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Dynamic changes and driving factors of rural settlements at the county level in a rapidly urbanizing province of China from 2000 to 2020

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Urbanization and industrialization in developing countries has contributed to great changes in rural settlements, which presents an increasing threat to rural sustainability. Spatiotemporal changes in rural settlements at the county level are significant to land use planning and are not clear in the highly urbanized regions. This study considered Jiangsu, one of the most urbanized provinces of China, as an example and investigated the spatial variation in rural settlements and their socioeconomic driving factors during the period of 2000–2020 using mixed geographic weighted regression. The results showed that the area of rural settlements in the highly urbanized province expanded from 2000 to 2015 following a decrease in the rural population, but then began to decrease from 2015. There were obvious spatial differences in the rural settlements in the counties of Jiangsu Province. The area of rural settlements in the different counties maintained a positive association with the rural population and cropland but had a negative correlation with the rural production value in 2000. By 2020, the area of rural settlements was only positively associated with the rural population. The correlation between the area of rural settlements and rural population continually decreased from 2000 to 2020. The area of rural settlements had no significant association with the area of urban settlements. The expansion of rural settlements mainly occurred at the expense of cropland. The decrease in the rural settlements was accompanied by an increase in the urban settlements and an expansion of cropland. The policy implications arising from this study are presented to provide guidance for rural development at the county level and ensure rural sustainability.

KEYWORDS

land use, human-land relationship, rural development, geographic weighted regression, spatial analysis

1 Introduction

Due to global urbanization, less than half of the world's population (46%) lived in rural areas by 2014, and the proportion is expected to further decrease to 34% by 2050 (Leeson, 2018). In 2018, rural communities still accounted for more than half of the population in other developing countries, such as India (65%) and Cambodia (76%). The

population of rural areas depends on agricultural and pastoral practices in agricultural societies and varies spatially and temporally, with changes driven by industrialization and urbanization, which has altered the livelihoods and social stability of rural communities (Wright et al., 2012). The rural population has been exhibiting a persistently declining trend (Song and Liu, 2014). Rural settlements represent a multifaceted blend of physical and non-physical resources that play a crucial role in sustaining farming livelihoods. They serve as a significant, tangible manifestation of the human-land relationship (Zhao et al., 2019; Zhu et al., 2020). As the rural population dwindles, the vitality of most rural communities has progressively diminished, posing a significant challenge to sustainable urban development and regional sustainability. Monitoring the spatiotemporal changes of rural settlements can offer valuable practical insights into the evolving interaction between rural populations and their environment, thereby promoting the sustainable development of rural areas.

The type, form, and configuration of rural settlements was investigated as early as the 1930s (Hall, 1931; Scofield, 1938; Trewartha, 1946). With the development of remote sensing (RS) and geographic information system (GIS) technology, many researchers have described and explained the location, distribution, patterns, structure, changing characteristics, and function transition of rural settlements (Rey and Bachvarov, 1998; Gude et al., 2006; Feng et al., 2007; Yan et al., 2014; Jiang et al., 2022). The factors and driving forces affecting the evolution of rural settlements have been clarified and include natural geographic elements, demographics, infrastructure, industrial transformation, macroeconomic policies, and household behavior (Long and Li, 2012; Conrad et al., 2015; Amado et al., 2018; Rosner and Wesołowska, 2020; Zhang et al., 2023). Changes to rural settlements have nonnegligible environmental impacts, such as farmland and paddy soil loss in metropolitan areas (Chen and Taniguchi, 2016; Zhou et al., 2022) and environment damage in watersheds (Liao et al., 2023).

Rural revitalization is officially conducted in both developed and developing countries (Chen Y. et al., 2022). Rural revitalization is a way of positively transforming rural areas for present and future generations to create vibrant rural areas that can attract and retain employed, educated, and healthy rural residents. Rural settlements are growing in some developed countries due to rural revitalization movements (Knight, 1994). In addition, the decline of agglomeration economies has led to counter-urbanization, and polarized urban areas have been replaced with medium cities and rural locations in Italy (Salvia et al., 2020). Since the reform and opening-up policies of 1978, China has experienced substantial socioeconomic development and rapid urbanization, which has been characterized by a large population shift from rural to urban areas. As the rural population has declined, rural settlements have experienced complex changes. Rural residents have tended to migrate to urban areas to seek employment opportunities, resulting in the "hollow villages" phenomenon (Chen et al., 2017; Ma et al., 2018; Huang et al., 2020). To revitalize rural areas, national macroeconomic strategies in China emphasized the building of a "new countryside" in the early 2000s (Long et al., 2012).

Due to rapid economic growth and the population increase in cities, built-up urban areas have continued to sprawl into the surrounding countryside, which has led to a reduction in the area of rural settlements. Conversely, it has been argued that the area of rural settlements is not diminished by rural–urban migration due to China's dual system of land ownership and dual-track structure of rural–urban development (Long et al., 2009). Rural settlements in China are part of a complex process and serve as crucial land control indicators that the Chinese government considers during the planning process (Zou et al., 2020). The spatial heterogeneity of these settlements at the county level is pivotal for sustainable rural development and regional planning. In China's top-down land planning system, the responsibility of planning tasks falls on county-level management departments. These departments respond to indicators provided by higher level departments (Han et al., 2021), focusing on the intensity and methodology of resource development, environmental quality, and degree of stress.

Understanding the spatiotemporal characteristics and driving forces behind the evolution of rural settlements at the county level is fundamental to developing plans for the construction of new rural areas and sustainable regional planning. While numerous studies have examined on the spatiotemporal variation of rural settlements (Tian et al., 2014; Qu et al., 2017; Li and Song, 2019; Jia et al., 2020; Chen Z. et al., 2022; Tang et al., 2022), the current methods for identifying the driving factors of rural settlements primarily rely on traditional statistical analysis techniques such as regression analysis (Wang and Zhang, 2021; Liao et al., 2023), coupled analysis (Zhu et al., 2020), and redundancy analysis (Li et al., 2020). However, these methods do not consider spatial heterogeneity, where sample distributions vary across different regions and the factors influencing the dependent variable differ significantly between regions. Therefore, it is necessary to incorporate spatial relationships into the model. Mixed geographically weighted regression (MGWR) can address the limitations of traditional statistical methods by considering spatial heterogeneity for investigating the socioeconomic factors driving the development of rural settlements, especially in regions with significant spatial disparities. In this study, we determined how rural settlements have changed at the county level from 2000 to 2020 in a developed province of China. We considered three key questions: What are the spatiotemporal characteristics of changes in the area of rural settlements in a rapidly urbanized area during the last 2 decades? Is the area of rural settlements reduced by urban land expansion? What is the spatial heterogeneity of rural settlements and its relationship with socioeconomic factors? The findings will contribute to an integrated urban-rural development model, and provide a reference for land use planning, enabling managers to respond to the pressure of rapid urbanization and regional inequality.

