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The evolutionary trajectory of the rural settlements in Southern Jiangsu in the past 20 years:
From the perspective of urbanization and land use

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Abstract: For a long time, due to lack of accurate data covering large areas, it is difficult to capture the continuous spatial evolutionary trajectory of rural settlements shaped by rapid urbanization and rural land use policies. To fill this gap, based on theoretical analysis this paper systemically detected the changing characteristics of scale, spatial morphology, distribution, and land use pattern of rural settlements in Southern Jiangsu in the past 20 years depending on the data of land resource survey in 2009 and 2019. The study suggests that the total area and per capita size of rural settlements declined by 30% and 2% respectively as a result of rural land consolidation and the influx of enormous immigrants from underdeveloped regions. The spatial density and average shape index dropped by 14% and 44% respectively in the recent decade, indicating an evident trend of decentralization in spatial distribution, and regularization in the spatial morphology. Furthermore, residential land within rural settlements decreased by 33% over the past decade while the land for industry and commercial service steadily increased, demonstrating that the function for manufacturing and diversified services had been strengthened. Considering the emerging issue of the aging population and new business opportunities in rural Southern Jiangsu, rural settlements regeneration might be the focus of future research.

Keywords: rural settlements; spatial morphology; land use; Southern Jiangsu

1 Introduction

Rural settlements, defined as locations where rural inhabitants reside and engage in production, embody a holistic manifestation of rural society, politics, economy, and culture (Muilu and Rusanen, 2004; Tan *et al*, 2021). Rural settlements not only carry all aspects of rural production and life but also play an important role in shaping the mode of rural sustainable

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development, which always serves as a central focus in the research field of rural geography, and the study of the spatial evolution of hamlets often revolves around land as a critical perspective (Jin, 1989; Long, 2012; Tu and Long, 2020). In the new era of industrialization, urbanization, and economic globalization, the interactions between internal and external factors have resulted in significant changes to the socio-economic system of the Chinese countryside, profoundly affecting the evolution of rural settlements (Kiss, 2000). As land is limited to some extent, the expansion of rural settlement is likely to be at the expense of cultivated land (Cao *et al*., 2013; Conrad and Rudloff, 2015; Cao *et al*., 2017). Since the reform and opening-up in China, there has been a rapid increase in agricultural productivity, rural non-agriculture employment, farming household income, and housing demand, which has led to a surge of house construction in the countryside and occupied a large amount of high-quality farmland, posing the increasing pressure on the protection of arable land resources and grain security (Qu *et al*., 2005; Long *et al*., 2012). It is important to curb the expansion of land consumed by rural settlements to maintain the total cultivated land area in the interests of agricultural sustainability and food security for a huge population (Song and Liu, 2014). Simultaneously, a large number of houses have been left vacant or abandoned due to the permanent or temporary exodus of youth caused by large-scale industrialization and urbanization (Wang *et al*., 2022). Consequently, this coexistence of low efficiency in land resource use and rural settlements decline challenges the sustainable development of rural areas (Violette and Marin, 1998; Wang *et al*., 2005; Liu *et al*., 2009; Chen *et al*., 2010; Li *et al*., 2010; Long, 2013; Qiao *et al*., 2015). In this context, scrutinizing the evolutionary law of rural settlements and developing scientific guidance for optimizing the land use layout of rural settlements can not only boost the protection of arable land and agriculture transformation, but also contribute to the implementation of the national strategies of the new type urbanization and rural revitalization (Yao *et al*., 2014).

Family nucleation, house construction, and the famous economic deelopment model of rural industrialization characterized by "lighting fires in rural settlements and smoke coming out of households"[1] in the 1980s jointly promoted the great expansion and diversification of land use types within rural settlements in Southern Jiangsu (Zhang and Gu, 2002; Zhang *et al*., 2009; Wang and Li, 2011; Li *et al*., 2015). Since the end of the first decade of this century, various rural land consolidation projects, such as the "three concentrations" (Zhou *et al*., 2018), "three optimizations and three guarantees"[2], and "increasing vs. decreasing balance" (Long *et al*., 2012; Long, 2022) that are aimed at protecting the arable land and raising the utilizing efficiency of constructing land, have been successively implemented and drastically reorganized the land use patterns of rural settlements through integrating the manufacture enterprises into the rural industrial parks, moving rural residents to the apartment buildings, and amalgamating the small farms into the large ones (Sun and Weng, 2018; Zhou *et al*., 2018). This great spatial transformation of rural settlements has attracted considerable

[1] The characterization was originally coined by the eminent sociologist Fei (1984) to refer to the rapid development of the regional economy and industrial expansion in Southern Jiangsu (Sunan) based on the massive surge of collectively owned TVEs that prospered from the 1980s to the early 1990s (Shen, 2004).

[2] A policy aimed at protecting cultivated land by optimizing the structure of agricultural land, optimizing the spatial layout of construction land to ensure development, optimize the layout of residential land in towns and villages to protect rights and interests, which originated in Suzhou city (Wu *et al*., 2018).

attention from scholars and researchers in the field of rural geography (Sevenant and Antrop, 2007; Yang and Long, 2016).

A large body of research work has deeply explored the land use evolution characteristics and spatial trajectories of the rural settlements and the driving factors behind them in Southern Jiangsu (Li *et al*, 2010; Chen and Xie, 2016) since the reform and opening-up in the late 1970s. For instance, Jin (1989) provided a qualitative exposition on the spatial characteristics of rural settlements in China, while Han and Cai (2011) pioneered the basic characteristics, evolution and development types of peri-urban rural habitats. Subsequent studies have focused on probing the spatial reconfiguration patterns and the integrated driving mechanism in typical cases. For example, Chen *et al*. (2015) analyzed the spatio-temporal variation, evolutionary mechanism and optimization of morphology and function of rural settlements in Huishan district of Wuxi city. In a similar vein, Li *et al*. (2019) explored the evolutionary characteristics and driving mechanism of urban-rural scale system, using the well-developed Zhangjiagang city of Jiangsu province as a case. Explorations into the diversified and multifunctional land use patterns in typical industrialized rural settlements have also been a focal point of research. Li *et al*. (2018) systematically collected and analyzed spatial vector data of rural industrial patterns in Changshu city, a typical representative of the "Southern Jiangsu Pattern". Meanwhile, Han *et al*. (2017) employed Gongyi city as an example to reveal the diversified and multifunctional settlement land use pattern in typical industrialized rural settlements. Recent studies have turned to the matching relationship between the population dynamics and rural settlement land use. Liu *et al*. (2018) analyzed the sequential variation characteristics, spatial heterogeneity rules and coupling relationship types of Chinese rural land resources and population during the period 2007–2015. Additionally, Tian *et al*. (2018) investigated the evolution of rural settlement land in Changshu city and discussed the land expansion mechanism within the context of population shrinkage. Yet, the overall changes in the land use structure and spatial morphology of rural settlements that are crucial for understanding the functional transformations of rural areas in developed regions during high-speed urbanization and urban-rural integration development are rarely examined, hindering a deep understanding of the comprehensive evolutionary laws of rural area and settlements within such dynamic contexts.

Given this background, this study takes the rural settlements in Southern Jiangsu (excluding major urban areas) as an example, and develops the conceptual frameworks based on the integration of existing literature on urbanization's influence on rural development and policies associated with rural settlements construction. From the perspective of evolutionary characteristics of the size and shape of the rural settlement land as well as the types and structure of land use since the 1990s, we intend to reveal the spatial and temporal change rules of rural settlement land in developed areas in the context of rapid urbanization, huge population inflow and rural land management policy innovation, and to discuss the existing problems and the future regulatory inspiration.

