

Article

The Impact of Urbanization on Food Security: A Case Study of Jiangsu Province

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Abstract: Food security has received extensive academic attention in recent years. However, research results analyzing cultivated land pressure from the perspective of urbanization are relatively few. This study used Jiangsu Province as the study area and analyzed the spatial pattern evolution of cultivated land pressure from 2005 to 2019 by constructing a formula for a cultivated land pressure index. The study used a spatial econometric approach to analyze the spatial relationship between urbanization and cultivated land pressure. Based on the spatial Durbin model, the impact of urbanization on the pressure on cultivated land is analyzed. According to the results, Jiangsu Province showed an obvious north–south divergence in the spatial distribution of the cultivated land pressure index, with the low-value areas of the cultivated land pressure index mainly distributed in northern and central Jiangsu, and the high-value areas mainly distributed in southern Jiangsu. The urbanization level and cultivated land pressure level in Jiangsu Province showed obvious spatial clustering characteristics, and there was a certain overlap between the high- and low-value clustering areas of the two, with significant positive spatial correlation features. The total urbanization had no significant effect on the cultivated land pressure. Population urbanization and industry urbanization showed a significant negative effect on cultivated land pressure in Jiangsu Province, while land urbanization showed a positive effect. Both population and land urbanization had a significant negative spatial spillover effect on cultivated land pressure. Plausible explanations of these results were provided and policy implications were drawn.



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1. Introduction

Cultivated land resources are the material basis for sustaining human social development; therefore, changes in the quantity and quality of cultivated land resources significantly affect regional food production and food security [1–3]. According to research results, by 2030, 3.7% of the world's cultivated land will be encroached upon due to urbanization [4,5]. The rapid development of urbanization and industrialization in China has profoundly affected the use of cultivated land and food production, especially under the situation of global climate change and the currently tightening international trade environment, and the seriousness of the food security issue has begun to be highlighted. Urbanization profoundly affects cultivated land use and food production, directly impacting Chinese food security. In the 21st century, the Chinese urbanization level has increased rapidly, with the urbanization rate exceeding 50% in 2011 and 60% in 2020, and the urban resident population already outnumbers the rural resident population [6,7]. Since 2004, Chinese grain production has increased continuously, but with the development of the economy and the continuous increase in food demand, the problem of food security in

China has not been fundamentally alleviated [8]. China's urban sprawl has resulted in massive encroachment on prime cultivated land [4]. China lost more than 14.5 million hectares of cultivated land between 1979 and 1995 and about 8.32 million hectares between 1996 and 2008 due to urbanization after the reform and opening up, which seriously threatens China's food security [9,10]. Based on the obvious reduction in cultivated land, the Chinese government has introduced a series of relevant policies, such as setting a red line of 1.8 billion mu (120 million hectares) of cultivated land and achieving a balance of cultivated land through land preparation [11]. However, the issue of food security has not been fully resolved, most newly reclaimed arable land is of low quality, and the cultivated land reserve is still insufficient [12,13].

With the rapid development of urbanization in China, the impact of urbanization on food security may not only be negative. On the one hand, farmers' income from farming in the countryside is significantly lower compared to the income from entering urban work [14,15]. With the progress of urbanization, the reduction in cultivated land and the loss of rural labor will make food production decrease. In the context of increasing food demand, this directly worsens the problem of food security in China. On the other hand, with the rapid increase in China's urbanization, urban areas and industries already have the ability to feed rural areas and agriculture [16,17]. Higher urbanization may imply higher technology levels, stronger agricultural investment levels, and more cultivated land per capita, promoting the mechanization and modernization of food production, which in turn boosts the China's food production. Thus, the relationship between urbanization and food security may be open to debate.

In China, the current situation of food security is serious; the ecological footprint of cultivated land in most of the major grain-producing provinces exceeds the ecological carrying capacity, resulting in an ecological deficit and showing an expansion [18]. Among these provinces, Jiangsu Province, as a major grain-producing and economically developed province in China, has a representative food security problem. Jiangsu Province has the most serious ecological deficit in the cultivated land system among the major grain-producing regions [18], and the province's grain supply and demand are already in a tight balance [19]. Jiangsu Province is also a province with rapid urbanization and urban ecological well-being performance, where urban ecological well-being continues to rise and consumption of resources continues to decline [20,21]. In addition, due to the long-term uneven development of the economy in Jiangsu Province, there is an imbalance in regional food production and consumption: central and northern Jiangsu are relatively less economically developed as the major food production regions, while southern Jiangsu is more economically developed as the main food marketing region. In this context, it is typical to investigate the relationship between urbanization and food security in Jiangsu Province, which is an economically developed province and a major grain-producing area. Simultaneously, counties in Jiangsu Province are economically developed, and as the smallest functional area of the study unit, they are more reflective of the relationship between regional urbanization and food security compared to municipal and provincial areas. This study took Jiangsu Province as the case area and counties as the study unit, focusing on analyzing the spatial pattern evolution of urbanization and food security in counties of Jiangsu Province, exploring the spatial correlation between urbanization and food security, using the spatial Durbin model to measure and calculate the influence of urbanization and food security. Based on a spatial perspective, this study utilized a spatial approach to more effectively reflect the impact of urbanization on food security. We expect to benefit Jiangsu Province and China's future urbanization development strategy.

Scholars generally use cultivated land pressure as a measure of food security. In the measurement of cultivated land pressure, non-Chinese scholars measure simple indicators and various perspectives, and they rarely explore the spatial and temporal evolution of cultivated land pressure [11]. One scholar measured the cultivated land carrying capacity under ten dietary structures through simulations using a biophysical model [22]. The pressure on the food supply for cultivated land was examined from the perspective of

increasing food demand due to continuous population growth [23]. One scholar measured the risk posed by urban expansion to regional cultivated land resources mainly from the perspective of changes in the amount of cultivated land [24]. Through continuous innovation of index models reflecting cultivated land pressure, Chinese scholars summarized a modified cultivated land pressure index model based on the interaction of region, population, cultivated land, and food, which was accepted by academia and widely used in regional food security evaluation [25]. At the scale of study, the main focus is on provincial and municipal study units.

