

Spatial Network Characteristics of Shrinking Areas in Shanghai Metropolitan Area: An Urban-Rural Population Flow Network Analysis

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Abstract

The development of the concept of growth as the mainstream has led to the neglect of the shrinkage phenomenon in China. However, identifying shrinkage areas is significant for regional coordinated development and urban-rural integration. There are few studies on shrinking areas from the perspective of the spatial networks and the characteristics of towns in the urban-rural spatial networks. The study identifies shrinking towns based on traditional demographic data in the Shanghai metropolitan area, then uses massive mobile phone positioning data to build urban-rural and rural-rural population flow networks to analyze the characteristics of shrinking towns and put forward planning strategies. This study explores shrinking towns from a new perspective of spatial networks and provides references for implementing shrinking area management policies.

Keywords: Urban-rural integration; Shrinking area; Mobility network; Shanghai metropolitan area

1. Introduction

In 2019, the National Development and Reform Commission of China issued the "Key Construction Tasks of New Urbanization in 2019", which proposed for the first time "shrinking small and medium-sized cities" and required "slimming down and strengthening", guiding the concentration of population and public resources to urban areas. The task indicated that the country began to attach importance to urban shrinkage. At the same time, many studies have shown that with the implementation of China's regional integration, urban-rural integration and other policies, under the siphoning effect of central cities at all levels, many integrated development areas such as urban agglomerations and metropolitan areas in China have different degrees and types of shrinkage. Currently, most Chinese scholars pay attention to the urban shrinkage caused by long-term dependence on resource-based industries in northeast China and pay less attention to the shrinkage phenomenon in economically developed regions, such as the Yangtze River Delta and the Pearl River Delta. However, some scholars have found that in the Yangtze River Delta, the central urban areas of Shanghai, some counties and small towns of Taizhou, Yancheng, Nantong, Jiaxing, Wuxi and other cities have shown shrinkage phenomenon (Cheng et al.,

2021; Wu, Long and Yang, 2015; Lu, Xu and Zhou, 2023). Therefore, for China, the logic of urbanization dominated by the traditional growth model in long-term planning practice may no longer be applicable. China's urban development has ushered in a post-growth era.

At present, the identification of shrinking areas is mainly based on population statistics. However, no consensus has been reached on the measurement standards due to the differences in the development background and urban statistical calibre of cities in different countries. At the same time, Martinez-Fernandez (2013, p. 303-308) proposed that from the perspective of global urban networks and mobile spatial networks, shrinking cities may also be represented by the gradual weakening or even interruption of the connection with global mobility space. However, there are few relevant studies on this theoretical speculation. Compared with urban networks, there are fewer studies on the characteristics of town networks or urban-rural networks. Therefore, this study hopes to explore the characteristics of shrinking areas in metropolitan areas from the perspective of regional spatial network correlation and the agglomeration ability of town population elements.

Compared with Western countries, population loss is not significant in Chinese cities due to the continuous urbanization process. Meanwhile, urban shrinkage is not only the function of cities themselves but also the result of regional correlation and spatial correlation. Therefore, looking at shrinking cities from the phenomenon and process of element flow can more effectively judge their future trend of change. The "spatial mismatch" of elements and resources is avoided, and the development elements also have the possibility and feasibility of artificial regulation to optimize the allocation of regional resources further and promote regional coordination and urban-rural integrated development.

This study takes all towns in the Shanghai metropolitan area as the research object. The area is a relatively developed area in China with frequent connections to various economic activities and has apparent characteristics of network connections. Firstly, the traditional demographic data is used to calculate the population change of each town and make a preliminary judgment of the shrinking towns. Secondly, by using massive mobile phone data, weighted degree centrality and connection strength, the urban-rural and rural-rural population mobility networks in the Shanghai metropolitan area are constructed, the spatial network characteristics of each shrinking town are extracted, and the spatial connection relationship with different cities and towns is explored. By comparing the spatial location and connection of nodes and the function, the research evaluates the characteristic types of shrinking towns from the perspective of the network, analyzes their main influencing factors, and puts forward optimization strategies. This paper attempts to analyze the characteristics of shrinking areas from a new perspective of population flow networks and provides a new experience for promoting China's coordinated regional development, urban-rural integration and implementing shrinking area management policies.

2. literature review

Although there have been abundant research results on shrinking cities, involving many

disciplines such as economics, geography and urban and rural planning, there is no consensus on the population base, changing years and total scale of shrinking cities due to the differences in the development background and urban statistical standards of different countries. The definition of a shrinking city mainly involves population, economy and time. Even though the definition of the Shrinking City International Research Network(SCIRN) has a high degree of acceptance, there are still many ambiguities, such as the inconsistency of the "city" scope, which makes it impossible to determine a clear statistical range. At the same time, the decrease in population is the concept of a period. If the change in population in a specific period is measured in another period, the conclusion may not be consistent (Wu and Qi, 2021). Although the discussion on shrinking cities in China is on the rise, due to the focus on the "reference" of shrinking cities and its theoretical analysis framework in other countries, the discussion on "Chinazation" is relatively lacking. At present, the concept of shrinking focuses on describing phenomena and ignores the relationship between element and function development (Sun, 2022). Therefore, the current definition of "shrinking city" based on a variety of factors is diversified, and it is difficult to determine a unified judgment standard for shrinking city.