2 The theoretical framework

While the natural factors, such as terrain, elevation, river, and so on, dominate the spatial characteristics of rural settlements (Guo *et al*., 2012), the socio-economic factors involving

industry structure changes, population growth and migration, infrastructure construction, and land use policy reforms remarkably affect the rural settlements' morphology evolution (Fan, 1994; Li *et al*., 2014; Kong *et al*., 2020) (Figure 1). Yet, each factor plays different roles in transforming the carrying functions and spatial patterns of rural settlements in the diverse development stages during the great process of urbanization (Zhu *et al*., 2014; Wang *et al*., 2023), and to some extent shapes the whole evolutionary trajectory of rural settlements (Tian *et al*., 2003; Li *et al*., 2022; Wu *et al*., 2022; Tao *et al*., 2023).

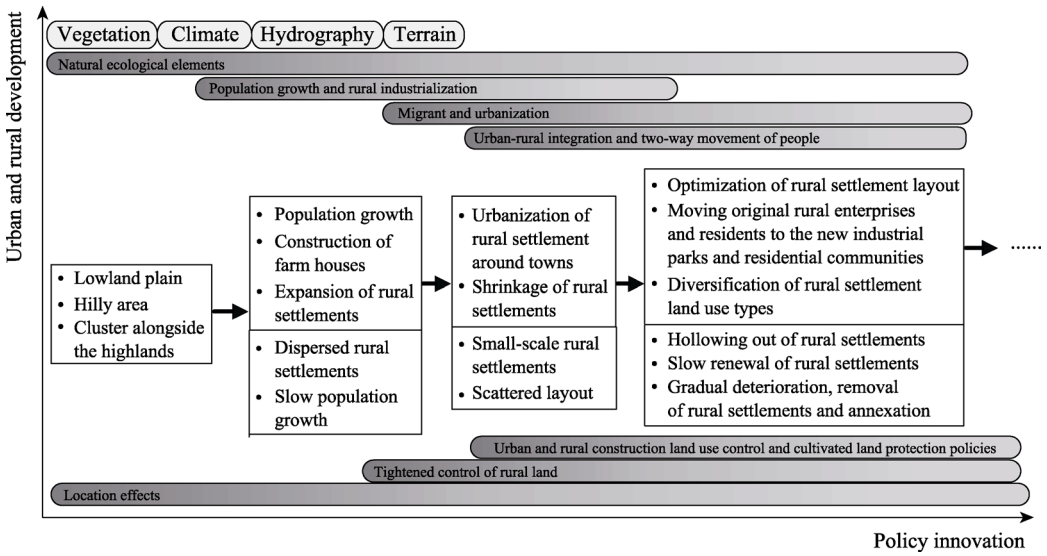

Figure 1 The framework for the evolutionary characteristics of rural settlements in the context of urbanization

A large body of scholarly work argued that in the agricultural-economic era, rural settlements were mainly clustered alongside the highlands for the reasons of strongly resisting natural flooding, conveniently getting water, and easily traveling by boat, especially in the lowland plain being full of lakes and rivers within the Taihu Lake basin (Feng *et al*., 2008; Huang and Zheng, 2021), while the spatial pattern of rural settlements in the hilly or gully region in the west was significantly characterized by the spatial distribution of the roads and cities (towns) to meet the needs of agricultural production and free flow of people and goods between rural and urban areas (Ma *et al*., 2012; Chen *et al*., 2015). The studies on the settlement evolution emphasized that accompanying the remarkable tendency of population growth and family nucleation in rural areas, waves of building new houses or renovating old buildings had surged multiple times, leading to the enormous expansion of rural settlements (Wang *et al*., 2005; Liu *et al*., 2009; Shan *et al*., 2012).

The research focusing on the rural economy development suggested that since the reform and opening-up, Southern Jiangsu had experienced an influential wave of rural industrialization, which boomed the rural economy, raised the local rural population's income level, and gathered plenty of immigrants from the less-developed rural areas closely related to the easing of strict regulation of rural-urban population flow, facilitating the continuous expansion of rural settlements along the main routes connecting to the towns and cities (Bibby, 2009; Wang and Li, 2011). Meanwhile, the spatial carrying functions and land use structure of ru-

ral settlements have undergone a systematic transformation with the prosperity of non-agricultural sectors, such as industrial manufacturing, warehousing and logistics, and commerce and services, which also increased the size of rural settlement patches (Wang and Li, 2011; Chen and Jin, 2015). Because of the less industrial and population agglomeration or even significant outflows of the local working-age population, the settlements within the remote rural areas remain fragmented and grow slowly (Xing *et al*., 2007; Zhou e*t al*., 2020).

The scholarly debates on rural land use management highlighted that in order to prevent the extensive expansion of urban, improve land use efficiency, and protect the farmland for grain security, since the mid-1990s, the Chinese government had begun to tighten the control of the growth of construction land and the encroachment of arable land. Consequently, the local authority accelerated the pace of land use management policy innovation to address the conflicts between urban and rural development and arable land protection (Chen *et al*., 2024). For instance, for grouping the planned new construction land quota approved by the central government and investing in large-scale industrial and urban development, the local government turned to rigorously constraining the rural dwelling construction and the expansion of rural settlements (Peng *et al*., 2014; Liu *et al*., 2016; Cui *et al*., 2022). Since the 2000s, the land use policy of "increasing vs. decreasing balance" (Long *et al*., 2012; Long, 2022) had been conceived, issued, and widely implemented by local and central governments respectively, which promoted the elimination of some scattered and vacant settlements and moved residents to centric villages and apartment buildings (Zhou *et al*., 2020).

Since 2008, similar rural land remediation projects, such as "three concentrations" (Zhou *et al*., 2018)and "three optimization and three guarantees", were widely carried out in Southern Jiangsu, and radically restructured the rural settlements by dismantling the hollow rural settlements, emerging the small and dispersed hamlets and farmland plots, and moving original rural enterprises and residents to the new industrial parks and residential communities (Wang and Li, 2011; Liu *et al*., 2012; Li *et al*., 2014; Song and Liu, 2014). In fact, these projects not only reshaped the holistic morphology of the original settlements, such as making them larger in size, more regular in shape, and dispersed in distribution pattern, but also composited their inner functional space, such as generating the specialized space for dwelling and leisure, industrial manufacturing, commerce, and services, and so on (Mann, 2009; Bittner *et al*., 2013; Li *et al*., 2014). The latest research soundly concerned that considering both the economic headwinds in the post-pandemic era and the new opportunities in the urban-rural integrated development stage, the spatial evolution of rural settlements might face serious uncertainty and unpredictability in the future (Chen *et al*., 2023).

From the perspective of the integrated framework for understanding the evolutionary trajectory of rural settlements in the context of urbanization described above, we proposed the following assumptions on the evolutionary characteristics of rural settlements within Southern Jiangsu region in the past two decades: (1) the scope and scale of rural settlement distribution have shrunk significantly; (2) the degree of spatial concentration of rural settlements might decline evidently; (3) rural settlement patches might begin to increase in size and become regular in shape; (4) residential area within rural settlement might decrease sharply, and the space for non-agricultural industry and commercial service might also witness obvious changes.