In terms of the impact of urbanization on food security, scholars have mainly measured the role of urbanization on food production and thus analyzed its impact on food security [26]. Scholars have conducted numerous studies on the relationship between urbanization and food production, mainly forming two views. First, there is a negative relationship between urbanization and food production; as urban areas continue to expand, the area of cultivated land gradually decreases, which leads to a decrease in the area of food sown, weakening the food supply capacity [27,28]. Simultaneously, the concentration of the rural population in cities has led to the abandonment of large areas of cultivated land, resulting in a decrease in regional food supply capacity [29]. In addition, urbanization can also cause soil environmental pollution of cultivated land, crowd out water resources, and constrain food production [30,31]. Second, there is a positive or equilibrium relationship between urbanization and food production, and some scholars found that population urbanization has a significant positive effect on food production at the Chinese national scale [32]. In addition, rural labor migration and reduction in cultivated land resources do not significantly threaten China's food security [33]. Moreover, urbanization can promote food production by upgrading food production technology [34]. From the case area of Jiangsu Province, both industry and population urbanization have a significant contribution to food production [35].

2. Materials and Methods

2.1. Study Area

For this paper, 65 county study units in Jiangsu Province were studied. They included Xuzhou City, Lianyungang City, Suqian City, Huai'an City, Yancheng City, Yangzhou City, Taizhou City, Nantong City, Nanjing City, Zhenjiang City, Changzhou City, Wuxi City, and Suzhou City. The northern Jiangsu region includes Xuzhou City, Lianyungang City, and Suqian City; the central Jiangsu region includes Huai'an City, Yancheng City, Yangzhou City, Taizhou City, and Nantong City; and the southern Jiangsu region includes Nanjing City, Zhenjiang City, Changzhou City, Wuxi City, and Suzhou City (Figure 1).

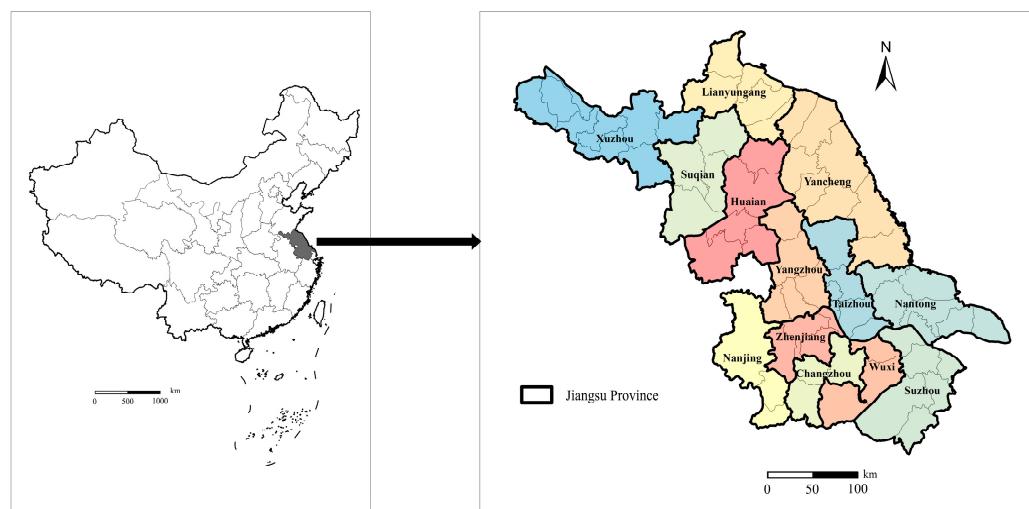


Figure 1. Location of Jiangsu Province.

2.2. Date Source

The data in this paper include two aspects: socio-economic data and land urbanization data. The socio-economic data were obtained from the Jiangsu Statistical Yearbook from 2006 to 2020. The land urbanization data were mainly obtained from the China Earth System Science Data Sharing Platform, and the ENVI5.3 software was used to decode and classify the land-use remote sensing data, extract and vectorize the spatial extent of construction land development in each region, finally use it as the basis to calculate the area of regional construction land.

2.3. Research Methods

2.3.1. Research Idea

The coordination of the population, industry, and land urbanization in a region is an important criterion for measuring the urbanization quality [36]. In terms of the relationship between the three, population urbanization promotes the flow of labor among different sectors and industries, which promotes industrial adjustment and structural upgrading and increases the development demand for urban land, and in turn reacts to the population and industrial development, forming a circular process [37]. Factor mobility between urban and rural areas is an important entry point for analyzing the relationship between urbanization and food security [32]. Based on this perspective, urbanization (population urbanization, industry urbanization, and land urbanization) affects regional food security by influencing agricultural labor, agricultural technology and capital, and regional cultivated land quantity and quality, respectively (Figure 2): ① The transformation of the rural population status causes changes in food production. As the process of population urbanization advances, capital, technology, population, and information continue to gather in the central towns, and the rural population flows from the countryside to the cities. This may lead to a reduction in food production due to insufficient rural labor inputs, or an increase in food production due to the promotion of large-scale cultivated land management as per capita cultivated land increases. ② Industrial investment preferences affect food production. In the process of industry urbanization, the inertia of urban priority development leads to the one-way concentration of capital in favor of secondary and tertiary industries in cities [38]. This leads to slow rural development and agricultural technology updating, due to the existence of the industrial-agricultural scissors difference, and a decrease in the food production, which in turn causes a decrease in the regional food security. However, if higher industrial urbanization is developed, the marginal effect of capital's returns in the cities decreases and promotes capital investment in rural areas, which also possibly promotes higher food production, thus ensuring regional food security. ③ Changes in the quantity and quality of cultivable land affect food production. As land urbanization continues, the area of cultivated land continues to shrink as construction land in regional cities expands. In recent years, although China has put forward the requirement of “balanced occupation” of cultivated land in the urbanization process, the status of “occupying the best and compensating the worst” is common. The area of high-quality cultivated land has been reduced, which has directly led to a decline in food production, thus threatening regional food security.

