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Spatiotemporal Evolution Patterns and Influencing Factors of Rural Shrinkage Under Rapid Urbanization: A Case Study of Zhejiang Province, China

Rongrong Zhuo [1,2], Xinni Xu [1], Yuchen Zhou [1] and Xinwei Guo [3,*]

[1] School of Public Administration, Zhejiang University of Finance and Economics, Hangzhou 310018, China; zhuorongrong@zufe.edu.cn (R.Z.); 230502011006@zufe.edu.cn (X.X.); 240502011006@zufe.edu.cn (Y.Z.)
[2] Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[3] School of Geographic Sciences, Xinyang Normal University, Xinyang 464000, China
* Correspondence: guoxinwei@xynu.edu.cn

Abstract: Under the context of urban–rural mobility driven by rapid urbanization, rural shrinkage is particularly pronounced in the developed regions of China, yet studies exploring its patterns and influencing factors are scarce. This paper uses Zhejiang Province as a case study to investigate the spatiotemporal evolution and influencing factors of rural shrinkage from 2000 to 2020. By employing spatial autocorrelation analysis and spatial econometric modeling, the study investigates both population and spatial shrinkage. The findings reveal the following: (1) a marked spatiotemporal imbalance exists in population and spatial dynamics in Zhejiang's rural areas, where the interplay between population and spatial shrinkage contributes to regional disparities. (2) From 2000 to 2020, population shrinkage shifted from a global shrinkage to a more localized decline in the northeast and southwest, while spatial shrinkage shifted from a global non-shrinkage to a focus on central and southwestern areas. (3) Urbanization significantly negatively impacts rural shrinkage, while the spatial spillover effect of urbanization is notably positive. In contrast, factors related to natural conditions, location, and agricultural investment show significant positive effects but also notable negative spatial spillover effects. This study aims to provide a comprehensive analytical framework for understanding rural shrinkage and offers valuable insights for rural development, infrastructure planning, and spatial governance.

Keywords: rural shrinkage; rural depopulation; spatial shrinkage; urbanization; spatial econometric model; rural China

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1. Introduction

The global phenomenon of urbanization, characterized by the emergence and rapid expansion of cities, has been accompanied by a unidirectional flow of land, labor, raw materials, and other essential production elements from rural areas to urban regions [1–3]. This demographic and spatial shift has resulted in a significant population decline and the loss of land in rural regions, raising critical socio-economic development concerns [4–6]. In the context of China's accelerated urbanization, the extensive flow of urban and rural elements has played a pivotal role in shaping social and economic progress [7–9]. Consequently, a nuanced understanding of the dynamics of rural element flow across diverse geographical contexts, alongside the urban–rural relationship that emerges from such interactions, has become paramount. Furthermore, addressing how to enhance the endogenous development capacities of rural areas and promote their sustainable development has emerged as a vital focus area within the broader framework of rural revitalization [10,11].

Rural shrinkage is a consequence of the flow of factors between urban and rural areas, referring to the decline in the social and economic structure and functions of rural regions due to factors such as population decline, economic recession, and decreased

land use efficiency. Since industrialization, a significant number of rural residents have migrated to cities in search of better employment opportunities [12]. The modernization of agriculture since the second half of the twentieth century has further exacerbated the surplus of rural labor. Additionally, the acceleration of globalization since the 1970s has prompted rapid population movements between regions, intensifying the outflow of rural resources. Consequently, the phenomenon of rural shrinkage has become a widespread global issue [13]. This trend is observed not only in countries and regions experiencing rapid economic development and urbanization [14] but also in underdeveloped areas grappling with challenges such as resource depletion, inadequate infrastructure, and a lack of essential services [15,16]. Even in highly developed and densely populated countries like Japan and Germany, small towns in rural areas are characterized by economic decline and demographic shrinkage, leading to a form of spatial inequality known as "peripheralization" [5]. As of 2010, nearly 27% of the remote rural counties in the United States had lost over 50 percent of their peak populations. This population decline is initially manifested through significant migration, which is later accompanied by issues such as decreasing fertility rates and increasing mortality rates. The influencing factors can be primarily examined from three perspectives: economic, persistent out-migration, population aging [17,18]. Empirical studies on rural shrinkage in Germany, Czech, and Japan have demonstrated that the loss of rural populations is often linked to economic decline and a lack of jobs, ultimately leading to the marginalization of rural areas [5,19]. In the context of domestic research on rural shrinkage in China, early attention was primarily focused on the phenomenon of "hollow villages" [20]. Along with the resultant "hollow villages" and "abandoned land", rural shrinkage has become a significant cause of rural decay and poses a critical challenge to the development of certain rural areas [21]. The process of urbanization has led to large-scale population movements from rural to urban areas, resulting in population outflow, vacant housing, and abandoned cultivated land [22,23]. Around 2010, the issue of rural hollowing began to emerge in both the developed coastal counties of China and the traditional agricultural regions of central China [24,25]. Since then, the scope and complexity of this issue have gradually expanded, becoming a significant challenge for China as it strives for urban–rural integration development [26,27]. It is evident that during the early and middle stages of rapid urbanization, rural shrinkage is primarily characterized by the phenomenon of "hollowing". The outflow of development factors from rural areas poses a significant challenge to their sustainable development, which warrants close attention.

However, with the continuous socio-economic development and a deeper understanding of the man–land relationship, rural shrinkage is increasingly viewed not merely as a negative issue, but as a potentially more efficient and intensive model for rural development. Consequently, some scholars have adapted the concept of "smart shrinkage", [28,29] originally used in urban studies, to rural contexts. This term describes rural areas that continue to exhibit strong economic vitality and community development despite population decline, as well as strategies for rural planning that address this population loss [30]. On the other hand, smart shrinkage also serves as a strategy for rural spatial governance. In some villages in China, a phenomenon of "population decline and land expansion" has emerged [31–33], which contradicts the pressing need to address the current tension between urban and rural construction land. The concept of smart shrinkage is highly applicable to the governance of this issue. Therefore, within the framework of smart shrinkage, the aim of rural spatial governance is to achieve sustainable development in rural areas by enhancing the functions of existing rural land and making rural production and living functions more intensive and efficient [34].

In summary, studies on the flow and spatial allocation of rural development factors have evolved through several conceptual stages, transitioning from "hollow villages" to "rural shrinkage" and ultimately to "smart shrinkage". Specifically, the term "hollow villages" primarily emphasizes the negative impacts of rural factor's outflow, while "rural shrinkage" focuses more on the factual phenomena and outcomes associated with the

factor's outflow, thus having a broader scope of application. Zhejiang Province, as a pioneer in China's reform and opening up, has undergone rapid urbanization and industrialization, leading to the substantial migration of the rural population to urban areas and a prolonged period of shrinkage in both the rural population and their living spaces. By adopting the relatively "neutral" concept of rural shrinkage as a lens for analysis, we can more objectively examine the spatiotemporal evolution of the endogenous development dynamics resulting from the flow of urban and rural factors in Zhejiang Province since the beginning of the 21st century. Consequently, this paper focuses on Zhejiang Province as the study area, utilizing counties as the unit of analysis, and covers the period from 2000 to 2020. This period is further divided into two distinct phases: 2000–2010 and 2010–2020. The study aims to explore the evolution characteristics of the spatiotemporal pattern of rural shrinkage at the county level in Zhejiang Province, considering both rural population decline and spatial contraction, while also investigating the mechanisms influencing rural shrinkage in the region.