3 Methodology

3.1 Study area

The study area includes a total of 30 county (district) units within Southern Jiangsu[3], which is situated on the south bank of the Yangtze River and lies within the Taihu Lake basin, covering an area of 2.66 million ha (Figure 2). This region boasts hills, lakes, and an intricate network of waterways, complemented by vast high plains, and has a long cultural heritage and a dense population residing in various rural settlements due to a long history of agricultural, industrial, and commercial development.

In line with the great transformation towards industrialization and urbanization in Southern Jiangsu since the reform and opening-up, there was significant progress in agricultural productivity and rural living standards. In 2020, the agriculture sector in this region achieved commendable milestones, with the comprehensive mechanization rate in agricultural production reaching 90% and contribution of scientific and technological progress to the total agricultural output exceeding 70%, both ranking at the forefront within the province. Additionally, the per capita disposable income in rural areas has been more than 33,000[4] yuan (RMB) per year, surpassing the provincial average by 1.4 times. According to the statistical data, despite an impressive overall urbanization rate of 82.3% in Southern Jiangsu, the countryside in this region is home to a substantial population of approximately 3.13 million,

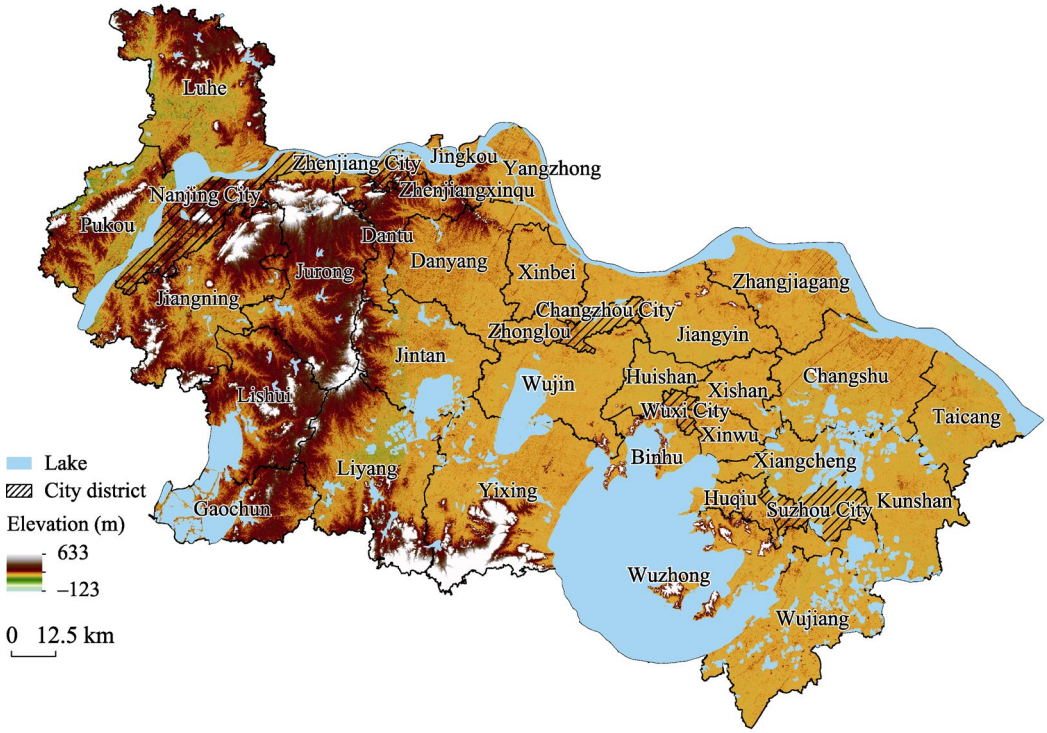

Figure 2 The overview of the study area (Southern Jiangsu, eastern China)

[3] Southern Jiangsu is the southern part of Jiangsu province, including Nanjing city, Wuxi city, Suzhou city, Changzhou city, and Zhenjiang city.

[4] Data come from Jiangsu Statistical Yearbook in 2021

and the proportion of permanent residents to registered population exceeded 90%, indicating the continued vitality of rural settlements compared to plenty of vacant rural settlements in other underdeveloped regions in the context of rapid urbanization (Tian *et al*., 2018).

Nonetheless, under the complicated context of intertwined transformation towards urbanization and agricultural modernization, the rural settlements within Southern Jiangsu have undergone a complex evolution in terms of both spatial morphology and functional structure.

3.2 Data collection and pre-processing

To precisely capture the changing trajectory of rural settlements within Southern Jiangsu, the data utilized in the paper incorporates essential geographic elements, administrative district boundaries, land use data of rural settlements, and demographic data.

Statistical data regarding rural settlements in 1999 was obtained from annual land use change survey (1999) results, which were primarily employed to underpin a comparative analysis of changes in the rural settlement scale. Furthermore, we extracted rural settlement land use data for the years 2009 and 2019 from land resource survey database, which significantly supported our investigation into the spatial dynamics of rural settlements. Through combing the methodologies of inverse superposition, remote image sampling verification, and interviews with land survey personnel, we rectified the internal land use categories within the rural settlements in land resource survey database in 2009 based on land resource survey database in 2019, calculated the proportion of non-construction land and gained the relatively precise boundaries of rural settlements in 2009. Then the rural settlement land use data in 1999 was corrected by applying the proportion estimated in the last step. All maps were superimposed on the base map provided by the Ministry of Natural Resources with the drawing review number GS (2019)1823, and the boundary of the base map remained unaltered.

Additionally, pertinent rural population and socioeconomic data were acquired from the census results involving the 5th, 6th, and 7th national population in 2000, 2010, and 2020, respectively, along with the statistical yearbooks and statistical bulletins at the county (district) level spanning the period from 1999 to 2019, and the data were segregated and integrated with the corresponding county (district) boundary (Figure 3).

3.3 Methods

To conduct a comprehensive time-series analysis of the transformations in the spatial morphology, distribution pattern, land use efficiency, and structure of rural settlements in Southern Jiangsu, the study employed an array of analytical methods including landscape analysis, proximity analysis, and spatial correlation analysis, etc., as follows:

Landscape shape index (LSI). Measuring the degree of morphological complexity of the rural settlement patch shape compared with the same area of the square, the formula is as follows:

$$LSI = \frac{0.25E}{\sqrt{A}} \tag{1}$$

where A is the area of the rural settlement patch, E is the perimeter, and LSI is the landscape shape index indicating the degree of difference between the shape of the rural settlement