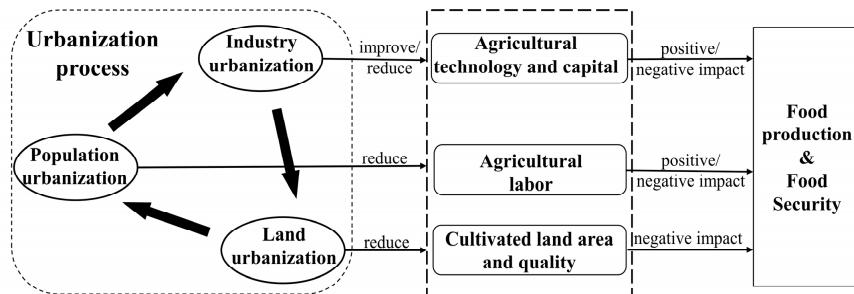


Figure 2. Mechanisms of the impact of urbanization on food security.

China's grain output increased continuously for 16 years from 2005 to 2020, while the years 2005–2020 were China's 11th, 12th, and 13th Five-Year Plan periods, the periods of rapid development of China's urbanization, and considering the impact of the COVID-19 in 2020, 2005–2019 was chosen as the time period for this study.

2.3.2. Indicator Construction

Cultivated Land Pressure Index

In terms of measuring food security at the country-regional level, there are mainly measures such as Prevalence of Undernourishment, Global Hunger Index, and Global Food Security Index [39]. Prevalence of Undernourishment, tools for measuring food availability, such as food balance sheets, have traditionally drawn from nationally aggregated data on food supply (i.e., total amount of food produced and imported) and utilization (i.e., the quantity of food exported, fed to livestock, used for seed, processed for food and non-food uses, and lost during storage and transportation) [40]. These indicators are used to estimate food shortages and surpluses, to develop projections of future food demand, and to set agricultural production targets. The Global Hunger Index (GHI), developed by IFPRI, aims to measure "hunger" using 3 equally weighted indicators: (1) undernourishment (i.e., the proportion of undernourished people as a percentage of the population); (2) child underweight (i.e., the proportion of children younger than 5 y who have a low weight for their age); and (3) child mortality (i.e., the mortality rate for children younger than age 5 y) [41]. This indicator reflects the extent of acute food insecurity in the region. The Global Food Security Index (GFSI) is another multi-dimensional tool for assessing country-level trends in food security. It was designed by the Economist Intelligence Unit (one of several companies of a publicly traded multinational, the Economist Group) and sponsored by DuPont. The index uses a total of 30 indicators within 3 domains of food security, affordability (6 indicators), availability (10 indicators), and quality and safety (14 indicators), to provide a standard against which country-level food security can be measured [42].

China's rapid urbanization, growing wealth, and emphasis on health are placing higher demands on food quality and safety [43]. China has a high rate of food self-sufficiency and is not dependent on imports; food security has been ensured [44,45]. However, in the long run, food security is most urgently faced with a shortage of cultivated land resources [46]. Therefore, in China, it is most appropriate to analyze food security from the perspective of cultivated land resources.

The cultivated land pressure index can be used to judge the cultivated land resource tension in a certain population area by the balance level of supply and demand of cultivated land, reflecting regional food security [47]. Specifically, the cultivated land demand can be expressed in terms of the minimum cultivated area per capita to guarantee food security; the cultivated land supply can be obtained from the actual cultivated area per capita [11]. In general, different geographical environments lead to differences in the efficiency and quality of cultivated land utilization, that is, the heterogeneity of cultivated land, which is the basic property of cultivated land [11]. Therefore, the cultivated land pressure index is corrected by introducing a cultivated land quality factor, and the corrected cultivated land pressure index is a combined pressure threshold that integrates the quantity and quality of cultivated land; the result is more effective [48]. This index can be calculated using the following equation:

$$K_i = \frac{AD_i}{AS_i} = \frac{\rho \cdot (F/W_i) \cdot Q_i \cdot R_i}{H_i} \quad (1)$$

$$G_i = \frac{K_i}{\sigma} = \frac{K_i}{(C_i \cdot R_i)/(C_n \cdot R_n)} \quad (2)$$

where K_i is the cultivated land pressure index of the i th county, AD_i reflects the food demand of the i th county and is the minimum per capita cultivated area that can guarantee food security, AS_i is the actual per capita cultivated area of the i th county, ρ is the food self-sufficiency rate (%), F is the per capita food demand (kg/person), W_i is the unit sown

area of the i th county grain yield (kg/hm^2), Q_i is the ratio of the sown area of grain crops in the i th county to the total sown area of crops (%), R_i is the replanting index of the i th county (%), G_i is the modified cultivated land pressure index of the i th county, σ is the correction coefficient of cultivated land quality, C_i is the grain yield per unit sown area in city i (kg/hm^2), R_n is the replanting index of the i th county (%), C_n is the grain yield per unit sown area in Jiangsu Province (kg/hm^2), and R_n is the replanting index of Jiangsu Province (%). According to related studies and the China's Grain Security Program for Medium and Long-Term (2008–2020) [49], it is proposed that the self-sufficiency rate of grain should have been kept above 95% by 2020. Thus, ρ was set at 95% in this study. The State Food and Nutrition Consultant Committee (<https://sfncc.caas.cn/> accessed on 15 April 2023) proposed that the objective per capita grain demand for a well-off society in an all-round way should be 437 kg/person; therefore, F was set as 437 kg/person.

With reference to the evaluation criteria for the cultivated land pressure index and the findings of related studies, the cultivated land pressure can be graded at five levels [11]: grain security zone ($K \leq 0.9$), alarm-pressure zone ($0.9 < K \leq 1$), low-pressure zone ($1 < K \leq 1.5$), medium-pressure zone ($1.5 < K \leq 2$) and high-pressure zone ($K > 2$).

