[4].

At present, scholars at home and abroad have carried out a lot of research on population change and spatial distribution, population distribution data statistics and simulation methods, and the relationship between population distribution and influencing factors[5–18]. The research scale is involved from the world, the country to the city and county level, and the research accuracy is becoming more and more precise. In recent years, some studies have also been carried out on the township level research scale[19–26]. In 2015, Bai Zhongqiang and others analyzed the population distribution characteristics and influencing factors of the township level research scale in 25 provinces (cities and districts) in China, and pointed out that the population distribution research from the township level research scale can more objectively and finely describe the spatial pattern of population distribution. However, due to the lack of data and the availability of data, Guangxi, Sichuan and other provinces and regions are not within the scope of their research. In addition, some scholars have studied the population spatial distribution characteristics and influencing factors of different landforms such as plateau and mountainous areas.

The similarities and differences between the population distribution of different geomorphic types such as plateau and mountainous areas and other regions are analyzed[27–30]. Due to the special terrain, landform and geological conditions, the population distribution and natural influencing factors in karst areas are different from those in other regions. There is relatively little research on the population distribution and related aspects in karst areas. The research units are mainly counties and cities (districts)[31–33]. The research content is to explore the relationship between the population distribution and various natural factors in karst areas. The zonal characteristics of various factors are the main factors, while the impact differences of various natural factors on population distribution in karst areas are discussed. The research on the impact intensity of population distribution after the superposition of various natural factors is relatively rare.

Karst mountainous area is the largest karst landform type area. Its basic feature is the vicious cycle of poverty and ecological environment, which is the epitome of China's sustainable development[34]. For a long time, unreasonable farming and the increase of population pressure have led to serious soil and water loss and the continuous expansion of rocky desertification, resulting in a vicious circle of ecological environment damage in karst mountainous areas. Taking the karst mountainous area in northwest Guangxi as the research area and the township as the research unit, this paper uses the spatial correlation analysis method to study the population spatial distribution characteristics of Karst mountainous area, and selects the main natural factors affecting the population spatial distribution of Karst mountainous area, The influence of different natural factors on population spatial distribution in Karst mountainous areas and the comprehensive influence intensity after the superposition and interaction of various factors are quantitatively analyzed by using geographic detectors, so as to provide scientific reference for sustainable development, ecological resettlement and optimal layout of urban system in karst mountainous areas.

2. Overview of the study area

Northwest Guangxi is located at the southeast edge of Yunnan Guizhou Plateau and the west of Liangguang hills. It is located at 104 ° 29' ~ 109 ° 09'E and 23 ° 41' ~ 25 ° 37'N. The total land area is 6.97 × 104 km^2, including Baise City and Hechi City, governing 23 counties (cities, districts) and 276 townships (**Figure 1**). In 2010, the total population was 6.836 million (data from the sixth national census). The terrain in Northwest Guangxi fluctuates greatly, and the altitude is distributed between 100

~ 2000 m, showing the characteristics of low in the southeast and high in the northwest. Mountainous areas account for more than 80% of the total land area. The karst landform in this area is widely developed, and the main karst landform type is mountainous, accounting for more than 80%. The carbonate rocks in the area are mainly composed of continuous limestone, limestone and dolomite, accounting for more than 70%. In addition, this is the main distribution area of rocky desertification in Guangxi (2 / 3 of the rocky desertification area in Guangxi is distributed in this area)[35]. The regional rocky desertification area accounts for more than 60% of the total land area, and the ecological environment is extremely fragile. The study area has a subtropical and mid subtropical monsoon climate, with an annual average temperature of 15 ~ 25 ℃ and an average annual precipitation of 1000 ~ 1600 mm, decreasing from southeast to northwest. Rivers mainly include Youjiang River, Hongshui River, Longjiang River and their tributaries.

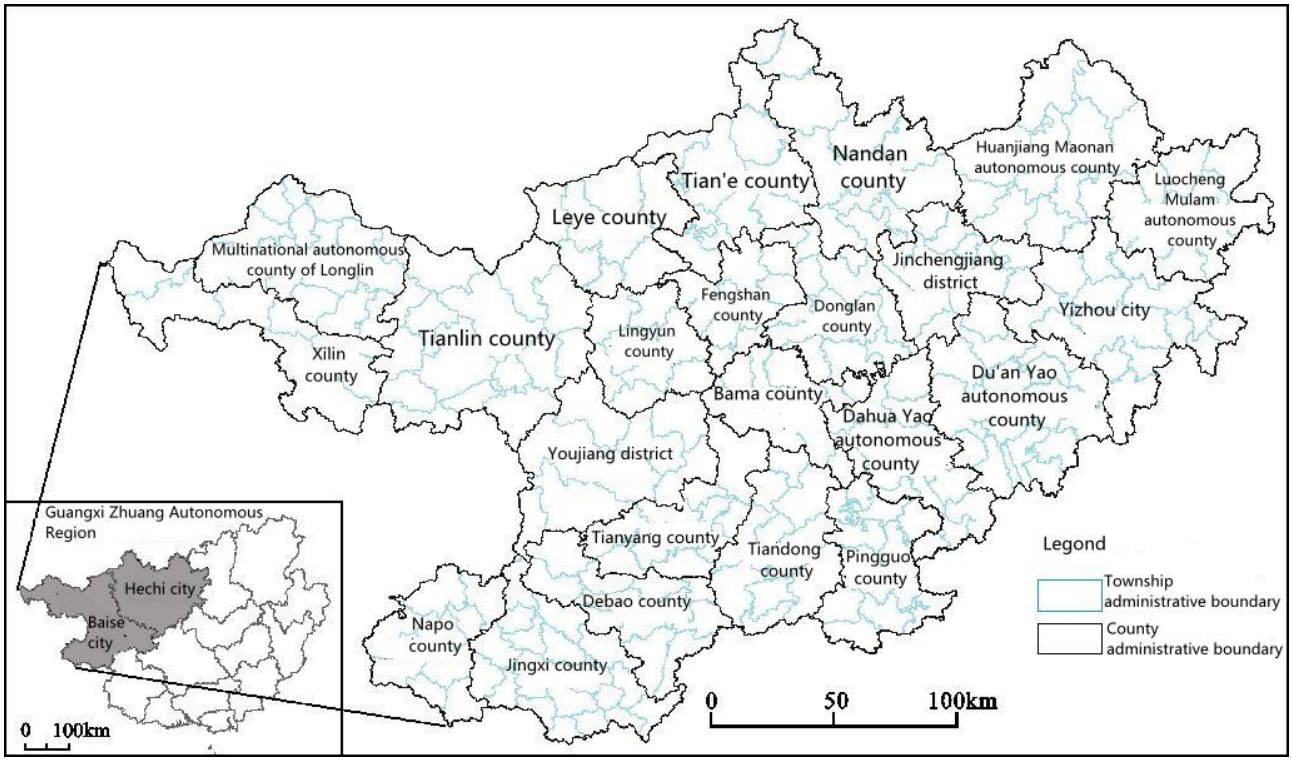

Figure 1. Location and scope of the study area.

3. Data sources and research methods

3.1 Data sources

The data of township population comes from the data of China's 2010 census by township, town and street published by China Statistics Publishing House[36]; Digital elevation model (DEM), 30 m × 30 m) the data of land use status and administrative division are from the data cloud website of the Chinese Academy of Sciences (http://www.csdb.cn/); Meteorological data comes from the national meteorological science data sharing service platform (http://data.cma.cn/); the data of karst landform comes from the geomorphic Atlas of the People's Republic of China (1:1 million) prepared by the Chinese Academy of Sciences[37]; the karst geological data is derived from the 1:1 million digital geological map of the People's Republic of China.

3.2 Research methods

3.2.1 Analysis method of population spatial distribution

1) Lorenz curve method. In this paper, Lorenz curve is used to analyze the balance of population spatial distribution. The drawing method of Lorenz

curve is as follows: according to the ranking of average population density of townships from small to large, calculate the cumulative proportion of population and land area of each township, take the cumulative proportion of population as the horizontal axis and the cumulative proportion of land area as the vertical axis, and draw the Lorenz curve of population distribution in the study area[38]. The curvature of Lorenz curve represents the balance of population distribution.

2) Spatial autocorrelation analysis. In this paper, the spatial autocorrelation analysis method is used to analyze the spatial correlation of population distribution. Spatial autocorrelation includes global and local spatial autocorrelation. Global spatial autocorrelation is the distribution of a phenomenon or attribute value in the whole region to judge whether the phenomenon or attribute value has aggregation characteristics in space. Local spatial autocorrelation is to reveal the distribution of the phenomenon or attribute value in local spatial units.

3.2.2 Geographic detectors

Geographic detector is a group of statistical methods to explore spatial differentiation and reveal its driving force[39]. Factor detection in geographic detector can identify influencing factors, and interactive detection can explain the interaction of influencing factors on dependent variables. It is an effective tool to study the driving mechanism of complex geographic factors[40].

1) Factor detection can detect the extent to which a certain influence factor explains the spatial differentiation of geographical elements and whether the changes of a certain influence factor and geographical elements have significant consistency in space. The calculation formula is as follows:

$$Q_{DY} = 1 - \frac{\sum_{i=1}^{L} n_{D,i}\sigma_{Y_{Di}}^2}{n\sigma_Y^2} \quad (1)$$

In this formula, Q_{DY} is the detection force value of detection factor D to geographical element Y; i = 1,... L, is the stratification of detection factors, i.e. classification or zoning; N is the number of units; n_D, i is the number of units in the detection factor layer i; σ_Y^2 and $\sigma_{Y_{Di}}^2$ is the variance of Y values of the whole region and layer i respectively. If $\sigma_{Y_{Di}}^2 \neq 0$, then the model is established and the value range of Q_{DY} is [0,1]. When Q_{DY} = 0, it indicates that the geographical elements are not driven by the influencing factors. The larger the Q_{DY} value, the greater the impact of the factor on the geographical elements. By comparing the factor detection force value Q_{DY}, the main influencing factors of the spatial distribution of geographical elements are detected.

2) Interaction detection can analyze the interaction between different influencing factors and evaluate whether their interaction will enhance or weaken the impact on the spatial differentiation of geographical elements. For example, to detect the interaction between factors A and B affecting the spatial distribution of geographical elements, first calculate the Q values of the two factors, and then overlay layers A and B to form layer C to obtain their interactive Q values. By comparing the influence values Q_a, Q_b and Q_c of layers A, B and C, we can evaluate the impact of the interaction of the two factors on the spatial differentiation of geographical elements and the impact of a single factor. There are five types of interaction between the two influencing factors on the spatial distribution of geographical elements. When Q (A ∩ B) < min [Q (A), Q (B)] is nonlinear weakening, min [Q (A), Q (B)] < Q (A ∩ B) < Max [Q (A), Q (B)] is single linear weakening, Q (A ∩ B) > Max [Q (A), Q (B)] is double factor enhancement, Q (A ∩ B) > Q (A) + Q (B) is nonlinear enhancement, and Q (A ∩ B) = Q (A) + Q (B) is independent.

4. Characteristics of population spatial distribution

4.1 General pattern of population spatial distribution

In 2010, the total population and population density of Karst Mountainous townships in Northwest Guangxi were quite different in space (**Figure 2**). Qingyuan town with the largest population had a total population of 155,900, and Sannong Yao Township with the least population was only 3,991 people, with an extreme value ratio of 39.06. Jinchengjiang

street with the highest population density is 5,377 people/km^2, while Baile Township with the lowest population density is only 21 people/km^2, 256 times of the latter. Overall, the spatial distribution of population in Karst Mountainous Areas in Northwest Guangxi shows the following characteristics: 1. The total population is more in the southeast and less in the northwest. The population is mainly distributed in counties (cities) in the East and south, and the population in the west, especially Tianlin county and Leye County in the northwest, is less. 2. The population density gradually decreases from southeast to northwest, and the relatively densely populated areas are Luocheng County, Yizhou city, Du'an county, Dahua County, Pingguo County and other places in the East and South; The population density in the west is low, and the population density in most areas is less than 60 people/km^2. 3. The total population and population density of the townships streets where the county (city, district) government is located are the highest in the county (city). For example, Qingyuan town is the seat of Yizhou district Party committee and Yizhou district government, with a population density of 494 people/km^2. Tianzhou town is the seat of Tianyang County, with a population density of 802 people/km^2.

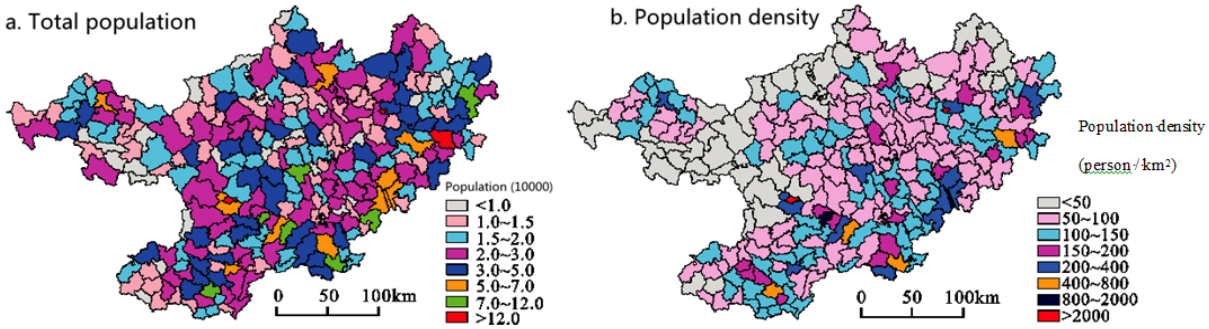

Figure 2. Spatial distribution of total population and population density in the northwestern Guangxi in 2010.

4.2 Balance of population spatial distribution

Lorenz curve is highly curved (**Figure 3**) and deviates from the absolute average, indicating that the spatial distribution of population is extremely uneven. The proportion of population and land area in different density levels is obviously unbalanced. In 2010, 10% of the population in Northwest Guangxi was distributed on more than 25% of the total regional area, and its population density is less than 50 people/km^2. When the cumulative population proportion is close to 70%, the total land area occupied by them is close to 90%, and the population density is less than 150 people/km^2. It can be seen that the population density in most areas of Northwest Guangxi is low. The area with a population density of more than 400 people/km^2 accounts for only 1.62% of the land area, but 12.94% of the population is distributed, indicating that a large number of people are gathered in some small areas in Northwest Guangxi, and the spatial distribution of population in the study area is extremely uneven.

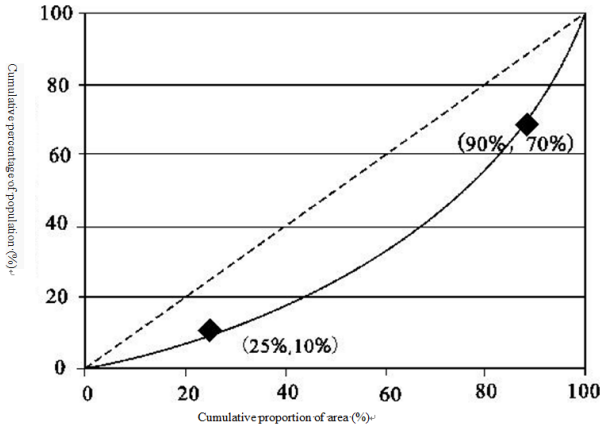

Figure 3. Lorenz curve of population distribution in the northwestern Guangxi in 2010.

4.3 Spatial autocorrelation of population distribution

The results of global autocorrelation analysis show that Moran's I of population density in Northwest Guangxi in 2010 is 0.027 (**Figure 4a**). After significance test, the Z value is 1.900, $P < 0.03$, showing a spatial positive correlation, indicating that the spatial distribution of population density in

Northwest Guangxi in 2010 is not completely random, but shows that the adjacent regional units in some spatial locations have the same attribute values. The results of local spatial autocorrelation analysis (**Figure 4b**) show that the high–high concentration areas of population density are mainly scattered in the central cities or key towns of Hechi and Baise, such as Baiyu town and Xin'an town. These townships have good natural conditions, relatively flat terrain, mainly plains and hills, relatively convenient land and water transportation, and high population density; the low oligomeric concentration areas with population density are mainly distributed in villages and towns far away from the central city, such as most townships in Tianlin county, Tian'e county and other counties. These townships have relatively poor natural conditions, more mountains and less regional population; the low high population density gathering areas are distributed in the townships around the two downtown areas, such as Yongle Town and Liuwei Town, whose population density is much lower than that of the surrounding central towns; the high oligomeric concentration area with population density is distributed in the central town far away from the central city, just like Le town. Although the township has the same high terrain as the surrounding township, it is rich in natural resources and convenient transportation. As the seat of the county, its population density is much higher than that of the surrounding towns.

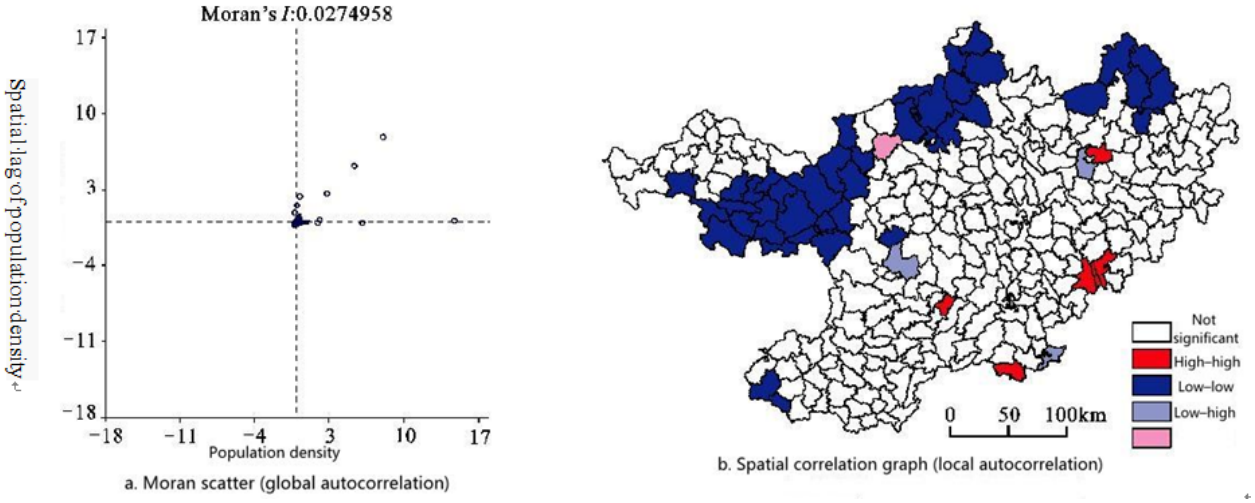

Figure 4. Moran scatter plot (global autocorrelation) and spatial correlation map (local autocorrelation) of population density in the northwestern Guangxi in 2010.

5. Influence of natural factors on population distribution in karst area of Northwest Guangxi

5.1 Relationship between natural factor distribution and population distribution

Altitude, ground slope, climate, hydrology and vegetation among natural factors are considered to be the main factors affecting population distribution, and altitude and karst geological conditions are considered to be the two main factors affecting population distribution in Karst Areas[34–43]. Based on the available research results and data, the natural influence factors selected in this paper are altitude (H), ground slope (SL), annual average temperature (Ta), river network density (Rn), forest coverage (Tr), karst distribution area ratio (Kr), karst physiognomy type (Km) and karst geological type (Ca).

5.1.1 Population density and altitude

Towns with an altitude of less than 200 m have the highest population density High, 541 people/km^2, about a township with an altitude of more than 900 M 6.5 times the population density, about 200 ~ 500 m above sea level 4 times the mouth density. Villages and towns with an altitude of 200 ~ 500 m are the main population gathering areas (**Table 1**), with a population density of 136 people/km^2, divided into It is distributed in most towns in the southeast of

Table 1. The relationship of natural factors and spatial distribution in the Northwestern Guangxi in 2010

Impact Factors	Classification	Proportion in total population(%)	Proportion in total land area (%)	Impact factors	Classification	Proportion in total population (%)	Proportion in total land area (%)	Impact factors	Types	Proportion in total population (%)	Proportion in total land area (%)
Altitude (m)	<200	4.35		River network density	0	5.20	5.40	Type of karst	Mountainous region	34.08	42.98
	200~500	45.04	32.51		0~0.01	61.30	71.34		hills	1.45	0.31
	500~700	15.56	23.14		0.01~0.02	20.47	15.02		Upland plain	18.56	15.11
	700~900	20.30	26.31		0.02~0.03	5.36	4.76		Mountain plain hills	15.58	11.58
	>900	14.74	17.25		>0.03	7.68	3.48		Mountain plain and hilly platform	6.09	2.66
Ground slope (°)	<15	8.60	2.93	Forest coverage (%)	<30	14.77	9.34		Others	7.72	6.87
	15~20	18.67	11.75		30~50	23.59	16.93		Non-karst	16.52	20.49
	20~25	51.99	59.59		50~60	19.84	15.20	Combination mode of karst geological types*	b	4.45	2.21
	25~30	19.36	24.52		60~70	20.08	23.70		ad	6.03	4.05
	>30	1.39	1.21		>70	21.71	34.84		abc	9.10	7.52
Average temperature of the year （℃）	<18	6.66	10.53	Karst distribution area ratio （%）	0	16.52	20.49		abd	18.67	17.15
	18~19	15.07	18.06		0~40	21.23	26.44		abcd	33.46	37.88
	19~20	26.26	31.51		40~60	14.81	12.16		Others	11.76	10.70
	20~21	25.02	24.22		60~80	11.76	11.89		Non-karst	16.52	20.49
	>21	26.99	15.68		>80	35.69	29.03				

the study area. Overall, the population is the characteristics of low altitude aggregation (**Figure 5a**).

5.1.2 Population density and ground slope

The townships with a ground gradient of less than 15 ° have the highest population density of 287 people/km^2. They are distributed in Toutang town in the south of the study area and Qingyuan town in the East (**Figure 5b**), which is 3.7 times the population density of townships with a ground gradient of 25 ° ~ 30 ° and 2.6 times the population density of townships with a ground gradient of more than 30 °. Villages and towns with a ground slope of 20 ° ~ 25 ° are the main population gathering areas (**Table 1**), but the population density is only 85 people/km^2. On the whole, the population density decreases with the increase of ground slope, and the population tends to gather in towns with small ground slope.

5.1.3 Population density and annual average temperature

The villages and towns with annual average temperature above 21 ℃ have the highest population density of 169 people/km^2, which is mainly distributed in some villages and towns in Tianyang county, Pingguo county and other counties in the south of the

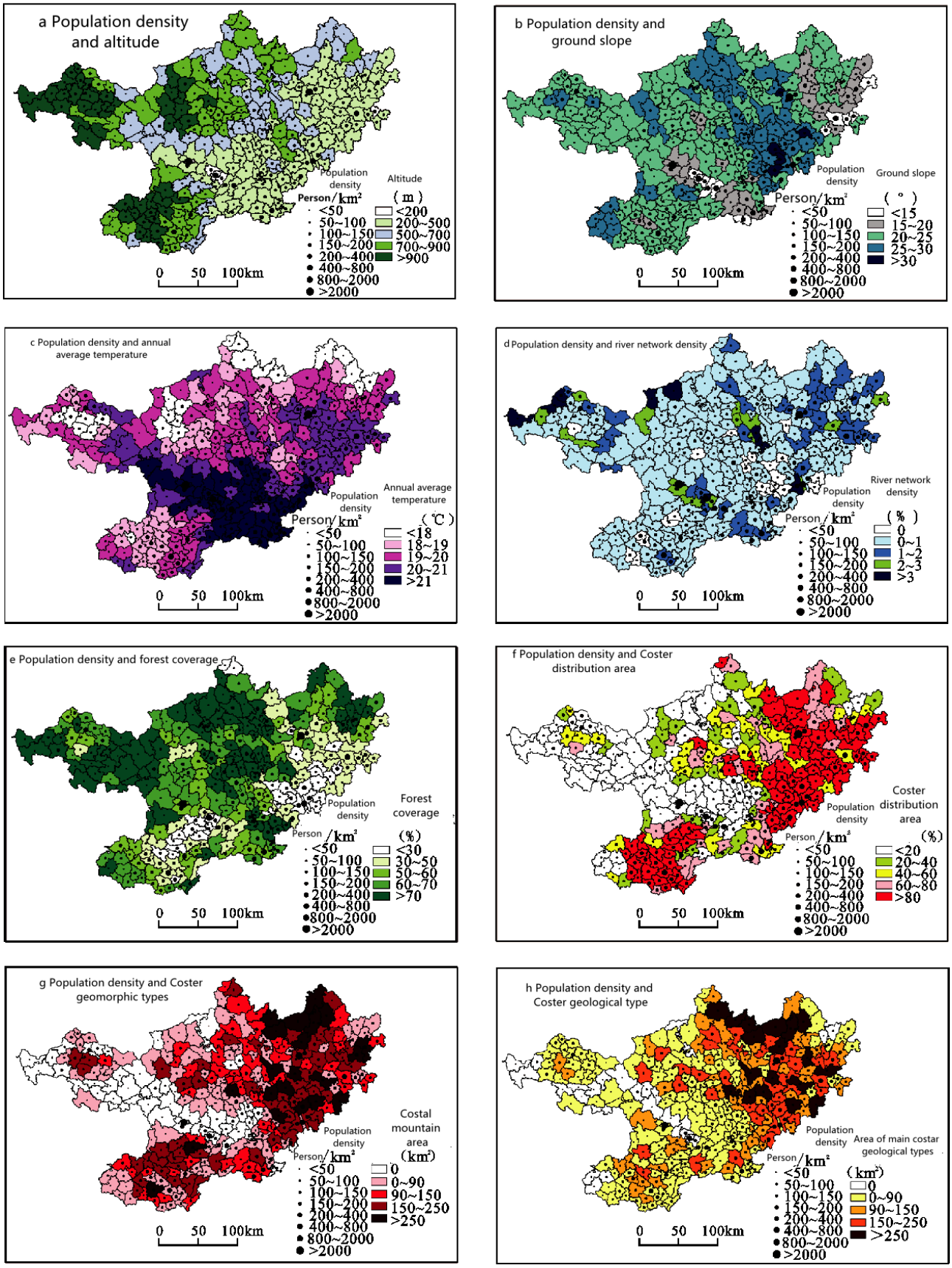

Figure 5. Spatial distribution of natural factors and population density in the northwestern Guangxi in 2010.

study area (**Figure 5c**), which is 2.7 times the population density of villages and towns with annual average temperature below 18 ℃. Villages and towns with annual average temperature above 20 ℃ are the main population gathering areas (**Table 1**), which are distributed in the research area In the South and east of the study area, the population density is more than 100 people/km^2. On the whole, with the increase of annual average temperature, the population density increases gradually.