At present, the identification methods of shrinking cities are mainly based on static data analysis and the need for dynamic analysis from the perspective of network connection and essential feature analysis based on the outflow of development factors. The current identification of shrinking cities is mostly from the population perspective, combining statistical and spatial data to build a multidimensional index system. Meanwhile, with the progress of technology, the model simulation method has gradually emerged (Liu, 2016). The measurement and identification units are mainly prefecture-level cities, and the identification studies of counties and towns as the units are gradually increasing.

At the same time, some scholars have proposed that from the perspective of the global urban network and mobile space network, shrinking cities may also be represented by the gradual weakening or even interruption of connections with global mobile space (especially knowledge flow and information flow) (Martinez-Fernandez, 2013, p. 303-308). Inequality is increasing between cities and regions integrated into global networks and those that are not (Allen and Storper, 2003). Shunned by the global network, shrinking cities will enter the black hole of globalization proposed by Castell (1989), so shrinking cities can also be considered in terms of their association with the urban element network, areas with weak or broken connections to the rest of the region can be explored to identify cities with shrinking trends.

Currently, relevant studies on shrinking cities still focus on describing the phenomena. However, with the continuous advancement of economic globalization and regional integration, the traditional "place economy" based on comparative advantages of resource endowment has been gradually replaced by the "mobile economy" centred on capital, technology, market and innovation, and flow space has become the mainstream of The Times (Shen and Gu, 2009). At present, some scholars in economics use total factor productivity combined with econometric methods as the basis for judging contraction or growth (Yang,

Wang and Tao, 2022). Wu and Yao (2021) utilized a unique dataset on intercity investment flows in mainland China to verify that centrality in the investment network is significantly positively correlated with urban population changes. They explored the relationship between shrinking cities and the loss of external investments. Sun (2022) proposed that urban shrinkage is a market behaviour in which the development elements mainly represented by population make "re-location" due to the relative or absolute decline of urban "agglomeration ability of regional development elements" in regional correlation. Population outflow is only a phenomenon, and urban shrinkage can be resolved from the perspective of element flow. With the proposal of the theory of flow space, the research on spatial network has been deepened, and the progress of information technology enables the big data generated by mobile phone signaling and Internet App to identify the flow of various elements. The algorithm is relatively mature and has been widely used in the research reflecting the spatial structure of urban agglomerations and metropolitan areas (Wang et al., 2022). It makes the measurement method of element flow mature gradually and provides the possibility to analyze the contraction area from the perspective of element flow.

3. Methodology and data

3.1 Research area and data source

The Shanghai metropolitan area, located in eastern China, is a vital component of the Yangtze River Delta. In 2022, the governments of Shanghai, Jiangsu Province, and Zhejiang Province issued the "Spatial Coordination Plan for the Shanghai Metropolitan Area," aiming to deepen the implementation of the national strategy for integrated development of the Yangtze River Delta. The planned scope includes the administrative regions of "1+8" cities such as Shanghai, Wuxi, Changzhou, Suzhou, Nantong, Ningbo, Huzhou, Jiaxing, and Zhoushan. The Shanghai metropolitan area exhibits diverse population agglomerations. As the leading area with the most concentrated functions in the Yangtze River Delta urban agglomeration, it experiences a highly concentrated and rapidly developing economy. It features multiple interconnected centres with closely associated networked relationships and demand for close cooperation, driving the coordinated development of various regions. Therefore, urban-rural integration development is also essential to the Shanghai metropolitan area. This study takes the Shanghai metropolitan area as the research area, dividing nine cities into 913 street (town) level administrative divisions. According to the "Statistical Compilation Rules for Administrative Division Codes and Urban-Rural Division Codes" (index no. 410A03-1201-201708-0006) from the National Bureau of Statistics in China, the urban-rural attributes of each street (town) level administrative division are classified based on the first digit of their urban-rural classification code: 1 represents urban, and 2 represents rural. A total of 428 urban streets and 484 rural towns were identified, with all towns within the Shanghai metropolitan area being the subjects of this study, as shown in **Figure 1**.