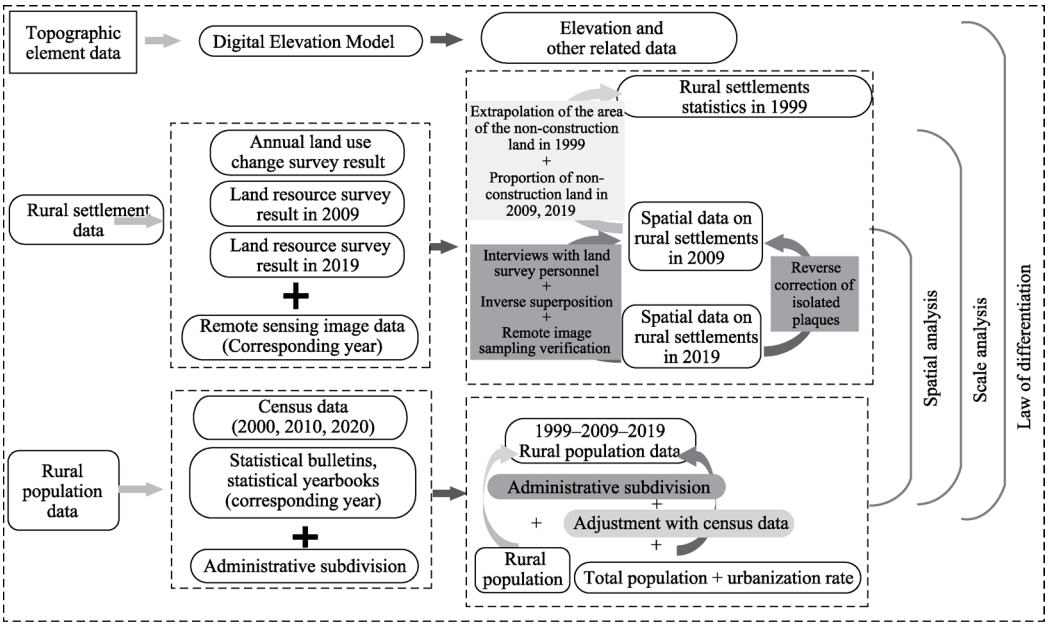

Figure 3 The workflow of data processing in this study

patch and the square. The value of the square patch index is 1. Therefore, the larger value of the landscape shape index indicates that the more the patch shape differs from the square the longer the patch shape is. When the value exceeds 3, the patch shape appears as a band.

Nearest neighbor analysis (ANN). The average distance between the center of mass of a rural settlement patch and the center of mass of its nearest neighbor patch is measured and compared with the expected average distance assuming a random distribution to characterize the degree of patch agglomeration, with the following formula:

$$ANN = \frac{\gamma_\alpha}{\gamma_\beta} = \frac{\sum \frac{d_{min}}{n}}{\frac{\sqrt{n/A}}{2}} = \frac{2\sqrt{\gamma}}{n} \sum d_{min} \quad (2)$$

where ANN is the average nearest neighbor index, γ_α is the average nearest-neighbor distance of the center of mass of rural settlement patches, γ_β is the theoretical average of the nearest-neighbor distances of the center of mass points under the assumption of spatial random distribution, d_{min} is the distance between the center of mass point of a rural settlement patch and the nearest-neighbor point of mass point, n is the number of rural settlement patches, A is the total area of spatial units, gamma is the spatial distribution density of rural settlement patches. If ANN<1, it is a spatially clustered distribution, and vice versa, it tends to be a spatially random distribution.

Grid density analysis (Fishnet). Using a 1 km×1 km standard unit grid instead of traditional administrative units, combined with spatial overlay analysis, the spatial distribution density of rural settlement patches was measured to support the analysis of spatial and temporal evolution characteristics.

Kernel density analysis ($f(x,y)$). The distribution density of rural settlement patches in a continuous spatial cell is estimated based on the observed values, and the specific formula is

as follows:

$$f(x,y)=\frac{1}{nh^2}\sum_{n}^{i=1}k\left(\frac{d_i}{n}\right) \tag{3}$$

where n is the number of observed locations (rural settlement patches) in the study area; h is the bandwidth or smoothing parameter, which determines the extent of influence of neighboring observations on the density estimation. A smaller bandwidth results in a more sensitive estimation to localized variations, while a larger bandwidth leads to a smoother overall estimate; k is the kernel function, a smoothing function that assigns weights to observed locations based on their distances from the point of interest, and d_i is the distance of the ith observed location from the point (x,y). A higher kernel density estimate indicates a denser distribution of rural settlement patches and vice versa.

4 Findings

4.1 Changes in the scale of rural settlements

The data presented in Figure 4 describes the continuous change in the total area of rural settlements in Southern Jiangsu over the past 20 years. The area of rural settlements hit 180,000 ha in 2019, representing an approximately 30% decline compared to 1999. Notably, the most substantial reduction in the area of rural settlements occurred between 2009 and 2019, accounting for about 70% of the total reduction in the area observed over the two-decade period, which might be attributed to the dismantlement and annexation of a significant number of rural settlements as a result of the implementation of rural land consolidation projects. During the same period, the rural population decreased from 13,691,000 to

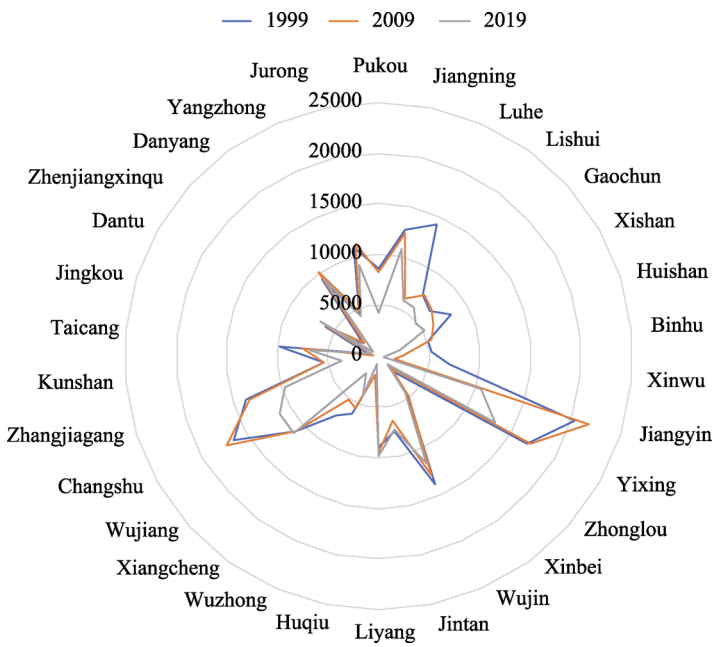

Figure 4 Statistics of rural settlements in each county-level city of Southern Jiangsu in 1999, 2009, and 2019 (ha)

9,782,900, and the per capita land use area of rural settlements reached 184 km^2 in 2019, down 2% compared to 1999. Unlike the traditional agriculture sector dominant regions (Long *et al*., 2009; Liu *et al*., 2010), the rural areas in Southern Jiangsu saw a distinctive phenomenon of obvious migrant influx since the reform and opening-up (Li *et al*., 2023). Consequently, the per capita land use area of the rural settlements "does not increase, but decrease", representing an evident improvement in the level of intensive utilization of rural settlement land.

The existing rural settlements are primarily concentrated in Jiangning district, Yixing city, Jiangyin city, Changshu city, Zhangjiagang city, and other county-level cities, which are located far from the central city in the plains along the Yangtze River and surrounding the Taihu Lake (Figure 5), accounting for roughly half of the total area of rural settlements in Southern Jiangsu. In places close to the central city, such as Luhe district, Wujin district, Xinwu district, Jintan district, Xiangcheng district, and Xishan district, the land use area of rural settlements fell more as a result of remarkable urban sprawl between 1999 and 2009. Conversely, large-scale land consolidation projects implemented between 2009 and 2019 facilitated the rapid decrease of rural settlements in the remote countryside regions far from the central cities, such as Jiangyin city, Changshu city, Zhangjiagang city, and the reduction of land use area of rural settlements within these areas accounted for about 4/5 of the total area of rural settlements disappeared in the past decade (Figure 4).