The remainder of this paper is structured as follows. Section 2 introduces the study area, data, and research methods. Section 3 presents an analysis of the changes in the area of rural settlements, and the spatial heterogeneity of rural settlements and its driving forces. Section 4 presents a discussion of the results and the policy implications of the study. Section 5 offers some concluding insights and perspectives for future research.

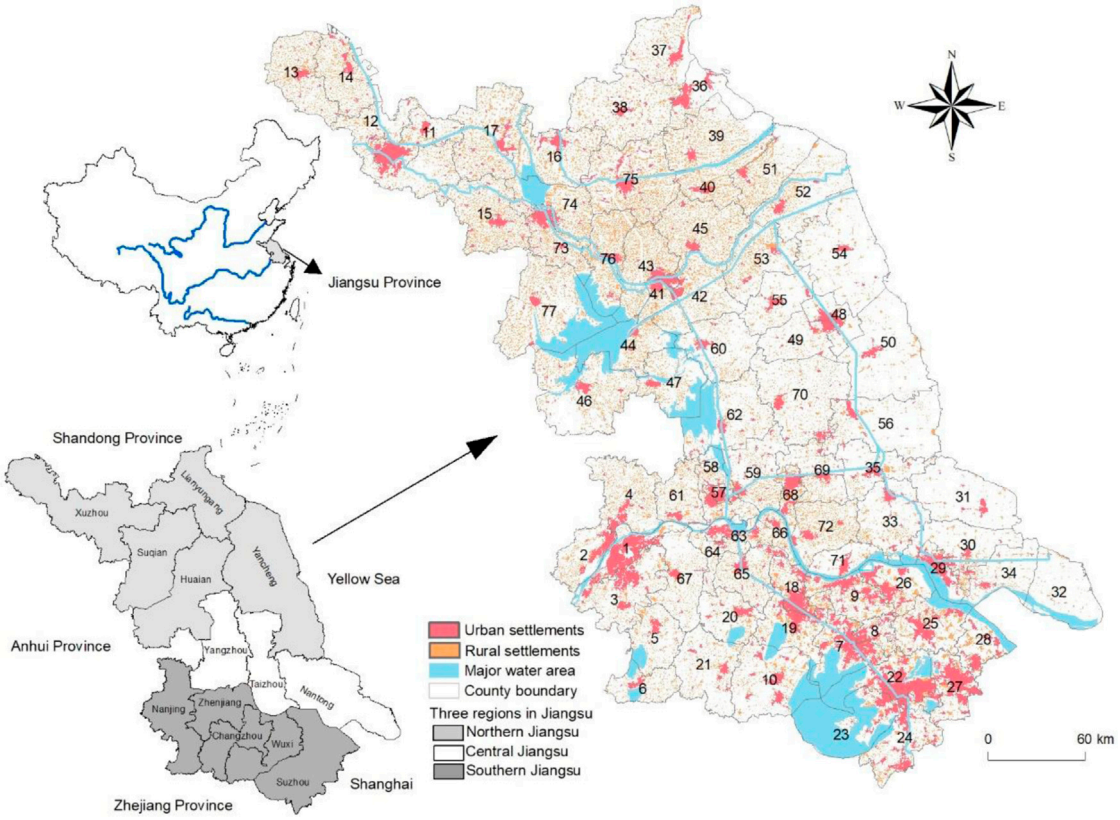

FIGURE 1
Location of the study area. The corresponding of the number and county name is at the Supplementary Table S1.

2 Materials and methods

2.1 Study area

Jiangsu is an eastern-central coastal province in China, and is one of the most developed and densely populated areas of the country. It is located between 116°18′–121°57′E and 30°45′–35°20′N (Figure 1). Jiangsu has the second highest GDP of all Chinese provinces, after Guangdong. The province has a population of 85.05 million, with a population density of 793 people per km^2 in 2021. It covers a total area of 107,200 km^2, including 13 prefecture-level divisions and 77 county-level divisions. The province can be subdivided into three regions, i.e., northern, central, and southern Jiangsu. Central Jiangsu can be considered a transition zone between southern and northern Jiangsu. It has benefited from the reforms of 1978, with the most rapid urbanization in China occurring in Jiangsu associated with industrialization and economic development. However, a large south–north imbalance has been generated in conjunction with the economic development (Wei et al., 2020). In 2000, GDP *per capita* was 22,297 CNY in southern Jiangsu, but it was only 9,298 and 6,288 CNY in central and northern Jiangsu. Thus, Jiangsu Province can be considered a rapidly urbanized area and a typical case study to investigate how rural settlements have changed under the pressure of urbanization and regional inequality.

2.2 Data source

Land use and cover data with a spatial resolution of 30 × 30 m for Jiangsu province in 2000, 2005, 2010, 2015, and 2020 were obtained from the Chinese Academy of Sciences (http://www.resdc.cn/, Figure 2). Land use data were classified as cropland, forest land, grassland, water area, urban settlements, rural settlements, other built-up land, and unused land. The economic and demographic data of the 77 counties in Jiangsu Province were collected from the Jiangsu Rural Statistical Yearbook (2001–2021).

2.3 Methods

2.3.1 Degree of change index

To represent the change characteristics of rural settlements during 2000–2020, an index of the speed of change in rural settlements was used to indicate the degree of change and intensity of rural settlements at different time intervals (Li et al., 2020):

$$CR = \frac{A_b - A_a}{A_a} \times \frac{1}{T} \times 100\% \quad (1)$$

where CR is the rate of change in rural settlements at different time intervals, A_a is the area of rural settlements in the first stage, A_b is the