Population–Industry–Land Urbanization Coupling Coordination Degree

Population urbanization, industry urbanization, and land urbanization referred to in this paper are all measured using single-dimension indicators, which are calculated using the following equations:

$$P_i = \frac{PU_i}{PT_i} \quad (3)$$

$$L_i = \frac{LU_i}{LT_i} \quad (4)$$

$$I_i = \frac{IS_i + IT_i}{GDP_i} \quad (5)$$

where P_i , I_i , and L_i are the population urbanization, industry urbanization, and land urbanization levels of administrative unit i , respectively; PU_i and PT_i are the urban population and total population of administrative unit i , respectively; LU_i and LT_i are the built-up area and the total land area of administrative unit i , respectively; and IS_i , IT_i , and GDP_i are the output value of the secondary and tertiary industries and GDP of administrative unit i , respectively.

The population–industry–land urbanization coupling coordination degree refers to the normalization of population urbanization, industry urbanization, and land urbanization, and the coupled coordination degree formula is applied to derive the result.

$$C_i = 3 \times \frac{(P_i \times L_i \times I_i)^{1/3}}{(P_i + L_i + I_i)} \quad (6)$$

$$D_i = \sqrt{C_i \times T_i}, \quad T_i = \alpha P_i + \beta L_i + \gamma I_i \quad (7)$$

where C_i represents the population–industry–land urbanization coupling degree of administrative unit i ; D_i represents the coupling coordination degree of administrative unit i ; P_i , I_i , and L_i are population urbanization, industry urbanization, and land urbanization levels of administrative unit i , respectively; and α , β , and γ are all taken as 1/3.

Based on the research demand, the coupling coordination degree was divided into five intervals according to the value domain, i.e., low-level coupling coordination degree (0–0.2), lower-level coupling coordination degree (0.2–0.4), medium-level coupling degree (0.4–0.6), higher-level coupling degree (0.6–0.8), and high-level coupling degree (0.8–1.0).

2.3.3. Impact Factor Selection

The factors influencing food security are multifaceted. The natural background is one of the essential factors of grain production and a possible condition influencing the

magnitude of cultivated land pressure [50]. Socio-economic factors, according to the type of action, can be divided into agricultural production conditions and urbanization [11]. Agricultural production conditions directly influence cultivated land pressure by changing the production performance of cultivated land [11]. In contrast, urbanization acts on cultivated land pressure either directly or indirectly through encroaching on cultivated land resources, stimulating the transfer of agricultural population, etc. [11].

- (1) Natural background. Jiangsu Province is located in a plain area with small slope variations and little difference in arable land fertility, and water resources are an important factor affecting grain yield. Therefore, we chose the water resource level to characterize the natural background.
- (2) Agricultural production conditions. The economic level, fertilizer application level, agricultural mechanization level, and labor input level are taken as influencing factors. That is, the regional economic level implies the strength of the local farmers' input to food production, which affects cultivated land pressure. The fertilizer application level affects cultivated land pressure by influencing cultivated land production performance. The agricultural mechanization level implies the input of agricultural machinery, which affects cultivated land pressure. The labor input level implies the number of people involved in food production and reflects the efficiency of food production.
- (3) Urbanization. Urbanization plays an important role in food production and is the focus of this paper. A healthy and efficient urbanization process is inevitably the coordinated development of urbanization in the three dimensions of population urbanization, industry urbanization, and land urbanization [36]. The population–industry–land urbanization coupling coordination degree can reflect the new urbanization development degree [36]. Therefore, we chose the population–industry–land urbanization coupling coordination degree, population urbanization, industry urbanization, and land urbanization as the core explanatory variables.

In order to clarify the impact of urbanization on food security, based on the regression model, the impact of overall urbanization on food security was first calculated with the population–industry–land urbanization coupling coordination degree as the core explanatory variable, and then the impact of the three different urbanization dimensions on food security was calculated with the degree of population urbanization, industry urbanization, and land urbanization as the core explanatory variables. Specific indicators are shown in Table 1.

Table 1. Definitions and descriptions of variables.

	Types	Indicator Selection	Measurement Method	Symbol
Core explanatory variables	Urbanization	Population–industry–land urbanization coupling coordination degree	Calculation of the coupling coordination degree of population urbanization, industry urbanization, and land urbanization	X1
		Population urbanization	Ratio of urban population to resident population	X2
		Industry urbanization	Secondary and tertiary sectors as a proportion of GDP	X3
		Land urbanization	Ratio of the built-up area and total land area	X4
Control variables	Agricultural production conditions	Economic level	Per capita GDP	X5
		Fertilizer application level	Fertilizer application per unit area of cultivated land	X6
		Agriculture modernization level	Total mechanical power per unit area of cultivated land	X7
		Labor input level	Percentage of agricultural workers	X8
	Natural background	Water resource level	Water resources per capita	X9

2.3.4. Spatial Measurement Methods

Global Spatial Autocorrelation

Global spatial autocorrelation expresses the spatial dependence of units within their spatial extent in terms of their total spatial extent. The use of univariate global spatial autocorrelation (univariate Moran's I) allows for the exploration of the spatial correlation characteristics of a given variable. The spatial association characteristics of the independent and dependent variables can be explored using bivariate global spatial autocorrelation (bivariate Moran's I). Moran's I is often used as an index to characterize the spatial association of units, and the formula is as follows:

$$\text{Moran's } I = \frac{\sum_{i=1}^n \sum_{j=1}^n (Y_i - \bar{Y})(Y_j - \bar{Y})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}} \quad (8)$$

where $S^2 = \frac{1}{n} \sum_{i=1}^n (Y_i - \bar{Y})^2$, $\bar{Y} = \frac{1}{n} \sum_{i=1}^n Y_i$, Y_i and Y_j denote the observed values of the i th and j th regions, n is the total number of each research unit, and W_{ij} is the spatial weight matrix. The range of Moran's I index values is $[-1, 1]$; the closer the value is to 1, the stronger the positive spatial correlation of the research units, and the closer the value is to 0, the stronger the negative spatial correlation; if the value of Moran's index is 0, it means that the spatial correlation of each research unit in the spatial range is 0.