2. Materials and Methods

2.1. Study Area

Zhejiang Province is situated in the eastern coastal region of China and encompasses 90 counties, covering a land area of 105,500 square kilometers. As of 2023, the province had a permanent population of 66.27 million and a per capita GDP of 125,000 yuan, ranking fifth in China. Between 2000 and 2023, the proportion of the urban population in Zhejiang's permanent population rose from 48.7% to 74.2%, while the rural population continued to decline. Given that the aim of this research is to analyze changes in land use and population in rural areas, and considering the availability of data and the consistency of research units across different periods, this paper consolidates each municipal district into the main urban area. This results in a total of 64 county-level research units, as illustrated in Figure 1. Generally, Zhejiang Province can be categorized into four regions based on geographical location and the level of regional economic and social development: northeast Zhejiang (including Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, and Zhoushan), southern Zhejiang (comprising Wenzhou and Taizhou), southwest Zhejiang (encompassing Quzhou and Lishui), and central Zhejiang (represented by Jinhua) [35]. From 2000 to 2020, the number of villages in Zhejiang Province declined from 25,270 to 16,377. At the same time, the area of arable land decreased from 1607 hectares to 1281 hectares, while the area of urban built-up land increased from 964 square kilometers to 3157 square kilometers. This indicates that rural shrinkage in Zhejiang Province has occurred concurrently with the expansion of urbanization.

Since the reform and opening up in 1978, Zhejiang Province has not only maintained its urbanization level and comprehensive socio-economic development at the forefront of the country, but the government has also significantly advanced rural development by restructuring the rural economy and fostering rural industries. Since 2000, rural areas have undergone industrial transformation, with services such as B&B (Bed and Breakfast), rural tourism, and e-commerce gradually emerging as new industrial forms for promoting rural development in Zhejiang Province. Compared to other regions in the country, the socio-economic development gap between urban and rural areas in Zhejiang is relatively small. In response, in 2021, the central government implemented policies to support Zhejiang to take the lead in establishing a demonstration zone for achieving common prosperity, marking a new phase in the integrated development of urban and rural areas in the province. Although indicators related to the urban–rural gap, regional development, and wealth levels in Zhejiang Province rank among the highest in the country, the process of urbanization has inevitably led to rural shrinkage. To reduce the urban–rural gap, it is essential to investigate the spatiotemporal pattern of rural shrinkage within the region and its influencing factors, as this serves as a crucial foundation for achieving this objective.

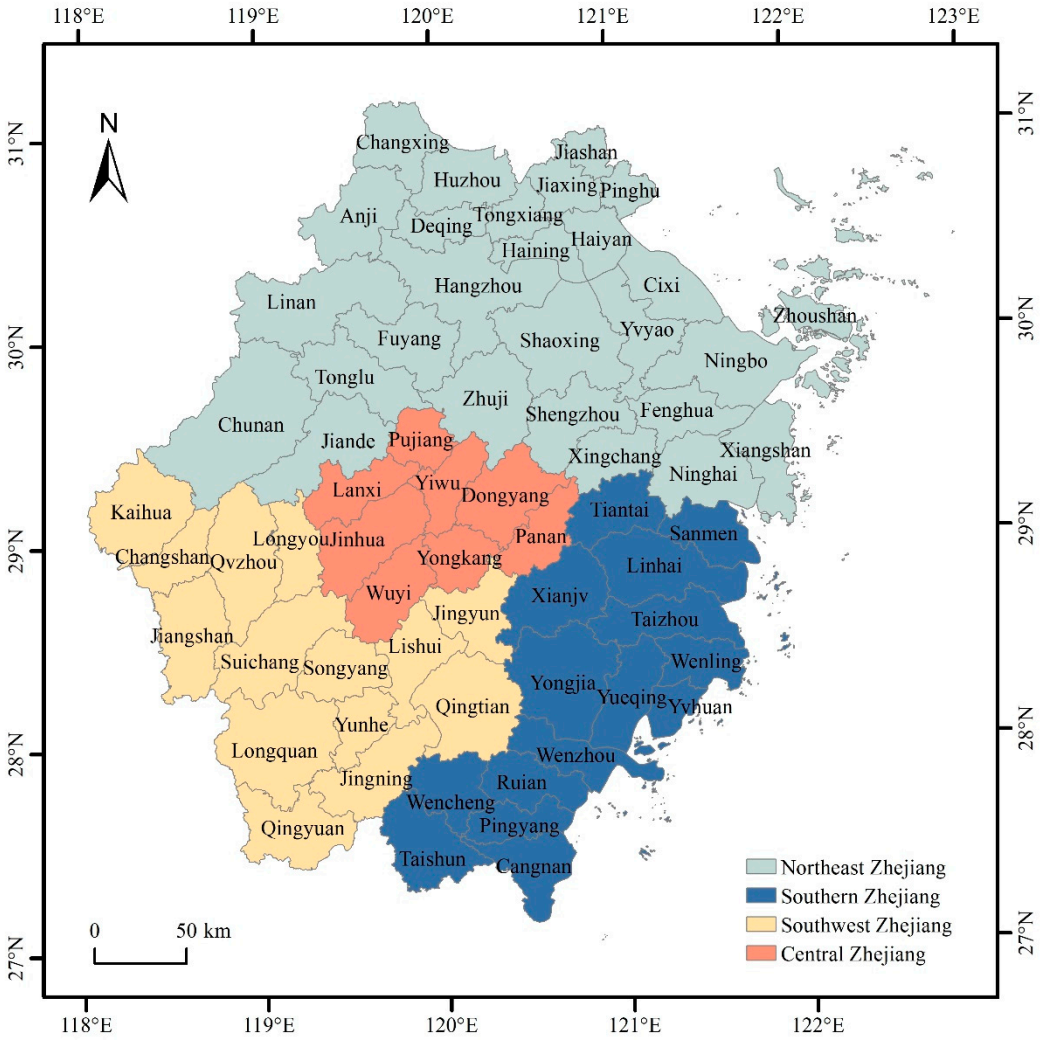


Figure 1. Location and county-level administrative divisions of Zhejiang Province.

2.2. Methods

2.2.1. Measurement of Rural Shrinkage

Currently, the definition and measurement of rural shrinkage primarily focus on the extent of population loss. Drawing from relevant research on urban shrinkage [36,37], this paper incorporates changes in land use within rural settlements into the measurement of rural shrinkage. We define rural shrinkage as a phenomenon characterized by the outflow of both population and land over a specific period. Building on this definition, the paper thoroughly investigates the spatiotemporal patterns and influencing mechanisms of rural shrinkage in Zhejiang Province, examining both population and spatial dimensions. Specifically, we calculate the rural depopulation index, rural spatial shrinkage index, and rural comprehensive shrinkage index to analyze changes in rural population and residential land area across various counties in Zhejiang Province during the study period. The calculation formulas are as follows:

$$S_{Pi} = (P_{it} - P_{it'})/P_{it'} \times 100\% \quad (1)$$

$$S_{Li} = (L_{it} - L_{it'})/L_{it'} \times 100\% \quad (2)$$

$$S_i = S_{Pi} + S_{Li} \quad (3)$$

where S_{Pi} represents the rural depopulation index for county i, while S_{Li} denotes the rural spatial contraction index for the same county. S_i is the comprehensive index of rural

shrinkage in county i. $P_{it'}$ refers to the rural population of county i at the beginning of the study period t', and P_{it} indicates the rural population of county i at the end of the study period t. Similarly, $L_{it'}$ is the area of rural settlements in county i at the beginning of the study period t', and L_{it} is the area of rural settlements in county i at the end of the study period t.