5.1.4 Population density and river network density

Towns with river network density greater than 3% have the highest population density of 216 people/km^2, distributed in Youping Township, Yachang Township and other towns (**Figure 5d**), which is 2.3 times the population density of towns without rivers. Villages and towns with river network density of 0 ~ 1% are the main population gathering areas (**Table 1**), but the population density is only 84 people/km^2. On the whole, with the increase of river network density, the population density shows an increasing trend.

5.1.5 Population density and forest coverage

Villages and towns with forest coverage of less than 30% have the highest population density of 155 people/km^2 and the population proportion is 14.77% (**Table 1**). They are distributed in some villages and towns in the north and northwest of the study area (**Figure 5e**), which is 2.5 times that of villages and towns with forest coverage of more than 70%, and the population density of villages and towns with forest coverage of more than 70% is only 61 people/km^2. On the whole, with the increase of forest coverage, the population density decreases gradually.

5.1.6 Population density and karst distribution area

Villages and towns with karst distribution area greater than 80% have the highest population density, reaching 120 people/km^2. They are the main gathering area of population (**Table 1**), distributed in the east and south of the study area (**Figure 5f**), which is 1.5 times that of villages and towns without karst distribution and with karst distribution area less than 40%. The population density of villages and towns without karst distribution is 79 people/km^2, which is distributed in the West and Central South of the study area. On the whole, with the increase of karst area, the population density first increases, and then decreases and then increases.

5.1.7 Population density and karst landform type

The karst landform in the study area is mainly mountainous. The areas with karst mountainous area greater than 150 km^2 are mainly concentrated in most towns in the northeast and south of the study area, and the areas with karst mountainous area less than 90 km^2 are scattered in the study area (**Figure 5g**). Other geomorphic types include karst hills, platforms and plains. There are 8 combination modes in towns and townships. Here, the 5 combination types accounting for a large proportion of the population are mainly analyzed (**Table 1**). In the villages and towns with no Karst Mountains and only karst hills, the population density is the largest, reaching 460 people/km^2. There are villages and towns of all four geomorphic types, with a population density of 224 people/km^2, mainly distributed in Beiya Yao Township, Huaiyuan town and other villages and towns in the East, which is 2.84 times the population of villages and towns without karst distribution. The villages and towns only distributed in karst mountainous areas, with a population density of 78 people/m^2, are the main population gathering areas, distributed in a small number of villages and towns in the East, South and North. On the whole, the towns with only Karst Mountains and no karst landform have the lowest population density. Except for the towns with only karst hills, the population density shows an increasing trend with the increase of the number of karst landform types, and the landform type with the greatest impact is Karst Mountains.

5.1.8 Population density and karst geological types

The karst geological types in the study area are mainly continuous limestone assemblage (a) and limestone and dolomite assemblage (b). Areas with

an area of major karst geological types greater than 150 km^2 are distributed in most towns in the East and southeast of the study area, and areas with an area of major karst geological types less than 90 km^2 are distributed in most towns in the west of the study area (**Figure 5h**). Other karst geological types include limestone plus clastic rock combination (c), limestone, dolomite and clastic rock combination (d), continuous dolomite (e), dolomite plus clastic rock combination (f). There are 22 combinations of 6 geological types in villages and towns. Here, the first 5 combination types accounting for a large proportion of the population are mainly analyzed. It is found that only the first type (b) has the highest population density, reaching 205 people/km^2, which is 2.3 times that of the fifth combination type (abcd combination) and 2.5 times that of the towns without karst distribution. The towns of the fifth combination type (abcd combination) are the main population gathering areas, but the population density is only 90 people/km^2, mainly distributed in Liuwei town, Changlao township and other towns in the east of the study area. Without karst distribution, the population density of villages and towns is at a medium and low level. On the whole, with the increase of the number of karst geological type combinations, the population density gradually decreases, among which the most influential are continuous limestone combination (a) and limestone and dolomite combination (b).

5.2 Analysis on influence intensity of natural factors on population distribution

The influence intensity of various natural factors and the increase and decrease relationship of influence intensity after the superposition of different natural factors can be quantitatively explored by using geographic detectors. Because it is impossible to directly quantify the combination of all karst landforms and geological types for geographic exploration and analysis, according to the situation of the study area, finally, the area of karst mountain and the area of main karst geological types are selected to replace, and the natural breakpoint method is used to divide the eight natural factors into different levels, and then discretized and analyzed by geographic detectors.

1) The results of geo detector analysis show that the 8 natural factors alone have a certain influence on the spatial distribution of population density, and the comprehensive influence of each natural factor after coupling and superposition is significantly enhanced (**Table 2**). The factor detection results show that the

Table 2. Interaction of natural factors in the spatial distribution of population in the northwestern Guangxi

A∩B=C	A+B	Comparison	A∩B=C	A+B	Comparison
H∩Kr=0.22	0.17+0.01=0.18	C>A+B	Km∩Ca =0.021	0.01+0.01=0.02	C>A+B
H∩Km=0.24	0.17+0.01=0.18	C>A+B	Km∩Rn =0.20	0.01+0.16=0.17	C>A+B
H∩Ca=0.24	0.17+0.01=0.18	C>A+B	Km∩Sl=0.05	0.01+0.02=0.03	C>A+B
H∩Rn=0.65	0.17+0.16=0.33	C>A+B	Km∩Ta=0.11	0.01+0.06=0.07	C>A+B
H∩Sl=0.85	0.17+0.02=0.19	C>A+B	Km∩Tr=0.20	0.01+0.05=0.06	C>A+B
H∩Ta=0.26	0.17+0.06=0.23	C>A+B	Ca∩Rn =0.22	0.01+0.16=0.17	C>A+B
H∩Tr=0.34	0.17+0.05=0.22	C>A+B	Ca∩Sl=0.05	0.01+0.02=0.03	C>A+B
Kr∩Km=0.08	0.01+0.01=0.02	C>A+B	Ca∩Ta=0.09	0.01+0.06=0.07	C>A+B
Kr∩Ca=0.05	0.01+0.01=0.02	C>A+B	Ca∩Tr=0.11	0.01+0.05=0.06	C>A+B
Kr∩Rn=0.46	0.01+0.16=0.17	C>A+B	Rn∩Sl=0.26	0.16+0.02=0.18	C>A+B
Kr∩Sl=0.07	0.01+0.02=0.03	C>A+B	Rn∩Ta=0.50	0.16+0.06=0.22	C>A+B
Kr∩Ta=0.17	0.01+0.06=0.07	C>A+B	Rn∩Tr=0.43	0.16+0.05=0.21	C>A+B
Kr∩Tr=0.08	0.01+0.05=0.06	C>A+B	Sl∩Tr=0.12	0.02+0.05=0.07	C>A+B
Ta∩Tr=0.23	0.06+0.05=0.11	C>A+B	Sl∩Ta=0.07	0.02+0.06=0.08	C>Max(A, B)

Note: H is the natural influence factor, altitude, SL is the ground slope, Ta is the annual average temperature, Rn is the river network density, Tr is the forest coverage, Kr is the karst distribution area ratio, Km is the karst landform type, and Ca is the karst geological type.

influence of various natural factors on population spatial distribution is altitude (0.17), river network density (0.16), annual average temperature (0.06), forest coverage (0.05), ground slope (0.02), karst distribution area (0.01), karst mountain area (0.01) and main karst geological types (0.01).

2) The interactive detection results show that except that the interaction between ground slope and annual average temperature is enhanced by two factors, the interaction of other factors is enhanced nonlinearly (**Table 2**). Among them, the intensity of superposition of altitude and various factors is large, especially after superposition with ground slope, its value is the largest, and the increase rate reaches more than 70%, mainly because northwest Guangxi is located in mountainous areas with great altitude difference, and other geographical elements are inevitably affected by altitude. When the river network density is superimposed with karst geological and geomorphic conditions, the impact intensity of population spatial distribution increases by more than 90%. It is mainly due to the poor water storage and retention capacity in karst areas, and human beings have a stronger tendency to river network and water system.

3) After the superposition of karst geological and geomorphic factors and other factors, the increase is large, most of which are more than 80%. It is mainly because the karst area in Northwest Guangxi is located in the subtropical zone, with good climatic conditions such as water and heat, and has natural conditions suitable for human habitation. Therefore, the influence intensity of karst geological and geomorphic factors on population spatial distribution is not obvious. However, the dissolution of carbonate rocks is strong, which will show higher sensitivity and vulnerability after superimposing natural factors such as uplift height and ground slope. For example, the elevation of sea level and the increase of slope can lead to the strengthening of dissolution, and the soil is easy to be lost along the slope. Finally, the soil layer may become thinner and even the bedrock may be exposed, which is not suitable for crop growth and human habitation. After the superposition of the unique geological and geomorphic factors in karst area and other natural factors, the impact intensity on the spatial distribution of population in karst mountain area will increase significantly.

6. Conclusion and discussion

6.1 Conclusion

1) The population spatial distribution at the township scale in the karst mountainous area of Northwest Guangxi is extremely uneven. The population quantity and density in the southeast are higher than those in the northwest, and the population density gradually decreases from southeast to northwest

The total population and population density of the township (town, street) where the (municipal) government is located are the highest in the county (city). The population distribution shows a certain aggregation. The high-value areas and low-value areas of population density are not completely random distribution. The radiation capacity of high-value areas is weak, and the radiation capacity of low-value areas is relatively strong.

2) The population distribution in karst areas of Northwest Guangxi shows obvious differences with the spatial distribution of different natural factors. The population density of towns without karst distribution in the northwest and Central South of the study area is low on the whole; the population density of villages and towns with high altitude, ground slope and forest coverage is relatively low, and the population density of villages and towns with high annual average temperature and river network density is relatively high. In the eastern and southern villages and towns with karst distribution, in addition to karst geological and geomorphic factors, the population density increases with the increase of natural factors suitable for human habitation, but shows a trend with the increase of karst area wave type variation characteristics. In addition, in villages and towns with single karst geological type or diverse geomorphic type, the population density is relatively high, and vice versa.

3) The greatest influence intensity of each factor on the spatial distribution of population is altitude,

and the smallest is karst geological and geomorphic factors. However, the superposition of any two natural factors can enhance the impact on population spatial distribution, and the strengthening methods are nonlinear enhancement and Gemini enhancement. The spatial distribution of population is affected by the spatial distribution of various natural factors. The change of any factor may affect the change of population spatial distribution. Although the impact intensity of karst geological and geomorphic elements on population spatial distribution in the study area is low when acting alone, the impact on population spatial distribution is significantly enhanced after their superposition with any natural factors, and most of the increase rate is more than 90%. In the karst area of Northwest Guangxi, the spatial distribution of population does not completely depend on the most influential factor among the natural factors, and the role of karst geological and geomorphic factors cannot be ignored.

6.2 Discussion

1) The area with karst distribution area of more than 80% in Northwest Guangxi has the largest population density and gathers a certain number of people. Although there are a wide range of karst landforms in the northwest of Guizhou Karst Plateau Area in Li Xudong and other documents, it also gathers a large number of people. This research conclusion has some similarities[42]. However, the population density of villages and towns with no karst distribution in Northwest Guangxi is close to that of villages and towns with only karst mountain distribution. The relationship between population spatial distribution and karst geological and geomorphic conditions is not a simple linear relationship, but is jointly affected by a variety of natural factors such as altitude.

2) Whether in karst areas or non karst areas, the spatial distribution of population is affected by both natural and economic factors. Natural factors also affect the distribution of economic factors. However, the natural ecological environment in karst areas is more fragile, and the influence of natural factors must be different from that in non karst areas, and further affect the spatial distribution of population through influencing economic factors. Compared with non karst areas, what is the difference in the extent to which population growth can break through the limitations of natural factors, how much impact can change the natural conditions of karst areas have on population spatial distribution, and how to reasonably carry out population spatial layout on the basis of protecting the ecological environment and ensuring economic development in karst areas.

Conflict of interest

The authors declare that they have no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Analysis of ecological security pattern of rare earth mining areas in South China based on MCR model

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ABSTRACT

The rare earth mining area in South China is the main production base of ionic rare earth in the world, which has brought inestimable economic value to the local area and even the whole nation. However, due to the lack of mining technology and excessive pursuit for economic profits, a series of environmental problems have arisen, which is a great threat to the ecosystem of the mining area. Taking Lingbei rare earth mining area in Ganzhou as an example, this paper discriminated and analyzed such aspects as the ecological source, ecological corridor and ecological nodes of the mining area based on the landscape ecological security pattern theory and the minimum cumulative resistance model (MCR) method, and constructed a landscape ecological security pattern of the mining area during the 2009, 2013 and 2018. The results show that: i) The patch area of the ecological source of rare earth mining area is small, mainly concentrated in the east and west sides of the mining area. ii) During the selected year, the ecological source area, ecological corridors, radiation channels and the number of ecological nodes in the rare earth mining area are increasing, indicating that the landscape ecological security of the rare earth mining area has been improved to some extent, but it remains necessary for relevant departments to make a optimized planning to further reconstruct the ecological security pattern of the rare earth mining area.

Keywords: Rare Earth Mining Area; MCR Model; Ecological Source; Ecological Corridor; Ecological Security Pattern

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1. Introduction

Ecological security pattern refers to the arrangement, design, combination and layout of various natural and cultural elements in a region with specific technology based on the optimization of ecological, economic and social benefits, and formulate a multi-objective, multi-level and multi category spatial allocation scheme composed of points, lines, areas and networks. Due to the continuous development of various resources on the earth, there is a serious ecological imbalance, and various ecological security problems arise, such as resource shortage, sharp reduction of species and environmental pollution. People from all walks of life and scholars are paying more and more attention to ecological research, and further think and discuss the definition and derivation of its concept based on ecological security research. Therefore, a series of related studies are carried out around the theme of ecological security[1,2].

In the 21st century, rare earth, as an extremely important national strategic resource, plays an important role in high-tech and military

fields such as military weapons and new material manufacturing[3]. Ion adsorption rare earth ores are scarce in many types of rare earth ores and have important mining value[4]. The main production area is located in the south of Jiangxi Province, China, and its reserves are as high as 80% of the world's total. However, due to its special mining process, the ionic rare earth mine in southern Jiangxi will bring direct damage to the surface vegetation and soil, resulting in a series of ecological and environmental problems, such as large-area vegetation degradation, farmland damage, soil erosion and desertification[5]. According to statistics, more than 100 km^2 of mountain forest land in Ganzhou City has been damaged due to rare earth mining[6]. The land that has been treated is very few, which puts great pressure on the ecology of the region. In recent years, the maturity of GIS and remote sensing technology has laid a technical foundation for the ecological monitoring of rare earth mining areas. As early as the end of the 20^{th} century, Horvath, Luise, and Monjezi analyzed and comprehensively evaluated the impact of open-pit mining on ecological security, and formulated a series of ecological restoration and optimization measures, which opened a good beginning for later research[7–9]. Domestic scholars have also opened the road of ecological security in the mining area and achieved many results. Liu Xitao, Fan Xiaoshan and Yang Jianjun all tried to establish an ecological security evaluation index system for the mining area[10–12]. They put forward suggestions for ecological management of the mining area. As a result, some ecological problems were alleviated.

When exploring the ecological security pattern, MCR is a widely used model, which reflects the internal relationship of ecological security, integrates applicability and scalability, and plays an important role in technical methods and practical application[13]. Based on the MCR model, many scholars have constructed the ecological security pattern of land use from many aspects and put forward corresponding optimization schemes[13–16]. However, for the current research, the Minimum Cumulative Resistance Model (MCR) is mainly used to evaluate the ecological security pattern of urban land, and is rarely used in rare earth mining areas. Therefore, the present paper takes the Dingnan Lingbei rare earth mining area in Ganzhou as the research area to further explore the changes in landscape and patterns in this mining area by using QuickBird multi temporal high-resolution images and fully considering the landform of the rare earth mining area based on the manual vector map of the area. MCR model is used to analyze the landscape ecological security pattern of rare earth mining area, so as to further understand the change characteristics of landscape ecological security pattern of rare earth mining area and provide basic data and scientific decision-making for controlling the ecological environment of mining area.

2. Overview of the study area

Lingbei rare earth mining area is mainly located in the north of Dingnan County, Jiangxi Province, between 114°58′04″ E ~ 115°10′56″ E and 24°51′24″ N ~ 25°02′56″ N, including towns such as Jingnao and Huangxiang (**Figure 1**). It is a subtropical monsoon humid climate area, with an annual average temperature of 19 ℃, precipitation of 1774.3 mm, and uniform and sufficient light and heat throughout the year[17,18]. Among them, Lingbei mining area is composed of Laohukeng, Chenaoxia, Qingjingtang, Longchuankeng, Zuojaxing, Jiazibei, Aobeitang and other major ore occurrences. The mining area is rich in minerals and the rare earth grade is among the best in China. So far, it has a mining history of about 30 years. Taking 2001 as the watershed, the previous mining methods were more traditional, mainly pool leaching and heap leaching. This method will directly promote the vegetation, alleviate the damage degree of vegetation, and relatively reduce the ecological pressure. However, the ecology of some ore spots has not been improved, indicating that this method cannot fundamentally solve a series of environmental problems produced in the process of rare earth mining.

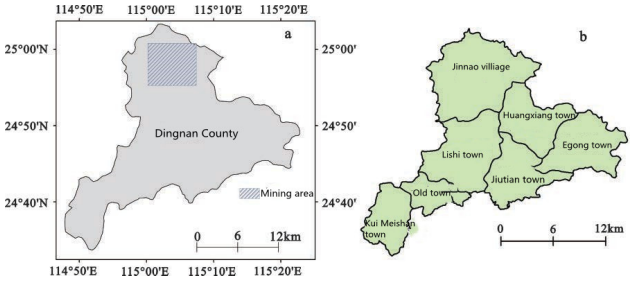

Figure 1. Location of the study area.

2. Data sources and research methods

2.1 Data sources

The land use classification data used in this paper mainly comes from QuickBird image data. The spatial resolution of the data is 2.44 m. The data comes from Google Earth. Combined with field investigation, the mining area is manually vectorized, which is mainly divided into water body, buildings, orchards, roads, tailings land (a large area of exposed area after mining) and sedimentation tank (including high pool), vegetation (mainly refers to natural forestland), reclaimed vegetation and farmland. DEM data has a spatial resolution of 30 m, mainly from geospatial data cloud platform (http://www. gscloud. cn). DEM is used to extract elevation and slope as resistance factors. The vector boundary is extracted from the national administrative division boundary map.

2.2 Research methods

2.2.1 Minimum cumulative resistance model (MCR model)

The minimum cumulative resistance model (MCR model) refers to the model of the total resistance that species need to overcome in the process from a "source" point to the target location[19]. Generally speaking, the resistance coefficient will be defined as a specific value, and the minimum resistance value is the source point, which is usually defined as 1. The determination of other impact factors is usually determined by comprehensively considering the actual situation of the mining area and the establishment path objectives of the study area. And the element resistance coefficient varies with different targets. The specific formula is expressed as follows:

$$MCR = f_{min} \sum_{j=n}^{i=m} (D_{ij} \times R_i) \quad (1)$$

where MCR is the minimum cumulative resistance of rare earth mining area, and f is the undetermined monotonic increasing function. D_{ij} represents the spatial distance from ecological land landscape units i to j. R_i is the resistance coefficient of landscape unit i to a certain movement; m, n represents the number of landscape units i and ecological sources j respectively.

2.2.2 Identification method of ecological source

Ecological source is the "source" of ecological land protection. It generally selects areas with strong ecological function and rich biodiversity. It is the habitat of existing species and the source of species exchange and diffusion. It is of great significance in meeting the ecological needs of rare earth mining areas and the integrity and healthy stability of landscape pattern[20–21]. The construction of ecological source shall at least meet the following three principles:

1) It is necessary to select the ecological source in the area with high habitat quality. Habitat quality refers to the living environment quality around species, which decreases with the increase of land use type intensity near the area[22]. Generally, it is defined as a large area of water and a large area of massive vegetation suitable for species habitat.

2) It is necessary to comprehensively consider the species diversity, land use type and environmental quality of the area in combination with the actual ecological status and land use of the mining area, so as to select the ecological source according to local conditions.

3) It is necessary to select the area with high ecological service function and can provide suitable habitat for species as the ecological source, which can make the ecological environment develop in a healthy direction and better serve the ecosystem.

3. Construction of comprehensive spatial resistance surface

The important influence on the construction of MCR model is the selection of its resistance factor[23]. The rare earth ore research area in this paper is located in the hilly area of southern China. According to the complex surface characteristics, the resistance factors such as slope, land use type and elevation that have a great impact on the mining environment are selected.

1) Land use type. The closer the land use type is to the protection source type in the study area, the smaller its resistance to the exchange and diffusion between species and its resistance value will be. The tailings land caused by rare earth mining is the most important factor affecting the ecological security of the mining area. As a land use type, combined with the unique landscape of the rare earth mining area, the land use type factor is determined to be the most important of all factors, and its weight is given to 0.8[24].

Due to the particularity of each study area, the land use types are different. At present, the research on the resistance value of land use types is mostly aimed at cities or larger areas. Due to the particularity of Gannan rare earth mining area, the resistance coefficient should be given its own value in combination with the actual situation of the mining area. In this paper, combined with the actual situation of rare earth mining area, various ground objects are arranged in the order of resistance from small to large, as follows: vegetation < water body, reclaimed vegetation < orchard < farmland < road < building < sedimentation tank (including high-level tank) < tailings land. See Table 1 for details. It can be seen from the table that the vegetation with the lowest resistance coefficient in the mining area has the greatest service value to the ecosystem; The resistance of reclaimed vegetation is also small, because it is closely related to the source land; Water body has little influence on ecological security pattern, and its resistance coefficient is also small. However, the mined tailings land is easy to cause many ecological problems such as soil environmental damage and water and soil loss, which makes its ecological service value the smallest, so the resistance coefficient is the largest compared with other types[13,22,25].

Table 1. Resistance factor and drag coefficient of land use type in mining area

Resistance factors	Resistance coefficients
Vegetation	1
Reclaimed vegetation	2
Water body	2
Orchard	3
Farmland	4
Road	6
Building	8
Sedimentation tank	9
Tailing land	10

2) Slope. Rare earth mining area is located in typical hilly and mountainous areas, with significant soil and water loss. Slope is one of the influencing factors of land environmental problems such as landslide and soil erosion. In addition, it will also have a certain impact on species exchange and ecological flow diffusion in rare earth mining areas[26,27]. Therefore, when constructing the ecological pattern of rare earth mining area, the influence of slope should be considered. Based on the DEM data of rare earth mining area, this paper extracts the relative slope of rare earth mining area as one of the resistance factors. Since the mountain slope in the mining area is relatively gentle and the impact of slope is relatively small, this weight is given 0.1. According to the actual situation of rare earth mining area, the slope factors are classified. See **Table 2** for details of different grades and resistance coefficients[13,25].

Table 2. Slope resistance factor and resistance coefficient in the mining area

Resistance factors	Resistance coefficients
0°~5° flat slope	1
5°~15° gentle slope	3
15°~25° steep hill	5
25°~35° steep slope	7
>35° extremely steep slope	10

3) Altitude. Elevation will also have a certain impact on species migration and the diffusion of ecological flow. When species migrate in areas with similar elevation, it will be easier to pass, otherwise it will be more difficult. The elevation is regarded as one of the resistance factors in this paper, and its

weight is given to 0.1. Since the elevation of the rare earth mining area in this paper is between 290 ~ 800 m, it is classified into four resistance factors. The resistance coefficients of different grades are shown in **Table 3**[19].

Table 3. Height resistance factor and drag coefficient of mining area

Resistance factors (m)	Resistance coefficients
<300	1
300~400	3
400~600	5
600~800	8

According to different resistance factors and resistance coefficients, the cost-distance tool in ArcMap software platform is used to obtain the resistance surface data of land use type, elevation and slope after calculation. The resistance surfaces of the three resistance factors are superimposed according to the weight. The superimposed formula is: slope factor resistance surface × 0.1 + elevation factor resistance surface × 0.1 + resistance surface of land use type factor × 0.8, the minimum cumulative resistance surface models of the study area in 2009, 2013 and 2018 are obtained after calculation by superposition formula (**Figure 2**).

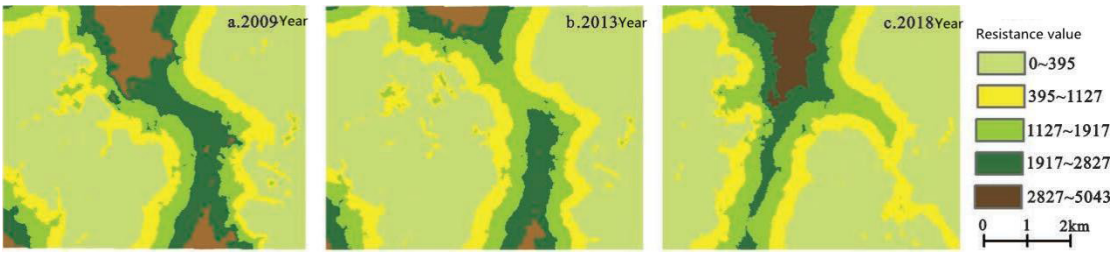

Figure 2. Schematic diagram of ecological sources in different years.

