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The Spatiotemporal Characteristics and Mechanism of Rural Spatial Shrinkage in Local County, Southeast China

Haiqiang Fan *, Xiaohua Li, Yan Liu and Huiying Dong

School of Architecture and Urban Planning, Fuzhou University, Fuzhou 350108, China; 221520019@fzu.edu.cn (X.L.); 19959112698@163.com (Y.L.); 221520004@fzu.edu.cn (H.D.)
* Correspondence: fhq1604@sina.com; Tel.: +86-139-6090-3612

Abstract: The rapid urbanization process has brought about the shrinkage of rural space as a typical issue. Nevertheless, due to the dearth of effective assessment approaches, the patterns of rural spatial shrinkage remain poorly grasped. This study intends to establish a quantitative assessment model to scientifically disclose the spatiotemporal characteristics and mechanisms of rural spatial shrinkage. The "Population-Industry-Function-Land" (PIFL) assessment model has been rigorously constructed, encompassing eight assessment indices, such as the ratio of permanent residents, rural population density, and the rate of abandoned cultivated land. The model was adopted to conduct an analysis of the spatial shrinkage scenarios of the 18 administrative villages in Panxi Town spanning from 2011 to 2021. The results indicate that the temporal dimension of rural spatial shrinkage exhibits an accelerating trend, with discernible declines or increases in the ratio of permanent residents, rate of the elderly labor force, and housing vacancy rate. The shrinkage of rural spaces displays spatial heterogeneity, with more pronounced shrinkage characteristics observed in villages located further from the central town. According to the comprehensive shrinkage index, the villages are categorized into four types: relative shrinkage ($0.2447 \leq Z \leq 0.2462$), mild shrinkage ($0.2463 \leq Z \leq 0.4423$), moderate shrinkage ($0.4424 \leq Z \leq 0.6125$), and severe shrinkage ($0.6126 \leq Z \leq 0.7988$). The research findings possess significant reference value for the governance of rural spatial shrinkage.

Keywords: mountainous countryside; rural space; spatial shrinkage; spatial and temporal characteristics; formation mechanism

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1. Introduction

The rapid urbanization process is facilitating the migration or transformation of rural population, land, capital, and other productive factors toward cities, thereby necessitating a fundamental reconfiguration of the human-land relationship in rural areas [1–4]. The urbanization rate in China increased from 36.22% in 2000 to 64.72% in 2021, leading to a significant decrease in the rural population and causing issues such as abandoned farmland, vacant houses, and inadequate service facilities supply, marking a notable shrinkage period for rural areas [5–7]. The feature of rural shrinkage is particularly pronounced in remote mountainous areas, where poor transportation and inadequate facilities exacerbate the situation. This phenomenon has emerged as a significant impediment to the development and rejuvenation of rural areas. Investigating the spatiotemporal characteristics and underlying mechanisms of rural shrinkage can offer valuable insights into facilitating transformation and fostering high-quality development of rural regions.

Rural spatial shrinkage is a phenomenon centered on population decline and further evolving into economic, land, and even service deterioration. It is a common social form in the rural development process of countries worldwide and also a hot issue of concern for academic circles and government departments [8,9]. Researchers have engaged in comprehensive discussions regarding the conceptualization, fundamental characteristics, causal mechanisms, evolutionary patterns, spatial configurations, driving forces, and

remedial models associated with rural depopulation [10–12]. The indicators of rural spatial shrinkage primarily encompass demographic shifts, industrial changes, land use modifications, and alterations in infrastructure [13]. Disparities in urban-rural development, policy frameworks, and population migration are fundamental factors contributing to rural shrinkage [14,15]. The process of rural spatial shrinkage can be delineated into the stages of inception, rapid expansion, and transition to stable development, with manifestations including diffusion, linear progression, and discontinuous leaps [16]. Scholars argue that addressing the issue of rural shrinkage requires a multifaceted approach, encompassing institutional development, promotion of urban-rural integration, fostering rural collective economies, enhancing grassroots leadership, and incentivizing skilled individuals to return to their hometowns for entrepreneurial endeavors [17,18]. In practical terms, in response to rural decline and shrinkage issues, the US government has promoted the concept of "rural urbanization". India has launched a nationwide movement for "comprehensive rural governance" and the shrinkage of "garden cities", while the Japanese government has spearheaded the "village creation initiative", emphasizing the idea of one village, one product. Additionally, South Korea has initiated the "New Village Movement" [19,20]. Theoretical frameworks and empirical investigations have significantly contributed to the revitalization of rural areas.