$S_{Pi} > 0$ indicates that there is no decrease in the rural population of the county. Conversely, $S_{Pi} < 0$ signifies a decrease in the rural population. For the spatial aspect, $S_{Li} > 0$ suggests that the rural space is expanding, while $S_{Li} < 0$ indicates that the rural space is contracting. Regarding the composite index, if $S_i > 0$, the county is not experiencing comprehensive rural shrinkage; however, if $S_i < 0$, it means that the county is undergoing comprehensive rural shrinkage.

2.2.2. Spatial Econometric Model

Spatial interaction plays a crucial role in understanding the mechanisms behind rural shrinkage from a geographical perspective. In this study, we identify key influencing factors and construct a spatial econometric model to analyze the spatial interactions among these factors, aiming to elucidate the mechanisms driving rural shrinkage in the study area. A spatial econometric model is a statistical approach that examines spatial dependence and interactions within spatial data, integrating theories and methods from economics, geography, and statistics to uncover the spatial correlations and dependencies among various phenomena in geographic space [38,39].

The spatial lag model (SLM) is a specific type of spatial econometric model designed to analyze the spatial dependence and mutual influences among research units [40]. This model is grounded in the principle of spatial autocorrelation, which posits that the values of variables in neighboring regions exert mutual influence on each other. In the spatial lag model, we not only consider how independent variables affect the dependent variable but also account for the influence of the dependent variable in adjacent regions on the dependent variable in the focal region. Specifically, the model assumes that the value of the dependent variable is influenced not only by its own explanatory variables but also by the values of the dependent variable in neighboring regions, indicating the presence of spatial spillover effects. The formula for the spatial lag model can be expressed as follows [41]:

$$Y_i = \rho W Y_i \times X_i \beta_i + \varepsilon_i \quad (4)$$

In the formula, Y_i is the dependent variable, which represents the rural shrinkage index of county i, X_i is the explanatory variable, ρ is the spatial autocorrelation coefficient, and W is the spatial weight matrix constructed in this paper, and the spatial relationship between counties is determined by the spatial weight matrix W. The spatial lag term $\rho W Y_i$ in the model represents the influence of the explanatory variable value of the adjacent county on the explanatory variable value of the county. β_i is the coefficient of the explanatory variable, which reflects the degree of influence of the explanatory variable on the dependent variable, and ε_i is the spatial error term of the explanatory variable.

The ArcGIS software 10.2 platform was employed to visualize the rural shrinkage index at the county level in Zhejiang Province, utilizing spatial autocorrelation methods to analyze its spatial agglomeration patterns and evolving characteristics. Moran's I index test was carried out on the rural comprehensive shrinkage index in 2010~2020 and 2000~2010, and the results passed the significance level test of 10%, and the spatial correlation could be analyzed by using the spatial econometric model. Taking the rural shrinkage index at the county level in Zhejiang Province as the dependent variable and the influencing factors of rural shrinkage as the independent variable, a panel data spatial econometric model with a time span of 2000~2020 was constructed. In order to reduce the heteroscedasticity of the data, the dependent and independent variables were made logarithmic. On this basis, the Lagrange multiplier test and its robust value test were used to determine which spatial econometric model to choose.

2.3. Data Sources and Processing

The data utilized in this study primarily consist of socio-economic and spatial data. The socio-economic data focus on indicators such as population and GDP, with sources including the Zhejiang Population Census Yearbook and the Zhejiang Statistical Yearbook. The spatial data encompass indicators such as rural settlements areas, the locational characteristics of these areas, county built-up areas, and precipitation, sourced from land-use remote sensing data and the annual spatial interpolation dataset of meteorological elements in China. Specifically, the data concerning rural settlements areas and county built-up areas were processed using ArcGIS software to analyze the remote sensing data on land use in China. Additionally, the locational characteristics of rural settlements were determined by calculating the spatial distance from the geometric center of these settlements to the county administrative center, also using ArcGIS. The meteorological elements were similarly processed with ArcGIS to analyze the annual spatial interpolation dataset of meteorological elements in China.

3. Results

3.1. Overall Characteristics of Rural Shrinkage in Zhejiang Province

Based on the classification methods derived from existing research and taking into account the specific context of rural shrinkage in Zhejiang Province, we define counties with a rural shrinkage index greater than 0 as non-shrinking. Conversely, counties with a rural shrinkage index less than 0 are categorized into four distinct types—mild shrinkage, moderate shrinkage, severe shrinkage, and collapse shrinkage—using the natural breakpoint method in ArcGIS.

Table 1 indicates that during the two periods of 2000–2010 and 2010–2020, rural areas in Zhejiang Province exhibited a noticeable shrinkage trend. Specifically, in terms of the rural depopulation index, most counties experienced slight to moderate population decline in both periods. The number of counties facing severe rural population shrinkage decreased from 8 to 4 between these two time frames. From the perspective of the shrinkage index, the average population shrinkage index for all counties was −0.132 for 2000–2010, while it improved to −0.122 for 2010–2020, suggesting that the trend of rural depopulation in Zhejiang Province slowed during the latter period.

Table 1. Statistics of county-level rural shrinkage in Zhejiang Province in 2000~2020.

Rural Shrinkage	Time Interval	Minimum	Average	Mild Shrinkage	Moderate Shrinkage	Severe Shrinkage	Collapse Shrinkage
Population shrinkage	2000~2010	−0.440	−0.132	17	31	8	0
	2010~2020	−0.472	−0.122	16	31	4	0
Spatial shrinkage	2000~2010	−0.002	0.993	0	1	0	0
	2010~2020	−0.889	−0.075	10	12	13	2
Comprehensive shrinkage	2000~2010	−0.106	0.861	4	0	0	0
	2010~2020	−1.199	−0.197	11	18	12	9

There is a significant difference in the rural spatial shrinkage index between the periods of 2000–2010 and 2010–2020. During 2000–2010, the average value of the rural spatial shrinkage index in Zhejiang Province was 0.993, indicating that most counties did not experience rural spatial shrinkage during this time. In contrast, from 2010 to 2020, the average rural spatial shrinkage index at the county level decreased to −0.075, revealing a clear trend of rural spatial shrinkage, with more than half of the counties (37 in total) experiencing this phenomenon. Among these, 10 counties exhibited slight shrinkage, 12 counties showed moderate shrinkage, and 13 counties faced severe shrinkage. These results indicate that land use in rural settlements at the county level in Zhejiang Province has undergone a trend of initial expansion followed by subsequent shrinkage.

From the perspective of the rural comprehensive shrinkage index, the overall shrinkage in rural areas of Zhejiang Province during the period of 2000–2010 was not pronounced, with an average value of 0.861. However, under the combined effects of population and spatial shrinkage, comprehensive rural shrinkage in each county primarily occurred during 2010–2020, revealing significant spatial disparities in shrinkage among the counties. Specifically, during 2010–2020, Zhejiang Province had the highest number of moderately shrinking counties, totaling 18. The numbers of counties experiencing mild and severe shrinkages were similar, with 11 and 12 counties, respectively. Although the number of counties classified as experiencing subsidence was the smallest, there were still nine such counties.