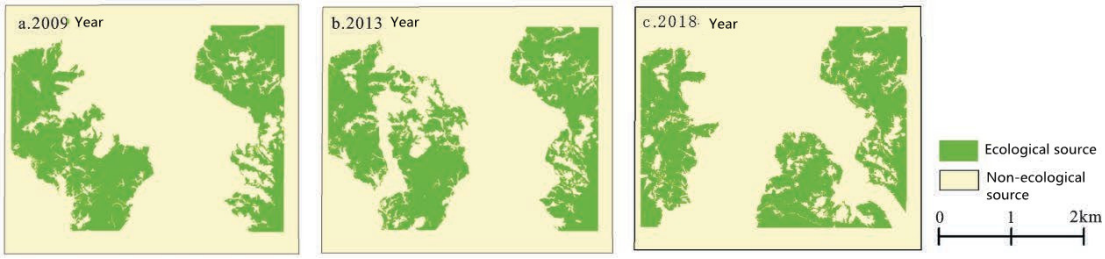

Figure 3. Model of minimum cumulative resistance surface in different years.

It can be seen from **Figure 2** that the overall resistance value of rare earth mining area was high in 2009. The main reason for this situation is that in the three years studied in this paper, the tailing land area of rare earth mining area was the largest in 2009, and the tailing land area gradually decreased after 2009. However, the tailing land is the largest resistance factor of the resistance factor of land use type, so it has a great impact on the overall ecological resistance value of rare earth mining areas.

4. Analysis on landscape ecological security pattern of rare earth mining area from 2009 to 2018

4.1 Spatial distribution of ecological source

According to the above source selection principles and landscape ecology knowledge, we know that high-quality ecological source areas have high ecological services and their value. Most scholars at home and abroad directly select ecological parks, large-area vegetation or water areas as the source of ecological security pattern[28]. However, according to the field investigation and the actual situation, the rare earth mining area in southern Jiangxi is located in the low mountain and hilly area in the south, and the vegetation is the main land use type. Therefore, the area with dense vegetation and of more than 10 km^2 is selected as the ecological source (**Figure 3**)[29]. Due to the long-term large-area rare earth mining in the middle of the area in 2009 and 2013, the vegetation in the middle of the mining area is seriously damaged, and the ecological source is mainly distributed on the east and west sides. However, after 2013,

the environmental protection department has formulated and implemented some mining area reclamation measures, and the ecological environment of the mining area has been improved to a certain extent. By 2018, based on the distribution characteristics of the first two years, the ecological source has also increased to a certain area in the south of the mining area.

4.2 Construction of ecological security pattern

The construction of landscape ecological pattern can effectively guide people's production activities in the mining area, including the ecological restoration and planning of key vulnerable areas, as well as the balanced and sustainable development between economy and ecology, so as to provide a theoretical basis for the rational planning of mining land. To construct the landscape ecological pattern, besides the selection of ecological source, it is also necessary to distinguish, select and combine the ecological corridor, ecological node, radiation channel, patch and ecological matrix[30]. Based on the cost-distance analysis technology, through the construction of ecological resistance surface and the synthesis of minimum cumulative resistance surface for the selection of ecological sources, it is also necessary to extract ecological corridors, nodes and radiation channels, so as to form the ecological security pattern of rare earth mining areas.

1) Identification of ecological corridor. Ecological corridor refers to the most efficient path for the maintenance and diffusion of different species, that is, the low resistance valley line between the two sources[31]. This paper identifies the ecological corridor based on hydrological analysis, so as to connect the two adjacent source patches in the mining area.

2) Radiation channel is similar to ecological corridor[32]. It plays a channel role in species diffusion and maintenance, that is, it is a low resistance valley line for the outward diffusion of ecological source, which plays a key role in the protection of species diversity and the evolution and development among species.

3) The ecological node is the tangent point of the equal resistance line between the ecological sources according to the morphological characteristics of the minimum resistance model of the mining area, so it is regarded as the ecological node of the rare earth mining area[33,34].

According to the landscape ecological security pattern of rare earth mining area in 2009, 2013 and 2018 (**Figure 4**), the number of 3a ecological corridors is 1, 4 and 6 respectively. The number of radiation channels is 14, 16 and 19 respectively, and the number of ecological nodes is 1, 4 and 6 respectively.

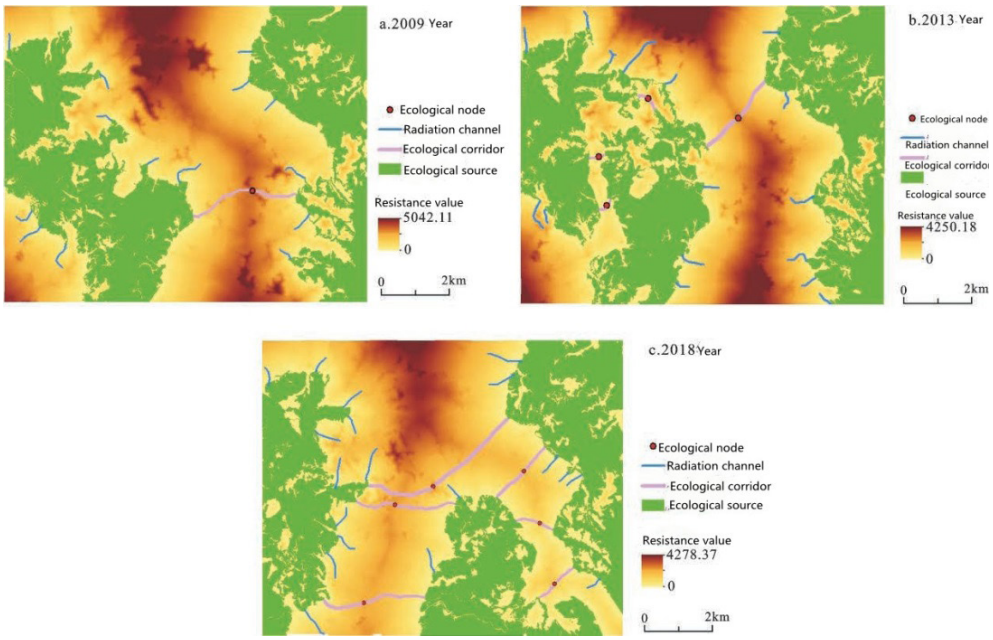

Figure 4. Integrated ecological security pattern of rare earth mining areas in 2009, 2013 and 2018.

Compared with 2009, the ecological source area, ecological corridors, radiation channels and the number of ecological nodes in the rare earth mining area increased in 2013, and the maximum resistance value decreased. In 2009, due to excessive mining in the middle of the mining area, a large amount of tailings was accumulated and the resistance value was high. The ecological source areas were mainly distributed in the east and west. There was only one ecological corridor and a small number of radiation channels, which greatly hindered the circulation of species between the east and the west. Combined with the images and field investigation, it can be seen that in 2013, due to the introduction of a series of environmental protection measures, such as the wide application of in-situ leaching technology, tailings land reclamation, returning farmland to forest, mining standardization, etc., the vegetation in the mining area has been protected to a certain extent. The area began to grow, and the ecosystem began to repair itself or man-made. It can be seen from Table 4 that the total area of source patch in the mining area in 2009 was 34.833 km^2, mainly concentrated in the vegetation position. The total source area in 2013 was 37.286 km^2, an increase of 2.452 km^2 compared with 2009. The source of the mining area tends to shift to the west, and the source areas in the middle and west have increased (**Figure 5**).

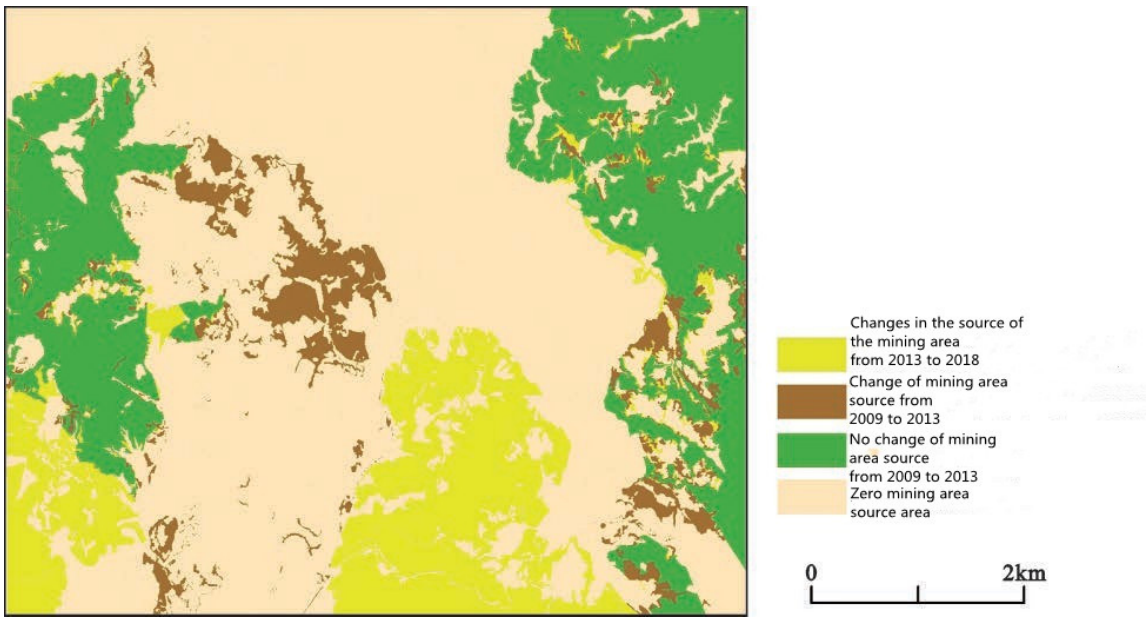

Figure 5. Spatial change of ecological source of rare earth mining areas in 2009−2018.

Table 4. Changes in ecological source area of rare earth mining areas in 2009−2018 (km^2)

Year	Total area of ecological source	Area change
2009	34.833	–
2013	37.286	Increased 2.452
2018	36.465	Decreased 0.82

Note: − means no data was available.

Compared with 2013, the area with high resistance value in rare earth mining area decreased, and the part with high resistance value moved eastward in 2018. Besides, the number of ecological corridors increased by 2, and the number of radiation channels increased by 3. Combined with **Figure 5** and Table 4, it can be seen that the ecological source area is distributed in the east-west south, and some source areas are transferred to the south. The total source area is 36.465 km^2, which has decreased by 0.820 km^2 compared with 2013, and the source area has become more concentrated, mainly because the source growth location was originally the tailings land of the mining area, and the land has been seriously damaged.

After 2013, benefiting from the instructions of Several Opinions of the State Council on Supporting the Revitalization and Development of Gannan and Other Former Central Soviet areas (http://www.gov.cn/zhengce/content/2012-07/02/content_4618.htm), the ecological environment in southern Jiangxi has been highly concerned by the party and the state.

Since then, the environmental protection department has issued a series of policies for the treatment of environmental problems in rare earth mining areas, and invested a lot in the treatment of ecological and environmental problems in rare earth mining areas. In these five years, the ecological security of the mining area has been further improved.

The ecological corridors in rare earth mining areas are mainly connected to two large source patches in the East and West. However, due to the accumulation of a large number of rare earth ore points in the middle of the mining area and the exploitation of rare earth ore points, there are a large number of rare earth tailings and sedimentation tanks in the middle of the mining area, so the resistance value in the middle of the mining area is high and there is poor connectivity between the eastern and western parts of the mining area. For only one ecological corridor connecting the eastern and western ecological source patches, and the two ecological corridors intersect with multiple roads and rare earth tailings, there are multiple vulnerable parts with insufficient stability. Once any problem occurs, it may lead to the fracture of the overall ecological structure of the mining area. The ecological nodes located in the mining points and construction areas are relatively dense, and its construction goal is to build a secondary source for the maintenance of ecological functions in the mining area. In this case, this type of ecological nodes are also most vulnerable to human interference and destruction, so the construction and protection of this type of ecological nodes should be strengthened. Due to the large number of sedimentation tanks and tailings in the central area of the mining area, affected by rare earth mining activities, it will also interfere with the ecological corridor and ecological nodes, which reduces the stability of the ecological security pattern of the mining area.

There is little difference in the size of patches in the ecological source areas of rare earth mining areas, and the distribution is relatively concentrated. The number of ecological corridors is small. The ecological nodes are mostly distributed near rare earth tailings and buildings. The connectivity and stability between the east and west parts are low, but the overall ecosystem stability is constantly improving in these 9 years, so relevant departments also need to further plan the ecological security space of rare earth mining areas.

5. Optimization measures of ecological security in rare earth mining areas

As the core area of the landscape ecological security pattern of the mining area, the ecological source is an insurmountable red line for rare earth mining and residents' life. The overall goal of the optimization of the ecological source of the rare earth mining area is to protect the existing ecological source and continuously expand the area of the ecological source. During the nine years, the ecological source areas on the east and west sides of the rare earth mining area are relatively stable and are the object of key protection and construction. Protective measures such as building buffer zones around them can be taken to protect the original vegetation and make it better play its role of ecological service; with the goal of restoring the original condition, the reclamation is accelerated at the junction of the original vegetation and the mining area. For the small patch sources increased in the later stage, artificial interference should be reduced to prevent damage, and construction and human activities of any nature should be prohibited to make them develop in the natural direction; For the area where the reclaimed vegetation becomes the source, because the vegetation coverage of the area is low and belongs to the ecologically weak area, measures such as supplementary planting and fertilization should be taken to accelerate the growth.

To increase the construction of ecological corridors in the East-West source areas, in the process of construction, the primary vegetation in the mining area should be selected, and a reasonable corridor width should be formulated according to the land use type, slope and elevation of the mining area, and the resistance value should be reduced to build the best ecological corridor in the mining area, reduce the flow obstruction between species in the East-West ecological source areas, and strengthen the connec-

tivity between the East and the West. The ecological corridor in the central area is increasing year by year, which is the concentration area of mining points. When the ecological corridor passes through artificial landscapes such as buildings, sedimentation tanks and roads, appropriate isolation zones should be established around the environment, buffer zones should be established by strengthening the construction and protection of artificial green spaces, and more ecological corridors and radiation channels should be built around the ecological source and it shall strengthen connectivity between sources. In previous years, farmland and orchards were mainly concentrated in the east, but in recent years, the construction of ecological corridors in this area has become better and better, and the number has gradually increased. When the corridors intersect with farmland or orchards, the natural components of the ecological corridor area or the land use types similar to the natural components should be preserved, so as to improve the ecological stability and prevent the fracture of the overall ecological corridor.

From the landscape ecological security pattern of the constructed rare earth mining area for 3 years, it can be analyzed that more ecological nodes are located near the tailings land of the mining area, which is also the weak part of biological exchange in the mining area. Especially in the part with high resistance value in the middle, the land use types are mostly tailings land and sedimentation tank. The reclamation measures for this location should be accelerated. The main land use types should be planting vegetation or building other land use types with low resistance coefficient. It is strictly prohibited to carry out rare earth mining, production and construction in the area of ecological nodes, so as to reduce the interference of human activities.

6. Conclusion and discussion

In this paper, patches with important ecological significance are extracted as the ecological source, and three factors as land use type, slope and elevation, which have a great impact on the ecological environment of the mining area, are selected to construct the ecological resistance surface based on the MCR model. On this basis, the best ecological corridor between adjacent ecological sources and the radiation channel connecting with the outside are identified, the ecological nodes with important ecological significance are determined, and the security pattern for protecting species diversity is constructed. The conclusions are as follows:

1) From 2009 to 2013, the area with high resistance value in the mining area decreased year by year, the location of ecological source continued to shift to the direction of high resistance value, and the source area also increased, which was concentrated in the east and west sides. The original land use types on the east and west sides were mostly tailings land and farmland, the area of reclaimed vegetation also increased, and the ecological pattern of the mining area became more and more reasonable. Land damage caused by mining has improved.

2) In the three years studied, the number of ecological corridors, radiation channels and ecological nodes in the mining area has increased, but the concentration area of mineral points in the middle is still the place with the highest resistance value, and the ecological security status of this area is the worst in the region. Moreover, the ecological corridors mostly intersect with roads, rare earth tailings and farmland, forming an ecological fragile area in the corridor. In order to maintain the stability of the ecological pattern and the connectivity of the ecological corridor, we should strengthen ecological regulation, focus on protecting the ecological land around the mining sites and timely reclamation, and advocate returning farmland to forest and primitive land use types, so as to ensure the circulation among species.

Considering the landscape connectivity of the mining area, the protection of biodiversity and the stability of the regional ecosystem, this paper comprehensively constructs the landscape ecological security pattern of the rare earth mining area, obtains the corresponding optimization measures for the landscape ecological security of the mining area and establishes the ecological corridor construction of the rare earth mining area, and makes the ecological security pattern of the mining area more systematic and complete. However, there remain some limita-

tions. It is one-sided to only select vegetation as the source patch identification while ignoring other land use types that may have little impact on the whole area but are of great importance to the local area, which should be further explored in the future researches.

Conflict of interest

The authors declare that they have no conflict of interest.

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ORIGINAL RESEARCH ARTICLE

Study on the distribution pattern and influencing factors of shrinking cities in Northeast China based on the random forest model

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ABSTRACT

Based on the population change data of 2005–2009, 2010–2014, 2015–2019 and 2005–2019, the shrinking cities in Northeast China are determined to analyze their spatial distribution pattern. And the influencing factors and effects of shrinking cities in Northeast China are explored by using multiple linear regression method and random forest regression method. The results show that: 1) In space, the shrinking cities in Northeast China are mainly distributed in the "land edge" areas represented by Changbai Mountain, Sanjiang Plain, Xiaoxing'an Mountain and Daxing'an Mountain. In terms of time, the contraction center shows an obvious trend of moving northward, while the opposite expansion center shows a trend of moving southward, and the shrinking cities gather further; 2) in the study of influencing factors, the results of multiple linear regression and random forest regression show that socio-economic factors play a major role in the formation of shrinking cities; 3) the precision of random forest regression is higher than that of multiple linear regression. The results show that per capita GDP has the greatest impact on the contraction intensity, followed by the unemployment rate, science and education expenses and the average wage of on-the-job workers. Among the four influencing factors, only the unemployment rate promotes the contraction, and the other three influencing factors inhibit the formation of shrinking cities to various degrees.

Keywords: Shrinking Cities; Northeast China; Demographic Changes; Linear Regression

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1.Introduction

In the history of random forest, the cases of urban decline and extinction are not rare, and the reasons are mostly from wars, diseases and disasters. Since modern times, the western world once ushered in the wave of high-speed urbanization. However, after World War II, especially in the 1960s and 1970s, due to the influence of many factors such as suburbanization, deindustrialization, post socialist society, globalization and population development transformation, many cities and regions that carried out urbanization earlier experienced serious population loss[1]. In western academic circles, this urban phenomenon characterized by population reduction and economic recession is called urban shrinkage, and the cities experiencing urban shrinkage are called shrinking cities. The German government funded project "shrinking

city research" found that in the past 50 years, 450 urban areas with a population of more than 1 million in the world have lost 1/10 of their total urban population[2]. Such a large-scale and substantial reduction of urban population is unprecedented. It is not caused by war, disease and disasters as people generally know. It occurs in the era of prosperity and peace[3]. In order to deal with the ill effects of urban contraction, foreign academic circles have already carried out research on urban contraction[4], which mainly focuses on the definition[5], classification[6], comparison[7], quantitative analysis[8], causes[9], countermeasures and suggestions of shrinking cities[10,11]. In China, due to the late start of China's urbanization and the rapid urbanization after the reform and opening up, the domestic academic circles mainly focused on growth and expansion[12]. However, with China's social and economic development entering the adjustment period, the decline of fertility rate and population aging, coupled with the proposal of "new urbanization" and other strategies, issues other than "growth" have attracted attention[13]. In this context, the phenomenon of urban contraction has gradually attracted the attention of domestic scholars[14,15]. The research shows that China's cities are also facing a more profound problem of urban contraction. Urban contraction has also occurred not only in the central and western regions, but also in the Yangtze River Delta, Pearl River Delta, Beijing Tianjin Hebei and other areas with better socio-economic conditions, in which the northeast is the hardest hit area of urban contraction[16,17].

At present, the domestic academic circles have a deep understanding of the phenomenon of urban contraction, but most studies still focus on the identification and judgment of shrinking cities, and the methods adopted simply rely on the construction of index system, without combining with the background of regional social and economic development[18]. Some scholars have made quantitative analysis on the deep causes of the formation of shrinking cities[19–21]. However, most of these scholars use linear analysis models with many restrictions and poor explanatory power in the face of complex nonlinear problems. The nonlinear stochastic forest model can overcome these shortcomings. The research shows that the random forest model has high prediction accuracy. It can process high-dimensional and multicollinearity data, and is convenient to calculate the nonlinear effect of variables[22].

Taking the northeast region, which is typical in the wave of urban contraction, as an example, this paper puts forward the judgment method of shrinking cities under the background of large changes in the overall population of the region, and analyzes the spatial distribution pattern of shrinking cities in the northeast region by using the method of spatial statistics. Multiple linear regression method and random forest regression method are used to analyze the influencing factors and their effects on the formation of shrinking cities in this area, in order to provide scientific basis and decision support for the research and management of shrinking cities.

2. Data sources and research methods

2.1 Data sources

Urban growth and contraction is a long gradual process, which requires a long time to observe the growth or contraction tendency of the city. Therefore, the time span should not be too short when observing[23,24]. Therefore, this study takes 5 years as a time unit interval, and selects 2005–2009, 2010–2014 and 2015–2019 as the basic observation time unit respectively. The time span of 5a is proper. On the one hand, the change of urban growth or contraction characteristics are obvious. On the other hand, it can also avoid the risk of increasing the difficulty and inaccuracy of data acquisition due to a long time span.

This study takes the prefecture level administrative regions in Northeast China as the basic research unit. Considering the adjustment of administrative divisions in some regions from 2005 to 2019, taking the administrative divisions in 2019 as the benchmark, 40 cities (including prefecture level cities, regions, autonomous prefectures and leagues) in Northeast China are finally determined as samples, including 14 in Liaoning Province, 9 in

Jilin Province (including prefecture level cities and autonomous prefectures), 13 in Heilongjiang Province (including prefecture level cities and regions), 4 in Mongolia (including prefecture level cities and League) (**Figure 1**). The socio-economic data comes from the statistical yearbooks and statistical bulletins of provinces and cities in each year. The nighttime lighting data comes from the National Geophysical Data Center of the United States (https://www.ngdc.noaa.gov); the land use data, DEM data, meteorological data and NDVI data used in this paper are from the Resource and Environment Science and Data Center (http://www.resdc.cn).

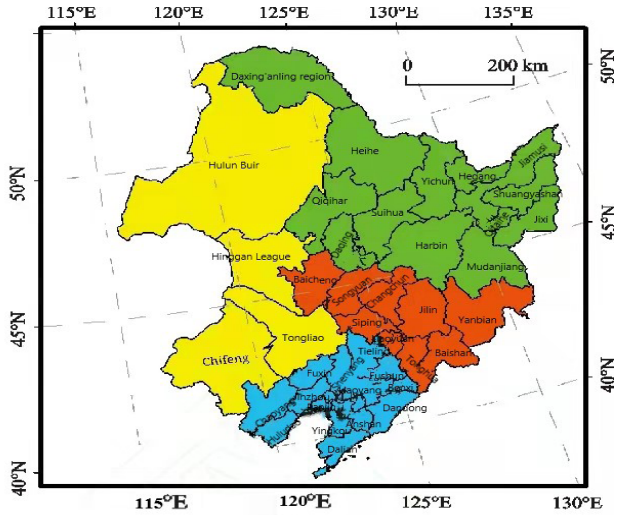

Figure 1. Sketch of study area.

2.2 Judgment method of shrinking cities

At present, there is no unified theory on the definition of shrinking cities at home and abroad[25,26]. Although there are still differences in the quantitative judgment of shrinking Cities in the world, the judgment of shrinking Cities based on population reduction has been widely recognized by the academic circles.

Combined with the background of China's population growth and population loss in Northeast China in the past ten years, this study defines the shrinking cities in Northeast China as: the population growth rate in a period of time (5 years in a short period and 15 years in a long period) is lower than that in Northeast China. The calculation formula is as follows:

$$D = \Delta p - \Delta P \quad (1)$$

In the formula, D is the difference between the population change rate of a single city and the population change rate of the whole northeast in this period. Δp is the population change rate of a single city during this period. ΔP is the population change rate of the whole Northeast during this period. The population change rate is calculated by the total registered residence population at the end of the year. To a certain extent, formula (1) can also reduce the deviation of the total household population at the end of the year. Based on the formula (1), the intensity of the urban population is calculated:

$$I = \frac{D}{|\Delta P|} \quad (2)$$

In the formula, I is the contraction intensity of a single city in this period. When $I < 0$, it means that the city is a shrinking city. The smaller the value is, the greater the population contraction degree of the city is.

2.3 Analysis method of shrinking urban distribution pattern

The standard deviation ellipse can be used to reveal the spatial distribution characteristics of geographical objects on the overall level and reflect the trend direction of geographical objects[27]. This study uses the standard deviation ellipse analysis to explore the centers of three shrinking cities and expanding cities in a short period of time, so as to obtain the moving path of population contraction and expansion.

Spatial autocorrelation analysis refers to the statistical correlation between certain attribute values of geographical elements in different geographical spatial distribution locations. The closer the distance is, the greater the correlation between the two values is[28]. This study uses spatial autocorrelation analysis to explore the spatial agglomeration characteristics of shrinking cities and expanding cities in four periods.

2.4 Analysis method of influencing factors of urban contraction

2.4.1 Selection of influencing factors

This study takes 5 years as a time unit. The se-

lection of socio-economic factors adopts the starting year data, and fully considers the lag of urban contraction. In addition, this study attempts to take into account natural and human factors, and selects 24 influencing factors in combination with relevant literature (**Table 1**)[29–30].