The existing literature predominantly focuses on research at the national, regional, or county level, with limited attention given to studies at the more granular town or village level [21]. In contrast to macro-level analysis, a micro-scale examination of rural spatial shrinkage can effectively delineate its characteristics and offer a specific foundation for governing rural shrinkage [22]. From a temporal perspective, researchers often analyze the characteristics of rural shrinkage at specific time points. However, studies on long-term continuous data remain relatively underdeveloped, hindering an accurate understanding of the dynamic evolution and fundamental issues of rural shrinkage [23]. From a methodological perspective, the current research approach continues to predominantly focus on qualitatively describing the shrinkage of rural space, lacking in quantitative analysis and a universally accepted set of indicators for quantifying this phenomenon.

This study is grounded in the typical rural regions of southeastern China. Through the shrinkage of an assessment model for rural spatial shrinkage and the establishment of an assessment index system, an analysis of the temporal and spatial characteristics of rural spatial shrinkage is conducted. The objectives are to precisely grasp the changing traits of rural spatial shrinkage in the temporal dimension and the regional disparities in geographical space, explore the formation mechanism of rural spatial shrinkage, and summarize the regularity of rural spatial shrinkage. Thus, it offers a foundation for the governance of rural spatial shrinkage. This article is composed of five parts. In the second part, the research basis is presented, data sources are expounded, and the framework of the assessment model is emphasized. For the four key elements of the rural population, industry, function, and land, an index system, such as the ratio of permanent residents, rural population density, and the rate of abandoned cultivated land is constructed, and the calculation methods and formulas of each index are elaborated. In the third part, via charts, text, and other forms, the alterations of each assessment index in the temporal or spatial dimension are analyzed in detail, reflecting the temporal and spatial characteristics of rural spatial shrinkage. In the fourth part, the temporal characteristics of rural spatial shrinkage, spatial differentiation, and the interaction mechanism of elements are discussed. The final part summarizes this article and presents the limitations of this study.

2. Research Area and Methodology

2.1. Research Area

Panxi Town is situated in the southwestern region of Fuding City within Fujian Province, China. It shares its eastern border with Taimu Mountain Town, connects to Zherong County in the northwest, borders Xiapu County in the south, and is linked to Bailin Town in the north. It belongs to the Taimu Mountain District, characterized by

undulating mountains and ridges, as well as a network of streams and valleys. The overall topographical trend slopes gently from west to east (Figure 1). There are 18 administrative villages in Panxi Town, including Panxi, Huanggang, Houping, Nanguang, Sanghai, Hulin, Youkeng, Lutun, Paiyang, Jingu, Chaoyang, Jiangyang, Xianpu, Dayang, Qingkeng, Wuyang, Chixi, and Dujia, as well as 2 state-owned forest farms and a tea farm. The total registered population of Panxi Town is 29,215, with the proportion of permanent residents comprising less than 30% of the total registered population. The phenomenon of significant population outflow is evident. Due to the emigration of young and middle-aged labor force, there is a widespread phenomenon of abandoned farmland. Schools, hospitals, and other service facilities are facing operational challenges and are frequently being deserted. The vacancy rate of residential properties is high, with the particularly prominent issue of abandonment of older residential sites. Panxi Town exemplifies a typical case of rural shrinkage, with all 18 administrative villages experiencing varying degrees of decline. The investigation and resolution of rural spatial shrinkage as well as the promotion of rural transformation, have emerged as pressing imperatives.

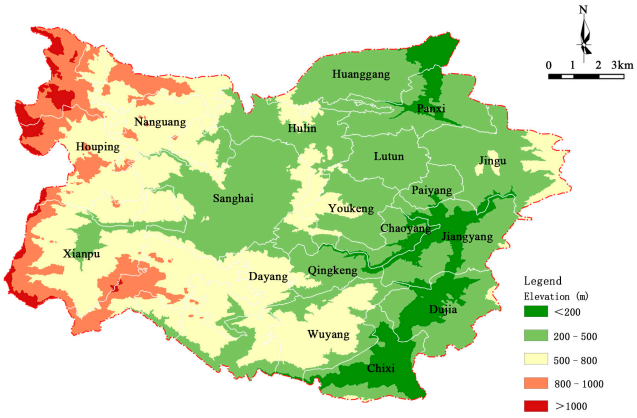

Figure 1. Elevation analysis of Panxi Town.