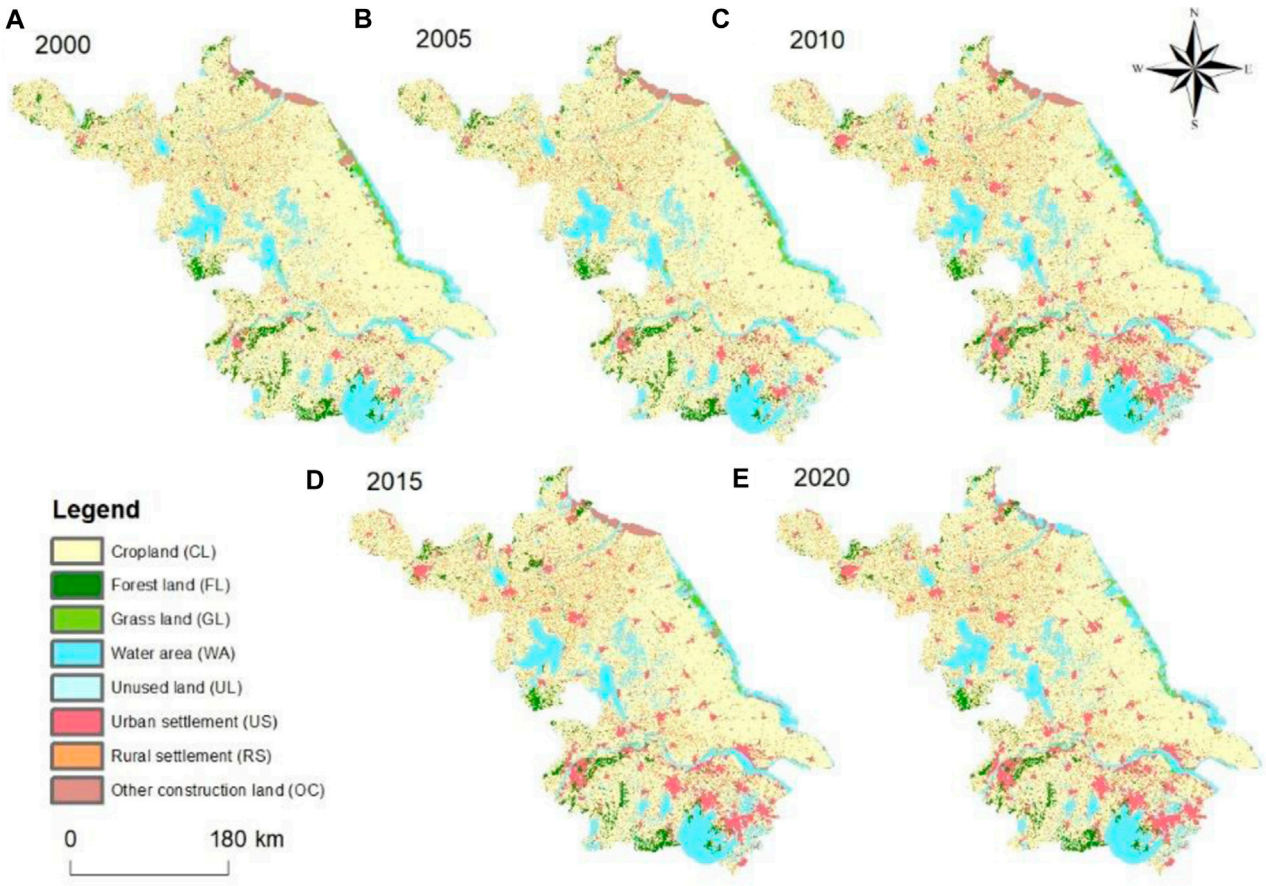

FIGURE 2
Classified land use map of Jiangsu province in 2000 **(A)**, 2005 **(B)**, 2010 **(C)**, 2015 **(D)**, and 2020 **(E)**.

area of rural settlements in the final stage, and T is the time interval between periods *a* and *b*.

2.3.2 Land use conversion index

In previous studies, the land use conversion structure significance index (CSS) has been used to quantify the proportional conversion of land use type i of the total net changes in rural settlements over a set period (Li et al., 2020). However, when applied in this study some information was lost in the net changes. Thus, the land use conversion index was calculated to identify the gross proportional conversion of land use type *i* in the total gross changes in rural settlements during the study period. The formula was as follows:

$$LCI_i = \frac{A_{r,i} + A_{i,r}}{A_{in} + A_{out}} \times 100\% \quad (2)$$

where LCI_i is the proportional contribution of land use type *i*, and LCI varies from 0 to 1; $A_{r,i}$ is the area of rural settlement converted from land use type *i*; $A_{i,r}$ is the area of rural settlement converted into land use type *i*; A_{in} is the total area of rural settlement converted from all other land use types; and A_{out} is the total area of rural settlement converted into all other land use types.

2.3.3 Mixed geographic weighted regression (GWR) model

The multiple linear regression (MLR) and mixed GWR models used in this research were used to identify the driving forces of the spatial heterogeneity of rural settlements. Geographic weighted regression is a regression technique that extends the traditional regression framework by allowing the estimation of local rather than global parameters. It is a useful regression model for working with non-stationary data because it can detect where locally weighted regression coefficients move away from their global values. In GWR, the fitted coefficient values of a global model fitted to all the data may not adequately represent the detailed local variation in the data. GWR is a typical regression model with geographically varying parameters that was considered suitable for location data processing in this research. The traditional MLR model assumes that the explanatory variables are spatially stationary and only provides the global effects (Xie et al., 2021). A mixed GWR model estimates the explanatory variables with both local and global effects (Kang et al., 2010), and was formulated as follows in this study:

$$y_i = \sum_j \beta_j(\mu_i, v_i)x_{ij} + \sum_m r_m Z_{im} + \varepsilon_i \quad (3)$$

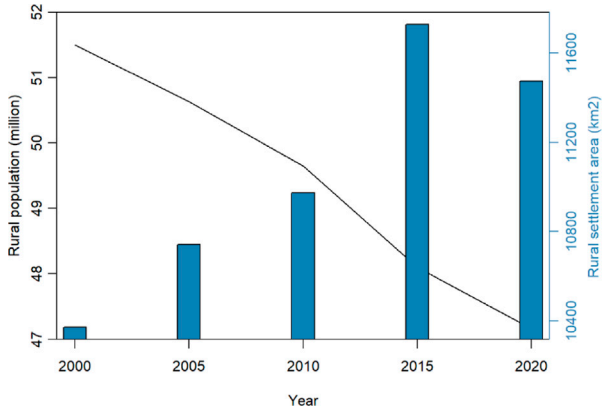

FIGURE 3
Rural population and the area of rural settlements during 2000–2020.

where y_i is the dependent variable at location i, which is the area of rural settlement in county *i*; β_j (μ_i,ν_i) is the value of the estimated parameter of the *j*th explanatory variable at location *i*; x_{ij} is the *j*th explanatory variable at location *i*, which could be rural population, rural production value, cropland area, and area of urban settlement in county *i*; Z_{im} is the *m*th explanatory variable without local effects; r_m is the coefficient of Z_{im} and is invariant across locations; and ε_i is an error term.

3 Results

3.1 Spatiotemporal characteristics of rural settlements during 2000–2020

The total area of rural settlements in Jiangsu Province showed a gradually increasing trend from 10,362.98 km^2 in 2000 to 11,718.07 km^2 in 2015. Interestingly, the increases in the area of rural settlements from 2000 to 2015 were not consistent with the changes in rural demographics (Figure 3). After 2015, the area of rural settlements at the provincial level began to decrease, reaching 11,467.05 km^2 in 2020. Figure 4 illustrates the spatial pattern of rural residential areas in Jiangsu Province, characterized by a higher concentration in the northern and western regions, and a lower concentration in the southern and eastern regions. The spatial distribution of *per capita* rural residential areas in this province generally aligns with the overall distribution of residential areas. Furthermore, there is a consistent upward trend in *per capita* rural residential areas throughout Jiangsu Province. The area of rural settlements in 77 counties of Jiangsu Province increased during 2000–2005 and 2010–2015, consistent with the provincial trend (Figure 5). The area of rural settlements in the southeastern and northwestern regions of Jiangsu Province decreased from 2005 to 2010, which differed from the provincial trend. The area of rural settlements around the Nanjing and Su-Xi-Chang metropolitan areas and the northern part of Jiangsu Province decreased from 2015 to 2020, which contrasted with the provincial trend.