Table 1. Influencing factors of shrinking cities

Influencing factors	Variable	Data description
Total population at the end of the year /person	X_1	Total population at the end of the starting year of the unit period
Birth rate/‰	X_2	Annual birth rate at the beginning of unit period
Proportion of population over 60/%	X_3	Proportion of population over 60 years old in the starting year of unit period
Population density/(person/km2)	X_4	Total population at the end of the starting year of the unit period / administrative area
Night light index	X_5	Night light index of starting year in unit period
Per capita GDP/10000 CNY	X_6	GDP in the starting year of unit period / total population at the end of the starting year of unit period
Investment in fixed assets/10000 CNY	X_7	Investment in fixed assets in the initial year of the unit period
Science education cost/10000CNY	X_8	Initial annual science education expenses in the unit period
Student teacher ratio/%	X_9	Number of primary and secondary school students in the starting year of the unit period / total number of primary school teachers in the starting year of the unit period
Unemployment rate/%	X_{10}	Initial annual unemployment rate in unit period
Per capita number of medical and health beds/piece	X_{11}	Number of beds in medical and health institutions in the starting year of the unit period / total population at the end of the starting year of the unit period
Number of buses/trams per capita/vehicle	X_{12}	Number of buses / trams per capita in the starting year of the unit period
Greening rate of built-up area/%	X_{13}	Greening rate of built-up area in the initial year of unit period
Paved road area per capita/km2	X_{14}	Road pavement area (length) in the starting year of unit period / total population at the end of the starting year of unit period
Average salary of on-the-job employees/CNY	X_{15}	Average wage of on-the-job employees in the starting year of the unit period
Waste utilization index	X_{16}	Average value of comprehensive utilization rate of industrial solid waste, urban domestic sewage treatment rate and harmless treatment rate of domestic waste in the initial year of the bit period
Shape fluctuation	X_{17}	Average topographic relief (grid space ratio is 90 m, and the window is 0.9 km)
Average slope/(°)	X_{18}	Average slope (grid spatial resolution of 90 m)
Average altitude/m	X_{19}	Average altitude (grid spatial resolution of 90 m)
Annual average temperature/°C	X_{20}	Average temperature (using spatial interpolation method)
Annual average precipitation/mm	X_{21}	Average precipitation (using spatial interpolation method)
Cultivated land index	X_{22}	Cultivated land index in the initial year of unit period (grid spatial resolution of 1 km)
Artificial surface index	X_{23}	Artificial surface index in the initial year of unit period (grid spatial resolution of 1 km)
NDVI	X_{24}	Normalized vegetation index (grid spatial resolution of 1 km) for the starting year of the unit period

2.4.2 Regression model and test

Taking the influencing factors in **Table 1** as independent variables and the calculated shrinkage intensity as dependent variables, multiple linear regression and random forest regression methods are used for fitting verification to explore the influencing factors of urban shrinkage in Northeast China.

In multiple linear regression, in order to eliminate the influence of irrelevant or low correlation influencing factors on the regression results, it is necessary to conduct correlation analysis between each independent variable and dependent variable[31]. During the construction of the regression model, the correlation between the respective variables is tested by the variance expansion coefficient VIF. The larger the VIF is, the more serious multicollinearity between the independent variable and other independent variables is. The result of the model is not

significant, so the model should be reconstructed.

Random forest model has randomness in the selection of samples and features. It has obvious and unique advantages in algorithm, good tolerance for noise. It is not easy to over fit. Now it is widely used in classification and regression problems[31–33]. In this study, the sklearn module is called on the Python platform for random forest regression. After many debugging, the parameter n_ estimators = 800, criterion = MSE is selected, other parameters are default.

In this study, judgment coefficient R^2 and mean square error MSE are used to evaluate the accuracy of regression model. Judgment coefficient R^2 is the fitting degree of fitting value after regression to observed value, and its value range is [0,1]. The closer R^2 is to 1, the better the fitting effect of the regression model is. The mean square error MSE is the average value of the sum of squares of residuals, which is one of the most commonly used loss functions in regression. The clearer MSE is, the smaller the model error is.

3. Spatial distribution pattern of shrinking cities in Northeast China

3.1 Overall distribution pattern

Calculate the shrinkage intensity of each city in each period according to formulas 1 and 2, and draw the polar coordinate map corresponding to the four periods (**Figure 2**), and visualize the shrinkage cities ($I < 0$) in each period on the map (**Figure 3**). As can be seen from **Figure 2**, Shenyang, Dalian, Daqing and Changchun were prominent in the four periods, while Jixi, Yichun and Daxinganling areas were at a low level for a long time. **Figure 3** shows that the number of shrinking cities was 24 from 2005 to 2009 and 26 from 2010 to 2014, and the spatial distribution of shrinking cities in the two periods is similar, that is, they are distributed in the east of Northeast China. The northern and western regions roughly correspond to areas with high terrain and large topographic relief such as Changbai Mountain area, Xiaoxing'an Mountain area and Daxing'an Mountain area, while cities dominated by population growth show an "inverted triangle". It is distributed along Harbin Dalian railway with relatively flat terrain and good traffic conditions and in central and southern Liaoning. From 2015 to 2019, the number of shrinking cities was 22, 13 cities in Heilongjiang Province were identified as shrinking cities, and only Changchun and Jilin in Jilin Province were not identified as shrinking cities. During this period, shrinking cities are mainly distributed in the North and East. For three cities in a short period, **Figure 4** shows that only Huludao, Panjin, Yingkou, Dalian, Changchun and Daqing have not experienced contraction. Most shrinking cities are located on the "land edge" of Northeast China. In the eastern Changbai Mountain

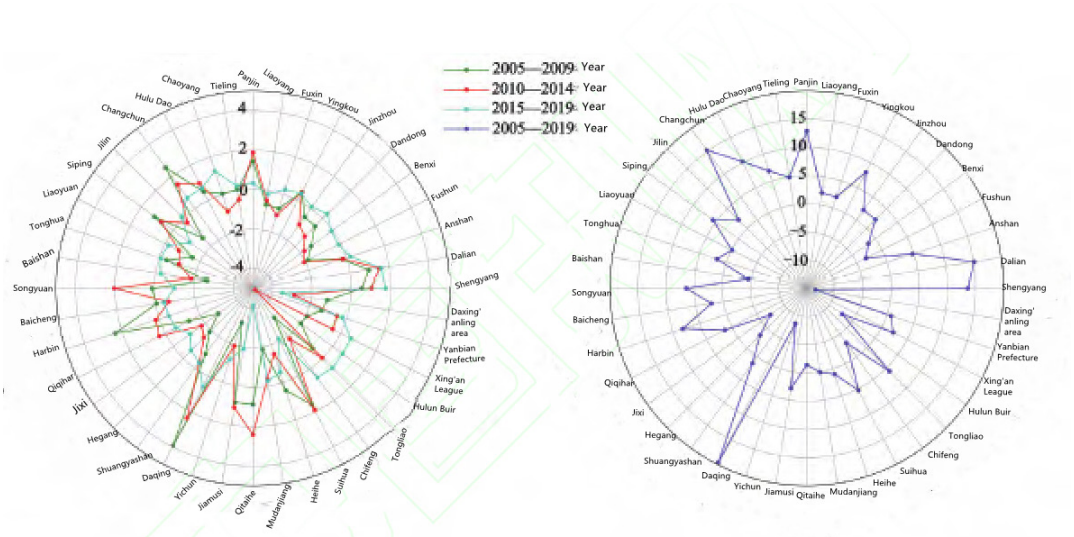

Figure 2. Polar map of shrinkage intensity I in Northeast China.

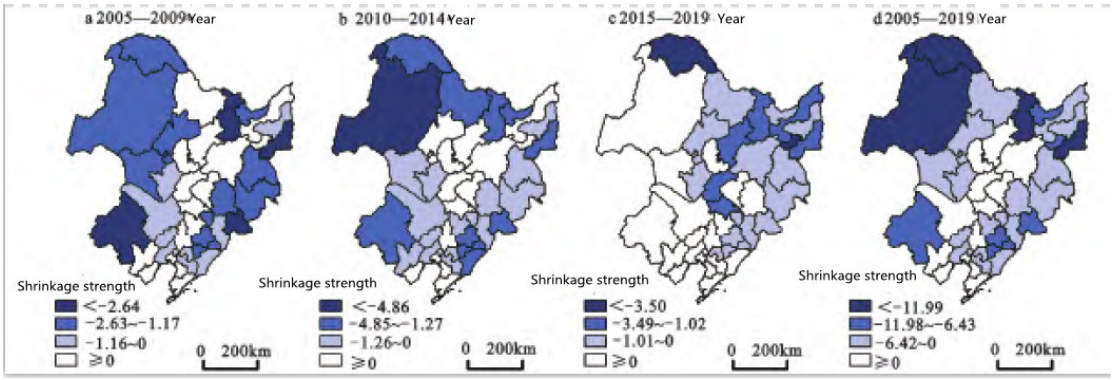

Figure 3. Shrinking cities in Northeast China in 2005-2019.

area, the number of urban contraction is generally large. The large topographic relief and low level of traffic accessibility may be the reasons for its contraction.

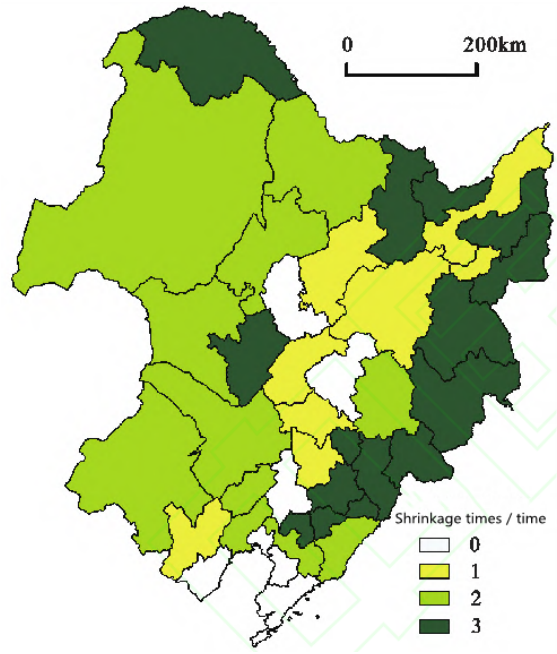

Figure 4. Urban shrinkage in Northeast China in 2005-2009, 2010-2014 and 2015-2019.

3.2 Analysis of spatial agglomeration characteristics

Taking the shrinkage intensity of three short-term shrinking cities ($I < 0$) and expanding cities ($I \geq 0$) as the weight, the standard deviation ellipse and its center of shrinking cities and expanding cities are obtained (**Table 2**). From 2005 to 2009, the shrinking city center was located in Dehui, Changchun City, and the expanding city center was located in Nong'an County, Changchun City. From 2010 to 2014, the shrinking city center was located in Mongolian Autonomous County of Qian Gorlos, Songyuan City, and the expanding city center was located in the jurisdiction of Changchun City. From 2015 to 2019, the shrinking city center was located in Tonghe County, Harbin City, and the expanding city center was located in Zhangwu County, Fuxin City. The shrinking urban ellipse and its center move northward obviously, and the expanding urban ellipse and its center move southward obviously. Generally speaking, in these three periods, the spatial transfer direction of urban contraction is northward and to the north of Heilongjiang Province; while the transfer direction of expansion is southward and to the Bohai Bay.

The standard deviation ellipse reveals the temporal and spatial distribution characteristics of shrinking cities from a certain level, but it does not fully show the agglomeration law among the research units. In order to fully reveal the spatial correlation of the shrinkage intensity of cities in Northeast China in various periods, this study uses the spatial autocorrelation method for research and analysis. The results show that from 2005 to 2009, 2010 to 2014 and 2015 to 2019, Moran's I were 0.132, 0.234, 0.241 and 0.184, and all passed the 0.1 significance test, which shows that there is a significant spatial positive correlation between urban population growth and reduction in Northeast China, and there is a trend of further strengthening.

Further local spatial autocorrelation calculation

Table 2. Parameters of standard deviational ellipse of shrinkage intensity I

Period	Types	Standard deviation ellipse parameter			
		Central coordinates	X-axis length / km	Y-axis length / km	Rotation angle
2005—2009	Shrinking City	44°37′N，125°55′E	933.55	718.78	43°50′
	Expanding City	44°40′N，125°32′E	873.21	332.56	22°49′
2010—2014	Shrinking City	44°45′N，124°52′E	1 007.42	817.51	179°27′
	Expanding City	44°11′N，125°23′E	1 002.49	356.46	27°43′
2015—2019	Shrinking City	46°2′N，128°45′E	686.51	417.75	47°8′
	Expanding City	42°37′N，122°10′E	788.28	394.90	171°48′

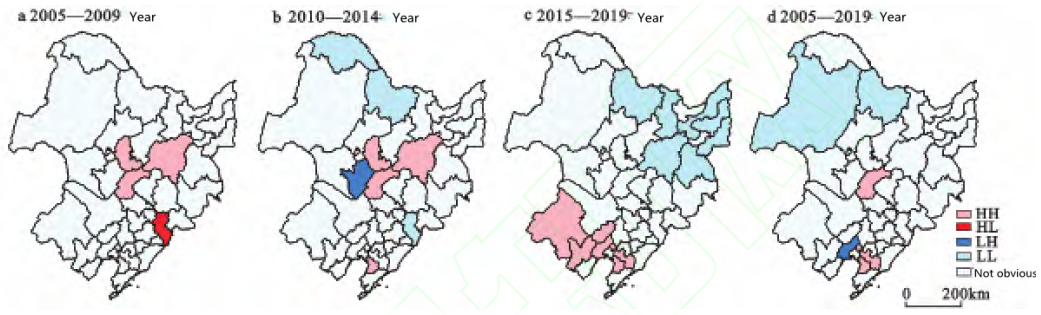

Figure 5. Spatial agglomeration characteristics of shrinking cities in Northeast China.

is carried out to obtain the LISA map of shrinking cities in Northeast China (**Figure 5**). On the map, the distribution characteristics of shrinking cities in Northeast China are divided into five levels in each period, that is, insignificant, “High-High” aggregation area (HH area), “High-Low” aggregation area (HL area), “Low-High” aggregation area (LH area) and “Low-Low” aggregation area (LL area). The results show that from 2005 to 2009, the areas with Harbin, Changchun and Daqing as the core formed HH area, that is population growth gathering area, while Tonghua formed HL area, that is contraction surrounding growth area. From 2010 to 2014, HH expanded to the coastal area of Liaoning with Yingkou as the core. LL area is mainly distributed in the northwest of Heilongjiang Province with Daxinganling area and Heihe River as the core. From 2015 to 2019, there is an obvious north-south differentiation, which is mainly manifested in that the southern area with the central and Western Liaoning Province and Chifeng City as the core is HH area, that is, population growth agglomeration area. And the northern and northeast areas with Sanjiang Plain as the core are LL area, that is, population contraction agglomeration area. From 2005 to 2019, HH district was mainly distributed in the central part of Jilin Province with Changchun as the core and the central and southern part of Liaoning Province with Yingkou as the core, while LL district was distributed in the northern part with Hulunbuir and Heihe as the core.

4. Analysis on influencing factors of urban contraction in Northeast China

4.1 Verification of multiple linear regression and random forest regression

Through the correlation analysis between the selected influencing factors and the shrinkage intensity of each city in each period, 16 of the 24 influencing factors passed the 0.01 significance test, of which 13 had a large correlation with the shrinking city ($r \geq 0.3$). Take these 13 influencing factors as independent variables for preliminary linear regression, and eliminate the influencing factors with high VIF (VIF ≥ 10). For the remaining 10 influencing factors, the

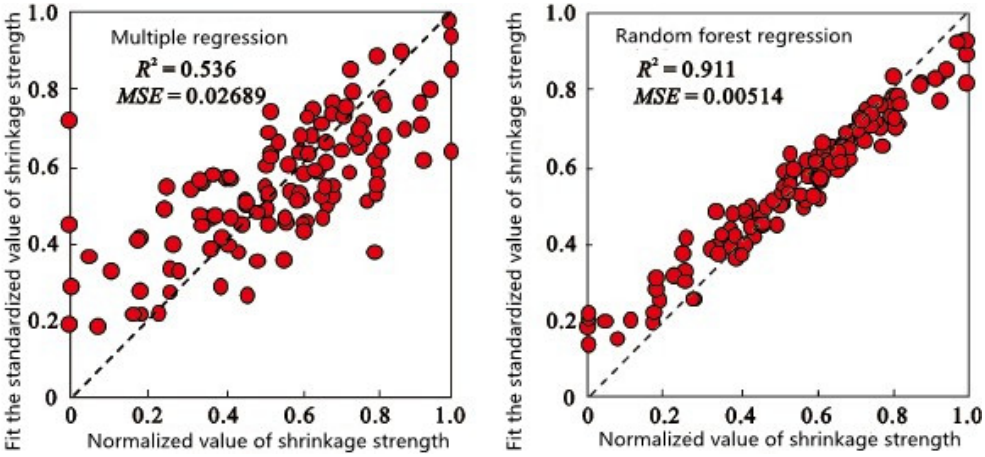

Figure 6. Fitted scatter plots of multiple linear regression and random forest regression.

second multiple linear regression was carried out again. The absolute values of the coefficients obtained by the second multiple linear regression are unemployment rate (−0.304), per capita GDP (0.266), science and education expenses (0.206), cultivated land index (0.195), average wage of on-the-job employees (0.173) and fixed asset investment (0.111), average altitude (−0.107), total population at the end of the year (0.057), topographic relief (0.024) and greening rate of built-up area (0.015).

Input the above 10 influencing factors into the multiple linear regression model and input all influencing factors into the random forest model to calculate the R2 and MSE with multiple linear regression and random forest regression respectively. Then we obtain the corresponding scatter diagram for the comparison between fitting values and observed values (**Figure 6**). The results show that R2 of multiple linear regression is 0.536 and MSE is 0.02689; R2 of random forest regression is 0.911 and MSE is 0.00514. The error of random forest regression is much less than that of multiple linear regression. Random forest has higher accuracy in this study and its results are more trustworthy.

4.2 Importance ranking and analysis of influencing factors

The importance ranking of influencing factors under random forest regression is obtained by using the IncMSE method. IncMSE is the average reduction value of precision. This method follows the principle of control variables. It assigns random values to each variable for many times and carries out prediction and fitting on the original model, and then calculates the MSE between the fitting results and the observation results. The more MSE increases, the more important the influencing factor is. The ranking results of IncMSE show that the top four influencing factors are per capita GDP (17.619%), unemployment rate (13.179%), science and education expenses (11.003%) and average wage of on-the-job employees (9.251%). However, the artificial surface index and cultivated land index ranked No. 5 are only 5.843% and 5.690%, which fully shows that the top four influencing factors are the leading factors of urban contraction. In addition, the total population ranked No. 18 at the end of the year, and IncMSE was 1.378%, which shows that the existing population has little impact on urban contraction. It can be found from the data that Qiqihar City, Anshan City, Tongliao City, Hulunbuir and Dandong Cities with large basic population are also frequently affected by urban contraction.

Based on the results of IncMSE, the random forest regression model is used to further analyze the impact of the top four influencing factors on shrinking cities. The standardized values of each influencing factor are input into the model and the average fitting results are fed back. The results are shown in **Figure 7**. As can be seen from **Figure 7**, only the unemployment rate has played a role in promoting the formation of shrinking cities, and in a period, the unemployment rate ≥ 0.44 has the strongest role in promoting the formation of shrinking cities. In addition

to the unemployment rate, the other three influencing factors have played a role in inhibiting the formation of shrinking cities. In a period, when per capita GDP ≥ 0.6, science and education expenses ≥ 0.35 and the average wage of on-the-job employees ≥ 0.84, the inhibitory effect on the formation of shrinking cities reaches the maximum and remains unchanged.

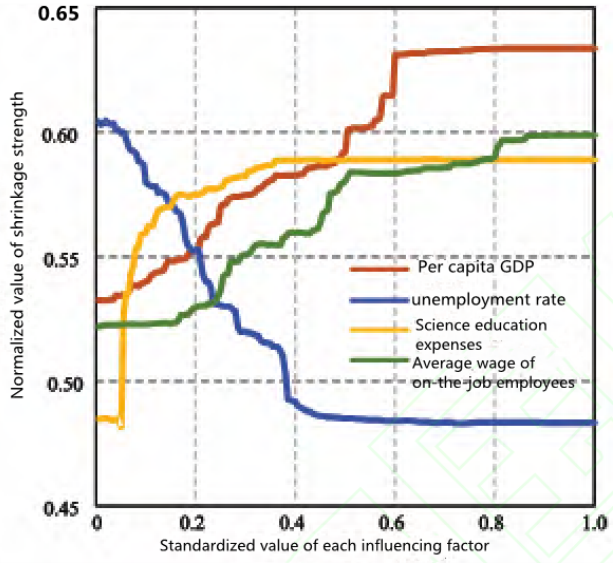

Figure 7. Impact of top 4 influencing factors on shrinkage intensity.

The per capita GDP reflects the urban development level and economic benefits under certain time and conditions, and is highly related to the living standard to a certain extent. In the random forest regression, the per capita GDP is the leading factor in the formation of shrinking cities, that is, Dalian, Shenyang, Changchun, Harbin, Daqing and other cities with high per capita GDP are less impacted by urban contraction. The employment rate can reflect a city's labor capacity and economic development. Good employment is an important factor to ensure social stability, while the unemployment rate is the reverse reaction of the employment rate. High unemployment rate will lead to violence and social unrest. When a city has high unemployment. The labor force tends to leave the city for other opportunities. In some resource-based cities in Northeast China, the imbalance of industrial structure leads to the problem of labor force allocation, which further leads to the emergence of a large number of unemployed people, which is the main reason why some resource-based cities in the north of Heilongjiang Province have been plagued by urban contraction for a long time. Science education is the potential source of urban and economic development. In terms of strength, the investment in science and education can develop science and technology and promote social progress. For cities, it can attract talents and drives the development of relevant industries. Because the four central cities of Dalian, Shenyang, Changchun and Harbin have a large investment in science and education and have more high-level colleges and Universities, they have a strong attraction for talents. Compared with other cities, they can slow down population loss by virtue of their excellent scientific and educational advantages in the wave of contraction. The average wage of on-the-job employees is the monetary wage per employee of each unit in a certain period of time, which can fully reflect the average social income level. Due to the low average income level in Northeast China, it is less attractive to talents. At the same time, many enterprises lack a reasonable and perfect reward mechanism, Lower wages have become an important reason for the outflow of talents in Northeast China.

5. Conclusion and discussion

This study analyzes the spatial distribution of shrinking cities in Northeast China from 2005 to 2009, 2010 to 2014, 2015 to 2019 and 2005 to 2019, and introduces multiple linear regression and random forest regression methods to analyze the influencing factors and effects of shrinking cities in Northeast China. The main conclusions are as follows: 1) In space, the shrinking cities in Northeast China are mainly distributed in the "land edge" areas represented by Changbai Mountain, Sanjiang Plain, Xiaoxing'an Mountain and Daxing'an Mountain. The main characteristics of these areas are poor traffic accessibility and large topographic relief, especially in Heilongjiang Province. The urban contraction phenomenon is weak in areas with better traffic conditions and gentle terrain, such as central and southern Liaoning and Harbin, Changsha. In terms of time, the contraction center in Northeast China shows a trend of moving north, while the expansion center moves south,

and the spatial autocorrelation between urban contraction and expansion is further strengthened with time. 2) The correlation analysis between the shrinkage intensity of each city in each period and the selected influencing factors show that the correlation coefficients of each influencing factor are quite different. In the multiple linear regression method, the unemployment rate has the strongest impact on the contraction intensity, followed by per capita GDP, science and education expenses, cultivated land index, average wage of on-the-job employees and so on. The random forest regression method has a larger R^2 and smaller MSE on the sample set, which has good fitting effect and more practical significance. Through the ranking of the importance of influencing factors by IncMSE, the ranking results are close to the results obtained by multiple linear regression. The top four are per capita GDP, unemployment rate, science and education expenses and average wage of on-the-job employees. Although the weight ranking of each influencing factor obtained by the two regression methods is not completely consistent, it is not difficult to find that socio-economic factors are the main factors determining whether the city shrinks or not. 3) The further calculation of impact under the random forest regression method can provide a clear direction for the control of urban contraction. The results show that among the top four influencing factors, only the unemployment rate plays a role in promoting the contraction of cities, and the promotion effect reaches the strongest and remains unchanged when its standardized value is ≥ 0.44 in a period. Combined with the ranking results of the importance of influencing factors, it can be seen that controlling the unemployment rate can effectively alleviate the current situation of urban contraction to a certain extent. In addition to the unemployment rate, the other three influencing factors have inhibited the formation of shrinking cities. In a period, when the per capita GDP ≥ 0.6, science and education expenses ≥ 0.35 and the average wage of on-the-job employees ≥ 0.84, the inhibition effect on the formation of shrinking cities reaches the maximum and remains unchanged.

At present, there are still great differences in the quantitative determination of shrinking cities in the academic circles. Taking the population change in the northeast as a reference, this paper determines and identifies the shrinking cities in the northeast from the perspective of relative shrinkage, and further compares the influencing factors of shrinking cities by using multiple linear regression and random forest regression, it provides a novel perspective for the study of shrinking cities. However, compared with the traditional shrinkage determination method, the relative shrinkage determination method in this paper may only be suitable for the Northeast where most cities in the whole region have population loss. In addition, due to the availability of data, the selection of influencing factors in this paper is not comprehensive, and there are still many potential factors affecting urban population change that have not been selected. Based on the above problems, we can continue to improve the theory of quantitative identification and judgment of shrinking cities in combination with the situation of different regions in the future, and find the potential factors for the formation of shrinking cities Based on different cases.

Conflict of interest

The authors declare that they have no conflict of interest.

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REVIEW ARTICLE

Castells's "network society theory" to human geography —Analysis and comparison based on Chinese and foreign quotations

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ABSTRACT

Based on 898 English documents and 363 Chinese documents citing the Rising of Network Society, it studied that the knowledge contribution of citation content analysis and citation context analysis methods, and the knowledge contribution of Chinese and foreign quotations to human geography. The study found that "mobile space" is the most quoted theoretical view in domestic and foreign literature, and the proportion of domestic research is significantly higher than foreign research; the focus of domestic and foreign research focuses on the external spatial form and its transformation, while foreign research pays more attention on the internal spatial dynamics of network society and three types of knowledge contributions, reflecting the influence of "network social theory" on human geography. Among them, critical references reveal the shortcomings of "network social theory" point out the abstraction of "spatial duality" the importance of local space, and the limitations of research data, methods, and time background, which provides new enlightenment for the future application and innovation of "network social theory" in the field of human geography.