2.2. Source of the Data

The data utilized in this investigation and their respective sources: ① These demographic, economic, and sociological data were sourced from the municipal government, local law enforcement agencies, and the Fuding City Statistical Bureau. ② The data for the third national land survey were sourced from the Fuding City Natural Resources Bureau. ③ Remote sensing image data are derived from historical imagery available on Google Earth. ④ The data on rural land use is derived from the "cadastral survey" conducted by the Natural Resources Bureau. ⑤ The digital elevation model (DEM) data, obtained from the Geospatial Data Cloud website (http://www.gscloud.cn), is utilized for the extraction of topographic information pertaining to township elevations and slopes. ⑥ The locations, dimensions, and utilization of public service facilities such as education, healthcare, and elderly care, along with the residential housing vacancy rate, are obtained through field research.

2.3. The Shrinkage of the Assessment Model (PIFL)

In consideration of the current absence of a consensus-based model for assessing rural spatial shrinkage, with the aim of comprehensively and accurately determining the characteristics of rural spatial shrinkage, this research undertakes to construct a model of universal significance and practical application value. The specific methods and steps are presented as follows:

(1) The Selection of Assessment Indicators

This research employs the literature statistical analysis approach to determine the critical elements that reflect rural spatial shrinkage. By means of the "China National Knowledge Infrastructure (CNKI)" database, the keywords "space shrinkage" and "hollow-

ing" were input separately for retrieval. A total of 1831 studies were retrieved, among which 265 were related to rural spatial shrinkage. Through statistical analysis, the frequencies at which keywords representing rural spatial shrinkage emerged were as follows: population, 32.6%; land, 21.5%; residence, 12.4%; industry (economy), 11.6%; education, 8.2%; society, 6.5%; culture, 5.1%; and others, 2.1%. Based on the analysis results and considering the feasibility of quantitative description, this research takes the population, the industry, the function and the land as the four key factors for judging rural spatial shrinkage. On this basis, diversified assessment indices are constructed.

Population, industry, function, and land constitute an interrelated and mutually restrictive organic whole, which are decisive factors for rural spatial development [24–26]. "Population" is the core element and source of vitality in the composition of rural space [27]. It supplies labor for industrial development and determines the shrinkage scale of rural service facilities and land. It serves as a fundamental indicator for measuring rural spatial shrinkage [28]. Industry is the basis for generating rural space and the driving force behind it. It offers employment opportunities to the population and determines the mobility characteristics of the population [29,30]. The state of development of the industry is directly related to regional prosperity and decline. Infrastructure, as a material support for the formation and evolution of rural areas, is an essential component in ensuring the normal operation of its social system [31,32]. Good infrastructure is attractive to the population. Land use is the mapping of population, industry, and function in spatial regions, reflecting the rise and fall of these elements (Figure 2).

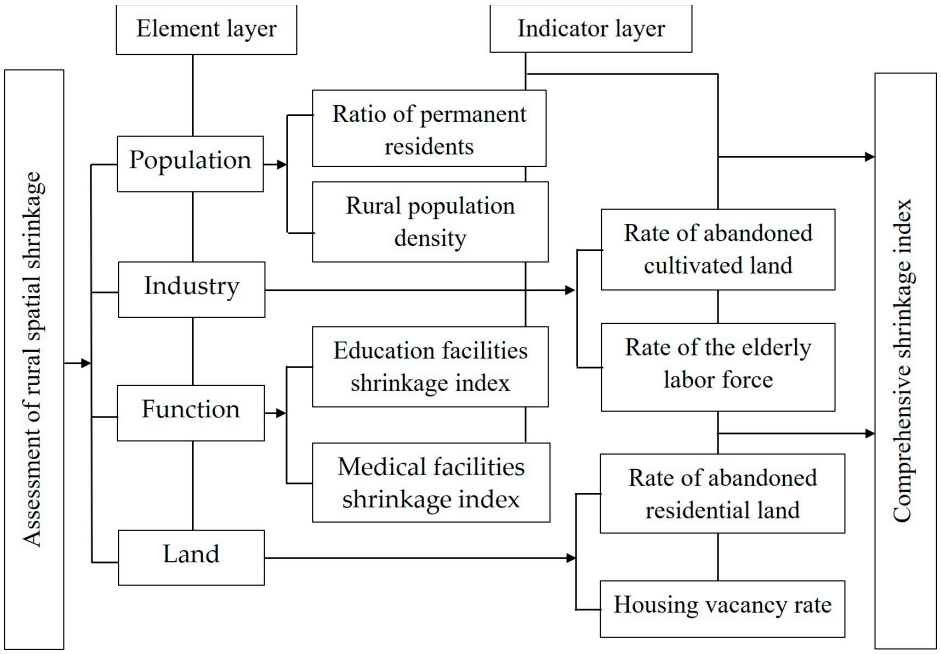

Figure 2. The framework of the model (PIFL).