3.2. Spatiotemporal Characteristics of Rural Shrinkage

1. From the perspective of the rural population shrinkage index, between 2000 and 2020, the majority of counties in Zhejiang Province witnessed a trend of rural population shrinkage (Figures 2 and 3). In terms of temporal changes, the spatial extent of rural population shrinkage in Zhejiang Province slightly decreased from 2010 to 2020 compared to the period from 2000 to 2010. Notably, counties in the central and southern regions displayed trends of population decline and stability during the 2000–2010 and 2010–2020 periods, respectively. It is important to note that the rural population shrinkage in counties such as Yiwu and Yongkang in central Zhejiang remained relatively mild throughout the study period, while the Lishui area in the southwest consistently exhibited a high rural population shrinkage index. In contrast, the rural population shrinkage in the Jiaxing area of northeastern Zhejiang intensified from moderate to severe levels during the study period. These findings suggest that the rural population shrinkage in Zhejiang Province is spatially uneven, following an overall trend of "first in the south, then in the north". This indicates that the shrinkage in rural population in southern counties occurred earlier than in northern counties and also diminished sooner. Furthermore, the southwestern and northeastern regions of Zhejiang, representing the most developed and least developed areas, respectively, both demonstrated significantly high levels of rural population shrinkage during the study period.

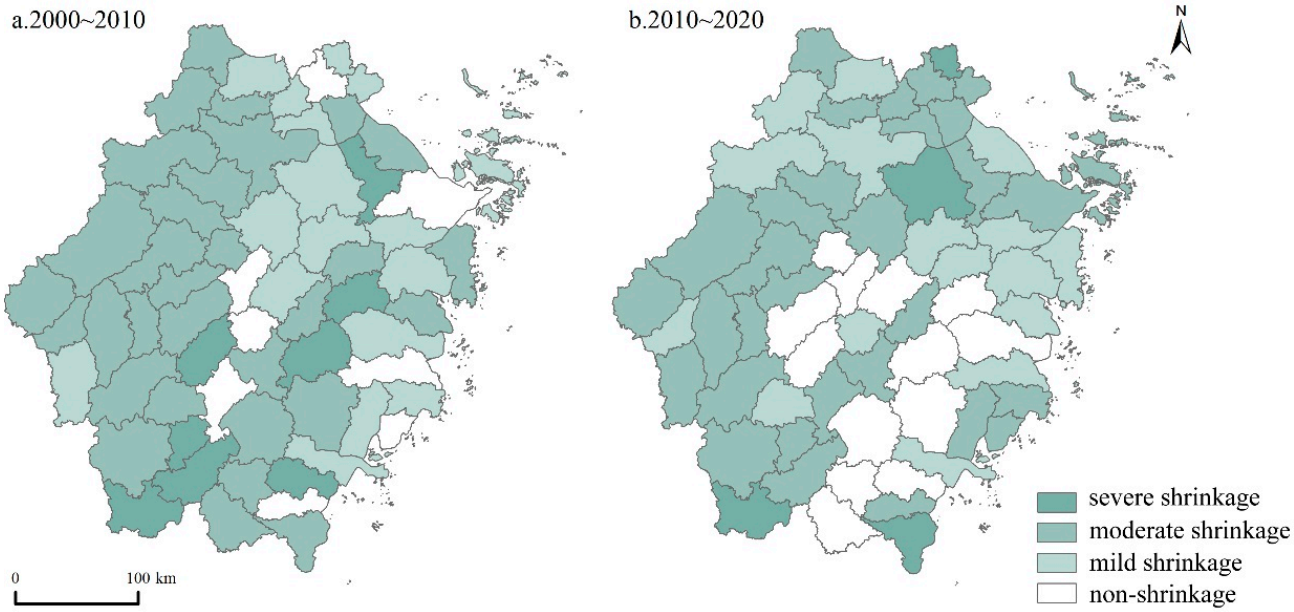


Figure 2. Evolution of rural population shrinkage pattern in Zhejiang Province from 2000 to 2020.

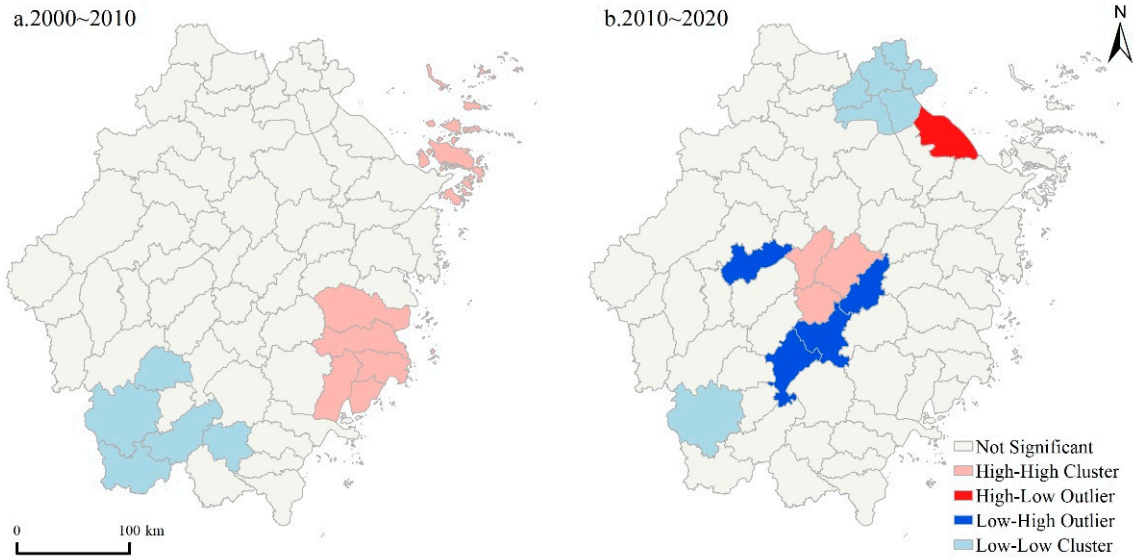


Figure 3. Spatial autocorrelation results of rural population shrinkage in Zhejiang Province from 2000 to 2020.

2. From the perspective of the rural spatial shrinkage index, rural shrinkage in Zhejiang Province shows significant temporal heterogeneities (Figures 4 and 5). Between 2000 and 2010, there were almost no signs of rural spatial shrinkage in the counties of Zhejiang, indicating that rural settlements during this period were not yet influenced by urban spatial expansion. However, from 2010 to 2020, the central and southwestern counties exhibited clear signs of rural spatial shrinkage, while the northeastern and southern regions displayed a distinct pattern of non-shrinkage clustering. This finding suggests that rural spatial shrinkage in Zhejiang Province is not an inevitable consequence of rapid urbanization; in fact, the rural areas in the more economically developed northeastern and southern regions did not experience rural spatial shrinkage, whereas the relatively underdeveloped central and southwestern areas showed a higher degree of rural shrinkage.