Local Spatial Autocorrelation

Global spatial autocorrelation is a measure of the overall spatial correlation of the variables and ignores local instabilities and local patterns in space, so bivariate local spatial autocorrelation is used to measure the spatial relationship between the independent variable in region i and the dependent variable in region j .

$$I_i = \frac{(Y_i - \bar{Y})}{S^2} \sum_{j=1}^n W_{ij}(Y_j - \bar{Y}) \quad (9)$$

where I_i represents the localized Moran's index for the i th region, $S^2 = \frac{1}{n} \sum_{i=1}^n (Y_i - \bar{Y})^2$, $\bar{Y} = \frac{1}{n} \sum_{i=1}^n Y_i$, Y_i and Y_j denote the observed values of the i th and j th regions, n is the total number of each research unit, and W_{ij} is the spatial weight matrix. Combined with the significance of I_i , local spatial autocorrelation maps can be drawn to identify cold hotspots where geographic elements are spatially clustered. There are four main types of spatial clustering: high–high (H-H type), low–high (L-H type), low–low (L-L type), and high–low (H-L type).

Spatial Durbin Model

The spatial Durbin model can examine the endogenous correlation of dependent variables and detect the direct and interactive effects of external factors, enabling a more accurate estimation of the spatial correlation of housing affordability in the Yangtze River Economic Belt and the degree of influence of the population–industry–land urbanization coupling degree, population urbanization, industry urbanization, land urbanization, and other impact factors [51].

$$y_{it} = \rho \sum_{j=1}^n w_{ij} y_{jt} + \beta x_{it} + \theta \sum_{j=1}^n w_{ij} x_{jt} + \mu_i + \varphi_t + \varepsilon_{it} \quad (10)$$

where y_{it} is the observed value of the dependent variable; x_{it} is the observed value of the independent variable; ρ reflects the spatial lag of the explanatory variable; θ is the spatial regression coefficient of the explanatory variable; β is the regression coefficient of the independent variable; φ_t and μ_i denote time fixed effects and spatial fixed effects, respectively; ε_{it} is a random error term obeying independent identical distribution, denoting other factors not included in the econometric model; and w_{ij} is the spatial weight matrix.

3. Results

3.1. Spatial Distribution and Evolution Characteristics

As shown in Figures 3 and 4, the spatial differentiation pattern and evolution characteristics of the cultivated land pressure index and urbanization level indicated that the spatial differentiation effect of the two is obvious.

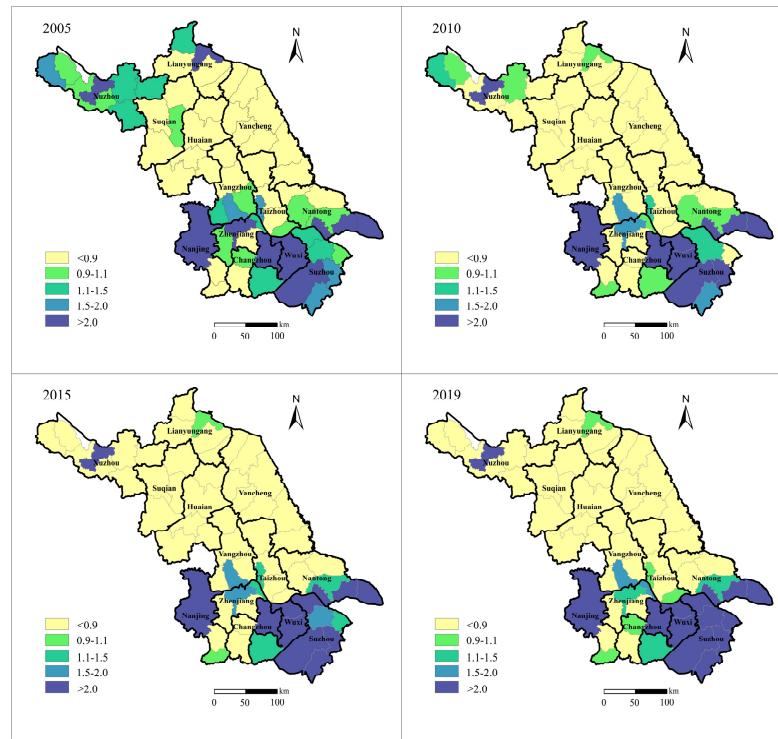


Figure 3. Spatial distribution of cultivated land pressure index.

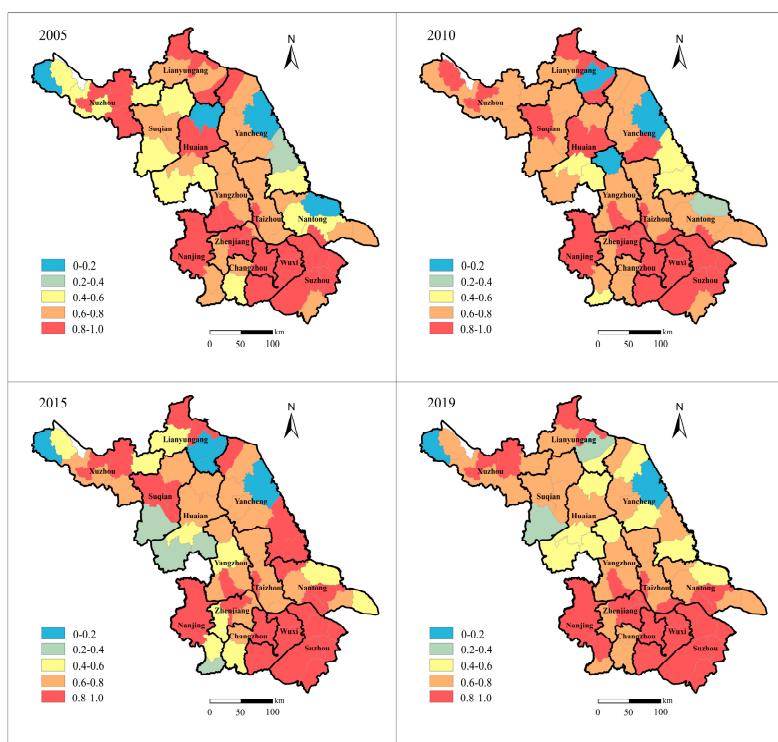


Figure 4. Spatial distribution of population-industry-land urbanization coupling coordination degree.