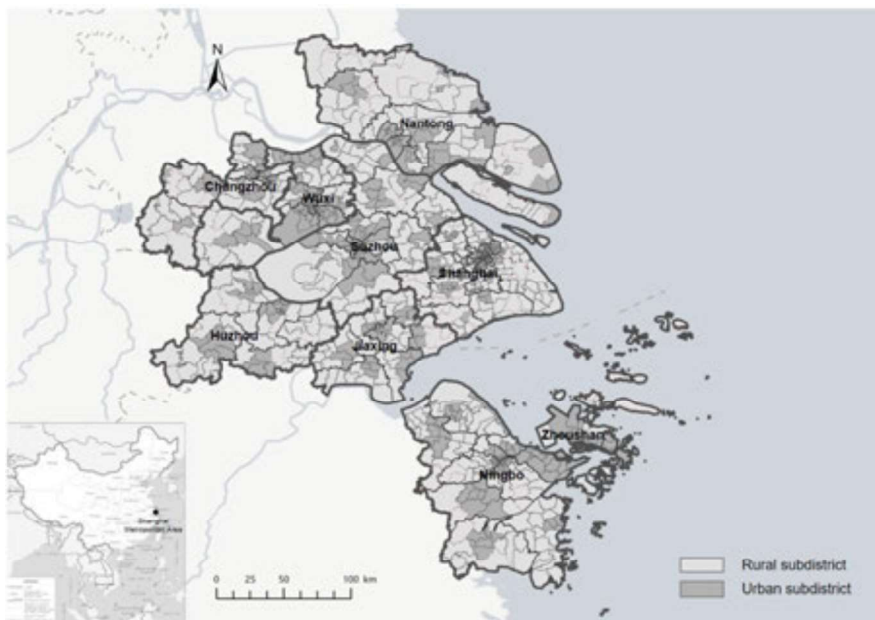


Figure 1. Location and urban-rural classification layouts of Shanghai Metropolitan Area

This study primarily employed statistical data and Baidu LBS (Location-Based Service) data. The population statistics data were sourced from the sixth national census of China in 2010 and the seventh national census in 2020, representing the resident population of each street and town. The LBS data consisted of Origin-Destination (OD) travel data for working days in September 2021. It utilized station grids to locate user travel, determining residential and workplace locations by statistically analyzing users' most extended daytime and nighttime stays. This encompassed home-based work trips, home-based other trips, and non-home-based trips. The population flow statistics for this study included all trip purposes.

3.2 Research approach and methodology

3.2.1 Research approach

In contrast to traditional studies that investigate the characteristics of shrinking areas solely based on statistical data, this study aims to explore the features of shrinking areas within the metropolitan area from the perspective of regional spatial network correlations and the clustering capacity of town population element. Therefore, this paper, departing from the traditional criterion of population quantity changes, first identifies shrinking areas with significant population decrease characteristics by calculating population growth rates. Secondly, based on big data on population mobility, population flow networks within the

Shanghai metropolitan area are constructed, examining the characteristics of shrinking towns in the network from both urban-rural and rural-rural population flow network perspectives. This can respectively characterize the connections between shrinking towns and urban streets or surrounding towns and, to some extent, reflect the clustering capacity of shrinking towns for population development elements in a relatively timely manner. This holds significant implications for the urban-rural integration and coordinated development within the Shanghai metropolitan area.

3.2.2 Identification of shrinking areas

Although the phenomenon of population shrinkage has garnered attention from numerous scholars, there still needs to be a consensus in the academic community regarding methods for identifying population shrinkage. Nonetheless, negative population growth remains a crucial criterion. The continuous development of urbanization in China has led to a sustained decrease in rural population. The Yangtze River Delta region, where the Shanghai metropolitan area is located, is an economically developed area in China with a high capacity for population aggregation. Its urbanization development process differs somewhat from the overall process in China. Therefore, considering the influence of the urbanization process, this study adopts the methodology referenced from relevant research (Wang and Xue, 2016; Cheng, Zhang and Liu, 2021). Firstly, the average annual population growth rate of towns in the Yangtze River Delta region (comprising three provinces and one municipality) from 2010 to 2020 is calculated. Then, the average annual population growth rate of each town within the Shanghai metropolitan area is calculated over the same ten-year period, subtracting the average annual population growth rate of townships in the Yangtze River Delta region from it, with an adjustment of -1.4%. This adjustment accounts for the difference in the urbanization process. The resulting relative population growth rate of towns, after excluding the influence of urbanization in the Yangtze River Delta, is used to define towns with a negative relative population growth rate as population shrinkage areas.

3.2.3 Analysis of population flow networks

Based on Baidu LBS data, this study calculates the total volume of bidirectional purposeful trips between streets and towns as the strength of network connections. Subsequently, an undirected weighted network is constructed. Network centrality is then analyzed, with methods referenced from relevant research (Xie, Zhen and Xi, 2022). To mitigate the impact of significant differences in the area between streets and towns, network centrality is calculated as the sum of the network connection strengths between each street or town and other streets or towns, normalized by the unit area of each street or town. Exploratory spatial data analysis is conducted using GIS platforms, employing natural break methods to visualize the spatial distribution characteristics of network centrality and network connection strengths. The network connection strengths and weighted centrality are calculated and ranked for the 484 towns at both urban-rural and rural-rural levels, with visual representations to explore the characteristics of each town within the urban-rural network.