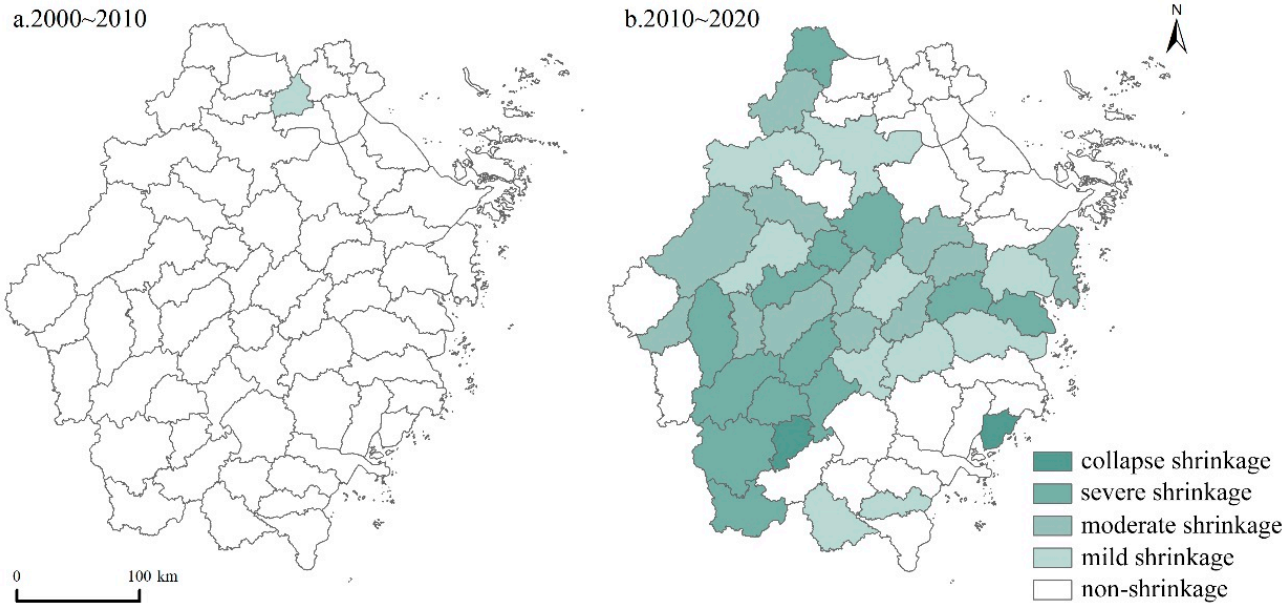


Figure 4. Evolution of rural spatial shrinkage pattern in Zhejiang Province from 2000 to 2020.

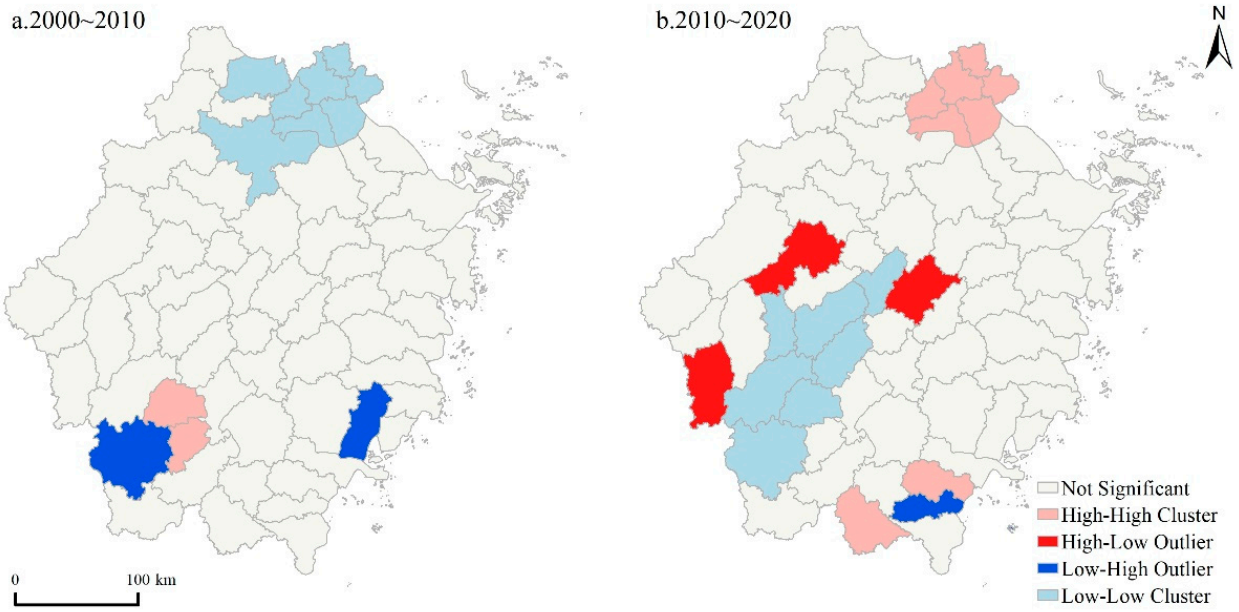


Figure 5. Spatial autocorrelation results of rural spatial shrinkage in Zhejiang Province from 2000 to 2020.

3. From the perspective of the rural comprehensive shrinkage index, the rural shrinkage pattern in Zhejiang Province shows a temporal trend of increasing intensity, influenced by both population and spatial shrinkage, and exhibits significant clustering characteristics (Figures 6 and 7). Between 2000 and 2010, counties such as Tongxiang and Haining in northeastern Zhejiang, as well as Xianju and Yongjia in the south, were the primary areas of comprehensive rural shrinkage in the province, primarily driven by population shrinkage. However, during the 2010 to 2020 period, the trends of rural population shrinkage in Xianju and Yongjia halted, which, in turn, stopped the overall trend of rural shrinkage. In the northern county of Tongxiang, while the extent of population shrinkage increased, the trend of spatial shrinkage reversed, leading to a near cessation of rural comprehensive shrinkage in that area ($S_i = -0.03$). Although the population shrinkage trend in Haining rose significantly, the increase in the spatial shrinkage index was even greater ($S_{Pi} = 0.30$), resulting in the cessation of rural comprehensive shrinkage there. The rural shrinkage trends in these four counties have weakened or even reversed. Furthermore, during the period from 2010 to 2020, the combined effects of population and spatial shrinkage led to rural comprehensive shrinkage in nearly all counties in southwestern, central, and northeastern Zhejiang, with the southwestern counties exhibiting a significant pattern of collapse and concentration. These findings suggest that when population shrinkage and spatial shrinkage do not occur simultaneously, rural comprehensive shrinkage is generally difficult to achieve; conversely, rural comprehensive shrinkage is more likely to occur when both population and spatial shrinkage are evident.

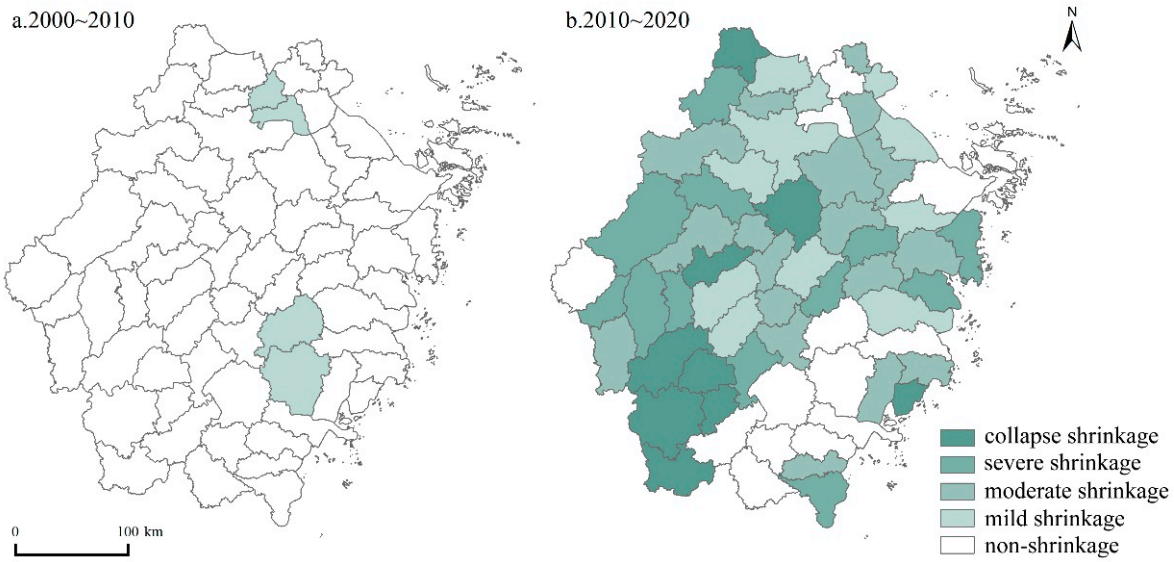


Figure 6. Evolution of rural comprehensive shrinkage pattern in Zhejiang Province from 2000 to 2020.