From 2005 to 2019, the spatial distribution of the cultivated land pressure index in Jiangsu Province has obvious spatial differentiation between the north and the south, with little change in spatial evolution. The areas with larger cultivated land pressure index values were mainly distributed in the municipal districts of the north-central Jiangsu Province region and in the southern Jiangsu Province region; while the areas with smaller index were mainly distributed in the north and center of Jiangsu Province as well as the main grain-producing areas in the south of Jiangsu Province.

From 2005 to 2019, there are certain characteristics in the spatial distribution of the population–industry–land urbanization coupling coordination degree in Jiangsu Province. The areas with high coupling coordination degrees were mainly distributed in the southern Jiangsu Province region, the municipal districts were also distributed in the central and northern Jiangsu Province region and clustered in the southern Jiangsu Province region. Study units with low and medium coupling coordination degrees were mainly distributed in central and northern Jiangsu Province, and the number of such units is gradually increasing.

As a result of the comparison, it is found that the cultivated land pressure index and the population–industry–land coupling coordination degree of high- and low-value agglomerations in the counties of Jiangsu Province showed certain overlapping characteristics. Study units with a high coupling coordination degree tend to have a higher cultivated land pressure index.

3.2. Exploratory Spatial Correlation Analysis of Urbanization and Cultivated Land Pressure Indices

In order to deeply analyze the spatial relationship between urbanization and cultivated land pressure in Jiangsu Province, based on the exploratory spatial analysis method, the univariate and bivariate Moran's I of urbanization and the cultivated land pressure index in Jiangsu Province were measured. Simultaneously, the local spatial autocorrelation of the urbanization and cultivated land pressure index was visualized and characterized. The results are shown in Table 2 and Figure 5. From 2005 to 2019, Jiangsu Province's cultivated land pressure index and population–industry–land urbanization coupling coordination degree had strong positive spatial accumulation, with the former showing an upward trend and the latter showing a downward trend. The global spatial autocorrelation between the population–industry–land urbanization coupling coordination degree and the cultivated land pressure index had an obvious positive spatial correlation and showed an increasing trend. It reflected that the spatial distribution of urbanization in Jiangsu Province showed a certain positive influence on the spatial distribution of cultivated land pressure.

Table 2. Moran's I value of cultivated land pressure index and population–industry–land urbanization coupling coordination degree.

Moran's I	Variable	2005	2010	2015	2019
Univariate	cultivated land pressure index	0.359 ($p = 0.001$)	0.235 ($p = 0.001$)	0.255 ($p = 0.001$)	0.343 ($p = 0.001$)
	population–industry–land urbanization coupling coordination degree	0.264 ($p = 0.001$)	0.22 ($p = 0.001$)	0.295 ($p = 0.001$)	0.322 ($p = 0.001$)
Bivariate	cultivated land pressure index–coupling coordination degree	0.235 ($p = 0.001$)	0.218 ($p = 0.001$)	0.251 ($p = 0.001$)	0.281 ($p = 0.001$)

From the results of the local spatial autocorrelation of the bivariate spatial autocorrelation of the population–industry–land urbanization coupling coordination degree and the cultivated pressure index in Jiangsu Province, the spatial distribution of the urbanization positively affects the cultivated land pressure index in adjacent study units in an absolute majority; the significant H-H zones (high urbanization–high cultivated pressure) are mainly located in Yancheng City, Huai'an City, Suqian City, and other areas in north and central Jiangsu Province, while the significant L-L zones (low urbanization–low cultivated pressure) are concentrated in Suzhou City, Wuxi City, Changzhou City, and other cities in southern Jiangsu Province. From 2005 to 2019, the significant L-L zone showed an increasing trend,

which indicated that the positive spatial spillover effect of the overall urbanization level on the cultivated land pressure in the northern and central regions of Jiangsu was enhanced.