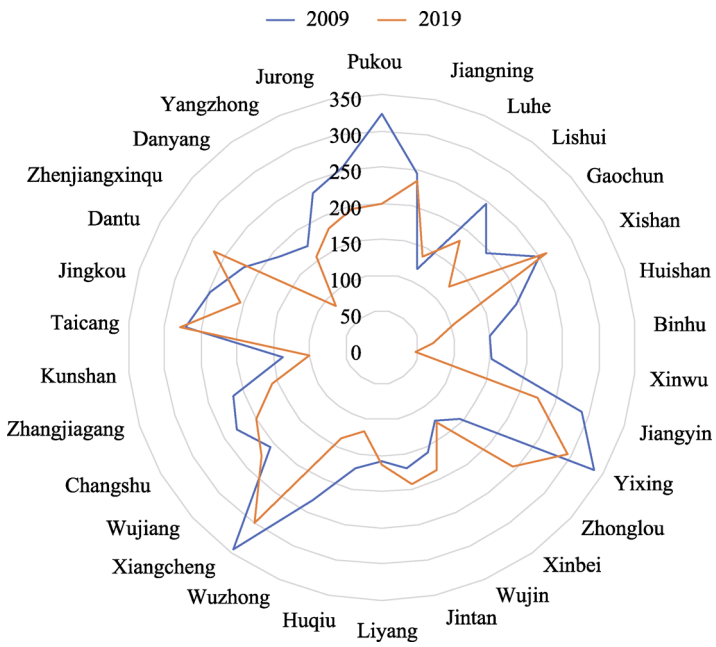

Figure 5 Statistics of per capita area of rural settlements in each county-level city of Southern Jiangsu in 2009 and 2019 (ha)

Although the land utilization of rural settlements in Southern Jiangsu tends to be more intensive compared to the other places, there is significant internal spatial differentiation. The level of intensive utilization of rural settlement land has increased more in places like Binhu district, Huishan district, and other districts or cities close to central urban areas, and

the rate of decline in per capita area of rural settlements has exceeded 40% (Figure 5). Our fieldwork suggests that low-rent rural houses near the urban areas or industrial parks are often the migrant laborers' preferred choice, which might be the crucial factor for improving the land-intensive utilization level of rural settlements in the outskirts of central urbans. In contrast, the per capita land use area of rural settlements has significantly increased in Jurong city, Danyang city, Yangzhong city, Yixing city, and so on, which are remote from the central urban area and experiencing the exodus of rural youth.

4.2 Changes in the spatial distribution patterns of rural settlements

According to the analysis of rural settlements at the land use patch level, the spatial distribution density of rural settlements has decreased from 12.9 to 11.1 per km^2 since 2009, the average area has less variance with a 40% decrease in variance and an overall tendency towards the median, and the patch landscape shape index has decreased from 2.5 to 1.4, which demonstrates that the spatial distribution of rural settlements in Southern Jiangsu tends to become decentralized, homogeneous, and regular during the past decade.

Spatial distribution density of rural settlements. The density of rural settlements declined by almost 14% between 2009 and 2019, while the nearest neighbor analysis index (ANN) climbed from 0.30 to 0.47, clearly indicating that the agglomeration degree of the rural settlements has obviously dropped in the past decade (Figure 6). Figure 7 shows that the rural settlements are densely spread along the Yangtze River's high plains, particularly in Yangzhong city, Danyang city, Xinbei district, Jiangyin city, Zhangjiagang city, Changshu city, and Taicang city, as well as in the low plain region near Gehu-Changdang Lake, and adversely the rural settlements in the southwest hilly regions are sparse, as well as in the vicinity of central cities. Especially, the regions with dense rural settlements shrank sharply between 2009 and 2019, and all the regions with rural settlements density higher than 60 per km^2 "disappeared" in 2019. On the contrary, the proportion of regions with low-density (less than 10 per km^2) rural settlements increased from 46.3% in 2009 to 53.0% in 2019. However, the rural settlements' general density distribution characteristics of "increasing from southwest to northeast" dominated by topography and industrialization and urbanization in Southern Jiangsu (Kong *et al*., 2020) remained over the past ten years.

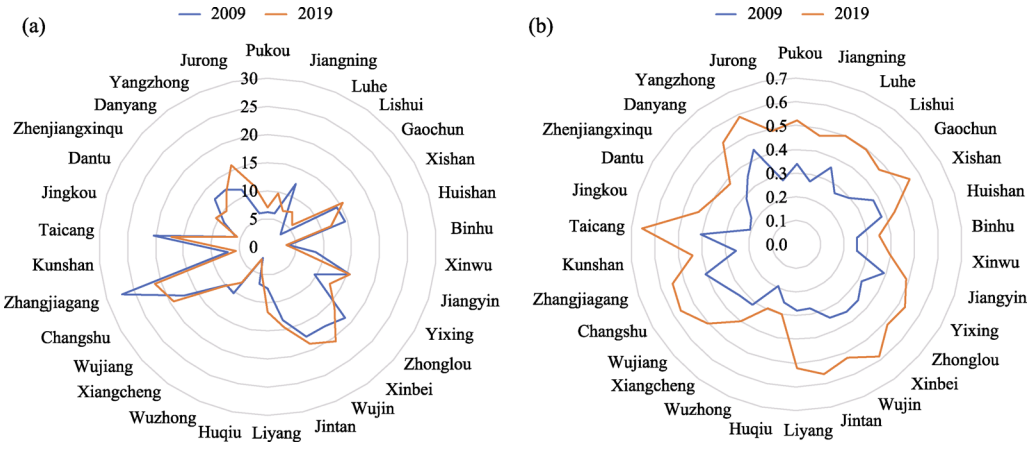

Figure 6 Rural settlements density (per km^2) (a) and ANN statistics (b) by county-level city in Southern Jiangsu in 2009 and 2019

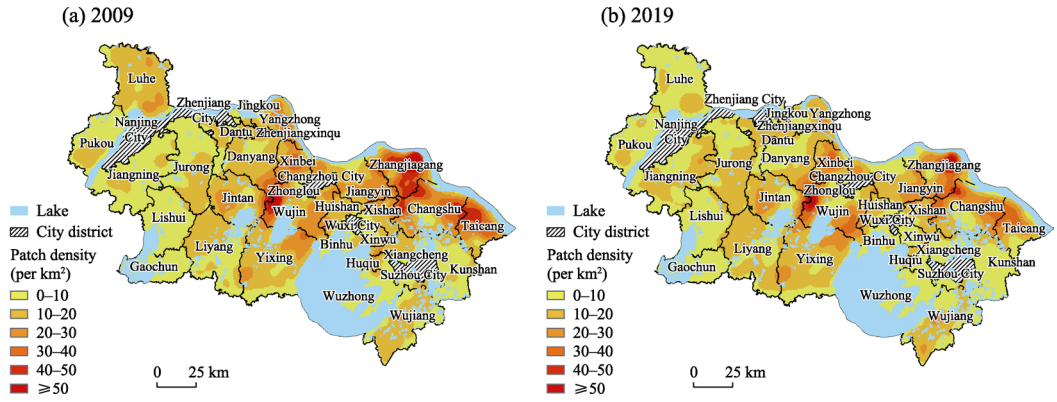

Figure 7 Spatial density distribution of rural settlements in Southern Jiangsu in 2009 (a) and 2019 (b)