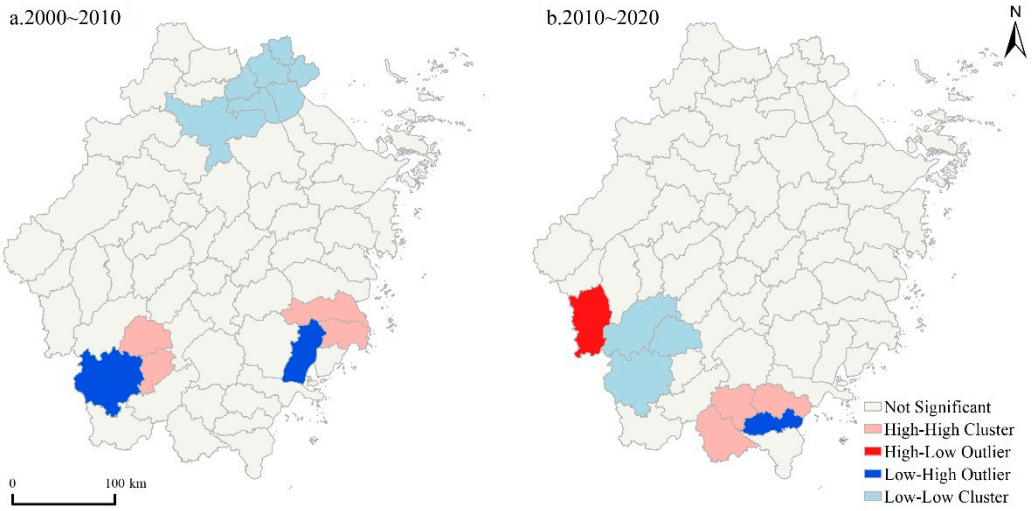


Figure 7. Spatial autocorrelation results of rural comprehensive shrinkage in Zhejiang Province from 2000 to 2020.

3.3. The Influencing Mechanism of Rural Shrinkage in Zhejiang Province

3.3.1. Influencing Factor Selection

The changes in rural population and land use in rural settlements are influenced not only by factors intrinsic to the countryside but also by the development of urban and rural areas, including the physical geographical environment and regional social and economic development. Drawing on research findings related to urban and rural shrinkage, we selected seven indicators from four categories: natural conditions, location, urbanization, and agricultural investment (Table 2) to examine the mechanisms driving rural shrinkage at the county level in Zhejiang Province. Based on existing research, the factors influencing rural development can be approximately categorized into four categories [42,43]: natural conditions, location, urbanization, and agricultural investment. Specifically, natural conditions primarily impact the scale of rural populations and land use from a macro perspective, including factors such as topography, precipitation, and slope [26]. Location refers mainly to the spatial distance between rural settlements and urban areas [44]; this factor determines the extent to which rural areas may be affected by the "siphoning effect" of urban regions on their population and land use. Urban areas are

the destinations of population and land outflow from rural areas, and, thus, urbanization more directly impacts rural populations and land use [45,46]. Agricultural investment indicates the level of agricultural development within rural areas and the strength of their agricultural functions [47]; greater investment typically correlates with a larger number of agricultural workers and cultivated land, thereby reducing the likelihood and severity of rural shrinkage. In summary, rural shrinkage results from the mobilities of elements between urban and rural areas, driven by external forces like globalization and urbanization, which, in turn, leads to changes in the natural and socio-economic conditions within rural areas (Figure 8).

Table 2. Influencing factors of rural shrinkage in Zhejiang Province.

Factors	Variables
Natural conditions	X1 Average annual precipitation
Location	X2 Density of the county road network X3 Distance from rural settlements to the county center
Urbanization	X4 Proportion of built-up area X5 Urbanization rates of population
Agricultural investment	X6 Level of agricultural mechanization X7 Proportion of the labor force in the primary industry

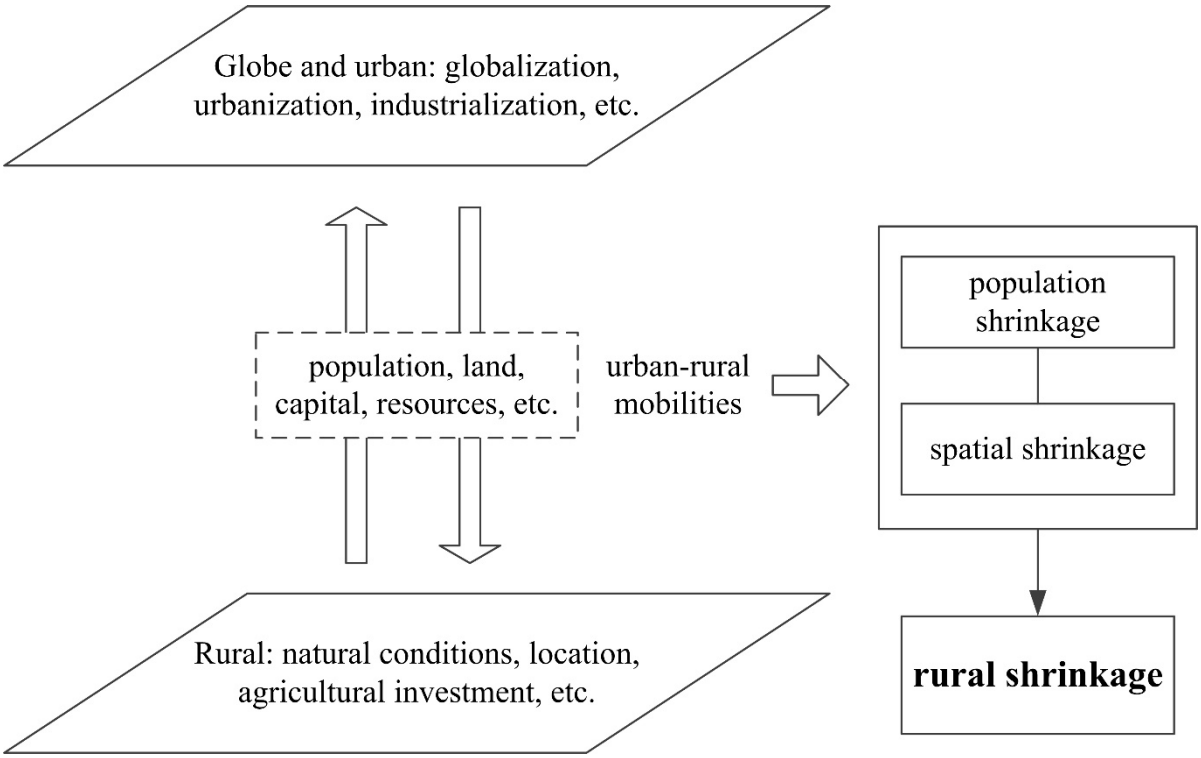


Figure 8. Framework of influencing mechanism of rural shrinkage.

The rationale for the selection of specific indicators and their definitions are outlined below.