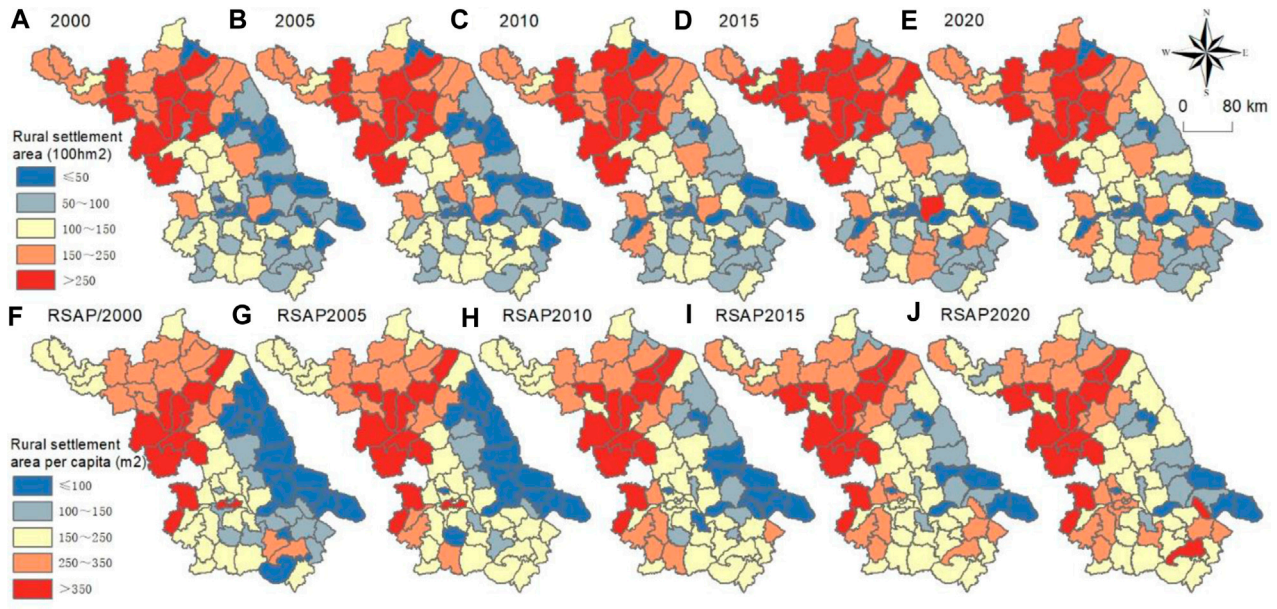

FIGURE 4
Rural settlement area of 77 counties in Jiangsu province in the years 2000 **(A)**, 2005 **(B)**, 2010 **(C)**, 2015 **(D)**, and 2020 **(E)**. Rural settlement area *per capita* of 77 counties in Jiangsu province in the years 2000 **(F)**, 2005 **(G)**, 2010 **(H)**, 2015 **(I)**, and 2020 **(J)**.

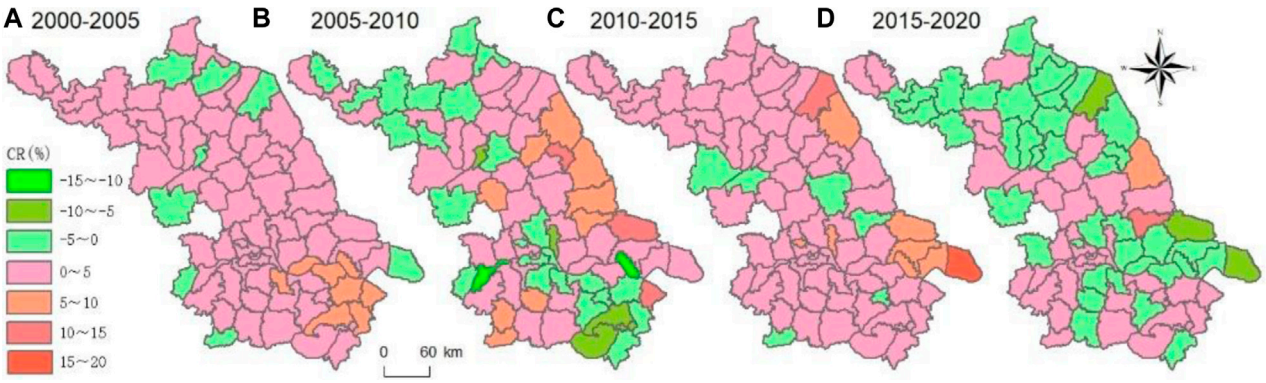

FIGURE 5
Changes in the area of rural settlements during **(A)** 2000–2005, **(B)** 2005–2010, **(C)** 2010–2015, and **(D)** 2015–2020.