The "size" of rural settlements. The variance of the individual size of the rural settlement patches in Southern Jiangsu has dropped by 40% between 2009 and 2019 (Figure 8), and is close to the median value, implying a clear homogenization process in sizes of rural settlements at the county (district) level in the past decade (Figure 9). ArcGIS 10.8 was used to map the spatial heterogeneity of rural settlements' size at the grid scale by calculating the average size of the rural settlements within each grid. According to Figure 8, the rural settlements larger than 1.5 ha in 2009 are primarily distributed in the plain areas of the north

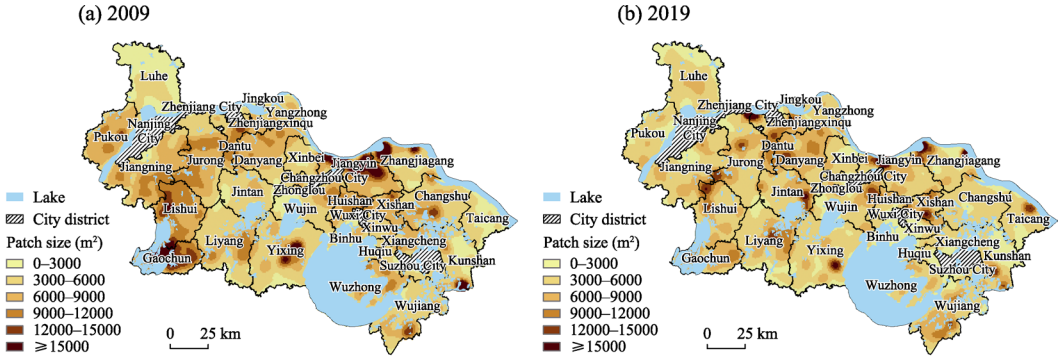

Figure 8 Average size of rural settlements by net in Southern Jiangsu in 2009 (a) and 2019 (b)

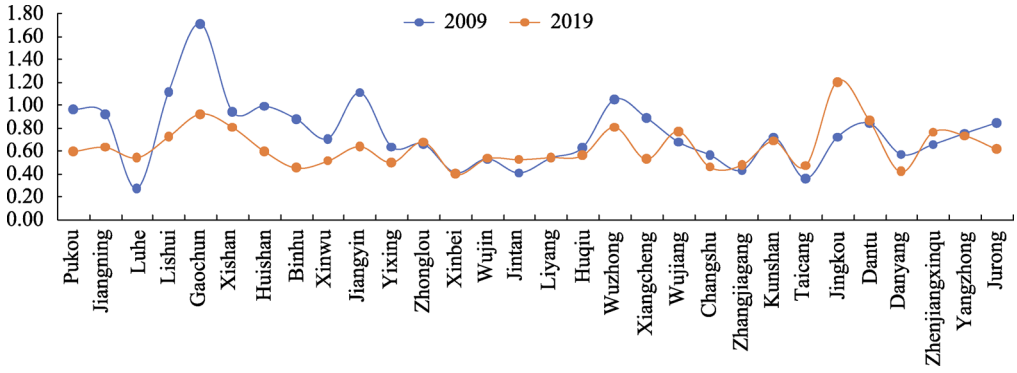

Figure 9 Average size of rural settlements by county-level city in Southern Jiangsu in 2009 and 2019 (ha)

along the Yangtze River. The rural settlements between 1.2 ha and 1.5 ha are scattered in suburbs like Lishui district, Jurong city, Huishan district, and other relatively developed areas, and the ones less than 0.6 ha are widely spread in the southwest hilly region. In 2019, there was a considerable decrease in the agglomeration area of rural settlements larger than 1.5 ha compared to that in 2009, and they appeared as islands scattered over some county-level cities, such as Lishui district, Jintan district, Jurong city, Jiangyin city, Zhangjiagang city, and so on. However, the concentration area of rural settlements between 1.2 ha and 1.5 ha has grown quickly, which are clustered in the outskirt districts of central cities, such as Xiangcheng district, Huqiu district, Zhonglou district, Jingkou district, and so on. The extensive rural settlement consolidation projects implemented during this period might be the key driver for this change.

The morphology of rural settlements. The landscape shape index (LSI) was employed to depict the morphology characteristics of rural settlements at the county (district) level. As demonstrated in Figure 10, the LSI of rural settlements in most county (district) units was close to 4.0 in 2009, and it showed that the overall morphology of rural settlements in Southern Jiangsu was close to long bands, which was closely related to the dense waterways and roads in this region (Ma *et al*., 2012). Yet, the LSI in many county-level cities declined to less than 1.5 in 2019, implying that the rural settlements in this region had seen significant external interference between 2009 and 2019, tending to be close to square or mass. Moreover, the LSI of rural settlements in the suburban areas, such as districts of Xinbei, Zhonglou, Huqiu, Binhu, and Xinwu is comparatively low, closer to 1, indicating that the recent rural settlements' "renewal and reconstruction" have been more intense, triggering a high degree of regularization and homogenization in the morphology of rural settlements.

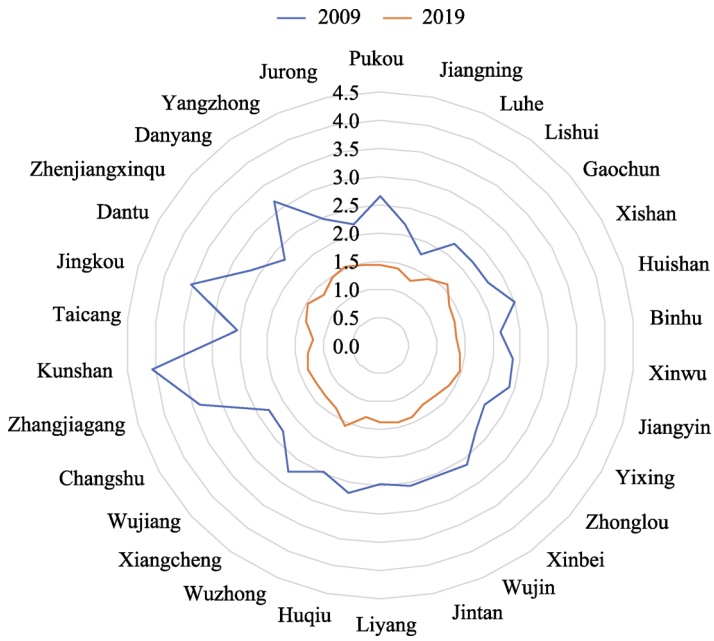

Figure 10 Landscape shape index of each county-level city of Southern Jiangsu in 2009 and 2019

4.3 Changes of the land use within rural settlements

Land use changes. In accordance with a considerable scale of non-agricultural economic activities, there is a considerable proportion of land for manufacturing and commercial service activities within the rural settlements in Southern Jiangsu, which is different from the rural settlements in the conventional countryside dominated by the agricultural sector (Cui *et al*., 2023). As shown in Figure 11, residential land and industrial land are the top two, accounting for 63% and 26% respectively, followed by land for commercial services, public management, and transportation at 11%. According to Figure 11, approximately 110,000 ha of rural settlements have been dismantled from 2009 to 2019 because of the implementation of rural land consolidation projects, involving residential, industrial and mining, transportation as well as public and commercial service land. Among the demolished rural settlements, the residential, industrial and mining, and transportation land are the top three, accounting for 65%, 21%, and 9% respectively. At the same time, a batch of new types of rural settlements has been developed, covering a total area of about 57,000 ha. Furthermore, approximately 45% of the newly added rural settlement land has been used for industrial and mining production, 30% for residential construction, 20% for commercial and public administration service provision, and 5% for transportation construction (Figure 11). Totally, from 2009 to 2019, residential and transportation land decreased by 55,000 ha and 6800 ha respectively, but industrial and mining land and commercial services and public administration land have increased by about 2800 ha and 5100 ha, respectively (Figure 11). It demonstrates while rural land consolidation initiatives like the “three concentrations” (Zhou *et al*., 2018) and the