4. Results and discussion

4.1 Characteristics of shrinking areas based on population changes

Based on the calculation of the relative population growth rates of towns after excluding the influence of urbanization in the Yangtze River Delta, there are a total of 85 shrinking towns with negative population growth in the Shanghai metropolitan area. These shrinking towns are visualized in GIS, as shown in **Figure 2**. Among the nine cities, Shanghai and Nantong have

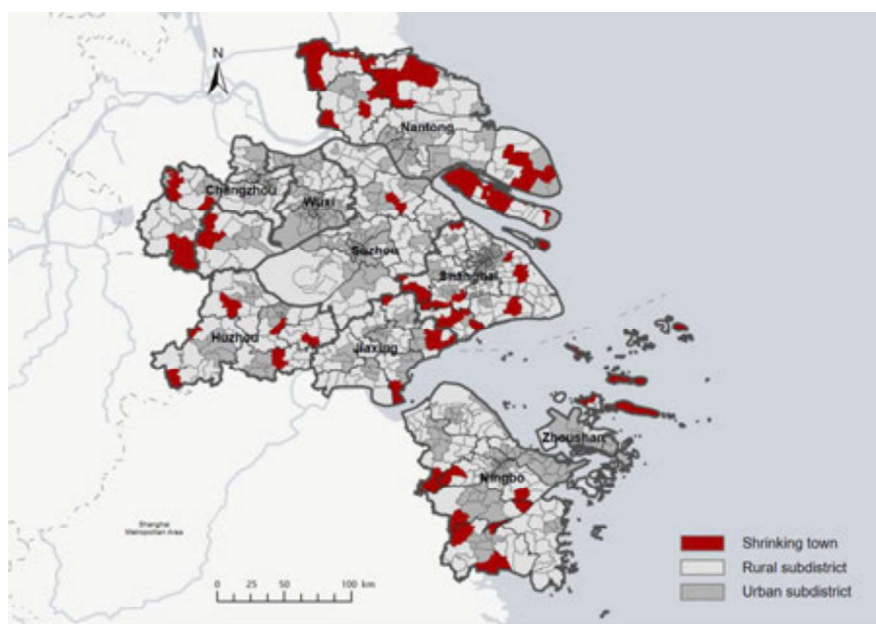


Figure 2. Location and urban-rural classification layouts of Shanghai Metropolitan Area the highest number of shrinking townships, with 23 and 20, respectively. Suzhou and Wuxi have fewer shrinking towns, with 1 and 2, respectively. Among the other five cities, Zhoushan has 12 shrinking towns, Ningbo has 10, Huzhou has 8, Jiaxing has 5, and Changzhou has 4.

From the overall spatial distribution characteristics, the towns in the Shanghai metropolitan area exhibit localized shrinkage phenomena, which are relatively concentrated or extended. They are primarily concentrated in the peripheral areas of the metropolitan area and at the boundaries between cities. For instance, the shrinking towns in Nantong, Ningbo, and Changzhou are mainly located in the peripheral border areas of the cities, where town development is significantly influenced by geographical location. Meanwhile, the shrinking towns in Jiaxing and Shanghai are mainly situated at the boundaries between the two cities, where the population is notably affected by the central urban area's suction effect. Some shrinking towns in Zhoushan and Shanghai are located on coastal islands and bear more ecological protection tasks, which also have specific impacts on population changes.

4.2 Characteristics of population flow network

4.2.1 Characteristics of urban-rural population flow network

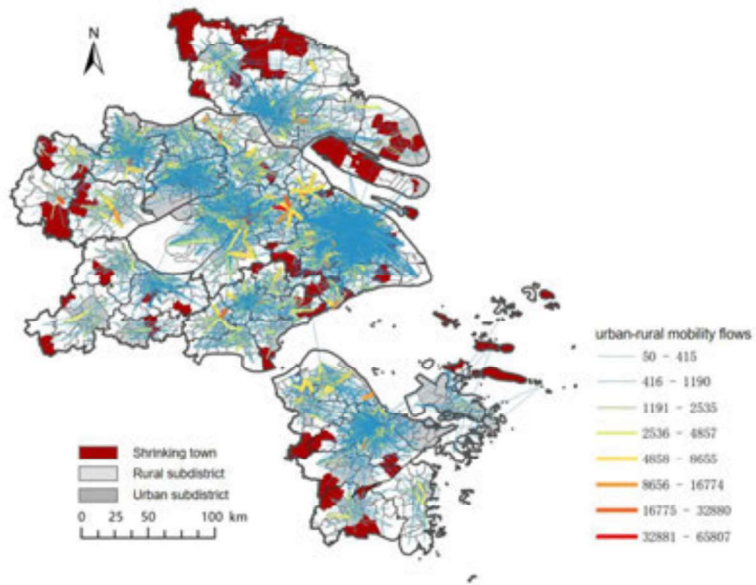
Through analysis of the urban-rural population flow network, using the natural break method in the GIS platform, the connectivity strength and weighted centrality of each town are classified, visually analyzed, and ranked, and relevant information about the shrinking towns mentioned earlier is filtered out.

The spatial characteristics of urban-rural population connectivity strength in the Shanghai metropolitan area are illustrated in **Figure 3(a)**. Overall, Shanghai and Suzhou exhibit relatively frequent urban-rural population connections, with higher connectivity strength within each county (district) and fewer connections across districts or cities. Only some areas have surpassed the constraints of administrative barriers, such as the central urban area of Shanghai with its internal towns and the border towns between Suzhou and Shanghai. However, these connections have limited flow distances, which are associated with the geographical locations of towns and the strong suction effect of Shanghai's central urban area. This indicates significant room for improvement in the urban-rural integration and development of the Shanghai metropolitan area.