(2) Shrinkage of Assessment Indicators

Construct diverse assessment indices for elements such as population, industry, function, and land.

① Population Shrinkage Indicators. In this study, the "ratio of the permanent resident population" and "rural population density" are adopted to reflect the spatiotemporal variations in the rural population. As the rural household registered population is relatively stable, while the variations in the outflow population and the permanent resident population are substantial, the ratio between the permanent resident population (left-behind population) and the household registered population can better reflect the extent of the rural population outflow and shrinkage. Rural population density, namely, the number of

the rural population per square kilometer, can reflect the alterations of the rural population in geographical space (Table 1).

② Industrial Shrinkage Indicators. Agriculture forms the foundation of rural industries, and cultivated land serves as the core resource of agriculture. The utilization efficiency of cultivated land reflects the development of agriculture [33,34]. In this study, the "rate of abandoned cultivated land" and "rate of the elderly labor force" are employed to represent industrial development status. The rate of cultivated land abandonment is defined as the ratio of the abandoned cultivated land area to the total cultivated land area. The coefficient of labor force aging is the ratio of the number of labor forces aged 60 and above to the total number of rural labor forces.

③ Function Shrinkage Indices. Education and medical care are two significant service functions in rural areas, exerting a strong appeal to the rural population. Adequate educational facilities form the fundamental condition for ensuring that young people can remain in the village. This study employs the "education facilities shrinkage index" and the "medical facilities shrinkage index" to reflect spatiotemporal variations in rural functions. The changes in these two indices are reflected by calculating the rate of change in the number of schools (kindergartens, primary schools) and health clinics.

④ Land Shrinkage Indicators. Land use shrinkage is a typical feature of rural spatial shrinkage, manifested as the abandonment of residential land and extensive vacancy of houses due to the outflow of the population. In this study, two indicators, namely "rate of abandoned residential land" and "housing vacancy rate", are employed to reflect the degree of shrinkage of rural space in land use. The rate of residential land abandonment refers to the ratio of the area of abandoned residential land to the total area of residential land. The housing vacancy rate refers to the ratio of the area of houses vacant for more than half a year to the total area of houses.

⑤ Comprehensive Shrinkage Index. Among the eight indicators, the negative indices "ratio of permanent residents" and "rural population density" are positively transformed. The comprehensive shrinkage index of rural space is computed through the weighted summation approach to express the combined shrinkage characteristics of rural space with respect to population, industry, function, and land. The greater this index is, the more significant the degree of rural spatial shrinkage and the more distinct the shrinkage characteristics. The analytic hierarchy process (AHP) was employed to ascertain the weight of each indicator. A total of 33 relevant personnel from 3 domains were invited to assess the significance of the indicator, encompassing 11 planners with practical experience, 11 rural researchers, and 11 villagers. Based on the assessment results, the judgment matrix is constructed, and normalization and consistency tests are conducted to obtain the weight of each index.

Table 1. Assessment indicators of rural spatial shrinkage.

Type	Index	Formula	Instructions
Population shrinkage characterization	Ratio of permanent residents	$R_s = \frac{P_c}{P_h} \times 100\%$	In the formula, R_s is the proportion of the resident population, and P_h and P_c are the rural registered population and resident population of the year respectively.
	Rural population density	$D = \frac{P}{S}$	In the formula, D is the population density, P and S, respectively, represent the number and area of the population of the administrative village.
Industry shrinkage characterization	Rate of abandoned cultivated land	$R_c = \frac{A_p}{A_0} \times 100\%$	In the formula, R_c is the abandonment rate of cultivated land, A_p and A_o are the area of abandoned land, and the total area of cultivated land, respectively.
	Rate of the elderly labor force	$L_0 = \frac{P_{(60+)}}{P_{(15-59)}+P_{(60+)}} \times 100\%$	In the formula, L_o is the aging coefficient of the rural labor force, $P_{(60+)}$ is the number of elderly agricultural labor force, and $P_{(15-59)}$ is the number of normal rural labor force aged 15–59.