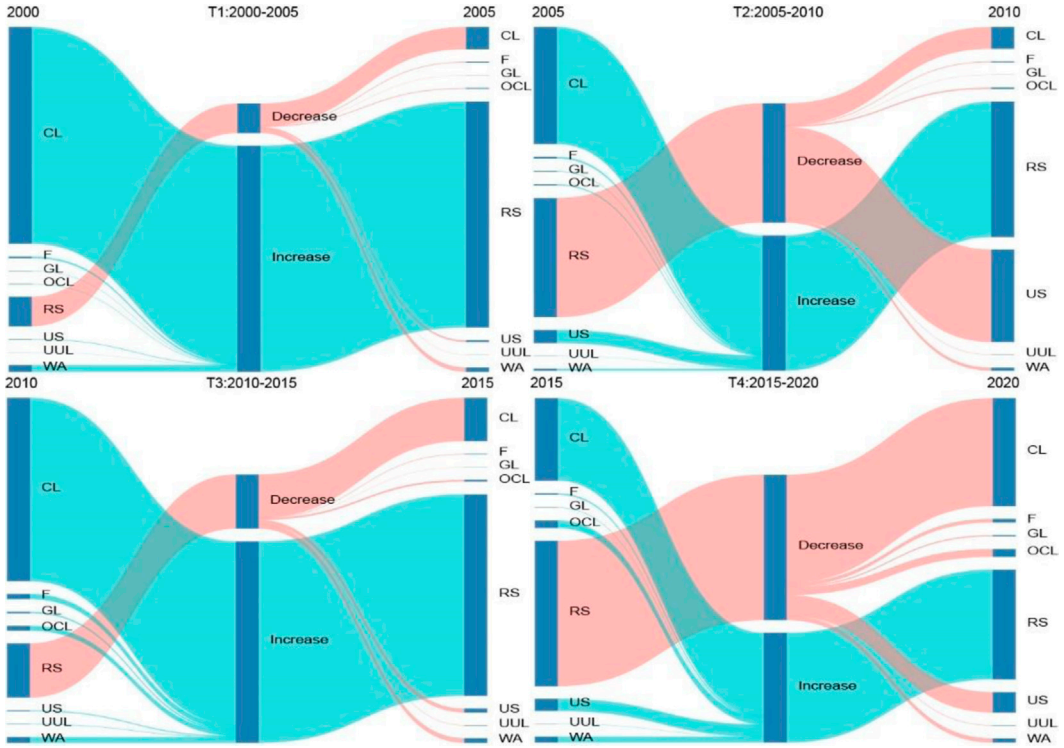

FIGURE 6
Land use transition in Jiangsu Province during (T1) 2000–2005, (T2) 2005–2010, (T3) 2010–2015, and (T4) 2015–2020. CL: cropland; F: forest; GL: grassland; OCL: other built-up land; RS: rural settlement; US: urban settlement; UUL: unused land; WA: water area.

3.2 Spatiotemporal characteristics of rural settlement transformation

As shown in Figure 6, there was a net increase in the area of rural settlements during 2000–2005 and 2010–2015. Cropland loss made a substantial contribution to the increased area of rural settlements, while only a small area of rural settlements was converted into cropland for food production. From 2005 to 2010, the decrease in the area of rural settlements was comparable to the increase. During this period, many rural settlements were consumed by urban settlement due to disorderly urban sprawl. From 2015 to 2020, the decrease in the area of rural settlements was much larger than the increase. Many rural settlements were converted into cropland for food production. Relatively little cropland was converted into rural settlements during the periods of 2005–2010 and 2015–2020. Changes in the area of rural settlements were mainly caused by

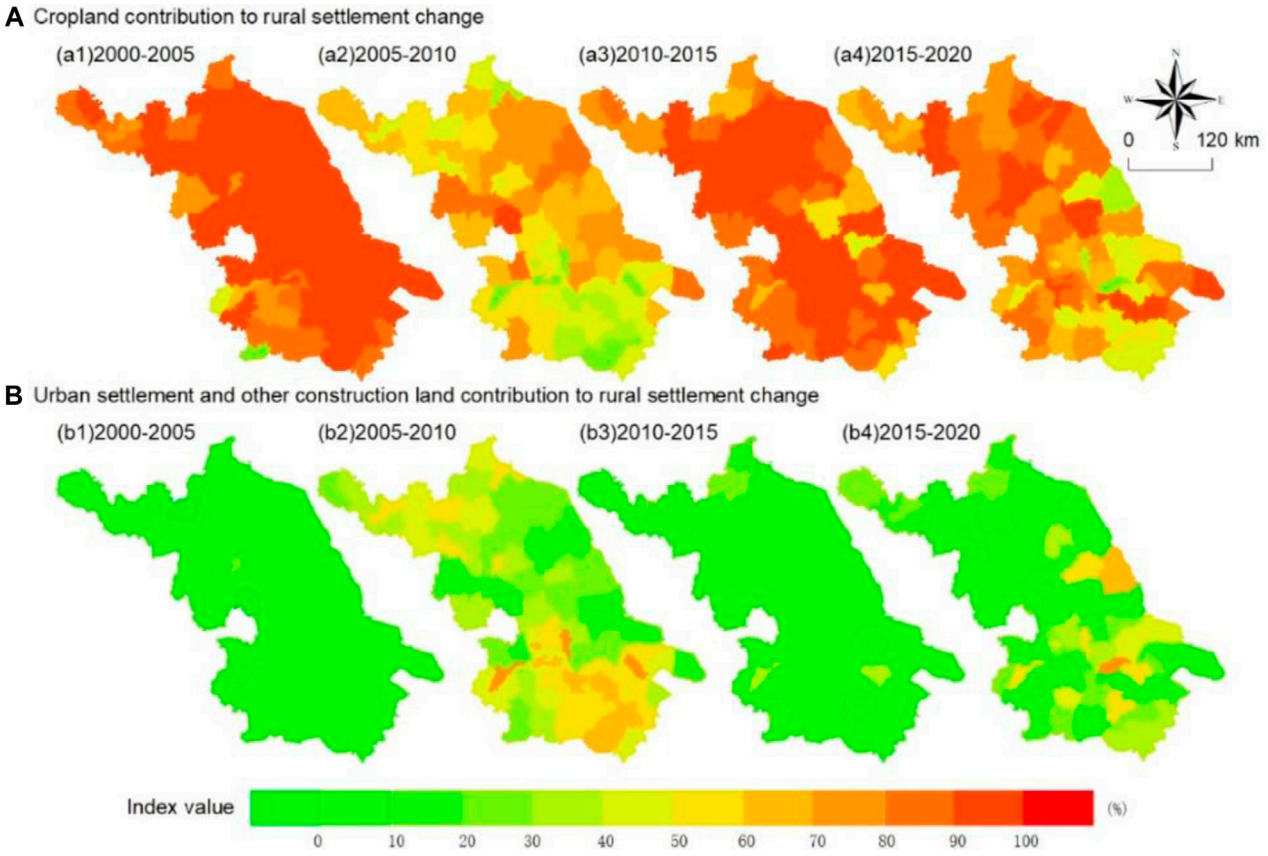

FIGURE 7
Proportional contribution of cropland to changes in the area of rural settlements at the county level in Jiangsu Province during (a1) 2000–2005, (a2) 2005–2010, (a3) 2010–2015, and (a4) 2015–2020. Urban settlement, and other built-up land to changes in the area of rural settlements at the county level in Jiangsu Province during (b1) 2000–2005, (b2) 2005–2010, (b3) 2010–2015, and (b4) 2015–2020.

land use transitions to cropland and urban settlements. Spatially, the proportional contribution of cropland to changes in rural settlements was very high in most counties of Jiangsu Province (Figure 7). The proportional contribution of urban settlements and other built-up land to changes in rural settlements was high in the southern counties of Jiangsu Province in both periods.

3.3 Factors influencing the spatial heterogeneity of rural settlements

The performance of the MLR and mixed GWR models was compared. All variables were standardized before the estimation and their parameters were directly comparable. The variance inflation factor (VIF) values (Table 1) were all much smaller than 10, suggesting that none of the explanatory variables had collinearity issues. Both the adjusted R^2 and AIC values suggested that the mixed GWR model outperformed the MLR model. The adjusted R^2 values in the MLR were 0.372 and in the mixed GWR were 0.786 in 2020.