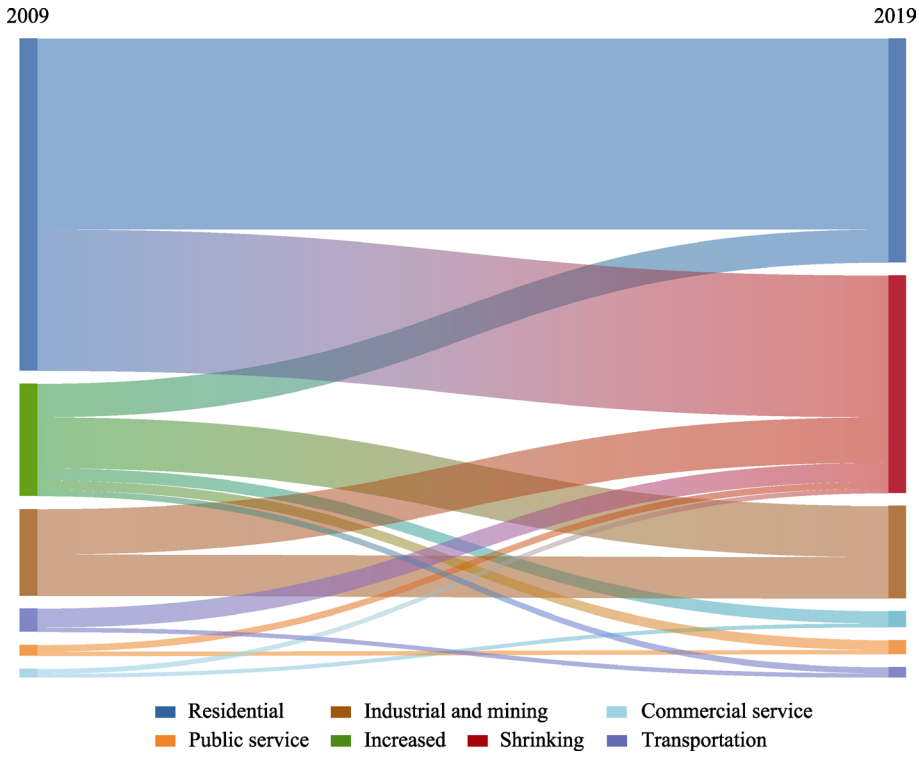

Figure 11 Land use types of transfer within the rural settlements in Southern Jiangsu in 2009 and 2019

"three optimization and three guarantees" have significantly "compressed" residential space in rural settlements in Southern Jiangsu, industrial and mining, and commercial service space did not reduce but increased slightly in the past decade.

Spatial differentiation of land use change of rural settlements. In the past 10 years, the residential land of rural settlements has reduced by nearly 33%, but the regional differences are obvious. At the county (district) level, the reclaimed rural residential land is primarily distributed in Zhangjiagang city, Lishui district, Changshu city, Jurong city, and other county (district) units along the Yangtze River as well as Wuzhong district, Wujiang district and other units surrounding the Taihu Lake, and the demolished rural residential land in each unit is more than 2000 ha. But in the other county (district) units near central urban, such as Luhe district, Jingkou district, Dantu city, Zhonglou district, Huqiu district, and so on, the rural residential land remediation scale is relatively small, which is generally less than 1000 ha (Figure 12a). Although the overall industrial and mining land in the rural areas of Southern Jiangsu increased, it mainly occurred in Wujiang district, Jintan district, Jurong city, Liyang city, Taicang city, etc., and some county-level cities along the Yangtze River and the Tahu Lake, such as Zhangjiagang city, Jiangyin city, and Wujiang district, have seen

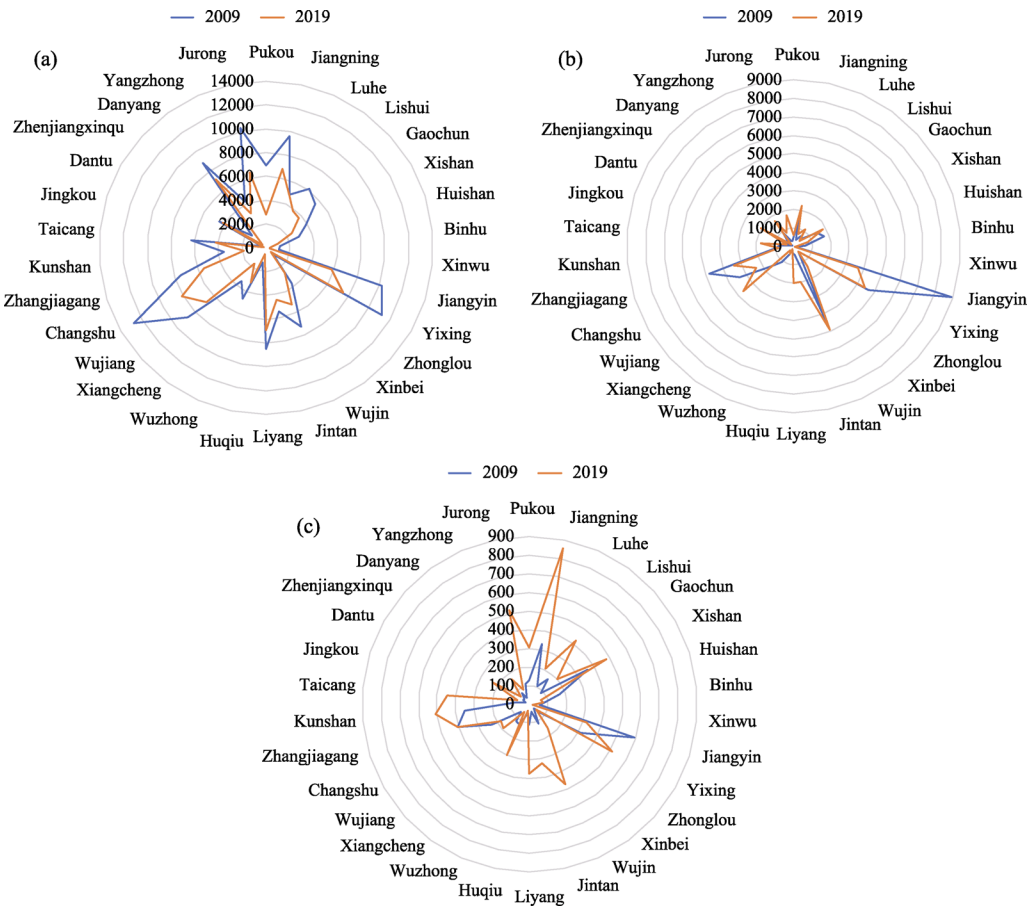

Figure 12 Statistics of land use types by county-level city in Southern Jiangsu in 2009 and 2019 (ha) (a. Rural residential land; b. Rural industrial and mining land; c. Commercial service and public administration land)

considerable shrinkage of industrial and mining land within rural settlements (Figure 12b). It suggests that the total scale of industrial space within rural settlements remains stable under the context of high-speed urbanization, while large amounts of rural industrial and mining land in the peripheral county-level cities have been reclaimed to meet the strategic goal of the intensive utilization of construction land at the county (district) level (Figure 12c). Additionally, rural settlement land for commercial services and public administration has expanded quickly, but it is mainly concentrated in Jintan district and Wujin district adjacent to the central urban, which is in line with the distribution characteristic of the population, especially the immigrants from underdeveloped regions (Figure 12c).