Keywords: Network Social Theory; Mobile Space; Human Geography; Knowledge Contribution; Citation Analysis; Citation Function

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1. Introduction

Manuel Castells is a world-famous urban sociologist, and regarded as one of the most famous social thinkers of the 20th century[1,2]. Custer has written numerous works on urban society. Among them, *The Rise of the Network Society* systematically discusses the theory of "Network Society" in the information age[3–5], and it has become the most cited and influential work of Castells.

Castells's "network society theory" based on the logic of network and globalization, expounded the transformation from traditional social space to network social space, from fixed space to liquidity space. Meanwhile, it explained the geographical space and urban form under network society. It put forward the concepts and proposition of mobile space, network, globalization and information city[3–5], guiding to for understanding the relationship between network information space and geographical physical space, which has attracted wide attention of human geography scholars and played an important role in the development of human geography in the information age[6].

Under the influence of Castell's "network social theory", humanities and geography scholars mainly explored the global urban network, domestic urban network, urban grade, urban spatial structure, the relationship between physical space and cyberspace, urban planning, information city and other research topics[7–18]. But specifically, what knowledge in the "network social theory" pays tribute to the field of humanistic geography. The dedication is yet to be clarified. To clarify the problem can promote the development, and innovation of complex "network social theory" in human geography, and continuously guide the application of network logic in human geography.

The method of bibliometric analysis can elucidate the contribution and influence of important scholarship theory. However, traditional bibliometry often measured the academic impact of the literature based on the frequency of citation, but thes indicators are clearly flawed. The simple method with the reference frequency as the core ignores the importance of knowledge itself and the citation. It also ignores the relationship between the literature and the cited literature[19,20]. And analyzing the references and the reference approach break through the limitations of the citation frequency study paradigm. Citation content analysis and citation context analysis belong to this research paradigm. Specifically, the adoption of citation content analysis and citation situation analysis methods can elucidate the specific contributions of classical works from the perspective of knowledge development[22–24]. Both citation content analysis and citation context analysis require an understanding of the quoted semantic content[22,25]. Citation content analysis is used to reveal the quoted knowledge, while the citation context analysis reflects the relationship between the citation literature and the cited literature and is commonly used to analyze the author's citation cause[24,26]. Both are often applied to in the field of bibliometry and management, but rarely in human geography[20,21,27,28].

In this article, the citation content and citation situation analysis method is adopted. It aims to explore the enlightenment of Castells "network society theory" to human geography. Which knowledge in "network society theory has been highly cited in the field of human geography? How does the "network social theory" contribute to humanistic geography? At the same time, the present research further reveals the future research focus and development direction of "network social theory" in human geography through the comparative analysis of Chinese and foreign quotations and the critical thinking of Chinese and foreign scholars.

2. Castells's "theory of network society" and its formation

Castells's "network social theory" takes the information technology revolution as the starting point, the network as the theoretical logic, and globalization as the main research perspective, and puts forward the basic view of "the network builds the new social form of our society"[3]. In the traditional sense, space is based on geographical proximity, while fixed cognition of space, time, and distance is completely subverted, and society is more and more building around flow[3]. Therefore, the new spatial form that dominates the network society transforms into "mobile space", that is, "the material organization of the social practice of shared time operating through the flow", forming the from three levels of material support, nodes and core and management elite[3]. Castells believes that there is structural splitting in the logic of flowing space and place space[3]. Although people live in the local space, places have gradually broken away from their historical and geographical roots and become functional networks, which leads to mobile space replacing place space in turn[3]. Thus, mobile space becomes the dominant of society, and the importance of local space in the network has gone beyond the importance of place itself[3,29]. In addition, Castells noted that network society is a global society and that global cities are the process of connecting advanced services, production centers, and markets in the global network[3].

The formation of Castells "network society theory" stems from the transformation of Castells research paradigm under social changes in the information age. Castells's international reputation began with his book "*Urban Issues*" published in 1970s,

which marked Castells's role as a leading theorist in "new urban sociology"[30]; Castells then continued to study urban social movements and migration around the orthodox Marxist paradigm; in 1979, Castells began working in the Department of Urban Sociology at UC Berkeley, shifting academic soil from European society to the United States; based on this change and the impact of the technological development environment in California, Castells began to embrace the epoch-making technology wave in the early 1980s, and in 1989 published "Information City", indicating the budding of information sociology and network social theory research[31]; in the 90s, Castells's most landmark *Information Age Trilogy* was published. The trilogy includes *The Rise of Network Society*, *Power of Identity and End of a Millennium*, fully exploring the economy, society and culture of the information age, with a comprehensive summary of the great shift at the turn of the century[4,5,32–36]. "The Rise of Network Society" is the top priority of the Castells trilogy, which further expands Castells's academic influence and lays an important theoretical foundation for relevant scholars to understand the new social form in the information age through the "network social theory"[2].

3. Data sources and research methods

3.1 Data source

This paper searches both *The Rise of the Network Society* (1996 and 2000) and *The Rise of Network Society* (2000) in the Web of Science (WoS) Core Collection database (webofknow-ledge, respectivelycom/) and the Chinese Academic Journal Network Publishing General Library (CNKI General Library, www.cnki.net/) retrieved the journal class citation literature from 1997 to 2015 (not including master and doctoral papers, conference papers, books, etc.)[3–5]. The search results were returned to 2879 English documents and 2362 Chinese documents, involving multiple research fields such as sociology, economic geography, news media, information science and more.

Based on the above search results, this paper further screened out the literature belonging to the category of humanistic geography research. Humanistic geography-related research is published not only in geographical journals but also in journals of similar disciplines. Therefore, in order to reflect the knowledge contribution of "network social theory" to humanistic geography as comprehensively as possible, this study appropriately expands the subject scope of humanistic geography, that is, including human geography, urban research, planning and development, regional research, etc. These areas of study were chosen because of their close association and obvious knowledge input and output relationships[37-39]. For English literature, WoS has classified its disciplines for all its included journals. This article filters out journal papers belonging to the "Geography" "Urban Studies" "Planning & Development" as well as "Area Studies"; for Chinese literature, this article filters out humanities geographic literature belonging to the above category according to the name, introduction, content style and etc. Meanwhile, for the screening results, this paper further judges the subject paradigm by reviewing the topics and abstracts of the cited literature. Finally, 898 English references and 363 articles were retained Wenshi literature was used as a study sample of this paper, and the literature inscription is recorded to the excel and download the full text.

3.2 Study method

Sieweke points out that concepts are a subset of theories that the theory contains a series of concepts that are closely related and can be used alone[26]. Therefore, this article first adopts the citation content analysis method, analyzing the cited concepts in Castells's "network society theory". Basic procedures are mainly: (1) for the reference literature, the reference content will be recorded to excel; (2) read and understand the references and then make the judgment for cited contents and summarize the theoretical viewpoint as the theory concept. If a reference contains more than one concept, then individually record and categorize each concept; for theories with the same meaning concepts are unified and classified; statistics of theoretical theory intro-

duce frequency and sort out the often cited concepts in "network social theory".

Second, the citation concept was judged using the citation context analysis method. The functional role of its theoretical view in the citation literature is reversed. How does the image citation influence the citation literature? It is worth mentioning that in foreign studies, both the "reference function" and the "reference motivation" reflect the citing reasons of the author, and both of them can replace with each other[25,40]. And the citation reasons can be interpreted from the perspective of the author's personal intent (e. g., salute to the pioneer, ceremonial quote). It can also be cast from the citation functional role angle in the cited interpretation reads (e. g., confirm theory opinion, presentation of the related study[24,41–44]. This paper considers that the function of the citation can reflect more objectively the degree of knowledge contribution of the citation. Therefore, this paper selects the citation function to analyze and interpret the citation contribution. The basic analysis steps are: (1) read and understand the reference and its context. (2) On the basis of the citation function relevant literature has revealed, combine with specific studies in the citation literature object and repeatedly deliberate, to judge the function of the citation in the citation literature use, and record the reference function of each concept[20,24,43–46]. Although some quotes are given in the citation literature appear only once but undertook more than one citation function[40]. This study only recorded the most important functional role. (3) Secondary analysis of the judgment results is made on the results, and at the same time, reference function classification is unified and streamlined. Finally, this article was integrated to 9 referencing functions (**Table 1**).

Table 1. Reference function and its interpretation

Citation function	Paraphrasing
Background information	The citation provide background information on the full text or one of these topics.
Historical document	The citation expounds the existing literature, and often appears in the theoretical exposition parts such as "introduction" and "literature review" to help readers understand a certain topic.
Strengthen demonstration	Cations appear near or in the author's views to explain and support them.
Theoretical basis	The citation is used as the theoretical basis for applying the citation literature.
Views	Cations inspire the authors to present their own research questions, perspectives or future research directions.
Case validation	Through empirical or case studies, the cited literature demonstrated the cited views, or had similar conclusions to the cited literature.
Knowledge extension	The results of the citation literature expand the knowledge conveyed by the citation.
Point out the deficiencies	The authors note the shortcomings of the cited literature.
No-valid reference	The citation appears only in the reference list but not in the main text, or the citation is misquoted.

4. References content analysis

The analysis found that the 271 concepts of The Rise of the Network Society were 1558 times cited by 898 English citation literature, of which there is 258 English citation literature citing twice or more content; 363 Chinese literature cites 102 concepts of the work, which collectively cites 542 times, and 113 literature cites twice and more content.

Table 2 lists the top 20 cited frequency concepts, which are the introduction frequency accounted for 71.2% of the total introduction frequency at home and abroad,and 62.1%, respectively. It suggests that these concepts can represent human geography scholars' opinions of the core focus of Castells's "cyber-social theory". And for the English literature, the focus of Chinese literature is more focused. As can be found in **Table 2**, Chinese and foreign citation literature consistently shows the content about the "mobile space" in the "network social theory" is the most cited. But the Chinese study cited the proportion of "flow space"(19.7%) is significantly higher than that cited in the English study (10.1%). The theory of flow space subverts the conventional void, providing interideas for scholars of humanistic geography to understand spatial morphology, the biggest contribution of geography that Castells's "theory of network social" made for the humanities, of great significance for scholars to regain their knowledge of the concept, form and its development of space of the information age[4,47,48]. In addition, "network

Table 2. Top 20 cited concepts of *The Rise of the Network Society*

English literature			
No.	**Concept category**	**Cited frequency**	**Proportion (%)**
1	Flowing space	158	10.1
2	Network society	130	8.3
3	Network	117	7.5
4	The relationship of flowing space and place space	91	5.8
5	The effect of information technology	76	4.9
6	Globalization	68	4.4
7	Knowledge	46	3.0
8	Stream	36	2.3
9	Global cities	31	2.0
10	Place space	25	1.6
11	Node	23	1.5
12	Innovation	22	1.4
13	Geographical distance	21	1.3
14	The effect of technology	21	1.3
15	Elite	21	1.3
16	Global network	17	1.1
17	City network	16	1.0
18	Cities	16	1.0
19	Information society	16	1.0
20	City is a progress	16	1.0

Chinese literature			
No.	**Concept category**	**Cited frequency**	**Proportion (%)**
1	Flowing space	107	19.7
2	The relationship of flowing space and place space	43	7.9
3	The effect of information technology	35	6.5
4	Network	28	5.2
5	Social theory of space	26	4.8
6	Network society	23	4.2
7	Global cities	17	3.1
8	Time and space	14	2.6
9	Place space	13	2.4
10	Global cities	12	2.2
11	Giant city	9	1.7
12	Stream	8	1.5
13	City is a progress	8	1.5
14	City network	7	1.3
15	The network has constructed a new social form	7	1.3
16	Globalization	6	1.1
17	Node	6	1.1
18	Cities	6	1.1
19	Information cities	6	1.1
20	De-localization	6	1.1

society", "network" and "the relationship between mobile space and local space" and "the influence of information technology" have also been highly cited by Chinese and foreign literature.

In comparison, Chinese and foreign literature has similarities and differences for the "network social theory" knowledge absorption. Both Chinese and foreign literature pay great attention to the network society association theory about the new space and social form, networked logic, information age background, and arguments about globalization. Besides, English literature pays more attention to Castells in the network social theory for the interpretation of economic and social development transformation and its connotation. For example, in the economic aspect, it reflects the knowledge of the information age as a factor of production and the attention of the innovation atmosphere in the new industrial space; in the social aspects, it reflects the attention for the essence of the dominant status in the mobile space and its special organization and information society formation[3,4]. Chinese literature paid more attention to Castells's cognition and understanding of spatial connotation and performance and new forms of cities in the information age. For example, Chinese literature pays more attention to the "social theory of space" and "time and space". Castells sees space as an interaction and fusion with time and society. He put forward the "space is the manifestation of society" and the "space is not a copy of society, space is society ", " space is the crystallization time " *et al.*[4]. In addition, "World City", "mega-City", "Information City" and other cognition of the new forms of cities in the information age have also attracted the attention of the Chinese literature. To sum up, for the "network society theory", the difference is essen-

tially reflected in that English focuses on the intrinsic spatial dynamics of the network society, while Chinese literature focuses on the external spatial expression of the network society. On the one hand, this difference may arise from the different social and economic backgrounds and development stages of Chinese and foreign human geography research, and on the other hand, it is due to the different paths of knowledge transmission. Specifically, due to the different stages of social and economic development, the attention of Chinese human geography research on information technology and the human shift of research paradigm lags behind western social[49], with more emphasis on the impact, role and support of material space itself and material space transformation on human behavior and activities[49]. Therefore, in the information age, the western humanities geography research not only focus on the "network social theory" in spatial, social and economic overall change, also highlights the internal performance of the change and the attention of human driving force, and Chinese humanities geography research is more focused on the information age spatial form change, for its internal social and economic driving force is less attention. From the point of the knowledge communication path, foreign scholars based on the original English works convenience can dig "more rich network social theory" content and connotation, and domestic scholars rely on translation, and for Chinese translation often hit the most relevant arguments with geographical space, especially on the rise of the network society in chapter 6 "related content of flow space", and through secondary communication to further strengthen the influence of these arguments.

5. Reference function analysis

Tables 3 and **4** present the functional contribution and knowledge development contribution of "network social theory" respectively in China and foreign literature. From the perspective of reference function, Chinese and foreign literature takes "network social theory" as the most historical literature and background data in the research, followed by "strengthening demonstration" and "theoretical basis", while the functional functions of "viewpoint inspiration", "case verification", "knowledge expansion" and "pointing out deficiencies" are the least reflected. In addition, 18 Chinese literature and 9 English documents have invalid references, accounting for 5.0% and 1.0% in the study sample respectively, reflecting the lax citation behavior of small literature, conducive to the development of "network social theory" in the field of human geography, and such a problem is more serious in Chinese literature.

The first 8 citation functions reveal 3 types of knowledge development contributions, namely "knowledge dissemination", "knowledge inheritance" and "knowledge innovation", reflecting the varying degrees of influence of "network social theory". Most of the promotion of the spread of "network social theory", enhances the popularity of the theory, Chinese reference (69.0%) and the analysis of English reference (71.5%). However, "knowledge dissemination" is a kind of shallow learning result, which promotes knowledge development is very limited[50]. Less than a third of the quotations bear the role of "knowledge inheritance" and "knowledge innovation". "Knowledge inheritance" indicates that the author inherited and recognized the knowledge view of Castells's "network society theory", applying the theory to research and strengthening the understanding of the theory. "Knowledge innovation" is the biggest contribution to the knowledge integration of degrees among the three, and it is an important reflection that "network social theory" develops again in the field of human geography in an innovative way.

"Knowledge Innovation" involves 4 categories of reference functions, which are illustrated below. In terms of "viewpoint inspiration", Dong Chao *et al.* put forward the flow space in the geographical sense according to the meaning of "flow space"[51]. On the "case validation" side, Beaverstock's empirical study on the transnational elite supports Custer's "flow space" logic[52]. Chinese and foreign literature has made "knowledge expansion" on "flow space" and 'the relationship between flow space and place space". For example, Zhen Feng expanded the "space dualism" of flow space and placement space, and

Table 3. Citation function in Chinese literature

Knowledge development contribution	Reference function	Induced frequency	Accounting for (%)	Top 10 cited concepts
Knowledge dissemination (374)	Background information	186	34.3	Flow space (32), the influence of information technology (22), the relationship between flow space and site space(21), Network Society (13), Network (11), World City (7), Social Theory of Space (5),Global city (5), the network constitutes the new social form (5), city (4), mega city (4),Stream (4), Time and Space (4)
	Historical document	188	34.7	Flow Space (36), Network (11), Impact of Information Technology (10), Social Theory of Space (9), Relationship between mobile space and place space (9), world city (9), place space (8), network club will (7), global city (6), City is a process (5), delocalization (5)
Knowledge inheritance (34)	Strengthen demonstration	119	22.0	Flow space (22), the social theory of space (12), the relationship between flow space and place space (9), Time & Space (7), Space (4), City is a process (3), Innovation (3), Elite (3), Network (3), Network Social (3), the Impact of Information Technology (3)
	Theoretical basis	16	3.0	Flow space (10), the relationship between flow space and place space (2), liquidity (2) and empty space Inter- (1), Network (1)
Knowledge innovation (16)	Views	4	0.7	Network (2), flow space (1), node (1)
	Case validation	3	0.6	Flow Space (1), Pearl River Delta (1), New Industrial Space (1)
	Knowledge extension	4	0.7	Flow space (2), the relationship between flow space and place space (1), Time and space (1)
	Point out the deficiencies	4	0.7	Flow space (2), the relationship between flow space and place space (1), Time and space (1)
Does not benefit from knowledge development	No-valid reference			Only occurrence or incorrect references in the reference list (18)

Note: numbers in parentheses are the frequency of citation.

proposed the ternary space composed of real space, virtual space and gray space. Nielsen found that although East Jutland is not a global city, it also has three levels of flow space characteristic, expanded the understanding of "flow space"[47,53].

The citation function of "pointing out the deficiencies" comes from the critical thinking of scholars, which provides important clues for the in-depth development of "network social theory" in humanistic geography. The English literature points out the limitations of "network social theory" rather than the Chinese literature. Overall, there is great debate about "flow space", "the relationship between flow space and local space" and "network". It can be found that the most concerned theoretical views are also often the most controversial views. This study is summarized in the main controversy below (where 1 and 2 were proposed mainly by foreign studies, 3 was proposed jointly by domestic and foreign literature).

1) "Spatial dualism" is too abstract and inhuman. Foreign research has critically on the theoretical defects of "spatial dualism" constructed by "flow space" and "local space". For example, Majoor criticized the absolutes of "spatial dualism", noting that "flow space" and "local space" are too abstract and he thought it might exist a space between the two[54]. Jakobsen *et al.* and Smith put a similar view, while arguing that "mobile space and "network" theories have obvious "technical deterministic" color, too much emphasis on the impact of information technology on the network, and not enough attention to actors in the network, and therefore inhuman[55,56].

2) In the network society, "mobile space" is not better than "place space", "local space" is equally important as "flow space". Foreign studies make critical thinking on the relationship between flow space and local space and question the superiority of flow

space to some extent. For example, Taylor stressed that global cities also have local characteristics, arguing that Castells's assertion that "global cities are not a place, but a process" denies the local characteristics of global cities. He believed that the flow can connect to global cities because global cities are first the "local"[57]. Marcinczak and van der Velde questioned the replacement of mobile space for local space, and pointed out that although mobile space was dominant in the network society, "mobile space" was not omnipotent leading to the loss of "local" self, local actors can control and influence local development, so "local" has the social and independent development ability that does not depend on "mobile space"[58].

3)Network studies lack targeted empirical data,

Table 4. Citation function in English literature

Knowledge development contribution	Reference function	Induced frequency	Accounting for (%)	Top 10 cited concepts
Knowledge dissemination (374)	Background information	472	30.3	Network Society (49), Mobile Space (37), the Impact of Information Technology (37), Network (31), Global Chemical (27), the relationship between flow space and local space (19), flow (12), knowledge (10), geographic distance from (9), City (8), Global City (8), Information Society (8)
	Historical document	642	41.2	Flow space (54), network (56), network social (48), the relationship between flow space and local space (39), Globalized (29), Impact of Information Technology (23), Knowledge (23), Flow (16), place space (14), Node (12), Innovation (11), Global City (10), Geographic Distance (10), Global Network (9), the Impact of Technology (8), Urban Networks (8), Multinationals (8), Global Economy (8), Networking Maforms a new social form (8)
Knowledge inheritance (34)	Strengthen demonstration	318	20.4	Flow space (33), network (23), network social (22), the relationship between flow space and local space (21), the Impact of Information Technology (13), Knowledge (13), Elite (12), Globalized (7), Innovation (6), The Impact of Technology (5), Global Network (5), City is a process (5), stream (4), Global City (4), Node (4), the Global Economy (4)
	Theoretical basis	76	4. 9	Mobile space (12), the global city (7), the relationship between mobile space and local space (5), the giant city City (5), Network Society (5), World City (4), City is a process (3), real virtual (3), Time Free Time (3), Urban Network (2), Network (2), Information Revolution (2)
Knowledge Innovation (16)	Views	4	0.3	Networks (1), relationship between flow space and local space (1), Impact of Information Technology (1), globalization(1)
	Case validation	4	0.2	Urban network (1), flow space (1), node (2)
	Knowledge extension	3	0.3	Flow space (1), labor (1), the relationship between flow space and local space (1)
	Point out the deficiencies	39	2.5	Flow space (8), global (4), network (3), the relationship between flow space and local space (2), Geographic distance (1), stream (2), network social (1), global urban (1), local space (1), node (1), the influence of technology (1), mega city (1), liquidity (1), network constitutes the new society Morphology (1), Airport (2), Mobile (1), neostructuralist (1), National (1), World City Network Vioxx (1), the difference between capital and labor (1), the global and local relationship (1), the role of location (1), a multinational company with the (1)
Does not benefit from knowledge development	No-valid reference			Only occurrence or incorrect references in the reference list (9)

Note: Numbers in parentheses are the conceptual frequency of citation.

effective measures, and considerations for mobile information technology. In foreign studies, Taylor pointed out that Custer mainly used national-level data, and that the data is too macroscopic will reduce the accuracy of network research[59]. Similarly, Wall *et al.* argue that Castells's empirical studies on globalization and world urban networks lack support for more micro-detailed data[60]. Devriendt *et al.* have pointed out similar data problems while pointing out the difficulty of data acquisition, and the lack of detailed targeted data is a common problem in world urban network studies[61,62]. In domestic research, such as Wang Mingfeng, Ning Yuemin and Shen Lizhen pointed out that Castells's network research mainly relies on some cases and lacks matching empirical evidence with it, so the explanation of complex network social theory is relatively limited. Due to Castell's simple measure of the urban network, Yao Yongling and Tang Yanzhe pointed out from the perspective of research methods that although Custer elaborated on the urban nodes in cyberspace, there was no suitable method was found to measure the factor flow and connection between cities[63–65]. In addition, due to the constraints of the time background, Zhen Feng *et al.* noted that Castells's network research emphasized the impact of fixed information technology without considering today's mobile information technology background[66].

6. Conclusions and discussions

This paper studies the knowledge contribution of Manuel castells's "network social theory" based on the analysis and comparison of Chinese and foreign quotations to humanistic geography by using the method of citation content analysis and citation context analysis. On the one hand, this study is beneficial to promote the application and innovation of network social theory in human geography. on the other hand, Castells is a famous sociologist, so the contribution of disciplines, which is beneficial to knowledge innovation.

The results of the citation content analysis found that the "flow space" is the most quoted theoretical view of domestic and foreign studies, and the citation proportion of domestic studies is significantly higher than that of foreign studies. In addition, there are some differences in the attention of the "network social theory" in domestic and foreign research. Domestic research pays more attention to the external spatial form and spatial transformation of the network society, while foreign research pays more attention to the internal spatial dynamics of the network society. On the one hand, this difference may originate from the different social and economic backgrounds and development stages of Chinese and foreign human geography research. On the other hand, it stems from the different paths of knowledge transmission.

The results of functional analysis show that "network social theory" has played nine functional roles and made three kinds of knowledge contributions in domestic and foreign research. Most of the citation literature will use the theoretical views of the network society as the historical literature and background data in the research, only a small number of studies are substantially inspired by the theory, or to verify, expand the relevant theories, or point out the shortcomings of the theoretical views. From the perspective of knowledge development, the citation content has made contributions to "knowledge dissemination", "knowledge inheritance" and "knowledge innovation", which reflects the progressive knowledge interaction from shallow to deep. Among them, most of the references promote "knowledge dissemination", but the influence on cultural geography is relatively shallow. Only a few studies have explored the theory at a deeper level and promoted the "knowledge innovation" of the theory in the field of humanistic geography.

"Point out deficiencies" reflects the critical thinking of scholars, but its occurrence probability is very rare. The English literature points out the limitations of the "network social theory" to a greater extent than the Chinese studies. Overall, scholars mainly point out the shortcomings of the "network society theory" from three aspects: "spatial dualism" is too abstract and single; "mobile space" is not superior to "local space"; the empirical data and measurement methods of the network research are flawed and lack mobile information technology con-

sideration.

Castells's "network society theory" provides a crucial basic theory for human geography re-understanding of space and society, and Chinese and foreign research on the focus of the theory and related scholars' critical thinking about the theory for the future from the perspective of humanistic geography research network society clarified the research focus and breakthrough direction. This article mainly summarizes it in the following four aspects:

1) breaks through the cognitive paradigm of "spatial dualism" and explores the discovery of diversified spatial forms. Humanistic geography scholars need to dialectically view the "spatial dualism" constructed by mobile space and local space. It is necessary to admit that "spatial dualism" provides new insights into understanding the spatial form of the information age, but the relevant theoretical views are more abstract and single. Therefore, it is necessary to break through the binary structure division of the space under the network society, at the same time to jump out of the thinking pattern of "technology determinism", based on the research thinking of "human technical space", explore and discover diversified spatial forms, to promote the perfect development of "network social theory" in human geography.