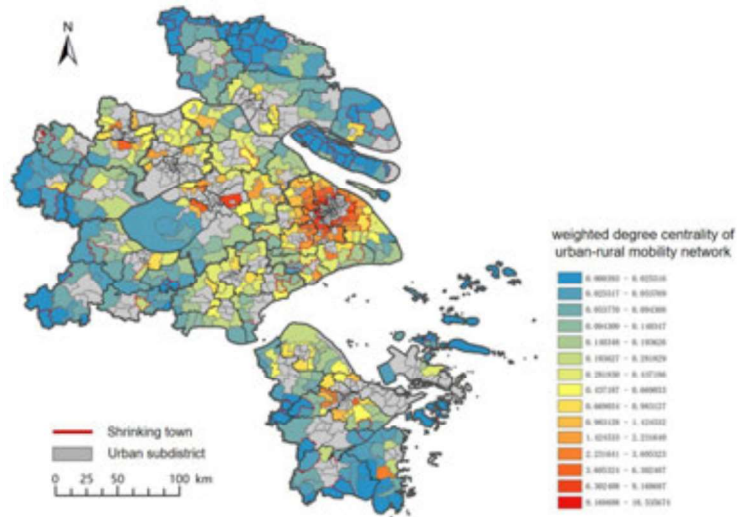
From the perspective of shrinking towns, most of them have low connectivity strength with

urban streets. Only some shrinking towns in Shanghai and Suzhou have strong connections

with urban areas. Examples include Jinqiao Town and Chuansha New Town in Pudong



(a)



(b)

Figure 3. Characteristics of urban - rural population flow network in shrinking towns of Shanghai metropolitan area: (a) intensity of urban - rural population connection, (b) weighted degree centrality of urban-rural mobility network

District of Shanghai and Chedun Town in Songjiang District. These towns have experienced significant population relocation due to the development of large-scale service projects or industrial parks, leading to a substantial decrease in population. However, their economic development remains robust, indicating that they are not in a state of shrinkage. This underscores the limitations of using population decline alone as a criterion for identifying shrinking areas. Additionally, the weak connections between most shrinking towns and cities indicate their marginal status in the process of urban-rural integration and metropolitan area coordinated development.

The centrality distribution characteristics of the urban-rural population flow network are shown in **Figure 3(b)**. Overall, the towns with higher centrality levels within the Shanghai metropolitan area are mainly distributed around the urban areas, closely related to geographical location. For example, there are a large number of medium to high-level towns in Shanghai, distributed in concentric circles around the central urban area. Compared to other cities, Suzhou and Jiaying, which are adjacent to Shanghai, have more medium to high-level towns, indicating a higher degree of integration between urban and rural areas.

From the perspective of shrinking towns, extracting the centrality rankings of each shrinking town reveals that half of the shrinking towns are ranked at the bottom of all towns in terms of centrality level. Examples include all shrinking towns in the Chongming District of Shanghai, most shrinking towns in Nantong, and the most shrinking towns in Zhoushan, generally located in the peripheral areas of the Shanghai metropolitan area or have implemented related ecological conservation measures. Shrinking towns located between Shanghai and Jiaying generally have higher centrality levels than other towns, reflecting the driving role of the central urban area of Shanghai on the surrounding towns.

Comparing the centrality levels of shrinking towns within each city, towns like Jinqiao, Chedun, and Chuansha in Shanghai, Guli in Suzhou, Lintuo in Jiaying, Daochang and Qianyuan in Huzhou, and Putuoshan in Zhoushan, are significantly higher than other shrinking towns in the same city. Investigations into the specific development situations of each town indicate that significant factors influencing development include the development of tourism industry brought by large scenic spots, industrial development brought by industrial parks, and geographical advantages adjacent to central urban areas, all of which contribute to the frequent population flow between urban and rural areas.

Overall, most of the shrinking towns identified based on population changes are positioned relatively low in terms of both connectivity strength and centrality within the urban-rural population flow network compared to all towns. They exhibit a notable "depression" phenomenon in the network, indicating lower frequencies of urban-rural population flow, which is unfavorable for urban-rural integration and regional coordinated development. However, the central urban area of Shanghai gradually exhibits a diffusion trend starting from the aggregation of population elements, influencing nearby cities and towns, thus maintaining a certain level of population flow and aggregation capacity at the urban periphery where shrinking towns are located. At the same time, a small number of shrinking towns still hold

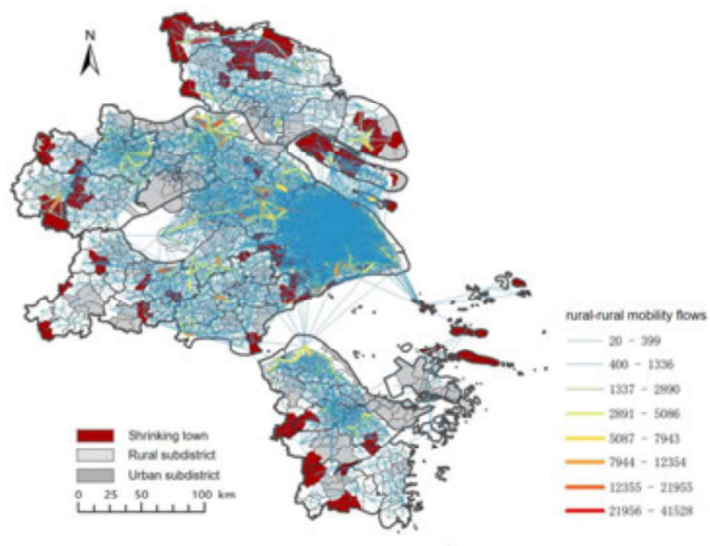
relatively high positions in the network, mainly influenced by factors such as town construction and geographical location, demonstrating higher population aggregation capacity. This also indicates the limitations of identifying shrinking areas based solely on population statistics standards.