For the four variables with global effects, the rural population was positively associated with the area of rural settlements, and both associations were statistically significant from 2000 to 2020 ($p < 0.001$). Cropland was positively associated with the area of rural settlements from 2000 to 2020, although the association was only statistically significant in 2000 ($p < 0.001$) and was not significant from 2005 to 2020. The rural production value had a negative association with the area of rural settlements from 2000 to 2020, although the association was only significant from 2000 to 2010 ($p < 0.05$) and was not significant from 2010 to 2020. The area of urban settlements had a negative association with the area of rural settlements; however, the association was not statistically significant from 2000 to 2020.

Table 1 summarizes the correlation coefficients estimated from the mixed GWR model, including the average, maximum, and minimum values. The rural population had the strongest association (0.677) with the area of rural settlements, followed by the rural production value (−0.372) and cropland (0.200) in 2000. The mixed GWR results indicated that all of the variables with local effects also produced a range of estimates.

3.4 Spatial distribution of the factors influencing the area of rural settlements

Figure 8 shows the spatial differentiation of the correlations of the explanatory variables with the area of rural settlements across the counties of Jiangsu Province in 2000, 2005, 2010, 2015, and 2020. In rural areas, the correlation coefficients were positive for all counties

TABLE 1 Standardized estimation results of the MLR and mixed GWR models.

Year	Independent variables	MLR			MGWR		
		Coefficient	t-value	VIF	Coefficient		
					Mean	Min	Max
2000	Rural population	0.785	5.103**	2.862	0.677	0.375	1.003
	Rural production value	−0.709	−3.559**	4.794	−0.372	−0.410	−0.348
	Cropland	0.454	2.664**	3.512	0.200	0.119	0.335
	Urban settlement	−0.003	−0.032	1.119	0.010	−0.134	0.141
	Constant		0.707		−0.017	−0.655	0.793
	Adjusted R^2	0.371			0.813		
	AIC	187			103		
	Function				Gaussian		
2005	Rural population	0.704	5.176**	2.28	0.632	0.300	0.960
	Rural production value	−0.532	−2.576*	5.256	−0.310	−0.325	−0.276
	Cropland	0.360	1.640	5.932	0.200	0.114	0.333
	Urban settlement	−0.157	−0.686	1.211	−0.078	−0.402	0.210
	Constant		1.027		−0.049	−0.645	0.647
	Adjusted R^2	0.383			0.799		
	AIC	187			109		
	Function				Gaussian		
2010	Rural population	0.655	4.871**	2.279	0.603	0.279	0.940
	Rural production value	−0.219	−1.058	5.410	−0.136	−0.170	−0.104
	Cropland	0.211	1.040	5.201	0.157	0.058	0.307
	Urban settlement	−0.035	−0.354	1.230	−0.166	−0.639	0.181
	Constant		0.426		−0.083	−0.639	0.574
	Adjusted R^2	0.397			0.817		
	AIC	185			102		
	Function				Gaussian		
2015	Rural population	0.586	4.080**	2.656	0.630	0.325	0.930
	Rural production value	0.018	0.085	5.524	−0.209	−0.264	−0.163
	Cropland	0.081	0.444	4.229	0.228	0.121	0.388
	Urban settlement	−0.024	−0.251	1.213	−0.190	−0.693	0.167
	Constant		0.388		−0.125	−0.625	0.464
	Adjusted R^2	0.410			0.807		
	AIC	184			106		
	Function				Gaussian		
2020	Rural population	0.502	3.200**	2.978	0.533	0.314	0.787
	Rural production value	0.153	0.722	5.468	−0.137	−0.179	−0.089
	Cropland	0.004	0.024	3.793	0.236	0.063	0.450
	Urban settlement	−0.002	−0.016	1.231	−0.153	−0.644	0.217

(Continued on following page)

TABLE 1 (*Continued*) Standardized estimation results of the MLR and mixed GWR models.

Year	Independent variables	MLR			MGWR		
		Coefficient	t-value	VIF	Coefficient		
					Mean	Min	Max
	Constant		0.586		−0.087	−0.618	0.554
	Adjusted R^2	0.372			0.786		
	AIC	189			114		
	Function				Gaussian		

Notes: The dependent variable is rural settlement area. *$p < 0.05$, **$p < 0.01$; MLR: multiple linear regression; GWR: geographically weighted regression; VIF: variance inflation factor.

in 2000. There were strong correlations in the northern part of Jiangsu Province and weaker correlations in the southern part. Negative associations of the rural production value with the area of rural settlements were found in all counties of Jiangsu Province at the 0.01 significance level in 2000. The correlation coefficients were similar among the different counties and were higher in the western part of Jiangsu Province. Regarding the correlation coefficients for the relationship between cropland and the area of rural settlements, most of the strong positive correlations were observed in the northwestern part of Jiangsu Province, most of which were statistically significant in 2000. There were weaker positive correlations in the eastern part of Jiangsu Province in 2000. The correlation coefficients decreased from 2005 to 2010 and increased after 2010.

4 Discussion

The spatial variation in the area of rural settlement and its relationships with the rural population, rural production value, cropland, and urban settlements was quantified at the prefecture level in the rapidly urbanized Jiangsu Province for the period from 2000 to 2020. In previous studies, rural settlements have often been investigated at the village (Liu et al., 2010; Wang et al., 2016) and town (Ma et al., 2018; Li et al., 2020) levels to investigate the changes in the area of rural settlements. However, planning to establish the goals and policies for long-term land use decisions typically occurs at the county level (Theobald et al., 2000). Spatial patterns and the socioeconomic factors influencing the area of rural settlements are the basic information required for regional planning. Traditionally, these driving forces have been explored using statistical models that do not consider the different spatial locations of the object being investigated (Su et al., 2020). A mixed GWR is the optimal method for analyzing the relationships among variables, particularly when there are large spatial disparities (Sun et al., 2017). This has policy implications for future sustainable rural development.

4.1 Changes in rural settlement following urbanization

Rural settlements have undergone significant changes due to urbanization and the increase in income for rural residents who move to work in cities. In developed countries, the counter-urbanization process, marked by a substantial number of people relocating to rural areas, spurs the growth of rural settlements (Gude et al., 2006). In Jiangsu Province, the trend of rural settlement expansion was observed from 2000 to 2015, followed by a contraction from 2015 to 2020, concurrent with steady decline in rural population due to urbanization (Figure 9). The average *per capita* residential area in rural sectors rose from 201.39 m^2 in 2000 to 243.85 m^2. However, it slightly reduced to 243.30 m^2 by 2020. Notably, the *per capita* rural residential land in Jiangsu Province significantly exceeds the Chinese village and town planning standard (GB50188-93) of 150 m^2 per person. Rural settlements increased in the early stages of urbanization in China, because a large number of rural residents worked in the city and took their salary back to the rural area to enlarge their settlements. After entering the rapid urban sprawl stage, some villages located near urban areas were swallowed by cities. We found that the total area of rural settlements was not reduced by the expansion of built-up urban area, which differs from previous studies that have concluded that the migration of residents from rural areas to the city for employment opportunities results in the shrinking of rural communities and settlements (Chen and Ye, 2014). Urban settlement has encroached upon cropland (57.14%) and rural settlements (23.42%) in Beijing (Liu et al., 2017). A similar situation has also been reported in Shandong Province (Qu et al., 2017). The expansion of urban and rural settlement in China has mainly been based on the loss of cropland, which has drawn the attention of the central and local governments because it endangers national food security. Since 2000, the government of Jiangsu Province has implemented several rounds of land consolidation planning (2001–2010, 2010–2020, 2015–2020). The aim of these initiatives is to increase both the area and quality of arable land, as well as promote the intensive use of construction land. Nonetheless, the *per capita* rural settlement area did not begin to decrease until 2015, finding that aligns with other studies (Rao, 2022). Concurrently, with a significant outflow of population, China's rural areas began to experience recession and an aging trend. Beginning in 2017, the Chinese government introduced the concept of rural revitalization to stimulate vitality in these areas. Rural revitalization will thus be another significant factor influencing regional rural settlement trends. The rural revitalization projects necessitate careful selection of rural villages to enhance their multifunctionality. In the national