2) strengthens the research and excavation of the independent development potential of local space, and promotes the balanced development of "mobile space" and "local space". In the network society, although the mobile space is considered as a new form of spatial development, the "mobile space" does not completely dominate the network society, and it cannot be ignored that the role and status of the "local space" in the network society and their independent development ability. Therefore, in the future, for the network society, humanistic geography research should constantly explore and explore the independent development potential of local space, and explore the influence and role of local actors on local space. At the same time, it is necessary to reveal the interaction relationship between flow space and local space through empirical analysis and case study and promote the balanced development of flow space and local space.

3) based on new data, new methods, new technology environment, support, and rich "network social theory". Given the data and methods of "network social theory", and future research should constantly discover and use new supporting data (including big data, real-time data, data from different social backgrounds and different spatial levels) and new research methods (such as dynamic simulation methods, machine learning methods, etc.) to support and enhance network research. At the same time, we should actively connect with the era of mobile Internet, study the network space based on mobile communication technology, and constantly enrich the "network social theory".

4) promotes network social research from the perspective of human geography from focusing on "objectivize space" to "human-oriented space". Domestic and foreign research for "network social theory" focus difference enlightenment China for network society research needs to focus from "materialized space" to "human space", not only focus on material space for residents behavior and support, more need to pay attention to people as a social body in the information age of life, production needs and individual differences, at the same time to obtain a geographical spatial change of human nature, thus based on this for material space. At the same time, Chinese research also needs to further explore the internal social and economic driving force of material space transformation, and find the action mechanism of social and economic transformation on material space reconstruction. In addition, Castells's "network social theory" is a systematic theory involving many aspects. It is also necessary for domestic research to deeply understand the rich connotation of "network social theory" through the original work system, and conduct dialectical thinking, to deepen the application of the theory in humanistic geography.

Although the method employed in this study has been widely used in bibliometry, it is inevitably influenced by subjective judgment and experience. It is necessary to establish a more objective judgment in the future.

For in-depth research, we can explore the use

of natural language processing technology, machine learning and text mining to study the knowledge contribution of classical theory to human geography[24]. In addition, since the mid-19 80s, Castells's academic thoughts on the information society have a certain relevance, so it is also of great significance to explore Casterlls's theoretical perspective from the perspective of integrity for the contribution of humanistic geography. At the same time, although Castells's theory is a typical representative of the global "network social theory", but other relevant scholars (such as Peter J Taylor) for the extension of the theory has also largely contributed to human geography, so it is necessary to explore the influence of "network social theory" from the perspective of integrated ideas on human geography.

Conflict of interest

The authors declare that they have no conflict of interest.

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REVIEW ARTICLE

Research progress and prospects of green development from the perspective of geography

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ABSTRACT

Influenced by global financial crisis in 2008, many countries around the world have realized the significance of sustainable development. And green development, as the most important pathway to sustainability, has been implemented by various countries. In this context, green development has drawn great attention from academic researchers both at home and abroad in recent years and has become an interdisciplinary-oriented research direction. As an applied basic research field for exploring the structural change of resources and environment as well as regional sustainable development, geography plays an essential role in the research of green development. Based on an intensive literature review, this article firstly summarized the connotation and analytical framework of green development. Secondly, it systematically outlined the progress of green development research from the perspective of geography and thus extracted seven themes, that is, the influencing factors of green development, assessment methods, spatial and temporal characteristics of green development, green development and industrial transformation, green transformation of resource-based cities, the effect of green development, and green development institutions and recommendations. Comments were made on the existing studies including their shortcomings. Finally, future research emphases were discussed, aiming to provide references for further study on green development from the perspective of geography in China.

Keywords: Green Development; Research Progress; Prospect; Perspective of Geography

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1. Introduction

After the industrial revolution, the continuous high-intensity economic activities have brought huge damage on our ecological environment. While reshaping the world economic geographical pattern, economic globalization promotes the flow of resource elements and environmental pollution on the global scale, and the spatial scale of the interaction between economic activities and environmental issues has also changed[1]. The interweaving of the 2008 international financial crisis and global climate change further promoted the reflection on the existing economic development mode, and governments have sought new economic development modes to get rid of the existing development crisis, in order to achieve long-term, stable and sustainable regional development. The philosophy of green development is just in line with that of sustainable development, both striving to explore a beneficial and environment-friendly economic development model. Since the proposition of Global Green New Deal (GGND) initiated by the United Nations Environment Programme (UNEP) in 2008, green development has been becoming a development consensus of more

and more countries and regions in the world and an important way to explore global sustainable development. Since the reform and opening up, China has taken just more than 30 years to complete the development tasks that western developed countries would accomplish in decades or even hundreds of years. The sharp compression of the spatial and temporal dimension had brought about China more complex regional development problems than any previous period, which also puts forward higher requirements for the government's governing power[2]. At present, China is experiencing an important period of economic transformation and upgrading as well as socialist modernization, with the conception of "promoting development through steady growth and structure reconstruction" as its main guidelines in economic development under the new normal situations. The scientific economic development will not only benefit our people, but also will have a far-reaching impact on the world development in the future. As an emerging civilization paradigm after industrial civilization, ecological civilization has become a strategic concept of realizing the sustainable development of the Chinese nation in the new era in recent years. Ecological civilization emphasizes the construction of a civilized society with production development, rich life and good ecology based on the carrying capacity of resources and the environment[3]. The fundamental direction of green development is to realize the symbiosis of economic, social and environmental development. Obviously, green development is the development concept and development model to meet the requirements of ecological civilization construction in the new era, while ecological civilization is the construction goal and objective result of green development.

With the increasingly recognition and popularization of the concept of green development, the academic research on the field of green development has also increased rapidly, attracting many scholars of various disciplines including geography, economics, sociology, environmental science, ecology, etc. Based on the core collection database of Web of Science, 438 papers, conference papers and reviewed literature of the subject—"green development" or "green economy" have been retrieved (**Figure 1**). It can be found that the number of documents on green development showed a rapid rise, especially since the outbreak of the international financial crisis in 2008, with the number of research papers in this direction increased by 12.03%. In the same way, 5,428 core journals and doctoral papers were retrieved in the CNKI database. Compared with the earlier boom of research on green development rising abroad, the relevant domestic research started relatively late, and the number of relevant documents began to increase after 2000, and increased significantly after 2008. It can be found that at present, green development has become a hot issue of research by scholars at home and abroad.

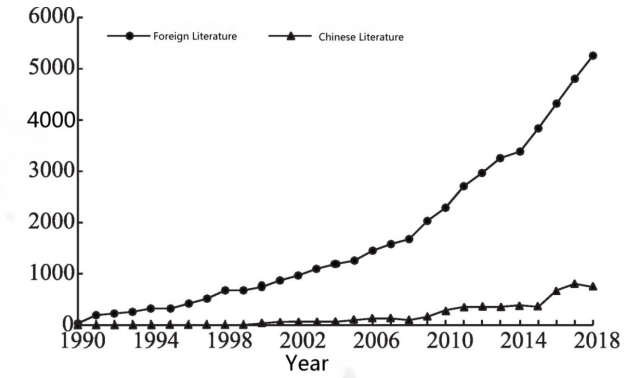

Figure 1. The number of publications on green development.

Geography is an applied basic discipline researching on resources, environmental structural changes and regional sustainable development, which can not only tell us what had happened in the past, but also can provide us ways to deal with the current issues and future events[4]. Its main task is to study the major theoretical and practical problems faced by the sustainable development of contemporary human society[5]. Since the 1980s, related theory, methods and technology of geography have become the foundation to solve related issues[6]. Due to its discipline characteristics as comprehensiveness, regionality and interdisciplinary geography owns some incomparable advantages in the field of green development. In this context, this paper expounds the origin, connotation and analysis framework of green development research, and summarizes the research progress and existing problems related to green development at home and abroad from the perspective

of geography. Through systematic summary and review, this paper hopes to provide relevant guidelines for the future research of Chinese geography in the field of green development, so as to provide corresponding reference for better understanding the research direction and purifying the research issues.

2. Origin, connotation and framework of green development research

2.1 Origin of the study

As a paradigm change of the economic development, green development can be traced back to the Spacecraft Economy Theory proposed by American scholar Bolding in the 1960s and a series of discussions on steady-state economy, green economy and ecological economy advocated by Daley and Pierce[7]. In the early stage, it was mostly applied to guide the development of ecological industry, and then gradually expanded to the whole economic system. As early as 2002, the United Nations Development Programme[8] developed the green development concept to research on Chinese issues. Since then, in order to solve the increasingly severe contradiction between the rapid economic growth and the environmental resources in the Asia-Pacific region, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) has put forward the green development strategy[9]. In the post-financial crisis era, green development, as a new economic development model addressing the human development crisis and providing beneficial solutions, has attracted increasing attention from international institutions such as Organization for Economic Co-operation and Develop (OECD), United Nations Commission on Sustainable Development (UCSD), United Nations Environmental Programme (UNEP) and World Bank etc. At the United Nations Conference on sustainable development in 2012 in Rio de Janeiro, Brazil, green development was formally established as one of the important means to achieve the sustainable development. Since the reform and opening up, with the rapid development of China's economy and society and high-intensity resource development, the evolution of Chinese man-earth relations has shown a diversified, complex and tenser characteristic[10]. In the 21st century, the Chinese government was committed to the harmonious and unified development of economic construction and ecological environment, and successively put forward the development concept of "Scientific Outlook on Development" and the construction of "Resource-conserving Society and Environmental-friendly Society". In 2009, Circular Economy Promotion Law of the People's Republic of China was implemented to promote sustainable development in the form of law. In May 2013, when President Xi Jinping presided over the sixth collective study of the Political Bureau of the Party of CPC Central Committee, he pointed out that "we should properly handle the relationship between economic development and ecological and environmental protection, and more consciously promote green, circular and low-carbon development". The Fifth Plenary Session of the 18th CPC Central Committee upgraded green development into one of the five development concepts guiding China's economic and social development during the 13th Five-Year Plan. As the concept of green development gradually became a global consensus (**Figure 2**), the relevant research has also entered a new stage.

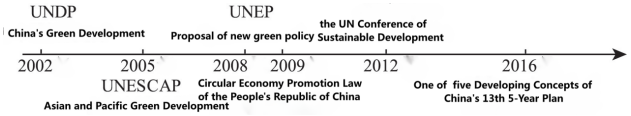

Figure 2. Green Development: global consensus.

2.2 Connotation and analysis framework

Green development belongs to the second generation of sustainable development concept (strong sustainable development), which is a reflection on the thought of "weak sustainable development", that is, the thinking of ecological limit is added on the basis of weak sustainable development, emphasizing that natural capital cannot be completely replaced by artificial capital, and it is necessary to achieve non-zero growth of key natural capital[11-12]. With the deepening of green development research and the integration of different disciplines, the connotation of green development is also constantly changing, from harmonious and unified development between the economy and ecology[8,13] at early stage to a more

multi-dimensional direction of evolution. The current mainstream is to define it from the perspective of regional economic system coping with resources and environmental problems and improving human well-being. UNEP pointed out that green economy is an economic activity aimed at improving human well-being in the long term while avoiding bringing about significant environmental risks and ecological scarcity to our next generation, with characteristics of low carbon, resource availability and social inclusiveness[14-15]. The World Bank[16] sees green growth as a way of making efficient use of natural resources while minimizing environmental pollution and influence and effectively dealing with natural disasters. Zhu Dajian[17] believes that two important dimensions of scale and fairness has been added on the green economy adds based on the traditional efficiency-oriented economic model, with the characteristics of economic efficiency, scale controllability and social inclusiveness.

Although different institutions and scholars have different perspectives and emphases on the connotation of green development, an agreement is reached on the essence of green development, that is, under the constraints of resources and environment, it shall strive to realize the symbiotic development of economy, social and natural system by developing low-carbon economy and circular economy so as to maximize the development benefits.

In terms of green development, many international institutions and organizations have put forward their analysis frameworks for green development according to their actual situations. Among them, the green growth framework established by OECD is widely adopted and applied[18]. The framework consists of four aspects: environmental and resource productivity, natural asset base, environmental factors related to life quality and policy response. Its biggest feature is taking other goods and services as production factors by taking full consideration of the value of natural resources, focusing on using a low-cost and high-effective way to relieve environmental stress. In addition, scholars and researchers began to put emphasis on constructing analysis framework of green development and there had emerged some valuable research fruits. For example, Hu Angang[19] put forward the "three circles model" for green development, including three systems of economy, society, and nature. And the symbiosis of the three systems formed coupling relationships among the green growth, green wealth and green welfare. In general, theories related to green development have been effectively expanded, gradually forming a comprehensive and coordinated theoretical description and framework construction of "economy-environment-society", and the research of such composite system is attracting the attention of scholars and researchers at home and abroad.

3. Main research topics for green development

3.1 Factors affecting green development

Study on the factors influencing green development is one of the main research directions of green development research, which directly reveals the causes and mechanism of action affecting green development level, and provides a decision-making basis for predicting the future regional development and formulating corresponding countermeasures. The existing studies mainly analyzed the factors affecting green development based on such approaches as regression model, obstacle degree model and geographical detector and so on. Overall, regional green development is affected at any period by multiple driving forces. Its influencing factors can be roughly divided into two categories of natural factors and social-economic factors. But the study on natural factors is relatively rare, and many studies focus on social-economic factors, always combining natural factors with current development. For example, Feng *et al.*[20] pointed out that people living in low altitude areas always has a relatively positive attitude in dealing with global climate change, and their corresponding regional green development level is higher.

In the Anthropoid period of Earth, as the social economic factors is becoming more active and easier to detect, how the social-economic factors affect human activities like economic development, industrial structure, financial instruments, environmental reg-

ulation, public behavior and other aspects has been highly valued (**Figure 3**). It is generally believed that the region with a good economic foundation always has a relatively high level of green development. However, the studies from Mu Xueying *et al.*[21] showed that the economic foundation is a necessary but inadequate condition for green development, and the regions with a good foundation for economic development do not necessarily have a high level of green development. After the international financial crisis, the global macro economy shows an uncertainty, which also affects the implementation of the green development strategy to a certain extent. Jin *et al.*[22], taking China as an example, pointed out that macroeconomic uncertainty has little impact on the green development level in developed and coastal cities, but it has an obvious inhibitory effect on the green development level in less developed cities. Technological progress and its bias are an important breakthrough to realize the coordinated development of economic growth and environmental improvement. The research of Sun Caizhi *et al.*[23] showed that the labor bias and capital bias in technological progress can promote the growth of local green economy, while capital bias can also drive the growth of green economy in neighboring areas, indicating the importance of increased human capital As the main link of human economic activities in the ecological environment, the rationality and advance of industrial structure are conducive to promoting the improvement of regional green development[24]. From the perspective of industrial scale, industrial agglomeration and regional green development efficiency show a "U"-shaped relationship. With the enhancement of industrial agglomeration, the green development efficiency will decrease at first and then increase[25].

In recent years, the research on the relationship

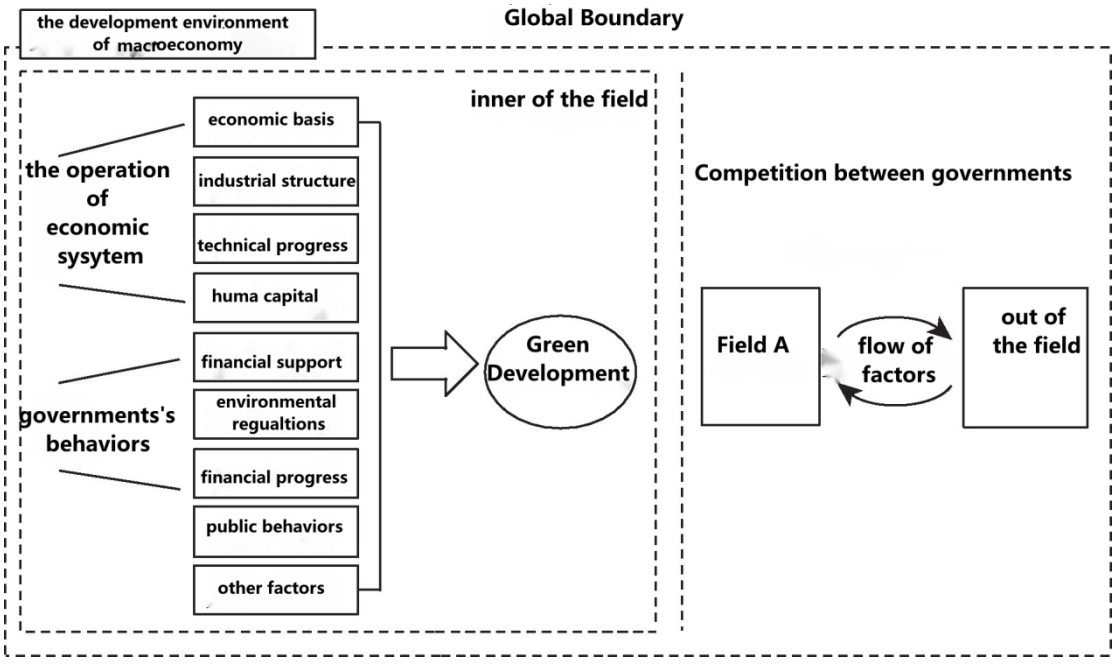

Figure 3. Main social-economic factors driving the change of green development.

between environmental regulations, financial development and green development has gradually increased. Wang *et al.*[26] believed that both formal and informal environmental regulations can promote the level of regional green development, but there are significant differences in the mode of action. Peng Xing *et al.*[27] divided environmental regulations into three types including command control, economic incentive and voluntary consciousness, pointing out that the enhancement of economic incentive-oriented environmental regulation and voluntary consciousness-oriented environmental regulation can significantly improve the level of green technology innovation and promote industrial green transfor-

mation. Financial development affects the regional green development from four aspects: capital support, resource allocation, enterprise supervision and green finance[28]. Compared with foreign countries, the economic development system dominated by the Chinese government determines the importance of local governments in regional development. He Aiping *et al.*[29] believes that the competition between local governments will curb the improvement of green development level, and the fluctuation of the government's choice between economic catch-up and environmental regulations, making China's green development efficiency continuously fluctuate at a low level. In recent years, the public has experienced a transition from passive response to active participation, and as an important supplement to environmental governance tools, non-governmental organizations (NGOs) play an increasingly important role in global climate change and environmental governance, and the effect of public participation depends on the level of public education and the determination of government governance[30].

3.2 Measurement for the level of green development

Research on the measurement for green development level will not only help scholars and deciders understand the current status of regional green development, but will also help explore factors influencing the improvement of green development level and formulate differentiated development countermeasures, which is crucial for the realization of green development goals. At present, a large number of methods have been used to explore the measurement for level of green development, which can be roughly divided into three categories: green efficiency evaluation, single index evaluation and comprehensive index evaluation.

Compared with the traditional method of efficiency evaluation, the green efficiency evaluation takes the environmental pollution caused by the operation of the economic system into consideration, emphasizing to invest less resource to obtain higher economic returns while producing less environmental pollution. At present, there are many methods of calculating green development efficiency, and the most commonly used method is data envelope analysis (DEA). After years of development, the DEA model has been continuously improved. Such methods as DEA model[31], SBM model[32], Super-SBM model[33] and Malmquist-Luenberger[34] have been widely used. In addition to the green efficiency measurement of the macroeconomic system, geographers have also conducted empirical studies on various industrial departments focusing on land use green efficiency[35], water resource green efficiency[36], and green innovation efficiency[37]. With the gradual enrichment of the measurement content, the selection for green efficiency model indicators also takes factors as technology, environmental protection[38] and haze[39] and so on into consideration based on the traditional input (labor, capital, resources) and output (economic benefits and environmental pollution).

The single index method is analyzed based on a certain side of green development from a certain framework, represented by green GDP accounting, decoupling index and carbon profit and loss. Green GDP includes resources and environmental costs as economic costs into the national economic production accounting according to the disadvantages of traditional national economic accounting, which is widely used in practice. Lei Min *et al.*[40] analyzed the green GDP of resource-based cities according to the SEEA2003 accounting system formulated by the United Nations; Zhang Hong *et al.*[41] calculated the green GDP of Fujian Province based on the SEEA2003 accounting system. Kunanutakij *et al.*[42] established a green GDP model based on the environmental extended input-put model (EIO-LCA) and took Thailand as an example. Decoupling originated in the field of physics and was later applied to resource and environmental research, which OECD[43] defines as breaking the association of environmental load and economic development. Lu Qiang *et al.*[44] took the decoupling index as a dynamic index of industrial green transformation and upgrading, and conducted the empirical analysis with Guangdong Province as an example. With people's increasing attention to carbon emissions, the concept of carbon source/sink is introduced, and the carbon profit and

loss caused by this has become an important basis for the regional policy formulation. Zhao Rongqin *et al.*[45] studied the carbon revenue and expenditure and the spatial differences of carbon balance in the Central Plains Economic Zone; Wang Xi *et al.*[46] analyzed the spatial and temporal changes of carbon profit and loss in Henan Province based on energy consumption data, the number of major industrial products and remote sensing data.

The comprehensive index evaluation method can comprehensively reflect the level of regional green development, and help understand the various factors affecting green development, so it is widely applied in practice. According to the different research subjects, the comprehensive evaluation index system of green development is increasingly rich. Hou Chunguang *et al.*[47] build a green evaluation index system including five aspects: economic growth system, green welfare system, green wealth system and green governance system; Kim *et al.*[48] have constructed the OECD national green development evaluation index system from five aspects: environment and resource production rate, environmental and resource production rate, ecological efficiency improvement, natural asset base, environmental quality, life quality and economic responses in the production process;; based on the information entropy and dissipation structure theory, Hou Caizhi *et al.*[49] established the regional green development evaluation index system in the perspective of support input entropy, pressure output entropy, prototype metabolic entropy and oxidative metabolic entropy; Based on the "P-S-R" model, Guo Fuyou *et al.*[50] have built a green development index system of restricted development zone from three aspects of green development pressure, green development state and green development response.

In general, the abovementioned three methods gradually enriched their research methods by absorbing research methods from economy and ecology in the process of application Due to the subjectivity of index selection and weight determination, it is difficult to compare the efficiency of relevant studies based on the efficiency evaluation and comprehensive index evaluation, while the index methods represented by green GDP accounting have a certain comparability. When selecting methods, the actual situation of the research area and research purpose need to be fully considered, so as to achieve the best evaluation effect. However, each method is faced with a series of problems and challenges, such as single data source, poor timeliness, and difficulty in applying at the micro scale.

3.3 Spatiotemporal evolution of green development

Spatiotemporal evolution analysis is a common content of geography. For a long time, scholars at home and abroad have carried out a large number of case studies in different regions, focusing on the spatiotemporal evolution of green development. Based on the evaluation of green development level, multi-timing statistics data were used to depict the spatial patterns and evolution laws of green development by such approaches as the spatial autocorrelation model[51], convergence model[52], nuclear density function[53] and other methods. Foreign researches on the spatiotemporal evolution of green development started earlier, but it mostly reflects the spatiotemporal characteristics of green development worldwide at macro level. Kumar's[54] study on green development efficiency in 41 countries worldwide from 1971 to 1992 shows that countries with active response to the global climate changes are always performed better in the green development. Lin *et al.*[55] also analyzed the green development efficiency of 70 countries from 1981 to 2007. The study pointed out that the global green development efficiency has been improved significantly during this period, and the green development efficiency of developed countries and emerging industrialized countries was higher than that of developing countries. In addition, most of the relevant researches are carried out in the following regions and organizations including East Asia[56], Latin America[57], inner of the European Union[58], OECD[59] and G20[60]. Compared with foreign countries, China's unique development environment also provides good empirical materials for green development research. Although the relevant research started late, it has achieved fruitful research

results and the research scale is relatively perfect. Compared with foreign countries, Sun *et al.*[61] found that although the level of green development in China has improved from 2000 to 2014, the level of green development was still at a relatively low level, and the level of green development was greatly different between the east, central and western areas. In addition to exploring the spatiotemporal evolution of green development at national and municipal administrative regional scales as city[62] and county[63], it also involved typical regions such as urban agglomeration[64], Yangtze River Economic Belt[65], old industrial bases[66], and resource-based cities[67]. A large number of research results show that the green development level of different countries and regions shows relatively different change trends in different periods, with obvious regional, dynamic and differential characteristics. Due to the impact of the international financial crisis, the level of green development declined after 2008. However, with the transformation of economic development mode and the strengthening of environmental policies, the level of green development began to rebound.

With the deepening of the research, scholars gradually began to explore the grid-scale green development evaluation research. For example, Yun Yinjuan *et al.*[68] conducted detailed studies on the spatial distribution of carbon sources/sinks in Shiyang River Basin based on MODIS-NDVI data; Liu Junhui *et al.*[69] designated important carbon fixation areas of typical Chinese land ecosystems based on land restoration data. With the continuous rise of earth big data, the grid research will become the mainstream research in the future.

3.4 Green development and industrial transformation

Green industry is an important branch of green economy, an effective entry point and an important driving force for the realization of green development goals. Green industry can be realized through two ways of industrial green transformation and the construction of new green industries[70], which reflects the different ideas to develop green industry.

Industrial green transformation refers to the transformation of industrial mode toward a more resource-saving and environmental-friendly direction both in its structures and efficiency[71], which is an innovation of the existing industrial development mode. The measure of industrial green degree is the key to industrial green transformation. Most of the studies were carried out based on such methods as decoupling models, EKC curves, and environmental entropy and so forth. For example, Wang Junhua *et al.*[72] used Tapio decoupling model to analyze the decoupling relationship between economic growth and CO_2 emissions in China; Fujii *et al.*[73] measured the greening degree of nine industries in OECD countries using EKC curves; Liu He *et al.*[74] took the SO2 emissions as an example to construct the industrial environmental entropy and the regional environmental entropy to study the industrial structure greening degree of Chengdu-Chongqing economic zone. The path of industrial green transformation is also the focus of scholars. Relevant research can be roughly divided into two categories: One discusses industrial structure optimization from a static perspective. For example, the linear planning model under the triple constraint of energy-environment and employment construction written by Song Tao *et al.*[75] have analyzed the industrial optimization path in the Beijing-Tianjin-Hebei region; The other analyzes the dynamic evolution of industrial structure adjustment based on the dynamic perspective. For example, Zhu Yongbin *et al.*[76] simulate the direction of industrial structure optimization and carbon emission trend in China by constructing a cross-stage optimization model. On this basis, some scholars further positioned the industrial development based on the actual situation of the regional development so as to guide the spatial layout of the industry[77–78].