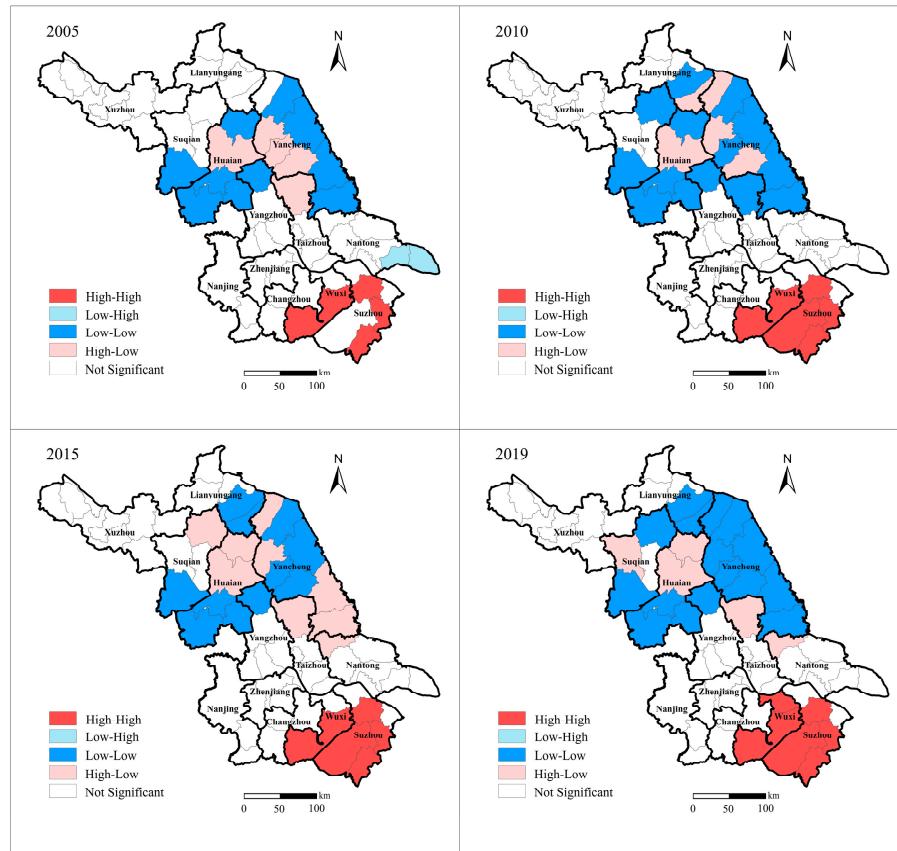


Figure 5. Spatial correlation pattern of population–industry–land urbanization coupling coordination degree and cultivated land pressure from 2005 to 2019.

3.3. Spatial Regression Analysis of Urbanization and Cultivated Land Pressure

3.3.1. Spatial Regression Analysis of the Impact of Total Urbanization on the Cultivated Land Pressure

Based on the panel data of 65 study units in Jiangsu Province from 2005 to 2019, the spatial Durbin model (SDM) was used to analyze the impact of total urbanization on the cultivated land pressure by taking the population–industry–land urbanization coupling coordination degree as the core explanatory variable and the cultivated land pressure index as the dependent variable. The number of observations was 975.

Firstly, the traditional mixed panel data model without spatial interaction effects was applied to the panel data of Jiangsu Province for estimation and residual testing to determine whether the spatial error model (SEM) and spatial lag model (SLM) were superior to the non-spatial model; then, the likelihood ratio (LR) test was conducted to determine whether SDM can be degraded to SEM or SLM; and finally, the Hausman test was conducted to determine whether to choose the fixed effects or random effects. After testing, the results showed that the SDM with fixed effects was the most appropriate. Generally, the fixed-effects estimates are given in the SDM, but due to the incorporation of the spatially lagged dependent and independent variables in the model, its marginal effects cannot be directly reflected, and it is difficult for its estimates to accurately measure the effect of the independent variables on the dependent variables [52]. Therefore, partial differential equations need to be used to calculate the direct and indirect effects of the respective variables [53]. The results of SDM parameter estimation are shown in Table 3.

Table 3. Regression results of SDM with the population–industry–land urbanization coupling coordination degree as the core explanatory variable.

Variable	Direct Effect	Indirect Effect
Population–industry–land urbanization coupling coordination degree	−0.018 ($p = 0.491$)	0.008 ($p = 0.923$)
Economic level	−0.000007 ($p < 0.001$)	0.000006 ($p = 0.869$)
Fertilizer application level	−1.234 ($p < 0.001$)	0.513 ($p = 0.558$)
Agriculture modernization level	0.021 ($p = 0.444$)	0.142 ($p = 0.031$)
Labor input level	−0.001 ($p = 0.909$)	0.01 ($p = 0.488$)
Water resource level	0.002 ($p < 0.001$)	0.008 ($p = 0.923$)

Note: We set the impact of influences to be significant when the p -value is less than 0.1; number of observations: 975.

It was found that the total urbanization level does not have a significant effect on cultivated land pressure. This indicated that the impacts of population urbanization, industry urbanization, and land urbanization on cultivated land pressure in Jiangsu Province are differentiated. Therefore, in the next step, population urbanization, industry urbanization, and land urbanization should be taken as the core explanatory variables to conduct regression analysis on the cultivated land pressure index again.

3.3.2. Spatial Regression Analysis of the Impact of Three Urbanization Dimensions on Cultivated Land Pressure

Taking population urbanization, industry urbanization, and land urbanization as the core explanatory variables, regression analysis was conducted using the SDM based on panel data of 65 research units in Jiangsu Province from 2005 to 2019. The number of observations was 975. After testing, the results showed that the SDM with fixed effects is the most suitable, and the parameter estimation results are shown in Table 4.

Table 4. Regression results of the SDM with population urbanization, industry urbanization, and land urbanization as the core explanatory variables.

Variable	Direct Effect	Indirect Effect
Population urbanization	−0.019 ($p = 0.06$)	−0.002 ($p = 0.02$)
Industry urbanization	−0.024 ($p = 0.07$)	0.058 ($p = 0.13$)
Land urbanization	4.06 ($p < 0.001$)	−1.424 ($p = 0.04$)
Economic level	−0.000013 ($p < 0.001$)	−0.00003 ($p = 0.578$)
Fertilizer application level	−1.32 ($p < 0.001$)	0.426 ($p = 0.507$)
Agriculture modernization level	0.067 ($p = 0.02$)	0.198 ($p = 0.002$)
Labor input level	−0.012 ($p = 0.128$)	−0.015 ($p = 0.34$)
Water resource level	0.0017 ($p < 0.001$)	−0.002 ($p < 0.001$)

Note: We set the impact of influences to be significant when the p -value is less than 0.1; number of observations: 975.

It was found that population urbanization had a significant negative impact on cultivated land pressure. This was due to the changes in food production caused by the transformation of the rural population status. The continued transfer of the rural population to the cities and the migration of surplus rural labor had caused a shortage of labor, but it had also helped the transfer of rural land and the realization of large-scale operations, which had increased the efficiency of food production and improved the food production level.