4.2.2 Characteristics of the rural-rural population flow network

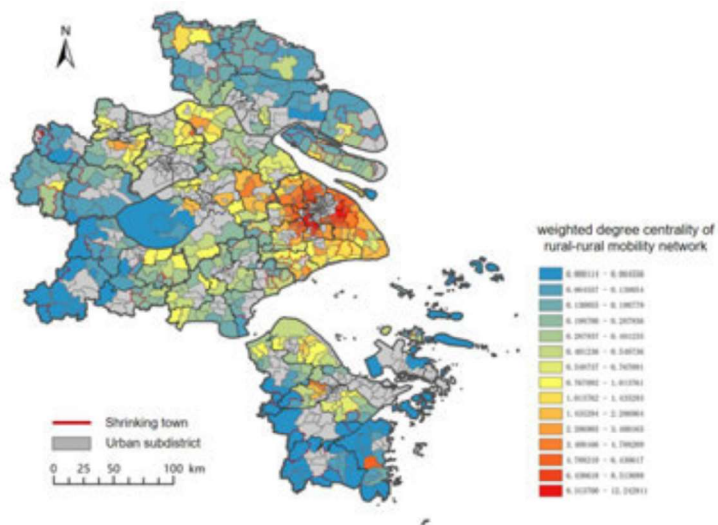
Following the same analytical process as the urban-rural population flow network, the spatial characteristics of rural-rural population connectivity strength within the Shanghai metropolitan area are illustrated in **Figure 4(a)**. Regions with higher rural-rural connectivity strength remain concentrated in Shanghai and Suzhou. While population movement predominantly occurs within each district or county, there is also a notable amount of inter-district flow, with administrative barriers exerting less restriction compared to urban-rural population movement, and longer distances of population flow.

Regarding shrinking towns, certain ones in Shanghai, Nantong, and Changzhou exhibit stronger population connections with other towns. Examples include Fengcheng Town in Shanghai, Tianmu Lake Town in Changzhou, and Huiping Town in Nantong. Fengcheng Town houses an economical park, Tianmu Lake Town incorporates the Tianmu Lake tourist resort, and Huiping Town serves as a significant centre for industry and agriculture. These towns have experienced population relocation due to ecological conservation or industrial park construction, but their industrial development has also stimulated surrounding areas, strengthening population connections between towns. For the majority of shrinking towns, the population connectivity strength with other towns is lower. Examples include shrinking towns in Ningbo, Zhoushan, and Huzhou, as well as shrinking towns at the border between Jiaxing and Shanghai. These towns are primarily influenced by geographical location, and the lower inter-town population connectivity strength within their respective cities indicates limited economic activity between towns.

The centrality distribution characteristics of the rural-rural population flow network are depicted in **Figure 4(b)**. Towns with higher centrality levels are primarily located in Shanghai and Suzhou, with notable centrality levels also observed in the eastern parts of Wuxi and Changzhou, as well as in Jiaxing and the northern parts of Ningbo. This clearly illustrates the frequent population activity radiating from Shanghai, influencing surrounding towns.



(a)



(b)

Figure 4. Characteristics of rural - rural population flow network in shrinking towns of Shanghai metropolitan area: (a) intensity of rural - rural population connection, (b) weighted degree centrality of rural-rural mobility network

Extracting relevant information on centrality from shrinking towns and ranking them, there are 26 shrinking towns ranked beyond the 400th position, compared to 45 in the urban-rural

population flow network, indicating that shrinking towns, on the whole, experience more frequent population movement than urban streets when compared to other towns. There are a total of 58 shrinking towns ranked beyond the 300th position, indicating that, overall, shrinking towns still occupy lower positions in centrality within the rural-rural population flow network, exerting some inhibitory effect on regional coordination.

Among these, shrinking towns located in the peripheral areas of Ningbo, Changzhou, Huzhou, Wuxi, and Zhoushan all exhibit the lowest centrality levels, indicating lower population aggregation capacity. Shrinking towns situated at city boundaries, such as those between Shanghai and Jiaxing, Shanghai and Suzhou, and Jiaxing and Huzhou, have relatively higher centrality levels, reflecting the radiating influence of central cities like Shanghai and Suzhou. Furthermore, compared to the centrality in the urban-rural population flow network, the centrality levels of shrinking towns in Nantong and Chongming District of Shanghai are relatively higher in the rural-rural population flow network, suggesting lesser functional connections with urban streets but more significant potential for coordinated development with surrounding towns.