In terms of the new green industry, scholars mainly conduct relevant research on the spatial layout and its influencing factors. However, since the statistical departments of various countries have not issued an officially recognized statistical caliber for the development of green industry, it also brings certain difficulties to explore the development of new green industry. To this end, scholars began to explore "bottom-up" data collection methods. In addition to

professional statistical databases, Shapira *et al.*[79] proposed a search method that combines linguistic text to identify green businesses and conducted empirical studies using UK small and medium green food businesses as an example. Based on South Korean business survey database data, Park *et al.*[80] analyzed the distribution of the new green industry during 2006–2012. The research pointed out that while the new green industries in South Korea tend to be located in the traditional manufacturing concentrated areas, they also form new green industry clusters. The green city industrial sectors tend to be located in or near big cities, while the new energy industries tend to be far away from big cities. Yi *et al.*[81] analyzed the spatial distribution of green enterprises in China based on the Dun & Bradstreet million dollar database. The study found that there is significant imbalance in the spatial distribution of green industries in China. Compared with other cities, cities that practice the clean energy policy own 54.3% of green jobs and 61.8% of green enterprises. In general, the definition of new green industries and the lack of relevant data are to a large extent restricting the new research on green industry.

3.5 Green transformation of resource-based cities

In the post financial crisis era, there emerged a great number of heated researches on "urban transformation" all around the world. Different with garden city, compact city, ecological city and low-carbon city, green city is a dynamic, harmonious and efficient comprehensive development model, which aims to promote the green growth of urban economy by reducing the negative externality of environment and reducing the negative impact on natural resources and ecosystem[82–83]. Resource-based cities refer to cities rapidly developed relying on their resource advantages. Due to excessive emphasis on the development of resource-based industries and the lack of long-term overall planning, resource-based cities are generally faced with problems such as resource depletion and the lack of alternative industries[84]. Since the 1960s and 1970s, the transformation and development of resource-based cities have been the focus of the government and academia. The transformation of resource-based cities started earlier in some foreign countries, and the concept of green development was fully reflected in the transformation process, for example, the new industrialization policy represented by the diversification strategy in the field of environmental technology implemented by Ruhr district, Germany in the 1980s[85]; the industrial diversification development strategy and high-tech industrial development model of Kitakyushu, Japan[86]. They all provided good ideas for the green transformation of resource-based cities.

Since 2001, China has piloted the transformation of resource-based cities. In 2008, Taiyuan City, Shanxi Province issued the Regulations of Taiyuan City on Promoting Green Transformation (Draft), becoming the first city in China to promote green transformation in the form of local legislation. And the National Sustainable Development Plan for Resource-based Cities (2013–2020) issued by the State Council in 2013 took green development as the guiding ideology for the development of resource-based cities.

In this context, Chinese scholars combined the green development theory with the transformation of resource-based cities, and deeply discussed the connotation, timing and path of green transformation of resource-based cities.

Generally speaking, the green transformation of resource-based regions is a process of gradual transition from the traditional "black" development model to the ideal "green" development model. The core is to promote the greening of industrial development and economic growth mode. The integration of resource-based economy and green-innovation is the driving mechanism to promote green transformation. And the construction of green transformation system constitutes the guarantee mechanism of green transformation[87]. The realization of green economy is not only to avoid "mining-exhaustion and urban-decline", but also to explore how to effectively use resources for sustainable development[88]. Due to the differences in life cycles among resource-based cities, it is difficult to regulate the life cycle of resource-based cities only by strictly controlling the

development intensity of leading resources. Thus, it is necessary to formulate comprehensive and systematic life-cycle optimization and regulation measures[89]. Therefore, the green transformation of resource-based cities is to seek for a more optimized development mode[90]. The green transformation of resource-based cities should be carried out in the growth period, mature period and early recession[91], and the coexistence of three modes of "resource continuation + resource substitution + undertaking industrial transfer" can be adopted to realize industrial transformation and upgrading[92]. For cities with overcapacity or poor environmental conditions, it is of great significance to control the industrial scale[93].

The green transformation performance of resource-based cities is also a hot issue concerned by scholars. Li *et al.*[94] studied the green development efficiency of 116 resource-cities in China and pointed out that at present, most resource-exhausted cities still have problems of development inefficiency. Zeng Xiangang *et al.*[95] studied the green transformation performance of 16 coal-resource-exhausted cities, which showed that the green transformation of coal-resource-exhausted cities is still in the primary stage, and the difference in selecting transformation path makes the transformation performance different among different types of cities. In terms of policy implementation, Guo Shufen *et al.*[96] analyzed the impact of the "comprehensive supporting reform pilot zone for resource-based economic transformation" on resource-based areas in Shanxi Province. The research showed that the establishment of the pilot zone promotes the quality of economic development by promoting the diversified development of industrial industries, but the effect of tertiary industry diversification is still not obvious, and the effect of policy implementation lags behind.

3.6 A study on the green development effect

As a common choice for governments to deal with multiple crises and challenges, green development will inevitably bring about a series of impacts on economic development, ecological environment and social life in the process of strategy implementation, which will form a complex feedback relationship between green development and economic-environment-social system. How and to what extent the implementation of green development strategy affects the development of human society has attracted scholars' attention.

Generally speaking, the green development strategy mainly affects the economic system by affecting the industrial structure, industrial operation form and industrial operation environment, and promotes the transition of economic development mode from traditional "brown economy" to "green economy". These all can bring the vitality of new economic growth. On the one hand, in the process of promoting green transformation, we need to pay the costs, including incremental investment and macroeconomic losses caused by the implementation of energy-saving and environmental protection technologies. And there are still some sunk costs in the green behavior of resource-based enterprises; On the other hand, it will generate energy-saving benefits and create new economic growth points[97]. Taking China as an example, Feng Chao *et al.*[98] studied the cost-benefit problem of transformation. The results showed that the economic benefits brought by the transformation of development mode are greater than the costs, and it can realize the win-win development of environmental economy. This economic effect accounts for about 3%–10% of GDP. Hall *et al.*[99] analyzed the economic effects brought by the development of new green industries in the United States, and the results showed that the development of new green industry promotes the improvement of economic benefits.

Then, the change of jobs is the most intuitive embodiment of the green development strategy. With the transformation and upgrading of traditional industries with "high pollution, high energy consumption and high water consumption" and labor-intensive industries, there will be a large number of job losses brought by the traditional manufacturing sectors, while the development of green industry can bring about new employment opportunities. Yi[100] systematically analyzed the impact of state and local clean energy and climate policies on employment in metropolitan areas of the United States since 2006.

The results showed that the implementation of state and local policies has a positive impact on employment at the urban level. For each additional policy, green employment in metropolitan areas will increase by 1%; Lehr *et al.*[101] simulated the impact of renewable energy on German employment under different scenarios. Almost all scenarios show a positive net employment effect. According to the prediction, the total employment will increase from 340,000 in 2009 to 500,000 ~ 600,000 in 2030.

At the same time, with the greening of economic development, the environmental effects brought by the implementation of green development strategy are gradually revealed, represented by reduction of carbon emission, reduction of major pollutant emissions and improvement of environmental quality, especially in areas with dense traditional industrial layout. Musango *et al.*[102] simulated the development of green economy in South-Africa under four investment development scenarios. The research results showed that green economy intervention measures can not only significantly reduce carbon emissions, the dependence of industries, especially the power industry relying on fossil fuels, but also promote the sustainable utilization of natural resources. Zhou Xiongyong *et al.*[103] took Fujian Province as an example to analyze the impact of different policies on energy conservation and emission reduction. The research pointed out that different policies have different effects on energy conservation and emission reduction. Tax, environmental protection and industrial policies have the most obvious effects on energy conservation and emission reduction, while financial, department of treasury, science and technology policies have weak effects on energy conservation and emission reduction. Rivera *et al.*[104] analyzed the impact of carbon tax on the carbon emission in Mexican. The result showed that without economic compensation, the implementation of carbon tax will reduce carbon emissions by 75% in 2050.

3.7 Advice on green development

Green system is the institutional projection of green civilization and also a way to promote the harmonious coexistence between human and nature[105]. If various restrictive factors as policy, economy and culture are not well considered, the green development strategy will not achieve ideal results[106–107]. Therefore, the improvement of green development system is of great significance to promote the transformation of economic development mode and ensure the realization of green development goals.

Government promotion and policy support are the basic characteristics of green development. Guiding with strategic planning, countries around the world have issued guiding policies in industry, finance and energy utilization to promote the establishment of green development system. Firstly, the green development route and action plan should cover the key factors of all dimensions of sustainable development, and clarify the short-term, medium-term and long-term objectives and binding indicators to be achieved[108]. Secondly, as an innovation of the current development model, the government should clearly analyze the fundamental interests of all groups in the process of green reform to make the development goals more inclusive[109]. In the specific policy-making process, Mathews[110] took South Korea as an example and pointed out that the government-led industrial green policy is completely feasible in democratic countries; and Ringel *et al.*[111] pointed out that active and effective energy policy is the key to realize green transformation, so energy policy should play an important role in the overall strategy formulation process; Dulal *et al.*[112] believed that the regional green development strategy should include active and effective fiscal policies. The introduction of market-oriented mechanism can form a “double-wheel-driving” development mechanism of green development. On the basis of clarifying the ownership and distribution of the government’s ownership, usufruct and income right of environmental resources, the market-oriented mechanism mainly determined the market-based resource and environmental property right trading system, and established diversified ecological compensation and environmental payment mechanisms, such as green tariff, carbon emission trading, carbon tax, etc., in which carbon tax has achieved better results in reducing carbon emission[113]. However, if it is unfeasible or

difficult to collect carbon tax in the region, it shall use the renewable energies to replace the high carbon-emission energies[114].

Laws and regulations are important bases for ensuring and standardizing the green development system. At present, relevant foreign laws and regulations are becoming more and more perfect and concrete. Since the 21st century, the Chinese government has successively improved relevant laws on ecological environment protection and has promoted the development of circular economy, such as "renewable energy law", "Circular Economy Promotion Law", "Ten items on protecting the atmosphere", "Ten items on protecting water resource", and "Ten items on protecting land resource", and so on. However, compared with Western developed countries, China has not yet formed a coordinated and perfect legal and policy system for green economy development[115]. Yang Jiejun[116] believed that in the future, China shall further promote green development from policy guidance and policy action to legal adjustment and implementation, so as to upgrade green development policy into legal mechanism, and it shall pay attention to the unity of policy guidance and legal guidance. At this stage, China's green development legislation should focus on such fields as climate change, energy issues and green finance[117]. In addition, a good ecological environment supervision system is a good supplement to the green development system. It is necessary to gradually establish an ecological environment supervision system dominated by government supervision and supplemented by non-governmental organization supervision.

4. Review and prospect

(1) It is widely acknowledged that the green development is of great importance in helping achieve the overall goals of sustainable development. As a discipline studying the relationship between human and earth, geography owns incomparable advantages in researching green development. Scholars have done a lot of research and practice on green development from the perspective of geography, including influencing factors, calculation methods, spatiotemporal evolution pattern, green development and industrial transformation, green development of resource-based cities, green development effects and institutional suggestions, etc., which has important reference for future researches. Compared with foreign countries, although the research on green development in China started late, it has achieved fruitful research results. It is not difficult to find that due to the different economic basis and development problems faced at home and abroad, there are some differences in green development goals. For example, foreign economies and institutions began to pay attention to the role of green development in coping with global climate change and poverty reduction earlier. While at home, it emphasized on economic development and ecological environment protection and then turned to increase people's well-being. In this context, there are some differences in the research of green development at home and abroad, including the selection of research methods, research scale and so on. Although the research fields of green development are increasingly rich, there are still some shortcomings in the existing research due to the complexity of green development and the imperfection of relevant research methods. With the continuous advancement of ecological civilization and the construction of a beautiful China, under the background of the new era, China shall made a further exploration and study in the following aspects in terms of geography researches: Green development is a multi-dimensional and complex system involving three subsystems: economy, environment and society. "Process-pattern-mechanism" is the basic method and way of comprehensive geographical research. The existing studies have described spatiotemporal evolution of green development in detail as well as its related influencing factors. However, there are relatively few studies on the systematic analysis of green development mechanism by coupling "process" and "pattern". Due to the distinct comprehensiveness of geography, it is urgent to establish an analysis framework with local characteristics based on geography. Then each scale is nested, and the interaction mechanism between the elements of green development is analyzed. The analysis of green development mechanism helps scholars better

simulate the evolution trend of regional green development under different scenarios, and provides decision-making basis for relevant policy-making.

(2) The relationship between human and earth is the core research issue of geography, which runs through all stages of geography. In recent years, with the change of the external development environment, as a bridge between "human" and "environment", human-earth relationship has drawn much attention from scholars and has been endowed with new connotations with the advances of the times. In the context of the new era, how to further apply the theory of human-earth relationship into practical research and application is an issue that geographers should focus on. Green development research also pays attention to the economic and social development and the changes of resources and environment, so as to pursue the harmonious development of human and nature. The future research on green development should take this as the starting point to strengthen the integration and coupling of green development with human-earth elements under different time and space scales, and apply relevant research results into the decision-making and management of green development.

(3) In recent years, China has put forward a series of initiatives and strategies as "The Belt and Road", "Urban Agglomeration", "The Yangtze River Economic Belt" and "The Revitalization of the Old Industrial Bases in Northeast China" etc. to further promote the economy development in such regions, which has brought about new opportunities and forces for the overall economy development of China. However, at this stage, all policy radiation areas are facing varying degrees of resource and environmental pressure, and it is urgently necessary to convert the old kinetic energy into new ones to achieve high-quality development. Geography is a practical discipline. Compared with foreign countries, China's geography has made great contributions to the decision-making related to major national development and has also effectively guided China's economic development and construction. Therefore, in order to optimize China's future economic development pattern and give full play to the effectiveness of development initiatives and strategic policies, it is necessary to further refine the research on green development in typical areas from the perspective of geography.

(4) Green development research needs the combination of multi-angle analysis and multi-research means. At present, the research on green development mainly uses socio-economic statistical data to obtain the information needed to understand the influencing factors and spatiotemporal evolution of green development. In recent years, although professional statistical databases, remote sensing data and questionnaire survey data have been applied in the research of green development, the application is far from being desired. In terms of research methods, descriptive analysis and quantitative means are mostly used to analyze the functional relationship of various elements of green development, but there is still a lack of comprehensive integration of traditional methods and new technical means. Due to the lack of research methods and data, the existing research did not take the scale and accuracy well into consideration. It is suggested that relevant departments should formulate statistical norms and standards for green industry as soon as possible and establish a more complete data database. In recent years, with the progress of Internet and remote sensing geographic information technology, it is possible to obtain large-scale and high-precision spatiotemporal data to represent human activities. In this context, it is worthy of continuous attempts for scholars to use the spatiotemporal big data to analyze and predict the spatiotemporal revolution of green development. (5) Green development is an interdisciplinary research topic involving many disciplines. From the perspective of geography, green development research has made some research achievements and formed seven main research topics, but there are still some deficiencies on the whole. In recent years, when analyzing and studying related problems, geography has introduced disciplines and methods such as economics, ecology and management in the research process, and has achieved ideal results. In the future, it is still necessary to strengthen interdisciplinary research to form a systematic and overall research perspective,

so as to further promote the research of green development and related fields. For example, in terms of system suggestions for green development, we should carry out multi-disciplinary researches according to the actual situation of China's existing green development system, so as to strengthen the top-level design and put forward perfect solutions to better promote green development.

Conflict of interest

The authors declare that they have no conflict of interest.

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REVIEW ARTICLE

Progress and implications of international rural space research

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ABSTRACT

Space is a product of society. Driven by industrialization, urbanization, informatization and government policies, China's rural space is undergoing drastic reconstruction. As one of the core contents of international rural geography research, rural space research are multi-disciplinary, multi perspective, multi-dimensional and multi-method, forming a rich research field. In order to comprehensively grasp the progress of rural space research abroad, this study reviewed international rural space research literature in recent 40 years. The study found that foreign scholars described the connotation of rural space from the aspects of material, imagination and practice, emphasize the importance of daily life practice. It introduced living space to construct a more systematic research framework of rural space by establishing a "three-fold model of rural space". With regard to the theoretical perspective, international research on rural space has experienced three stages: functionalism, political economics and social constructivism. In the evolution of time, it has realized the transformation from productivism to post-productivism; in the spatial dimension, it realizes the multiple superposition of settlement space, economic space, social space and cultural space. As a whole, international research on rural space has realized the transformation from material level to social representation, from objective space to subjective space, and from static one-dimensional space to dynamic multi-dimensional space, which enlightens us on the importance of interdisciplinary research and "social cultural" research on rural space. The construction of rural space in China needs to pay attention to the subject status of farmers and multifunction of rural space, respect the role of locality and difference of various places, and recover the function of production of meaning of rural space.

Keywords: Rural Space; Reconstruction of Rural Space; Social Constructivism; Post-productivism

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1. Introduction

With the advancement of industrialization, urbanization, globalization and informatization, as well as economic development and policy drive, China's rural space is undergoing drastic reconstruction. First, the elements, structure, function and organizational relationship of rural settlement space have changed dramatically. Taking the changes of population, land and industry as the core[1], the rural structure in employment, land use, industry and architectural landscape have changed accordingly. The function of rural settlements has changed from simple residence and some agricultural and sideline production to diversified and comprehensive functions such as residence, industrial and agricultural production, consumer market, leisure tourism and ecological protection[2]. Rural settlement space has changed from "homogeneity" to "heterogeneity", which is increasingly differentiated and diversified. Urbanization, specialization, hollowing out, decline and even extinction constitute a variety of scenes for the spatial reconstruction of rural settlements in China[3]. Second, the rapid development and innovative

application of modern information technology have profoundly changed the way of integrating rural resources. "Internet +", "ecology +", and "tourism +" have been infiltrating every field of the countryside, giving birth to many new industries, new formats and new business models[4] and the economic space of the countryside is changing from the production landscape to the consumer landscape. Third, technology empowerment comes with technology going to the countryside. Modern technology and industry are profoundly changing farmers' lifestyle, thinking mode and village governance mode. The communication between farmers has changed from highlighting blood relationship and geographical relationship to industry relationship. Farmers become increasingly professional and specialized. The village governance mode has also changed from overall governance to technical governance, indicating China's rural social space is undergoing reconstruction. Fourth, under the impact of modern forces such as technology, industry and culture, the rural cultural space presents a mixture of vernacular and modernity.

It can be seen that the rural space in practice presents the overlapping and mixing of settlement space, economic space, social space and cultural space. The rural space has become a dynamic, heterogeneous, networked and meaningful system. However, in terms of theoretical research, in CNKI, taking "countryside" + "space" as the theme word and CSSCI as the source journal, as of November 30, 2018, a total of 968 research papers have been retrieved. Most of the research subjects are rural geographers and rural planning scholars. The research contents mainly focus on rural spatial transformation, land use, spatial differentiation, spatial reconstruction and spatial planning, centering on material space. Some scholars have also studied the rural spatial system from the overall perspective[5,6], but they generally paid little attention to social cultural space[7], and the theoretical research of rural space generally lags behind the practice of rural space reconstruction. The foreign researches emphasize on the "cultural turn" of rural space[8], "rurality"[9] and "post-rural"[10], as well as the application of "post-modernism" and "post-structuralist methods"[11], which can provide reference and inspiration for the theoretical research of rural space in China. Therefore, this paper attempts to systematically sort out the basic theories and trends of foreign rural space research to promote the combination of the frontier theories of foreign rural space research with China's diversified and differentiated rural space reconstruction practice, so as to provide theoretical support for China's rural space reconstruction and rural revitalization.

2. What is "rural space"?

2.1 Four-level implication of rural space

There is no consensus on the division of "rural space" abroad. In the UK, rural areas are usually defined within the scale of local government areas[12], while in the United States and Australia, rural areas are described as the larger scale of non-metropolitan areas[13]. To define "rural space", we should not only consider the scale of "rural", but also consider its uniqueness in culture, competition and commercialization[14].

Halfacree[14] analyzed the connotation of rural space from four levels. First, rural space as material, that is, the locality of rural space. The locality of rural space is constantly produced, reproduced and potentially changed. To identify rural areas, at least two conditions must be met: one is to clarify the criteria for the delimitation of local spatial scale, and the other is that the description of rural space must be able to distinguish rural areas from cities. In short, there must be distinguishing criteria to define "rural"[15]. However, under the influence of the perspective of political economy, many scholars question whether the rural areas in today's developed countries can still be identified[16]. The internal spatial structure of capitalist society is constantly rewritten, and the importance of "rural" scale is constantly destroyed by diversification. From a local, national and international (global) perspective, the countryside is outdated[17] and rural space is disappearing[18]. Second, rural space, as imagination, is the social representation of rural space. As an "analytical distinction or rhetorical device"[18], rural space gets rid of the material internality and becomes the common imagination of

specific groups[17]. Rural space may have material expression, but this is not important. The cognitive representation of rural space rather than its performance in social and natural landscape is the starting point of research. This is not influenced by whether rural areas are recognized. Third, rural space, as material and concept, is embodied in "locality" and "social representation". As a "locality", it has the following characteristics: agriculture and other basic production activities, low population density, inconvenient transportation and consumption behavior. As a "social representation", rural space is the rural landscape and community imagined by comparing with other spaces such as cities and suburbs. Fourth, rural space, as practice, emphasizes that space and time are inseparable, concerning about how the material space in rural areas exists through the practice of structural process, and how the conceptual space represented by rural society exists only through the practice of discourse interaction. Therefore, the research on rural space (time) needs a strong situational method.

2.2 Triple model of rural space

Halfacree[14] believes that the concept of rural space under the dual definition of "locality" or "social representation" is incomplete. Locality is the physical space at the perceived level, and the definition method is academic, while social representation comes from the conceptual space of the subjective mind, and the definition method is secular[6]. However, besides two types of discourse, a series of discourse between secular and academic should also be stressed[19], which shows the hybridity and even infinity of rural space. Therefore, only via the close concern of the context can we reveal the "truth" of rural space. Space is not only a product, but also a medium of production[20]. More humanistic dimensions must be considered. Therefore, Halfacree believes that a more comprehensive description of the spatial structure should be made from the perspective of synergy, so as to establish an architecture enabling the better integrity of rural space[21]. Halfacree established the "triple model of rural space" based on the production of space theory of Lefebvre[22], namely rural locality, representations of the rural and everyday lives of the rural[14]. Rural locality refers to the rural areas characterized by spatial practices such as production or consumption; the representations of the rural refers to people's subjective space such as cognition and image of the countryside, as well as the way in which the countryside is integrated into the (capitalist) production process; everyday life of the rural includes personal and social cultural factors of understanding and identification with rural life. Compared with the dual definition of "locality/social representation", the "triple model of rural space" starts from the rural subject, emphasizes the importance of daily life practice, introduces experiential and living space, and makes up for the incompleteness of the concept of rural space under the dual definition. This theory is a more systematic theoretical framework for foreign rural space research, and has important enlightenment significance for domestic scholars to deepen the understanding of rural space.

2.3 Three perspectives of rural space research

In the 20th century, three different theoretical perspectives have been developed in the field of rural research abroad: one is the functionalist perspective popular in the 1970s, which determines the rural space by clarifying the unique functional characteristics of the countryside. The theory holds that the rural nature features the dominance of extensive land use (especially agriculture and forestry), small-scale, low-level settlements and an environment-friendly and high-quality lifestyle[23]. The second is the political economic perspective popular in the 1980s, which links the countryside with the dynamics of national and international politics and economy, emphasizes the power field and institutions of social production, and tracks the transformation of social relations from Fordism to post-Fordism[24]. The third is the social constructivism perspective popular in the 1990s, emphasizing the role of culture in the uniqueness of rural space. The relationship between rural social and cultural structure and nature has become the focus of rural research. Halfacree believes that due to the increasingly diversified social representation of rural areas, the symbol of village (rural)

is more and more deviating from its meaning (rural meaning)[25]. In addition, symbols and meanings are increasingly disconnected from their reference (rural geospatial). Therefore, the rural space constructed by society has become more and more divorced from its regional function, which is called "post village" by Murdoch *et al.*[10]. Social constructivism may lead to the existence of future villages, communities and landscapes as a super real commodity[26], showing a virtual pastoral scenery.

3. Historical evolution of foreign rural space research

Foreign rural space research has realized the transformation from "productivism" to "post-productivism". From World War II to 1970, western countries realized that free market and laissez faire policies could not guarantee sufficient food production, so they continued the wartime planning and intervention policies, basically adopted the policy paradigm of producer system, and food self-sufficiency and income equality became the top policy priorities of the whole developed countries. Therefore, the research on rural space mainly focuses on agricultural production. At this stage, "rural areas mean agriculture" and "agriculture means rural areas". During the 20 years from 1970 to 1990, the excessive emphasis on productivism caused a series of problems, and the rural space of productivism was destroyed. With the increasing environmental pressure, the research on sustainable development has become the focus of rural research. In the 1990s, rural space research realized the cultural turn and post-modernism turn. Scholars began to view rural problems from the humanistic dimension, and the post-productive rural space research rose.

3.1 Rural space under productivism

The period from the Second World War II to 1970 was dominated by the concept of agricultural productivism. At this stage, western countries are in the recovery period of post-war reconstruction. For the sake of food security, countries have strengthened their policy support for rural production[26]. Under the guidance of the concept of productivism, scholars have conducted a lot of research on commodity agriculture, discussing technological change, globalization and agricultural production under the joint force of government macro-control[28]. Based on the agricultural landscape, productivism is oriented by food production and pursues the maximization of agricultural production[29]. The key is that productivism is not only influenced by agricultural communities, but also permeates into every corner of rural life, which is the cornerstone of the consistency of rural local structure. Rural space in the period of productivism has three characteristics: Firstly, rural areas are remembered through the dominant agricultural practice, including farmers' daily and seasonal activities, diversified and professional support services and the increasingly industrialized food production model. Secondly, outside the farm, this performance has been sustained and strengthened. From harvest festivals and other celebrations in the village to the service role of the market town, the activities and functions of the whole rural area are carried out around agriculture. For example, non-agricultural institutions related to agriculture tend to recognize and accept the leadership of agriculture[30]. Thirdly, productive agriculture is related to the wider rural society, and rural daily life is mainly realized from the perspective of productivism.