- Average annual precipitation was selected as an index representing the influencing factors related to the physical geographical environment. This metric serves as a crucial indicator of a region's climatic conditions, directly impacting local agricultural production and the livelihoods of residents.
- Location primarily characterizes the geographical advantages of rural settlements, including proximity to regional centers and external accessibility. To assess these factors, we selected the distance from residential areas to the county center and the

density of the county road network. The closer a settlement is to the county center, the greater the influence and attraction of urbanization, facilitating the flow of rural residents and land into urban areas. Additionally, road network density reflects transportation accessibility, which significantly affects rural residents and land use by enabling cross-regional mobility of people, capital, technology, and more.

- The urbanization rate primarily exerts a "pull" effect on rural shrinkage. This influencing factor can be expressed through the urbanization rates of population and land—specifically, the urbanization rate of the population and the proportion of built-up area. The urbanization rate indicates the mobilities of people between urban and rural areas; a higher urbanization rate in a specific region correlates with a smaller rural population. Conversely, the proportion of built-up area reflects spatial competition between urban and rural areas during the urbanization process; a larger built-up area typically results in a smaller rural area.
- Investment in agricultural development determines the level of agricultural progress and plays a significant "pushing" role in rural shrinkage. To represent this, we selected two indicators: the proportion of the labor force in the primary industry and the level of agricultural mechanization. The proportion of the labor force in the primary industry reflects the scale of personnel engaged in agricultural production and indicates the industrial structure of the county. The level of agricultural mechanization signifies the degree of mechanization in rural agricultural production, which not only reduces the dependence of land on rural labor but also frees up a substantial number of surplus rural workers, thereby creating conditions conducive to the outflow of the rural population.

3.3.2. Spatial Econometric Analysis of Influencing Factors

The Lagrangian multiplier test and the robustness value test corresponding to the spatial lag model passed the significance test of 5%. After that, the fixed-effect model was determined by Haussmann's test to be the most suitable form of model for this study. Based on the above results, the spatial lag model of fixed effect was selected to study the influencing factors to explore the main influencing factors of rural shrinkage and whether each influencing factor has a spatial spillover effect. The regression results of the spatial lag model are shown in Table 3, and the spatial autocorrelation coefficient is significantly negative (−1.140), indicating that the influence of various influencing factors on rural shrinkage has a significant negative spatial spillover effect. The specific results are as follows.

Table 3. Results of spatial lag model regression.

Variables	Main Effects	Indirect Effects
X1 Average annual precipitation	4.591 *** (4.743)	−2.630 *** (−2.758)
X2 Density of the county road network	1.295 *** (3.235)	−0.720 *** (−2.660
X3 Distance from rural settlements to the county center	1.698 *** (3.574)	−0.962 *** (−2.960)
X4 Proportion of built-up area	−0.254 (−1.081)	0.136 (0.970)
X5 Urbanization rates of population	−3.081 *** (−3.834)	1.751 *** (2.937)
X6 Level of agricultural mechanization	0.118 (0.367)	−0.082 (−0.464)
X7 Proportion of the labor force in the primary industry	0.417 * (1.643)	−0.233 (−1.560)
Spatial rho	−1.140 *** (−2.757)	

Note: * $p < 0.05$; *** $p < 0.001$.

1. Average annual precipitation

There is a positive correlation between average annual precipitation and the rural comprehensive shrinkage index, indicating that higher precipitation at the county level is associated with a higher rural shrinkage index and a lower degree of rural shrinkage.

However, the indirect effect coefficient for this index is significantly negative, suggesting a negative spatial spillover effect of average annual precipitation. Specifically, as average annual precipitation in a county increases, the rural comprehensive shrinkage index in neighboring counties decreases, leading to a higher degree of rural shrinkage. This phenomenon implies that increased precipitation exacerbates rural shrinkage in adjacent counties, potentially due to significant differences in the natural environment across Zhejiang Province. The low spatial agglomeration of natural factors like precipitation at the county level indicates that the natural environments of neighboring counties may vary considerably, making it difficult to establish a positive spatial spillover effect. Therefore, the spatial spillover effects of precipitation and other natural environmental factors warrant further empirical investigation.

2. Density of the county road network

There is a positive correlation between the county road network density and the rural comprehensive shrinkage index, with a main effect coefficient value of 1.295 and a significance level of 1%. This indicates that greater transportation accessibility at the county level corresponds to a larger rural comprehensive shrinkage index, thus reflecting a lower degree of rural shrinkage. Theoretically, a higher road network density implies more convenient transportation conditions and an increased likelihood of spatial mobilities for rural residents. However, the findings suggest that while transportation development theoretically facilitates the migration of rural populations to urban areas, it has not exacerbated rural shrinkage. Moreover, the indirect effect coefficient of county road network density is significantly negative, indicating that a higher road network density in adjacent counties is associated with an increased degree of rural comprehensive shrinkage in the county.

3. Distance from rural settlements to the county center

There is a significant positive correlation between the distance from the center of a settlement to the county center and the comprehensive shrinkage index of rural areas, with a main effect coefficient of 1.698. This indicates that the closer a rural settlement is to the county center, the smaller the comprehensive shrinkage index and the higher the degree of rural shrinkage. A reduced distance provides rural residents with more opportunities to seek non-agricultural livelihoods in urban areas, facilitating the mobilities of resources—such as infrastructure, capital, and urban consumption—into the countryside. This, in turn, drives the development of rural industries and accelerates the conversion of cultivated land to non-agricultural uses.

4. Urbanization rates of population

The main effect coefficient of the population urbanization rate was −3.081, with a significance level of 1%. This indicates that a higher urban population rate during the study period correlates with a lower comprehensive shrinkage index for county villages, meaning a greater degree of shrinkage. The indirect effect coefficient of this index is significantly positive, suggesting that the urbanization rate in a given county not only does not contribute to an increase in rural shrinkage levels in neighboring counties but actually decreases them. As a result, there is no spatial interaction between counties regarding rural shrinkage caused by urbanization.

5. Proportion of the labor force in the primary industry

The main effect coefficient of the proportion of the labor force in the primary industry was 0.417, with a significance level of 5%. This indicates that the higher proportion of the labor force engaged in the primary industry during the study period correlates with a higher comprehensive shrinkage index for rural areas in the county, meaning a lower degree of contraction. A greater proportion of the labor force in the primary industry signifies that a larger share of the population is involved in agricultural production activities within the county.

In conclusion, from a direct effects perspective, the urbanization rate of population has a significant negative impact on rural shrinkage in counties; as urbanization rates increase,

rural shrinkage also rises. Conversely, factors such as the proportion of the labor force in the primary industry, county road network density, distance from rural settlement to county centers, and average annual precipitation exhibit significant positive effects. This indicates that favorable conditions in a county—such as strong social and economic development, advantageous natural conditions, and effective agricultural inputs—can help mitigate rural contraction. From an indirect effects perspective, the significant influencing factors identified in the regression analysis all demonstrate spatial spillover effects. Notably, the spatial spillover effect of urbanization rates of population is significantly positive, suggesting that rapid urbanization in adjacent counties does not contribute to rural shrinkage in the focal county. This is largely due to the "centripetal" population flow towards Hangzhou, the provincial capital.

In contrast, the influencing factors such as the proportion of the labor force in the primary industry, county road network density, distance from rural settlement to county centers, and average annual precipitation exhibit significant negative spatial spillover effects. This implies that when neighboring counties enjoy better natural conditions, location advantages, and higher levels of agricultural development inputs, rural shrinkage levels in the focal county tend to increase. These findings indicate that there are spatial spillover effects among counties in Zhejiang Province related to the aforementioned factors. A county that excels in conditions favorable to urban development is more likely to exert a "siphon effect" on surrounding villages, thereby exacerbating the level of rural shrinkage in neighboring counties.