Industry urbanization had a significant negative impact on the cultivated land pressure index. From 2005 to 2019, the process of industrialization in Jiangsu Province continued to advance, with the industrialization rate increasing from 92.4% to 95.7%, so that industry urbanization reached a high level. With the rapid industry urbanization, the marginal effect of capital profit from the secondary and tertiary industries in the city decreased, and the flow of capital began to shift from the city to the countryside and from the secondary and tertiary industries to the primary industry. Urban areas supported the countryside, industry fed agriculture, and other related policies were implemented more and more vigorously; agricultural management was upgraded, agricultural technology was modernized, human habitat was improved, and rural development was changing rapidly. Therefore, industry

urbanization played a positive role in promoting food production, thereby reducing the cultivated land pressure.

Land urbanization showed a significant positive effect on the cultivated land pressure index. Changes in the quantity and quality of the cultivated land affect food production. In 2005–2019, which was a period of rapid urban expansion in Jiangsu Province, the construction land area expanded by 2.5 times. As urbanization continued, regional urban construction land continued to expand, and the cultivated land area continued to shrink. In recent years, although China had put forward the requirement of “balanced occupation and compensation” for the occupation of cultivated land in the urbanization process, the status of “occupying the best and compensating for the worst” has been common. The area of high-quality cultivated land had been reduced, and the reduction in the quantity and quality of cultivated land had led to a decline in the level of food production, thereby exacerbating the pressure on arable land. The reduction in the quantity and quality of high-quality cultivated land directly contributes to the decline in food production, which in turn aggravates cultivated land pressure.

Industry urbanization had no significant effect on adjacent study units, which indicated that industry urbanization had no spatial spillover effect on cultivated land pressure in adjacent areas. Population urbanization and land urbanization had significant negative spatial spillover effects on cultivated land pressure in adjacent areas. With the rapid advancement of population urbanization and land urbanization in the southern Jiangsu region and the important cities in the northern and central Jiangsu regions, there was an agglomeration of population, industry, and capital and a large number of urban land-use indicators. This led to the loss of agricultural employees, the slow process of land urbanization, and a continuous increase in per capita arable land area in the surrounding relatively underdeveloped areas. As advanced agricultural technologies and management models were promoted and large-scale cultivation was realized, the food production capacity of these areas increased.

4. Discussion and Conclusions

4.1. Discussion

The spatial distribution of urbanization and cultivated land pressure in the counties of Jiangsu Province had a clustering effect and an obvious positive spatial correlation characteristic. Therefore, it is necessary to consider the spatial effect when analyzing the impact of urbanization on cultivated land pressure. It was found that total urbanization had no significant effect on the cultivated land pressure level in Jiangsu Province, and we further analyzed the effects of three different dimensions of urbanization on cultivated land pressure. According to the results of Xu, population urbanization and industry urbanization played a positive role in the level of the food security threshold at the scale of Jiangsu Province, while land urbanization showed a negative role [35]. This study confirms this result at the county scale of Jiangsu Province. This paper has two theoretical contributions. First, this paper considered spatial and temporal factors in analyzing the impact of urbanization on the cultivated land pressure index, and it explored the spatial spillover effect of the former on the latter based on the SDM. Secondly, this study explored not only the impact of total urbanization on the cultivated land pressure, but also the impact of population urbanization, industry urbanization, and land urbanization on the cultivated land pressure. Therefore, this paper analyzed the research problem by adopting a sound methodology and derived reasonable conclusions, which contribute to the study of rural geography.

This paper also has shortcomings. The impact of urbanization on food security is dynamic, and due to limitations of length, this paper does not measure the impact of urbanization on food security for each year, while this measurement idea could be more intuitive for reflecting the changes in the impact of urbanization on food security within an interval. The urbanization and cultivated land pressure between the north and south of Jiangsu Province showed large differences, and in the future, the authors will conduct regression analyses on

the samples from the north and the south, separately, and make comparisons. Moreover, the authors will also conduct a comparative analysis of the impact of urbanization on food security between provinces with different economic development levels.

4.2. Conclusions

The impact of regional urbanization on food security has received extensive attention from academics in recent years. For this paper, a cultivated land pressure index model was constructed to analyze the spatial pattern of food security in Jiangsu Province, and the spatial relationship of urbanization and cultivated land pressure as well as the impact of urbanization on cultivated land pressure were analyzed based on spatial econometrics. The main conclusions are as follows:

An obvious north–south divergence was shown in the spatial distribution of the cultivated land pressure index, with the low-value areas of the cultivated land pressure index mainly distributed in northern and central Jiangsu and the high-value areas mainly distributed in southern Jiangsu. The urbanization level and cultivated land pressure level in Jiangsu Province showed obvious spatial clustering characteristics, and there was a certain overlap between the high- and low-value clustering areas of the two, with significant positive spatial correlation features. The total urbanization had no significant effect on the cultivated land pressure. Population urbanization and industry urbanization showed a significant negative effect on cultivated land pressure in Jiangsu Province, while land urbanization showed a positive effect. Both population and land urbanization had a significant negative spatial spillover effect on cultivated land pressure.

The findings of this paper offer two policy recommendations for Jiangsu Province. First, optimize the urban–rural development paths. In northern and central Jiangsu Province, the government should set out to educate and train the labor force left behind in the countryside to become professional farmers, improve the quality of the labor force, actively renovate the hollow villages, level the land, realize land transfer, and promote the large-scale operation of cultivated land relying on advanced management technology, so as to improve the regional food supply capacity. In southern Jiangsu Province, the government should optimize the land-use mechanism, avoid disorderly urban expansion, conscientiously implement the land-occupancy-supplement balance policy, and implement the most stringent system of cultivated land protection to safeguard the level of food production in counties and cities. Second, build a regional coordination mechanism for food supply and demand. Cultivated land pressure in Jiangsu Province shows a spatially differentiated pattern of high in northern and central Jiangsu and low in southern Jiangsu. The government should promote the coordination of food supply and demand between northern, central, and southern Jiangsu and encourage cooperation between food-producing and food-selling regions. Meanwhile, communication in the agricultural sector between counties should also be strengthened to achieve higher levels of food production through the spatial spillover effects of agricultural and management technologies.

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