Table 1. *Cont.*

Type	Index	Formula	Instructions
Functional shrinkage characterization	Education facilities shrinkage index	$E_v = \frac{\lvert A_e - \mathrm{B}e \rvert}{B_e} \times 100\%$	In the formula, B_e is the number of primary schools, and A_e is the number of final schools.
	Medical facilities shrinkage index	$M_v = \frac{\lvert A_m - \mathrm{B}_m \rvert}{B_m} \times 100\%$	In the formula, B_m is the number of primary clinics, and A_m is the number of terminal clinics.
Land shrinkage characterization	Rate of abandoned residential land	$H_r = \frac{I_r}{H_q} \times 100\%$	In the formula, H_r is the rate of homestead abandonment, I_r is the area of the abandoned homestead, and H_q is the total area of the rural homestead.
	Housing vacancy rate	$H_v = \frac{A_k}{A_k + A_y} \times 100\%$	In the formula, H_v is the vacancy rate of the house, A_k is the vacant house area, and A_y is the area of the house in use.
Composite shrinkage index		$Z_t = \sum_{n=8}^{i=1} w_i x_i$	Where, Z_t is the comprehensive shrinkage index, W_i is the weight, and X_i is the index.

3. Analysis of the Results

3.1. Characteristics of Population Shrinkage

The rural population shrinkage in Panxi Town has intensified, leading to a noticeable decline in the proportion of permanent residents. Over the period from 2011 to 2021, the proportion of permanent residents in Panxi Town decreased significantly from 55.08% to 37.47%, marking a decrease of 17.61 percentage points. Specifically, there was a decrease of 2.12 percentage points from 2011 to 2016 and a further decrease of 15.49 percentage points from 2016 to 2021, indicating an escalating trend of population shrinkage over the past five years. In Panxi Town, all 18 administrative villages have experienced population outflow. Among them, the proportion of the permanent population in Qingkeng Village, Nanguang Village, and Houping Village is 22.05%, 24.41%, and 26.64%, respectively, all falling below the threshold of 30%, indicating a more pronounced demographic decline. Conversely, Chixi Village and five other villages exhibit a higher proportion of the permanent population of over 45%, suggesting a relatively milder demographic shrinkage (Figure 3). The extent of rural depopulation increases from Panxi Village and Chixi Village in an east-to-west direction (Figure 4), with particularly severe depopulation observed in the western mountainous rural areas.

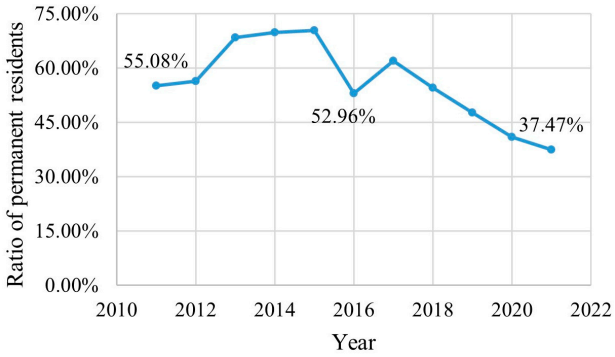

Figure 3. Changes in the ratio of permanent residents from 2011 to 2021.

The overall population density exhibits a trend of dilution, with variations observed in the eastern, central, and western regions. From 2011 to 2021, the average population density in Panxi Town decreased from 220 individuals per square kilometer to 130 individuals per square kilometer, indicating a general decline in population density. Population density changes demonstrate disparities across the town: significant dilution of populations is evident in the mountainous western areas, with Panxi Village, Dayang Village, and nine other villages displaying clear declining trends, collectively leading to a reduction of 50% in village numbers. Reduction rates for Sanghai Village, Dayang Village, and Nanguang

Village exceed 15 individuals per square kilometer at decreases of 23.96%, 20.20%, and 15.38%, respectively-far surpassing the town's average decrease rate. Population density changes are relatively gradual within central villages such as Huanggang Village and Lutun Village, which also exhibit varying degrees of reduction. Conversely, Chixi Village in the east has not experienced a decrease but rather shows an increasing trend (Figures 5 and 6). These observations are primarily linked to topographic conditions within Panxi Town, where higher elevations and limited transportation contribute to substantial out-migration from western areas, while proximity to the town center results in concentration effects toward the east. Overall trends indicate that population densities diminish with terrain flatness, a pattern manifesting as shrinkage from east to west, resulting in uneven spatial distribution across the town.