5 Conclusions and discussion

5.1 Conclusions

This study took the rural settlements in Southern Jiangsu, which had witnessed the transformations of rural industrialization, high-speed urbanization, and rural-urban integration, as the research objects, and focused on detecting the spatial evolution trajectory of rural settlements during these continuous transformation processes. Drawing on the previous literature on rural economy transformation, rural settlements, and rural land management, this paper constructed the theoretical analysis framework and introduced the spatial and comparative analysis methods. Based on the land resource surveys, socio-economic statistics, and field interview data, this study explored the evolutionary characteristics of scale, morphology, spatial distribution, and land use of rural settlements within Southern Jiangsu in the past 20 years to deepen the understanding of the evolution of the rural system in developed regions. The conclusions are as follows:

(1) Population growth, improvement of living conditions, and rural industrialization have promoted the rapid growth of rural settlements in Southern Jiangsu in the early stage of reform and opening-up. Increasingly "tightened" rural housing construction control and rural land remediation actions for arable land protection and intensive utilization of construction land have not only successfully prevented the continued expansion of rural settlements, but also fundamentally transformed their land use characteristics. The analysis shows that the rural settlements in Southern Jiangsu have shrunk by 29.7% from 1999 to 2019 and the residential land within the rural settlements has decreased by 32.6% in the past decade, partly confirming the first and fourth hypotheses mentioned in the framework section. Spatially, the dismantling of rural settlements mainly took place in the adjacent areas of the central cities between 1999 and 2009, while the rural settlements consolidation primarily happened in the hilly and mountainous areas in the southwest and the plains along the Yangtze River in the later 10 years. Meanwhile, the per capita area of rural settlements has decreased by nearly 2% due to the migrant influx attracted by more local job opportunities and relatively low living costs compared to that in cities, implying an obvious improvement in intensively utilizing the land resources that are different from the conventional countryside.

(2) Rural housing construction and rural industrialization led to the early expansion of rural settlements, and through demolishing the small, scattered, and chaotic rural settlements and building new types of communities, the recent rural land consolidation projects have radically restructured the spatial morphology and distribution characteristics of the rural settlements in Southern Jiangsu. The empirical analysis found that the average density of rural

settlements decreased by 14%, the average nearest neighbor index increased 56.7% (still less than 1), the average shape index decreased by 44%, and the average area of the rural settlement patch was closer to the median of individual patches area from 2009 to 2019, fully supporting the second and third assumptions proposed in the section of theoretical framework and indicating a remarkable tendency of homogenization and regularization in the spatial morphology and a clear trend of decentralization in spatial distribution of rural settlements in the later 10 years.

(3) Despite the fact that rural industrialization, high-speed urbanization, and rural land consolidation have significantly altered the spatial characteristics of rural settlements in Southern Jiangsu, the overall spatial distribution pattern has not fundamentally changed over the recent ten years. The low plains in the central, north and southeast areas continue to be densely populated with rural settlements, while the hilly and mountainous areas in the southwest are still widely dispersed. However, as a result of widespread urban sprawl and rural settlements amalgamation activities, the density of rural settlements in the eastern low plain of the Taihu Lake has been significantly reduced, and the traditional rural landscape in the plain crisscrossed with waters become more and more “bleak”.

(4) The considerable non-agricultural economic activities within the rural areas not only contribute to maintaining the rural vitality but also result in the diversification of land use of rural settlements within Southern Jiangsu. From 2009 to 2019, rural residential land has declined by 32.6%, industrial and mining land has expanded by 6.4%, and commercial and service land has evidently increased in Southern Jiangsu, leading to a higher degree of diversification in land use of rural settlements and partly corroborating the fourth assumption. This also demonstrates that over the recent ten years, the specialized space for industrial production has steadily been expanded, the service space for commerce, leisure, logistics, and so on, has also seriously improved, and the living space within rural settlements has “shrunk” significantly corresponding to the depopulation reality in the countryside. But this change in the land use of rural settlements provides a better space guarantee for the stable and diverse rural economy in Southern Jiangsu.

5.2 Discussion

(1) In this study, the edge and land use type of rural settlements in land resource survey data in 2009 were reconstructed by the reverse superposition of land resource survey data in 2019, and the expertise of the land investigators and the remote images of the suspected land patches were combined to rectify the reconstructed rural settlements (delete the non-construction land patches and correct the edges of rural settlements). The proportion of non-construction land in the reconstructed rural settlements of each county (district) unit was used to rectify the statistical data of rural settlements in 1999. We have to acknowledge that the “reconstructing” and “rectifying” process implemented in this study has some limitations and might affect the accuracy of rural settlement data in 2009 and 1999, while it could satisfy the general requirements for the comparable analysis on scale of rural settlements between 1999 and 2019 and the spatial analysis on morphology, distribution, and land use of rural settlements in 2009 and 2019. On the other hand, we have not succeeded in building the completely changing data of rural settlements ranging from pre-industrialization to post-urbanization because of the huge difficulty in acquiring comparable data in the 1970s

and 1980s. Thus, we hope further studies could do better in fulfilling this gap to fully examine the theoretical framework established in this paper. In addition, due to the frequent adjustments of administrative divisions, it might have a certain negative impact on the calculation results of the per capita area of rural settlements. Lastly, the findings in this paper still need to be further verified by follow-up or peer research.

(2) The rural settlements regeneration actions in the recent decade have optimized the distribution and land use structure of rural settlements to some extent, improved the rural living and working conditions, and offered ideal rural space for steady and sustainable rural socio-economic activities. Yet, with the advancement of agricultural modernization and urbanization, it might be difficult to avoid the problems of rural and settlements recession similar to those in conventional rural areas dominated by the agriculture sector, despite the fact that the influx of migrating laborers has to some extent concealed the issues of outflow of local youth and aging population in Southern Jiangsu. Fully considering the concept of consumerism countryside in the post-urbanization stage and the consumption preference and huge consumption demand of urbanites in Southern Jiangsu, accelerating the commercialization of rural settlements and excavating and marketing the value of the countryside in Southern Jiangsu may be an important direction worthy of attention in the future study of sustainable development of rural settlements.

(3) In the new development stage, the conventional rural settlements management rules should be reformed as soon as possible. Taking the weakened demand in new urban construction land in the post-urbanization period, it might not be necessary to promote the large-scale consolidation of rural settlements in Southern Jiangsu, which not only help alleviate the local governments' budget burden, but also might reduce the number of social conflicts occurring in the rural areas (Tan, 2012; Chen, 2022). On the other side, for supporting the new innovation and entrepreneurship activities operated by the possible reverse rural-urban migration groups in the context of economic downturn in the post-pandemic era and rural revitalization, the local governments need to deeply relax the management of rural settlements and encourage the in-movers to renew the functions of rural settlements for hosting the new economic activities such as leisure residence, cultural innovation, and the other new businesses, by depending on their own resources. Nevertheless, for facilitating the urban-rural integration development and rural revitalization, the ongoing improvement of rural infrastructure and public services provision should be emphasized forever.

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