3.2 Crisis of rural space under productivism

During the 20 years from 1970 to 1990, the excessive emphasis on agricultural production led to problems such as overproduction and land degradation. Sustainable agriculture has become the theme of world agricultural development. Productivism-oriented agriculture faces a "structural crisis" that cannot be solved by technological repair[31]. Rural areas are affected by both economic restructuring and social restructuring[32], and agricultural practices are forced to adjust from coping with surplus and overproduction to dealing with the recognized consequences of environmental damage[33]. Individual farmers and their family life are increasingly affected by insecurity and uncertainty. High levels of debt and depression are the most acute expressions[34], which makes the role of farmers as rural guards

and the impact of financial support more and more questioned[35]. Other commercialization methods in rural areas have emerged because: in terms of rural leisure, the British Conservative government published a report entitled "happiness, leisure and work: Tourism" in 1985, which heralded the beginning of the enterprise stage with the focus shifting from highlighting social welfare to meeting market demand through the private sector. This more diversified commercialization also impacts agricultural culture[36], making agricultural culture more competitive, diverse, flexible and responsible for the environment[37]. Constitutionally, in 2001, the Ministry of Agriculture, Fisheries and Food was replaced by the new Department for Environment, Food and Rural Affairs, which abolished the prominent position of "agriculture" in rural policy. In the 1990s, British villages focused on the discussion of post-productive transformation, reduced food production and state support, and realized the internationalization of food industry in a freer global economic market, resulting in three bipolar dimensions: from strengthening to expansion, from concentration to dispersion, and from specialization to differentiation[38]. This emphasis on diversity not only prompted people to discuss the transformation of post-productivism, but also triggered a discussion on post-productivism villages[39]. Agriculture is considered to exist in rural space and society, not the opposite.

3.3 Rural space under post-productivism

In the 1990s, the shift of rural consumption became the concern in developed countries. Driven by post-productivism and the concept of rural multi-function, rural space has expanded its function from single agricultural production to industrial production and service. Rural tourism, rural consumption and rural cultural landscape protection are booming[26], providing diversified and non-linear goods and services for urban residents[40]. With the socio-cultural turn and post-modernism turn of rural space, the concern about rural consumption has expanded from material space to non-material fields and diversified groups[41], and some new concepts and research perspectives have emerged. For example, Murdoch *et al.* put forward the concept of post rural from the perspective of post-modernism, emphasizing "production of meaning"[10]; Hopkins[42] believes that rural areas are changing from physical places dominated by agricultural production to constructive places dominated by symbols and spirit, and outsiders play a key role in the process of rural branding publicity[43]; Woods introduced the sociological spatial ontology theory to explore the connotation and extension of "rurality", and believed that the rurality is jointly expressed by rural residents and rural immigrants, tourists and tourist attractions, policy makers, media and academic researchers[44]. Therefore, the countryside is no longer a place without competition[45], but is a heterogeneous space socially constructed by participants according to their own will and experience. Marsden summarized the heterogeneous post productive rural space into four ideal types, namely, preserved countryside, contested countryside, paternalistic countryside and clientalist countryside[46]. The concept of post-productive countryside embodies the radical spatial imagination of super productivism, consumptive pastoral life and pastoral scenery, imagining the countryside as a manifestation of a diverse family accessible to everyone, as well as a daily experience of celebrating local and personal significance[47]. However, post-productivism villages are often mixed, because they focus on the struggle between the new differences and the existing space of (rural) capitalism.

4. Comprehensive multidimensionality of international rural space research

After the 1970s, with the crisis of rural space led by productivism, the research of rural space began a social cultural turn, emphasizing the unique role of social culture in the formation of rural space. Since then, the rural space research has realized multi-dimensional expansion in content, from the research of settlement space and economic space to the research of social space and cultural space, formed a rural space research system including settlement space, economic space, social space and cultural space, and realized the deepening from concrete space to ab-

stract space and from real space to virtual space. The research on settlement space mainly focuses on land use, architectural landscape, ecological environment, settlement origin and structure; economic space research mainly focuses on rural production practice and economic space differentiation; social space research has formed three research themes: social change, social differences and rural power. Cultural space research mainly focuses on institutional policies, pastoral intentions and values. In the following section, researches on international rural space will be elaborated from the above-mentioned four aspects.

4.1 Settlement space

The research on rural settlement space abroad has roughly experienced four stages[48]. The first is the initial stage from the 19th century to the 1920s, during which the studies mainly center on the settlement form, the causes and conditions of settlement, the types of settlement, the relationship between settlement space and natural geographical environment, and preliminarily puts forward the theoretical basis of rural settlement. Generally, the research content is not rich, and the research method is mainly description. The second is the preliminary development stage from 1920s to 1960s. The research on rural settlements is gradually enriched and expanded. The research content involves the location characteristics, formation process, development conditions, functions and planning of rural settlements. The research method is mainly small-scale field investigation. The third is the expansion and transformation stage from 1960s to 1980s, with three important theoretical reforms. First, I. Burton's slogan of "quantitative revolution" has greatly promoted the study of rural settlements. The second is the slogan of "behavioral revolution" by R.M. Downs, which attaches importance to "spatial behavior" and "spatial induction", and emphasizes the role of human decision-making behavior on settlement distribution, form and structure[49]. Moreover, the concept of sustainable development has promoted the "rebirth" of western rural geography. The research content of rural settlements is very rich, and almost touches all fields of rural social economy[50]. At this stage, there is a trend of combining qualitative and quantitative research methods. Fourth, the stage of transformation and reconstruction since 1980s. Under the influence of philosophical thoughts such as post-modernism, post-structuralism, radical geography and humanistic geography, the research on rural settlements begin to transform to the direction of society and humanities, with the content mainly involving rural conflict[45], rural population migration[51], local government and rural discourse[52], environmental sustainable development[53], rural reconstruction[54], the relationship between rural community types and residential areas of the elderly[55], *etc*. As a result, a variety of disciplines (such as architecture, geography, sociology, landscape ecology, urban and rural planning) and technologies (RS, GIS, GPS, landscape model, etc.) have been comprehensively applied into the study of rural settlements, and research methods such as grounded theory, semi-structured interview, concern groups, participant observation and literature analysis have been continuously developed and applied[56]. In addition, Q methodology has made significant progress in breaking the distinction between qualitative and quantitative research[1].

4.2 Economic space

Marxism believes that in the developed capitalist society, there is no longer any characteristic rural space, because all spaces will eventually be colonized by capital. Nevertheless, under the influence of multiple factors such as resource endowment and cultural values, there is a pattern of economic spatial differentiation between urban and rural areas and within rural areas, and elements and information flow between different economic spaces and transform each other under certain conditions. Marsden clearly pointed out that the policy not only needs to get rid of the rural concept of strict geographical definition, but also needs to recognize the differentiation of rural space in regional, national, international supply chain, network and regulatory dynamics[57].

(1) Economic spatial differentiation between urban and rural areas. Rural economic space is generally dominated by the production of primary

products, which is often associated with backwardness, poverty, lack of opportunities, traditionalism and isolation. Urban economic space is dominated by manufacturing and service industries, which are often associated with wealth, opportunity, modernization and concentration. Additionally, the speed and intensity of urbanization have exacerbated urban overcrowding, class conflict, moral corruption and environmental pollution. Therefore, nostalgia for the ideal rural environment began to rise in cities. In the mid-1870s, the development of infrastructure and telecommunications technology, the pursuit of cheap labor by capital, the motivation to develop new markets, the need for a better life and raising children promoted the flow of goods and opportunities to many rural areas in Europe and North America[58]. Regions are thoroughly infiltrated and shaped by societies far away from them[59]. Globalization has led to the possible homogenization of all spaces. Rural areas attract suburban immigrants by building their own unique niche, which Marsden calls consumption villages[40]. The flow of capital and opportunities has had a profound impact on the rural economy and social structure. The local economy shows diversity and mixing, and culture has become the main determinant of the local economic model[60].

(2)Economic spatial differentiation within rural areas. Due to the difference of economic development level, resource endowment and cultural values, the rural economic space has formed a circle structure from the center to the edge, namely entrepreneurial economy, dependent economy and rent-seeking economy. i) The income of entrepreneurial economy mainly comes from the value of local resources, and meets people's demand for high-quality goods in the process of globalization through the tacit knowledge of local society. Traditional commodities (local food, furniture, rural tourism, etc.), integrated into the modern marketing structure, are equipped with the characteristics of postmodernism[61]. These rural characteristics and modern infrastructure will attract industries fleeing the city[62]. Besides, local enterprises rely on cultural factors[63] and social capital[64] to form cooperative networks and realize economies of scale[65]. ii) Dependent economy refers to areas where income mainly depends on external sources. Cheap labor and the "friendly" environment brought by the national infrastructure construction and services did help a lot for these areas to attract external resources. However, the dependent economy is vulnerable due to the lack of control over the source of investment, which can be alleviated by learning the skills and attitudes of entrepreneurs and moving towards "entrepreneurial economy". iii) The rent-seeking economy is dominated by agriculture and extractive industries. Relying on the advantages of natural resources to obtain "rent", landlords can obtain surplus without investment. However, the rent-seeking strategy will hinder economic growth due to insufficient investment[66]. In addition, due to the class polarization and closed culture, there will be inevitably appear the oligopoly economy, which will not only reduce the landlords' demand for local economic diversification, but also will be easy to cause a zero-sum game, resulting in local instability and difficulty to attract external investment. The social structure of economic power and the characteristics of local value system render the rent-seeking economy in low-income status and marginal areas[67]. In the spatial pattern of urban and rural economy, metropolitan areas are located at the core of territorial space. They extract raw materials and commodities from rent-seeking economies located in the most marginal areas, finished products from dependent economies, and high-quality commodities from entrepreneurial economies[68]. The change of types leads to the increasing differentiation and regionalization of rural space. Different types of economies can also achieve mutual transformation. The key lies in whether local communities are willing or able to respond to the increasing opportunities in the process of globalization.

4.3 Social space

Rural social space research attempts to understand how people experience and organize rural life, how families manage farms, how communities construct cultural identity, and how marginalized groups negotiate against inequality, so as to conceptualize social forms or systems and identify the processes

and relationships that affect rural life practice. The study of rural society has formed three key analysis themes, namely change, difference and power.

(1) Social change is the most lasting theme of rural social research. The research in the 1960s and 1970s recorded the process of modernization, industrialization and urbanization of rural society[69]. It mainly focused on the change of population structure and population migration, mainly adopting methods of positivism and quantitative research. However, hermeneutics believes that a single empirical and quantitative method can not explain the diversity of social experience and process[70], and advocates the use of ethnography to explain how the changing rural society realizes diversification[71]. Marxism and feminism expound social changes through the study of agricultural production and its relationship, and provide critical comments and cases for agriculture and agricultural structure adjustment. Generally, the study of change has always been the constant analysis theme of rural society. The macro attention to social system and relationship enables scholars to explain the material and cultural changes that change rural life, system, culture and landscape. In terms of research methods, most quantitative studies were conducted from 1970 to 1980, and most radical studies were conducted from 1980 to 1990. Recently, more researches have been carried out using post-structural and post-modern methods[11].

(2) The second core analysis theme is the study of rural social differences. A large number of studies have proved the differences of rural social groups in economic, cultural, political activities, experience and interests. Early difference studies used property and labor relations to analyze people's social status, which was reflected in Marxist social class research. Recently, under the influence of the feminist movement, gender is regarded as an important dividing line between human labor, community life and rural spatial experience, resulting in increased research on rural gender inequality. The study of class and gender is the core explanatory variable to understand rural social differentiation, but it should be admitted that other types of social differences also exist. Some scholars recorded rural social differences based on age and intergenerational relations, poverty and exploitation, race and disability, which laid the foundation for the research and evaluation of rural society in the 1990s.

(3) The third analytical theme concerns the consideration of power. The traditional research on rural power focuses on formal political topics, diversified concepts of power and political interests. Therefore, the analysis of agricultural political interests and political consciousness is the most common[69]. The research on resources and the operation process of power shows that how ruling groups, classes or interest groups grasp or mobilize power unevenly to "cover up, suppress or seize" interests and groups that may challenge the dominant power[72]. These works focus on resources such as property and capital, as well as processes such as labor relations, sponsorship and charity, which maintain (and sometimes mask) the legitimacy of dominant minorities[73]. Marxist and feminist methods critically analyze the power of agricultural social organizations and show the class and gender characteristics of property and management. Similarly, community studies also focus on systems and relationships that maintain social differences (such as class and gender) and specific interests[74]. It can be seen that power plays an indispensable role in understanding rural change, spatial and community planning and political struggle[75]. Recently, the research scope of power relations in rural society has expanded from conservatism or historical hegemony[76] to new political units such as the New Testament Group[77].

4.4 Cultural space

Cultural space is a unique space form of human beings based on human discourse system, representational activities and order concept. It is an unrealistic and ideal social space[78]. For many rural researchers, the support of social constructivism represents the cultural turn, which means that rural research deviates from the basic core of concern about rural socio-economic change. Others believe that rural studies have not yet accepted the full deconstructive power of cultural turn. On the whole, the cultural turnaround is increasingly focused on the foreground

cultural issues such as the significance, identity, expression, difference and resistance of social science, resulting in a variety of manifestations of cultural turn: from the increased use of cultural texts and high reflection on language roles to the introduction of post structural epistemology and the emphasis on non-representational theory. Generally speaking, the evaluation of cultural turn is mixed. The evaluation of cultural turn by people who are more in favor of cultural projects can be summarized into four points: first, cultural turn separates social science from society and begins to study structure, space and inequality. Gregson called this "social withdrawal"[79]. Second, the cultural turn focuses on the non-material process, inter subjectivity and transcendence of identity politics, which is a non-material social science. Third, the cultural turn depoliticizes social science. The debate of post structuralism leads to political silence and academic intellectualization[80]. Fourth, the cultural turn is far from deconstruction. The cultural focus of social science is excessively conservative and still dominated by constructivism.

In an editorial in the Journal of Rural Studies, Cloke believes that rural research has begun to enter the process of cultural turn, reflecting the potential of rural re-conceptualization of natural social relations, high sensitivity to rural experience and imaginary discourse, and incisive consideration of rural cultural symbolic text, and rural life and landscape with a strong emphasis on mobility rather than fixity[8]. The cultural turn of rural space is mainly reflected in two aspects: on the one hand, through actor network theory (ANT)[81] and hybrid research[82], we have constructed innovative opinions on the relationship between non-human actors and their networks and rural environment. ANT focuses on how networks transcend space and time, and how rural actors are involved in distant and unexpected events. On the other hand, the concept of "dwelling"[83] is used to show how animals, plants and humans work together to form a specific place. The intellectual stimulation of cultural turn has also appeared in other fields of rural research, including the use of imaginative texts to investigate the representativeness of rural areas, and the discourse understanding of rural aesthetics and rural poetics becomes increasingly important. It reemphasizes the identity and subjectivity related to rural masculinity/femininity, sexual orientation, disability and children, as well as the research on differences and neglected "others" in rural areas[8].

5. Dimension expansion of international rural space research

5.1 From material level to social representation

Rural social representation is a subjective space that describes people's cognition and image of the countryside[25]. In the past, rural space research mainly focused on rural material space such as agricultural economy, land use, landscape architecture and ecological environment (settlement space and economic space in this paper). Material space is a realistic and concrete space composed of real things. It is the most basic starting point for understanding rural space. After 1980, with the rise of the perspective of political economy and the emergence of the theory of "space production", social space generated by human practical activities became a public concern. Social space is not a concrete physical space, but a spatial relationship between human social behaviors[78]. Since the 1990s, with the rise of social construction theory and the theoretical orientation of postmodernism and post-structuralism, the study of rural cultural space has sprung up. Cultural space permeates with material space and social space, and transforms material space by influencing social practice. Social space is between material space and cultural space. It is not only an abstract material space, but also a breakthrough into cultural space. Material space, social space and cultural space are progressive layer by layer, realizing the transformation from concrete to abstract, from objective space to subjective space, and from real space to virtual space[6]. Therefore, the research on rural space has realized the transformation from material level to social representation.

5.2 From objective space to subjective space

The actor network theory has great inspiration for us to understand the shift from "objective space"

to "subjective space". Unlike social constructivism, which focuses on social relations, nature and non-human are only regarded as the place and background of human activities. Actor network theory realizes that nature and non-human are also legal and lively subjects of rural construction, and emphasizes that the essence of society is a network connection composed of many heterogeneous elements. Nature and "non-human" have changed from the object of human practical activities to the subject of actor network. The relationship between society and nature, human and non-human can be reinterpreted. Latour's actor network theory[84] reflects the rural nature of human and non-human subjects, as well as local, national, global and other interest subjects, puts nature and society, human and non-human subjects in the same important position, and reflects the recognition of the subject status of multiple actors in the rural world. Material and action are no longer the object of understanding the countryside, but are affirmed as a subjective force. Therefore, the understanding of rural space has deepened from objective space to subjective space.

5.3 From static single dimensional space to dynamic multi-dimensional space

The early theoretical perspective regarded rural space as static, homogeneous, established and absolute. Since the 1990s, the countryside has experienced the transformation from productivism to post-productivism[14] and from production landscape to consumption landscape[85]. Rural space is no longer regarded as a simple material space, but a superposition of multiple spaces such as material space, social space and cultural space. With the cultural turn of social constructivism and the promotion of postmodernism on difference, network, connection and mobility, the countryside is no longer regarded as a static and closed geographical entity, but as the interweaving of complex power relations, social communication, discourse practice and institutional forces. They are constantly combined and reorganized, which is called "post-rural". "Post rural" is regarded as "hybrid and networked space"[86]. It has the characteristics of diversity, difference, mobility and uncertainty. It is a process of continuous production and reproduction. Rural development is no longer regarded as the result of the action of a single factor, but involves multiple subjects, spanning multiple scales, intertwined flow relations, embedded in mixed social construction, spatial practice and network interaction[87]. Therefore, the understanding of rural areas has realized the transformation from static single dimension to dynamic multi-dimension.

6. Enlightenment and reference

This paper combs the expansion of foreign rural space research in different perspectives, times and dimensions. International rural space research is a research system composed of settlement space, economic space, social space and cultural space. Generally, foreign rural space has changed from a static, homogeneous, established and absolute system to a dynamic, heterogeneous, uncertain, hybrid, networked and multi-meaning system. Accordingly, international rural space research has also experienced the transformation from material level to social representation, from objective space to subjective space, from static one-dimensional space to dynamic multi-dimensional space, forming a progressive and deepening research process. In addition, foreign rural space research also has multi-disciplines (such as geography, economics, sociology, urban and rural planning, public policy), multi-perspectives (functionalist perspective, political economy perspective, and social constructivism perspective), multi-dimensions (settlement space, economic space, social space, cultural space), multi-methods (RS, GIS, GPS, grounded theory, semi-structured interview, participant observation, Q method, post-structure and post-modernism method), presenting a rich research picture. Compared with foreign rural space research, domestic rural space research has a long way to go and needs to strengthen efforts in the following three aspects:

(1) Expand the research group and realize the integration of multiple disciplines and methodological systems. At present, the research groups of China's rural space are mainly geographers and urban and rural planning scholars. Scholars in the fields of

economics, sociology and public policy have also carried out active exploration, but interdisciplinary research still needs to be strengthened. Rural space includes not only settlement space and economic space, but also social space and cultural space. Therefore, only by attracting scholars from different research fields, observing rural space from different perspectives and methods, and effectively integrating the research of different dimensions, can we build a complete system of rural space research. In terms of research methods, standardized qualitative research and supplement quantitative research should be applied to realize the combination of qualitative and quantitative research. Rural space includes not only settlement space and economic space, but also social space and cultural space. Therefore, only by attracting scholars from different research fields, observing rural space from different perspectives and methods, and effectively integrating the research of different dimensions, can we build a complete system of rural space research. In terms of research methods, we should standardize qualitative research, supplement quantitative research, and realize the combination of qualitative and quantitative research.

(2) Expand the research content of rural space and the concern of the "social cultural" space.

China's rural space research mainly focuses on rural space transformation, land use, settlement space, spatial differentiation, spatial reconstruction and spatial planning in developed areas. The research perspective is mainly from the perspective of functionalism, the research object is mainly production landscape, and the research focus is on material space. The report of the 19th National Congress has clearly put forward the "Implementation of the Rural Revitalization Strategy" and the general requirements of "Industrial prosperity, Ecological livability, Rural civilization, Effective Governance and Well-off Life". In practice, rural production, life, ecology and other fields have also put forward new and higher requirements, which need a positive response from the theoretical circle. Firstly, we should turn from the perspective of functionalism to the perspective of political economy and social constructivism, put the research of rural space in the regional, national and even global background, and pay attention to the influence of power and cultural factors on the shaping of rural space. Secondly, we should expand the research from production landscape to consumption landscape. At present, China's rural tourism, leisure industry and e-commerce are booming in rural areas, which has changed China's rural landscape to a great extent. Domestic scholars have carried out relevant research. For example, some scholars have studied the process and effect of rural space reconstruction from the perspective of actor network theory[88,89]. Wu Qianbo *et al.* studied the characteristics of the development of beautiful villages in Hangzhou from the perspective of consumption space production[90]. However, compared with the booming practice, the theoretical research is still relatively backward and weak. Thirdly, we should expand to the field of "social culture" space. The research on rural space in China mainly focuses on material space, especially the research on rural settlement space[89], and lacks study on social cultural space. Although Zhang Xiaolin and Li Hongbo have discussed the rural space system to some extent, such research on the rural space system is rare. Next, efforts should be made to the power and cultural turn in rural areas and the research on "the neglected" in rural areas, such as class and gender, intergenerational relations, poverty and exploitation in rural space.

(3) Express more concern about the practical problems in rural areas and guide the practice of rural space reconstruction with advanced ideas. Foreign frontier theories such as "rural", "post rural", "triple model of rural space", post productive rural theory, social constructivism perspective, post-modern and post structuralist methods provide a rich theoretical base and serve as a great source for China's rural space reconstruction.

First, follow the "human logic" and restore the subjective status of farmers. In the process of China's rural space capitalization, the countryside has become a tool for capital profit. Farmers are in a weak position in the discourse competition with politics and capital. They have been reduced from the main body of rural society to a marginalized role. They can only passively accept the discipline and

transformation of rural areas by cities based on their own needs and imagination. Farmers' production and living space is marginalized and their sense of relative deprivation is enhanced. Farmers are the main body of rural "daily life practice", and their main position should be respected. In the process of rural revitalization, we should not only cater to the logic of capital, but also respect the voice and decision-making power of farmers for their production and living space, promote the return of rural humanism and restore rural warmth and care.

Second, emphasize the multi-function of rural space and create a rural space with the integration of "production, life and ecology". The emphasis of post productive rural theory on rural "versatility" enlightens us that rural space is not only production space, but also living space and ecological space. Rural space has multiple meanings and values. The unique regional landscape, cultural landscape and characteristic agricultural products in rural areas provide rich resources for the development of a large agricultural system integrating primary, secondary and tertiary industries in rural areas; the tranquility, leisure and ease of the countryside make it a place for urban residents to escape modernity, and the whole set of life ethics, life significance and social attitude developed by rural farming civilization allow the countryside "healing value". Therefore, both of the "rural gentrification" in the West or the "new return movement" in China can be regarded as the performance of rediscovering "rural life". The simple judgment that "green water and green mountains are golden mountains and silver mountains" is undoubtedly the best footnote to the rural "ecological function"[91]. However, in the process of China's rural space reconstruction, many villages with good industrial and economic development emerge, but their ecological environment, public services, life and leisure and other functions have not been followed up in time, and even the phenomenon of "anti-left behind" in rural development emerges, indicating that the elderly and children stay in the city, and the young and middle-aged labor force "go to the village to work". Hence, in the process of rural revitalization, full attention should be paid to the multi-function of the countryside and create a rural space with production development, happy life and ecological livability.

Third, respect the "regionality" and "difference" of rural space and realize the integration of tradition and modernity. The emphasis on rural diversity and diversity in the western "post rural theory" has important enlightenment for explaining the diverse and violent reconstruction of China's rural space and understanding China's rural nature[92]. The "regionality" and "difference" of China's rural space are reflected in that the Chinese nation is a comprehensive civilization with vast territory, multi-ethnic coexistence, and great differences in the natural environment such as geography, climate and ecology among all ethnic groups. On this basis, a variety of production and life styles, values and life significance have been derived. The localization, locality and difference of rural space can effectively "hedge" the high standardization, formatting and homogenization of modern society and iron out the "scar of modernity"[91]. However, in the process of China's rural space reconstruction, in order to meet the consumer demand, the rural landscape and rural culture tend to dissolve, and the non-native culture and life are transplanted or symbolically misappropriated, resulting in the disappearance of the original rural nature. Therefore, only by fully respecting the rural tradition can we make "the countryside more like the countryside", so as to maintain the unique value of the countryside.

Fourth, pay attention to the "social cultural" turn of the countryside and restore the meaning production function of the countryside. In the process of China's rural space reconstruction, there are some problems, such as the loss of rural cultural landscape and tradition, the rupture of social relationship network and ethical decline, the alienation of rural space and the lack of spatial justice. Definitely, some villages, such as Dashan Village, Yaxi Town, Gaochun, Nanjing, are no longer passive followers and blood losers in the process of urbanization, but actively undertake "reverse cultural output" to the city based on their "rural" basis. In some concentrated communities, we can also see that the traditional culture characterized by blood, geography, beliefs and customs still plays an important role in maintaining

the close human land relationship after de-agriculturalization. The cultural significance and production function of the countryside are the "root" of the countryside. Only the rural modernization based on this foundation can be viable and sustainable.

Conflict of interest

The authors declare that they have no conflict of interest.

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