rural revitalization plan, rural villages are classified into categories of urban-rural integration, concentration and enhancement, and preservation and demolition, all aimed at promoting rural development. The primarily reduction of rural settlement is seen in villages categorized for demolition.

4.2 Socioeconomic driving factors of rural settlements

Rural settlements have strong connections with the rural population. From the perspective of the 77 counties in Jiangsu

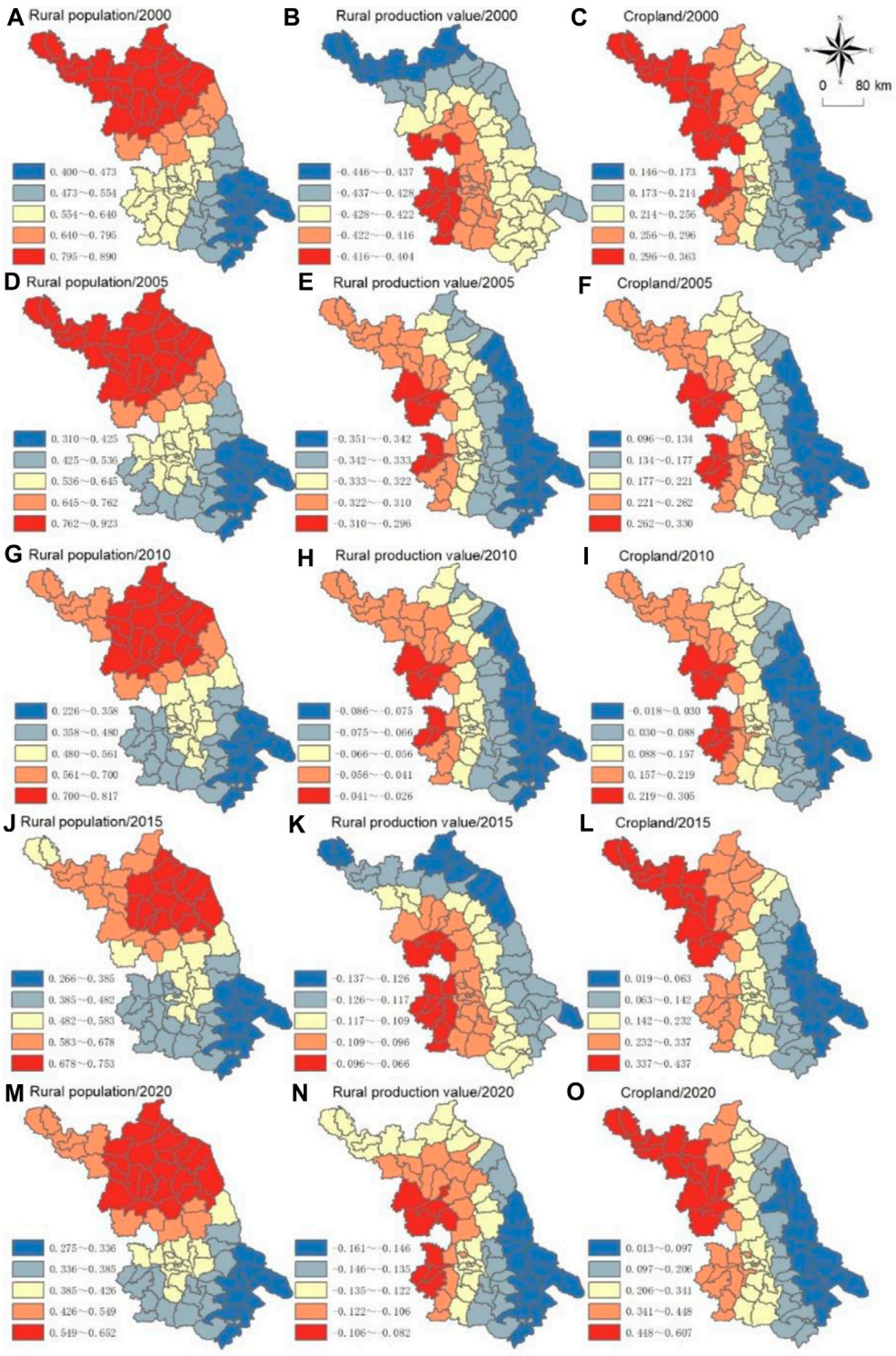

FIGURE 8
Spatial distribution of the impacts of the rural population on the area of rural settlements in the years 2000 **(A)**, 2005 **(D)**, 2010 **(G)**, 2015 **(J)**, and 2020 **(M)**. Spatial distribution of the impacts of the rural production value on the area of rural settlements in the years 2000 **(B)**, 2005 **(E)**, 2010 **(H)**, 2015 **(K)**, and 2020 **(N)**. Spatial distribution of the impacts of the cropland on the area of rural settlements in the years 2000 **(C)**, 2005 **(F)**, 2010 **(I)**, 2015 **(L)**, and 2020 **(O)**.

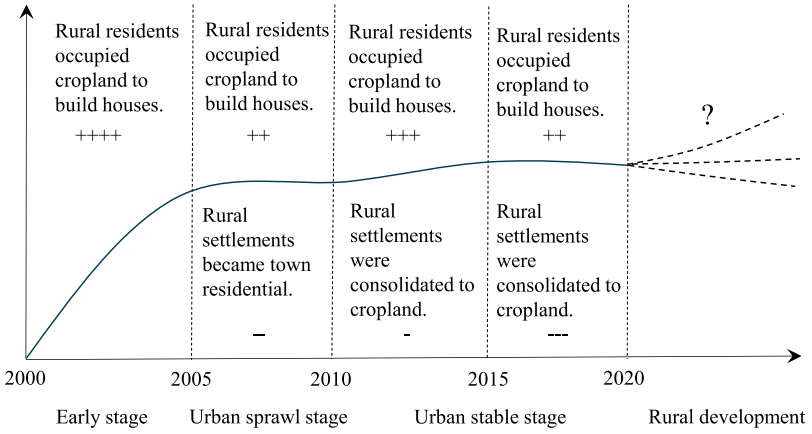

FIGURE 9
Changes in rural settlements following urbanization.