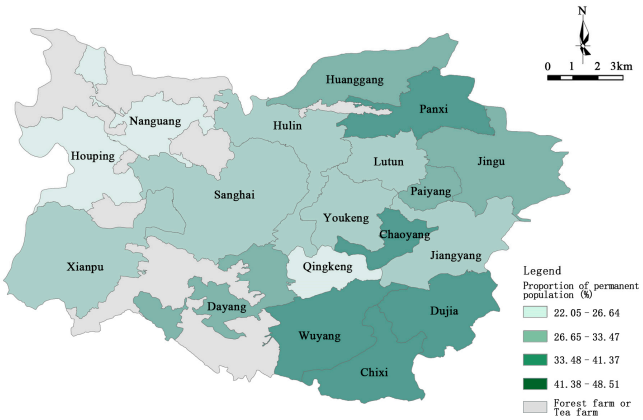

Figure 4. Proportion of permanent resident population in each village in 2021.

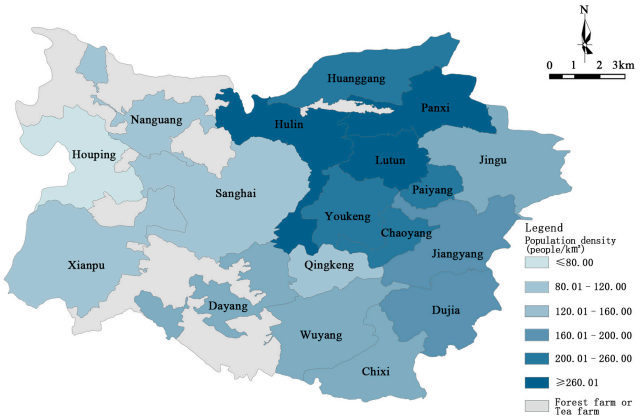

Figure 5. Population density of Panxi villages in 2011.

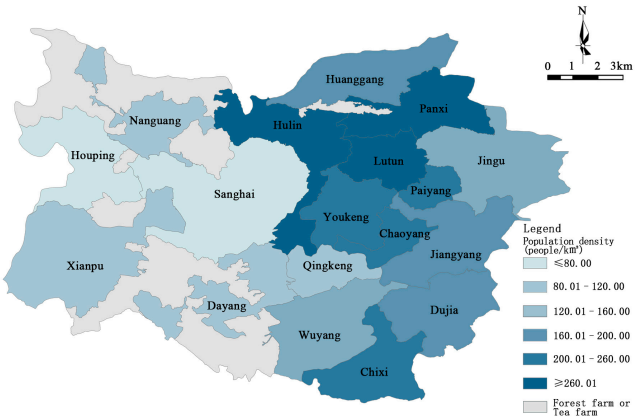

Figure 6. Population density of Panxi villages in 2021.

3.2. Characteristics of Industrial Shrinkage

The shrinkage of agriculture in Panxi Town has been substantial, accompanied by a notable increase in the proportion of abandoned farmlands. Over the past decade, from 2011 to 2021, the rates of abandoned farmland have risen from 41.58% to 57.88%, marking an increase of 16.3 percentage points with an average annual increment of 1.63 percentage points. This trend reflects a low utilization efficiency of farmland within the region, particularly evident in Qingkeng Village and Nanguang Village, where abandonment rates exceed 70% (Figure 7). These high rates can be attributed to the predominance of single-crop structures focused on rice cultivation, resulting in diminished output efficiency and, subsequently, higher abandonment rates among local farmers. Calculation of nucleus density reveals that abandoned farmlands exhibit a scattered distribution pattern with small-scale agglomerations, decreasing from central administrative villages toward peripheral natural villages (Figure 8). This phenomenon is primarily influenced by topography and field distribution; under mountainous environmental constraints, Panxi Town experiences severe fragmentation of its agricultural land, which impedes effective mechanization and necessitates manual labor for farming activities.

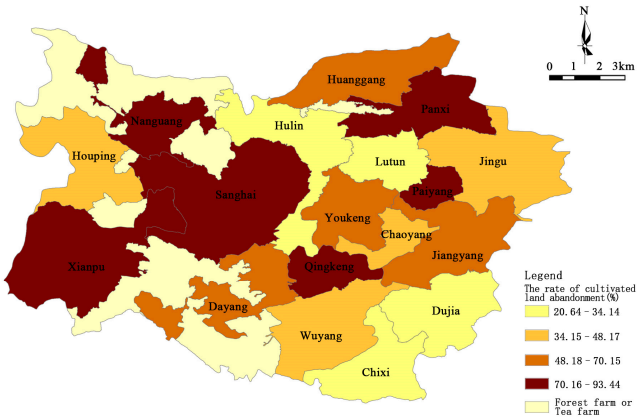

Figure 7. Rate of Panxi Town's cultivated land abandonment in 2021.