Overall, most shrinking towns exhibit weak population aggregation capacity, low centrality, and connectivity strength within the rural-rural population flow network. This is likely to negatively impact the coordinated development of surrounding towns and hinder the smooth flow of population elements within the region. Simultaneously, some towns hold lower positions in urban-rural networks, yet they experience a specific elevation in their positions within the rural-rural network. This indicates their clustered development with surrounding towns. Shrinking towns located in cities like Shanghai demonstrate higher network characteristics, which correlate closely with their industrial development and geographical location.

4.3 Classification and influencing factors of shrinking towns

Above, Based on population changes, shrinking towns in the Shanghai metropolitan area were identified and characterized from both urban-rural and rural-rural population flow network perspectives, providing a dynamic reflection of their population aggregation capacity. Overall, combining with the analysis content of the three parts, the shrinking towns can be roughly divided into four types, and have different influencing factors.

The first type of shrinking towns, both in the urban-rural and rural-rural population flow networks, exhibit high levels of connectivity, with frequent population interactions with urban streets and other towns, showcasing strong population aggregation capabilities. These towns are predominantly located in Shanghai, such as Chuansha New Town, Jinqiao Town, Chedun Town, Tinglin Town, Caojing Town, and Dushangang Town in Jiaxing. The primary influencing factors for these towns include: 1. Prime Geographical Location: Benefiting from their strategic geographical positioning and the radiating influence of the central urban area of Shanghai, these towns maintain active population interactions and functional connections with surrounding areas. 2. Development of Tourism Areas or Economic Industrial Parks: The

presence of developed tourism areas or economic industrial parks in these towns drives frequent population movements and functional connections. For instance, Chuansha New Town's Disneyland, despite causing population relocations, has spurred rapid economic growth, while Jinqiao Town's proximity to the Shanghai Zhangjiang Hi-Tech Park has facilitated functional connections in the surrounding areas. Although these types of shrinking towns may experience a decline in permanent population numbers, they still possess significant population aggregation capabilities and hold potential for development.

The second type of shrinking towns exhibit high levels of connectivity in the urban-rural population flow network but lower levels in the rural-rural population flow network. Examples include Guli Town in Suzhou, Qianyuan Town in Huzhou, and Putuoshan Town in Zhoushan. These towns have close functional connections with urban streets but interact less with surrounding towns. The primary influencing factors for these towns include: 1. Proximity to Urban Streets: Being adjacent to urban areas and within the radiating range of cities, these towns have close population connections with urban areas, such as Qianyuan Town. 2. National Scenic Spots: Some of these towns are renowned for their national scenic spots, such as Guli Town, a famous ancient town in Suzhou, and Putuoshan Town, which attracts a large number of tourists due to the Putuoshan scenic area. As a result, these towns have close transportation links with urban areas. These types of towns maintain a stable level of economic development due to their inherent resource endowments. Changes in the permanent population numbers may not accurately reflect their current situation.

The third type of shrinking towns exhibit lower levels of connectivity in the urban-rural population flow network but relatively higher levels in the rural-rural population flow network, with frequent population interactions with surrounding towns. Examples include Luxiang Town, Langxia Town, Fengcheng Town, and Jianshe Town in Shanghai, as well as Tianmu Lake Town in Changzhou. The main influencing factors for these towns with high connectivity to surrounding towns include: 1. Service Function for Surrounding Areas: Some towns serve as functional hubs for surrounding areas, such as Fengcheng Town's bus station acting as a transportation hub for the surrounding region, providing service functions for external connectivity. 2. Interlinked Industrial Development: Towns like Luxiang Town, with its carpet industry, Langxia Town, with mushroom cultivation, and Tianmu Lake Town, primarily focused on tourism engage in synergistic cooperation and development with surrounding towns. These shrinking towns possess a certain development foundation and collaborate with neighbouring towns in a cluster-based development model. However, they may also experience population loss due to insufficient developmental momentum.

The fourth type of shrinking towns exhibits low levels of connectivity in both the urban-rural and rural-rural population flow networks, a characteristic shared by most shrinking towns. These towns demonstrate a noticeable "depression" phenomenon in the regional spatial network, with insufficient population aggregation capabilities hindering the smooth flow of population elements within the region. The primary influencing factors include: 1. Geographical Location: Most of these towns are situated on the periphery of the metropolitan

area, experiencing significant population outflow due to the suction effect of central cities. Additionally, transportation conditions in some areas, such as the reliance on waterways for transportation in towns in Zhoushan, are also hindering population mobility, heavily influenced by external conditions. 2. Lack of Key Industries: The absence of critical industries and lagging economic development result in labor outflow and a lack of inherent population aggregation capabilities. 3. Implementation of Ecological Protection Policies: The implementation of ecological protection policies restricts regional development, leading to population outflow. Overall, these types of towns lack vitality in regional development and have limited functional connections with surrounding areas. Under the processes of urbanization and development of central cities, they may continue to shrink in the future.