Province, we found that rural settlement had a strong positive relationship with the rural population, i.e., the greater the rural population, the greater the area of rural settlement. However, this relationship weakened over the period from 2000 to 2020. However, across the whole province, the area of rural settlements has shown a tendency to increase since China's reform and opening up despite the continuous decline in the rural population. An important reason for the impact of population on changes in the area of rural settlements is the household registration system (commonly known as the hukou system) in China. Due to this system, rural–urban labor mobility only enables access to job opportunities rather than the acquisition of urban citizenship. Migrant peasant workers from rural areas are marginalized and excluded by the social security and household registration systems that prevent them from securing residency permits. These migrant workers and their families are unable to make use of the facilities and services available to non-migrant urban residents, including social insurance, healthcare, education, municipal services, and affordable housing. Therefore, they tend to keep their houses and land in rural areas and have been described as forming a "migratory bird group" in urban areas due to their bird-like migration pattern. China's dual system of land ownership decrees that rural collectives' own farmland and the state owns urban land. Rural residents have homestead rights although they are migrant peasant workers. They are not forced to return these rights to their collective economic organizations and therefore are inclined to hold the homestead as a rural security system. This also explains the "hollow village" phenomenon (Huang et al., 2020). In 2004, the central government of China promulgated a new land use policy named "increasing vs decreasing balance" (Gao et al., 2021). From 2005 to 2010, there was a large decrease in the area of rural settlements to accommodate the expansion in urban settlements. From 2015 to 2020, a large area of rural settlements was transferred into cropland. The costs of converting rural settlements were so high that they were covered by urban land rents and cropland conservation foundations.

In addition to the rural population, the rural production values of counties in Jiangsu Province also had a negative relationship with the area of rural settlements in 2000. Traditionally, rural settlements are associated with agriculture. For the residents of rural areas, agricultural production is the main source of family income and employment. In counties with a high rural production value, rural settlements will have agglomeration benefits (Meijers and van der Wouw, 2019). Therefore, the higher the rural production value, the lower the area of rural settlements. However, other types of rural communities have arisen due to the changing economic trends within the rural regions. The development of non-agricultural industries such as business, tourism, and manufacturing has led to a new relationship among land, people, and industry in rural areas (Rosner and Wesołowska, 2020). As one of the most developed and urbanized regions in China, Jiangsu, and particularly southern Jiangsu, has been at the forefront of rural industrialization in China. Rural enterprises and industries are considered a major vehicle in the development of rural areas, which will evolve into multifunctional rural regions.

4.3 Policy implications

Rural settlements in different counties have experienced different spatial and temporal changes due to the combined effects of multiple driving factors. The *per capita* rural residential area across various counties in Jiangsu Province significantly surpasses the standards established by the Chinese rural township system. Consequently, the task of consolidating and planning land and rural residential areas in Jiangsu Province presents substantial challenges. The consolidation and planning of rural residential areas within this Province should be conducted with regional differentiation in mind, specifically considering the unique needs and characteristics of the northern, southern, central, and eastern regions. For remote regions far from metropolitan areas, such as the northern, central and eastern part of Jiangsu Province, the construction of small towns and concentration of rural settlements is an important pathway for urbanization and rural development. In rural areas near to metropolitan areas, such as the southern part of Jiangsu, urban and rural construction growth need to be strictly monitored and controlled because the area of rural settlements will increase with urban land expansion, which could cause a reduction in the

extent of both natural land and cropland. Although the "increasing vs decreasing balance" land use policy might appear to resolve the conflict between the demand for built-up land and the preservation of agricultural land, it is not easy to implement due to the huge financial, administrative, and social costs. The policy has been criticized because it has become a campaign to consolidate villages, and built-up land quotas and revenues have been used for urban construction rather than rural development.

A further policy implication arising from the results of our study is the need to provide affordable housing for urbanized rural residents in cities. A policy to provide affordable housing would motivate migrant peasant workers to move to urban areas and thereby give up their reliance on the rural residential land they retain as a social security system. However, the current affordable housing system in China is targeted only at urban dwellers who have city residence permits as part of the household registration system. Migrant workers, floating populations, and others without urban residence permits are not included. The government could provide affordable housing by subsidizing commercial housing purchases or by offering low-rent public housing to urbanized rural families. With a reform of the household registration system, migrant peasant workers who can access affordable housing would be likely to settle in urban areas and exchange their rural residential land for urban accommodation. Such an affordable housing policy would be effective even without a state-led policy of land consolidation, because the cost of the affordable housing would be regulated by the market mechanism and would be financially sustainable. Such a policy would be particularly important for south Jiangsu because an increasing number of migrant workers are moving there from the center and north of Jiangsu and north-central-south regional inequality is increasing.

Due to the lack of land use data for rural enterprises, the spatiotemporal characteristics of the changes in built-up rural land for industrial and production activities were not analyzed in this study. However, to determine how the economic and industrial policies in China have affected the spatiotemporal patterns of land use for rural enterprises and industries since the adoption of the reform and opening-up policy there is a need to assess the characteristics of changes in built-up rural land over the past 2 decades. This analysis will require more detailed land use information to be extracted from rural settlements.

5 Conclusion

This study investigated spatiotemporal changes in rural settlements under the pressure of rapid urbanization and widening regional inequality at the county level, taking Jiangsu Province in China as a case study. Following urbanization in the Jiangsu Province, rural settlement increased from 2000 to 2015 due to rural migrant workers expanding their settlement after making money in urban areas. Rural settlements decreased from 2015 to 2020 because of the land consolidation planning designed by the government. In accordance with policy guidance, numerous rural residential areas were transformed into towns between 2005 and 2010, and then re-designated as cultivated land from 2015 to 2020. In 2000, the area of rural settlements exhibited a positive correlation with the rural population and cropland, but a negative correlation with the rural production value. The correlation between the area of rural settlements and population decreased from 2000 to 2020. Spatial disparities between rural settlement areas and the rural population mirror the existing south-center-north imbalance. Therefore, government planning and policies should acknowledge the regional differences in the northern, central, eastern, and southern parts of Jiangsu Province. They should innovate within the rural-urban dual system and implement land consolidation strategies based on rural population size to promote sustainable rural development. Although this study revealed some details of the spatial distribution and different features of the changes in the area of rural settlements under the background of rapid urbanization and regional inequality, further studies are needed to fully address the unresolved issues.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

YX initiated this study, conducted the whole data analysis and wrote this manuscript. RZ and WW suggested the methods for this research. CY, CX, DC, and YL collected data and conducted some data analysis. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1213548/full#supplementary-material

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