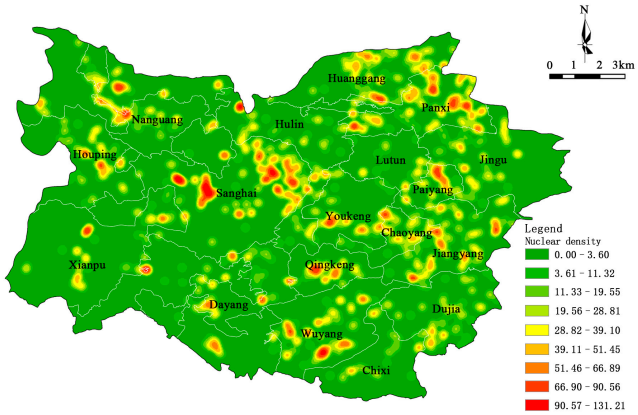

Figure 8. Analysis of the kernel density of desert land distribution.

The agricultural sector is experiencing a lack of momentum in its development, while the aging of the labor force is becoming more pronounced. Between 2011 and 2021, the proportion of elderly individuals within the labor force in Panxi Town increased from 21.36% to 37.01%, marking a rise of 15.65 percentage points, as depicted (Figure 9). In line with the criterion that "individuals aged 60 or above account for at least 10% of the total population", it was observed that Panxi Town's labor structure surpassed this defined threshold for aging back in 2011. As urbanization continues to advance, a significant proportion of young and robust laborers from Panxi Town have been consistently relocating

to areas with higher levels of economic development, resulting in an adverse trend where the core agricultural workforce is progressively diminishing and hollowing out, a situation expected to further exacerbate over time. From a village-level perspective (Figure 10), most villages exhibit labor force aging rates ranging between 30% and 40%. Notably, Nanguang Village stands out with the highest level of labor force aging at approximately 46.22%, indicating that nearly half of its rural workforce comprises elderly individuals. Similarly high levels are also evident in Dayang Village, Wuyang Village, and Youkeng Village at around 39.51%, 39.62%, and 39.85%, respectively, -approaching or exceeding the 40% mark. The decline in the strength of the agricultural labor force has led to a substantial dearth of momentum for industrial development.

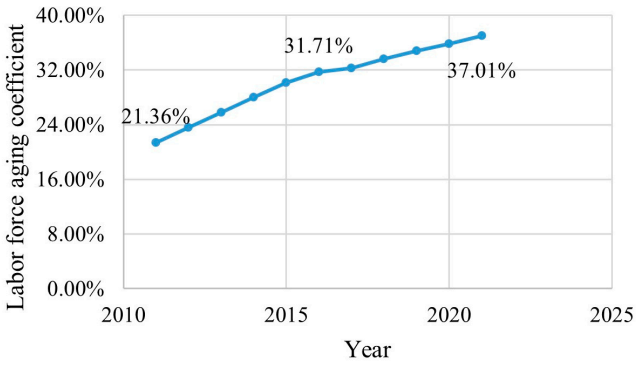

Figure 9. Change in labor force aging coefficient from 2011 to 2021.

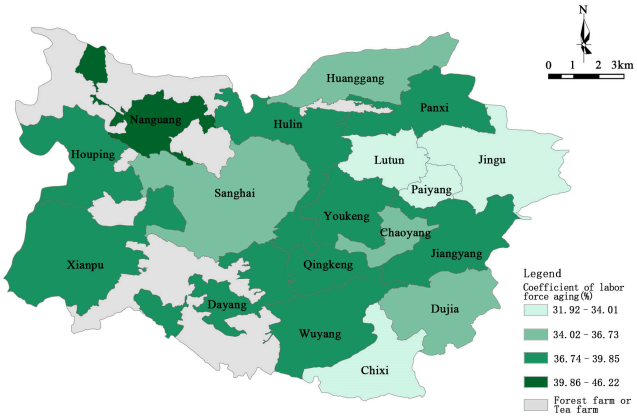

Figure 10. The aging coefficient of labor force in each village in 2021.

3.3. Characteristics of Functional Shrinkage

The number of educational and medical institutions has significantly declined, leading to a shrinkage in the provision of education and healthcare services. The provision of education and healthcare services is essential for the sustainable development of rural areas [35]. In 2011, Panxi Town was equipped with 15 kindergartens, 15 primary schools, and two middle schools. However, as of 2021, the number has dwindled to only five kindergartens, four primary schools, and two middle schools. It is noteworthy that approximately 69% of the kindergartens and about 73% of the primary schools have either been decommissioned or repurposed for alternative uses, such as serving as village committee offices. The reduction in the educational infrastructure is in line with the decline in the population. As a result of the emigration of young people, there has been a decrease in the number of school-age children in rural areas, which is insufficient to sustain the operation of schools, leading to the abandonment of numerous kindergartens and primary schools. The quantity and distribution of medical facilities exhibit a pattern of "dual deficiency". In 2011, Panxi Town was equipped with one municipal hospital and 38 rural clinics. By 2021, the number of municipal hospitals had increased to two, while the number of rural clinics had

decreased to 20, marking a reduction of 47%. Not only has there been a significant decrease in the number of primary healthcare facilities, but their operational efficiency is also low, leading to an unsustainable situation (Table 2).