4.4 Development advice for shrinking towns

Based on the overall characteristics and types of shrinking towns, and in conjunction with the existing planning in the Shanghai metropolitan area, this study proposes the following recommendations:

1. Attention to Shrinking Areas in Metropolitan Area Coordination: Given the current development context, shrinking areas should be given attention in the coordinated development of metropolitan areas. Current domestic planning primarily focuses on the development of central areas, overlooking regions with relatively lower overall development levels. These areas often create structural "depressions" in the regional coordination network, hindering the free flow of various elements within the region and adversely affecting urban-rural integration. Furthermore, while using population quantity as a criterion for identifying shrinking areas has its limitations, it can preliminarily screen out areas with shrinking trends. Thus, a deeper assessment of shrinking areas should integrate the aggregation capacity of development elements.

2. Breaking Administrative Boundary Constraints: Fragmented administrative boundaries pose obstacles to coordinated planning by impeding the free flow of elements. Most population movements, whether urban-rural or rural-rural, predominantly occur within cities or even within districts and counties. The fragmentation of administrative jurisdictions poses certain obstacles to coordinated planning. Currently, local governments provide corresponding public service facilities based on administrative boundaries, resulting in weak and poorly connected public service facilities in border areas, hindering the cross-border flow of population elements.

3. Development Strategies for Shrinking Towns: Effective strategies should be formulated to drive regional coordinated development based on the characteristics represented by the aggregation capacity of the shrinking towns. Different response strategies should be adopted for each type of shrinking town:

- For the first type of shrinking town, which still retains high aggregation capacity, exclusionary strategies should be implemented. Despite a decrease in population, these towns still possess significant development potential.
- For the second type, existing advantages such as location should be prioritized to promote complementary urban-rural functions, drive the flow of urban-rural elements, fully utilize existing regional advantages, and achieve differentiated urban-rural development.
- The third type, characterized by solid linkage with surrounding towns, should initially adopt cluster development models to achieve functional complementarity with surrounding towns. Leveraging their own industrial advantages, active promotion of cluster development should be pursued, along with strengthening transportation links and industrial cooperation with urban areas to promote urban-rural integration.
- For the fourth type, which is more common, efforts should focus on strengthening infrastructure such as transportation to enhance connections with surrounding areas. Towns under ecological policy protection can consider developing tourism or agriculture under permitted conditions. Towns without pillar industries should actively seek coordinated development with surrounding areas. Aging or severely hollowed-out towns could consider moderate village integration and relocation in line with current development trends.

5. Conclusions

Under the national development strategy of fostering urban agglomeration and metropolitan areas, coordinated development and urban-rural integration have always been topics of concern. This research, based on traditional population data analysis, initially identifies shrinking areas. Leveraging big data technology and network analysis methods, constructing urban-rural and inter-town population flow networks within the Shanghai metropolitan area to deeply analyze the network characteristics of shrinking towns, revealing the following main findings:

1. Based on the traditional population data analysis, the towns in the Shanghai metropolitan area show a phenomenon of local contraction of relatively clustered or extended branches, mainly concentrated in the peripheral areas of the metropolitan area and the border areas between cities. Cities with a large number of shrinking towns include Nantong, Shanghai, Zhoushan, Ningbo, etc.
2. Most of the shrinking towns identified based on population change are at a lower level in the rural-urban population flow network. A few shrinking towns still have a higher level in the network under the radiation of Shanghai and other central cities, which are mainly affected by town construction and, geographical location and other factors, and have a higher population gathering ability.
3. Most of the shrinking towns have weak population gathering ability in the rural-rural population flow network, which will adversely affect the coordinated development of surrounding towns and hinder the smooth flow of population elements within the region.

Some towns have a lower status in the urban-rural network. However, their position in the rural-rural network has been improved to a certain extent, indicating the different development modes from the surrounding towns.

4. Based on the characteristics of the network, the shrinking towns can be divided into four types according to different energy levels, and the influencing factors of the four types of shrinking towns are different. The towns with higher energy levels in the urban-rural and rural-rural population flow network should be considered excluded from the shrinking towns, which are mainly concentrated in Shanghai. Different development strategies should be adopted for the other three types of towns. In general, the shrinking towns from the perspective of the network are mainly concentrated in Nantong, Zhoushan, and Ningbo. Due to its strong radiation effect, the inner towns of Shanghai still have a high factor agglomeration ability.

Through the refined analysis of population flow at the street and town scale, this study finds the limitations of judging shrinking areas by population change as the standard and analyzes shrinking areas from the perspective of regional correlation, which can essentially judge their future development trend. In addition, the theory to view shrinking areas from the perspective of urban network and mobile spatial network is preliminarily verified. Most shrinking areas are indeed weakened or even interrupted in the network connection with surrounding areas. By identifying the shrinking areas from the perspective of element flow and differentiating the types simultaneously, we can better judge their development direction and formulate strategies through human manipulation, which will also provide a clearer optimization direction for the coordinated development and urban-rural integration of the Shanghai metropolitan area.

At the same time, this study still has some things that could be improved due to the limitations of time, data and other factors. First, the purpose of LBS data has yet to be fully mined to distinguish the differential characteristics of commuter and non-commuter flow. Secondly, an in-depth coupling analysis of the related factors, such as traffic conditions and economic industries, needs to be conducted. These are the directions that need further research in the future.

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