4. Discussion

This paper takes Zhejiang Province, a developed region in eastern China, as a case study to examine the spatiotemporal patterns and influencing mechanisms of rural shrinkage at the county level from 2000 to 2020. Using population and spatial shrinkage indexes, we calculated the evolution characteristics of rural shrinkage in Zhejiang Province. Subsequently, we employed the ArcGIS spatial autocorrelation analysis method to investigate the spatial patterns of rural shrinkage within the province. Following this analysis, we selected relevant influencing indicators and utilized spatial econometric methods to explore the underlying mechanisms driving rural shrinkage.

Spatial disequilibrium is evident in the asynchronous patterns of population and spatial shrinkage. Generally, population shrinkage occurs before spatial shrinkage, contributing to a lower degree of rural shrinkage in the study area during 2000–2010 compared to the period of 2010–2020. Specifically, the spatial trend of population shrinkage shifts from a global shrinkage to a focus on the northeastern and southwestern regions, while spatial shrinkage evolves from a state of overall non-shrinkage to shrinkage primarily in the central and southwestern areas. The temporal and spatial imbalances in population and spatial shrinkage collectively contribute to the regional disparities in rural comprehensive shrinkage observed in the study area. The asynchrony of population decline and spatial shrinkage in Zhejiang Province align closely with the findings of existing research on rural population dynamics and land use changes across China [14,48,49]. In other words, the outmigration of rural populations in China's developed regions tends to precede the loss of arable land, a phenomenon that is intricately linked to the process and characteristics of urbanization in the country. Furthermore, in the case of Zhejiang, the spatial variations in population density and topography within the region mirror its economic disparities, serving as fundamental factors influencing patterns of rural shrinkage. The northeastern and southern regions of Zhejiang feature extensive plains, high population densities, and relatively developed economies, while central Zhejiang ranks next in terms of development. In contrast, the southwestern mountainous areas exhibit low population densities and underdeveloped economies. This disparity may contribute to the asynchronous temporal and spatial dynamics of rural shrinkage.

Specifically, the factors influencing rural shrinkage are multifaceted and complex. Notably, the impact of the urbanization rate of population and average annual precipitation

is substantial, underscoring the vital roles of the natural environment and urbanization in rural development. Firstly, greater precipitation translates to more abundant water resources and more fertile soils, which create favorable conditions for agricultural production. In turn, developed agriculture increases the willingness of rural residents to settle in these areas. Additionally, a favorable natural and ecological environment provides opportunities for the development of eco-tourism, leisure agriculture, and other industries in rural areas. Secondly, the direct impact of urbanization on rural shrinkage is significant; however, there is no spatial spillover effect. In recent years, rural tourism in Zhejiang Province has flourished, evolving into various formats such as homestays, cafes, shared farms, natural museums, and rural research centers. This phenomenon is related to the regional economic development pattern of Zhejiang Province and the direction of cross-regional population mobilities influenced by it. Aside from Hangzhou, the provincial capital, which has a significantly higher GDP than other cities in the province and serves as the main hub for population inflow, the differences in social and economic development levels between prefectures and cities in Zhejiang Province, as well as among counties within the same prefecture-level city, are relatively small. Consequently, the population mobilities between counties and cities is not pronounced, leading to the conclusion that the urbanization rates of the population in neighboring counties does not result in an increased level of rural shrinkage in a given county.

As for the location factors, this study posits that although accessibility for rural residents to urban areas has significantly improved, it has also enhanced the appeal of rural life and increased residents' willingness to remain in rural spaces, thereby reducing the likelihood of population outflow. However, the indirect effect coefficient for the location indicator is significantly negative, suggesting that as the distance from rural settlements in adjacent counties to the county center increases, the rural comprehensive shrinkage index decreases, leading to a higher degree of rural shrinkage. The results of this study imply that in counties with a low centripetal force at their centers, there may be instances of rural shrinkage driven by cross-regional population mobilities from more remote rural settlements.

As for the agricultural investment factors, the agriculture-dominated structural inertia allows some rural areas to maintain a favorable agricultural production function, resulting in a higher number of individuals engaged in agricultural work residing in rural areas, thereby contributing to a lower degree of rural population and spatial shrinkage. However, the indirect effect coefficient of the proportion of the labor force in the primary industry is significantly negative, suggesting that a higher proportion of labor in the primary industry in adjacent counties is associated with an increased degree of rural comprehensive shrinkage in the county.

In addition, the proportion of built-up area and the level of agricultural mechanization have no significant impact on rural shrinkage, which may be because the cultivated land in rural areas has not been taken into account. The insignificance of the built-up area proportion may stem from the fact that this study characterizes rural spatial shrinkage using rural settlement land, which does not include rural cultivated land. In Zhejiang Province, the urban land expansion process has resulted in less encroachment on rural settlement land, while there may be more encroachment on cultivated land surrounding rural settlements. As a result, the relationship between the shrinkage of rural settlements and the expansion of urban land is difficult to measure. For similar reasons, the level of agricultural mechanization is highly correlated with rural cultivated land, and its impact on rural population shrinkage and spatial shrinkage is more indirect and hidden. Future research could consider integrating rural cultivated land with rural settlement areas to jointly measure rural spatial shrinkage, enabling an exploration of rural spatial shrinkage from the perspective of production and living space.

5. Conclusions

In the era of globalization, rural development can no longer be viewed as a static and isolated matter merely "about the countryside". Instead, it should be explored within the context of an urban–rural regional continuum, or even on a broader global scale [50,51]. Rural shrinkage refers to the transformation of rural landscape patterns resulting from the movement of rural elements within a specific geographical area. By studying the patterns of rural shrinkage across different regional types, we can gain insights into the endogenous development of rural areas [52,53], allowing us to analyze the urban–rural development patterns within those regions.

Future research on rural shrinkage can focus on the following aspects. Firstly, by integrating diverse data sources, such as land use, points of interest (POIs), and residents' behavior, along with GIS, simulation, and predictive methods, researchers can more precisely identify phenomena related to rural depopulation and spatial shrinkage. Secondly, it can focus on more granular spatial scales by examining typical villages as case studies to explore the impact mechanisms of rural shrinkage across various factors—such as environmental conditions, socio-economic factors, and cultural traditions—and identify distinct regional patterns of rural shrinkage. Last but not least, based on an understanding of the complex mechanisms and differentiation modes of rural shrinkage, rural shrinkage research can inform rural spatial governance practices, providing valuable insights for rural spatial planning and governance [54]. The equity of facilities and services between urban and rural areas following shrinkage should be a matter of concern. For this matter, the experiences gained from rural shrinkage and smart shrinkage planning in the Global North countries can offer valuable insights [55–57].

From the perspective of influence mechanisms and spatial effects, rural gentrification and rural resilience are closely linked to the themes of rural shrinkage. These topics are currently at the forefront of rural development discussions, as they seek to understand the changes and reconstructions of rural society, economy, culture, and adaptability driven by globalization and urbanization [26,58]. The process of rural gentrification typically accompanies urban population migration and capital influx, resulting in alterations to the original rural community structure and lifestyle, which, in turn, affects the social dynamics and economic development patterns of rural areas. Rural resilience refers to the capacity of rural communities to recover and adapt in the face of challenges such as economic decline, population loss, and climate change. Therefore, conducting in-depth research on rural shrinkage in conjunction with rural gentrification and rural resilience can illuminate the interactions between rural shrinkage and the socio-economic fabric of rural areas, ultimately guiding policy interventions that promote rural revitalization and sustainable development.

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