Over the past decade, despite multiple rounds of rural infrastructure improvement projects implemented by the government, the overall effectiveness of these facilities has been suboptimal. With financial support, the government has enhanced rural elderly care, commerce, culture, and sports facilities. Nevertheless, owing to a significant decline in the rural population, these facilities have a limited impact and fail to attract rural residents. Many cultural and sports facilities are utilized less than 20 times annually.

Table 2. Changes in education and medical facilities in Panxi Town.

Functional Type	Facility Project	Service Content	Quantity in 2011	Quantity in 2016	Quantity in 2021
education	kindergarten	Protect and teach preschool children aged 3 to 6.	15	9	5
	Primary school	Meet the admission requirements for young people aged 6 to 12.	15	8	4
	Middle school	Meet the requirements for children aged 12 to 18.	2	2	2
Medical treatment	Health center	Prevention, medical treatment, health care, rehabilitation, health education, family planning, etc.	1	1	2
	Village health office	Medical treatment, prevention, and rehabilitation of common diseases.	38	25	20
Provide for the aged	Old people's home	Comprehensive services such as daily living, catering services, medical care, culture, and entertainment are provided for self-care, assistance, and care for the elderly.	0	0	1
	Activity room for the aged	Elderly exchanges, recreational activities, etc.	0	0	2
	Happiness Won	Catering, recreation, fitness, medical care, etc.	0	0	8
commerce	Rural convenience store	Convenience business can include mail delivery services and other functions.	52	67	86
	Fair market	Agricultural and sideline products, daily consumer goods trading.	1	1	1
	Postal premises	Including post offices, post branch offices, and other postal facilities, as well as other express logistics business facilities.	1	1	1
culture	Township cultural activity center	Carry out activities such as reading books, spreading and education of popular science knowledge, ball games, chess, science and technology, and art.	0	1	1
	Cultural activity station	Provide books and newspapers, reading, painting, entertainment, fitness and so on.	0	18	18
Physical education	Township sports center	Activities such as reading books, publicity and education of popular science knowledge, movie and video halls, dance halls, and entertainment halls should include the service functions of children's homes.	1	1	1

3.4. Characteristics of Land Use Shrinkage

The abandonment rate of homesteads and the vacancy rate of houses have increased, while the utilization of village shrinkage land has become less efficient. The abandonment rate of homesteads was 0.28% in 2011, 1.46% in 2016, and 5.31% in 2021, showing an increasing trend year by year. The degree of abandonment in 2021 was nearly 19 times higher than that in 2011. In terms of the abandonment of homesteads in each village, Chaoyang Village has the highest level at 12.92%, Panxi Village has the second highest

level at 10.26%, and Dayang Village and Paiyang Village have also abandoned homesteads (Figure 11). Using kernel density estimation to visualize the spatial differentiation of abandoned rural homesteads, it was found that they are characterized by sporadic and scattered layouts, which are mainly located in peripheral rural areas and remote natural villages (Figure 12). The reason for this is that, on the one hand, the highlighting of the asset attributes of rural homesteads in the process of urbanization [36,37], has accelerated the function transformation from "living space" to "family assets", and "to be demolished" has gradually become the rational choice of homesteads users. On the other hand, as the cost of living increases for residents commuting between urban and rural areas [38], owners of rural homesteads in remote areas will be more inclined to settle in cities, resulting in an increase in the proportion of abandoned homesteads. In terms of the vacancy rate of houses over half a year, the vacancy rates in 2011, 2016, and 2021 were 44.92%, 47.04%, and 62.53%, respectively, with an average increase of 1.76 percentage points per year, and the situation of unoccupied houses is getting more and more serious (Figures 13 and 14). In 2021, the vacancy rates of 18 villages in Panxi Town exceeded 50%. Among them, the vacancy rate of Qingkeng Village is the highest, reaching 77.94%, and the villages are in a depressed and dilapidated state, with many natural villages becoming "unoccupied villages" and the quality of the physical space declining significantly.

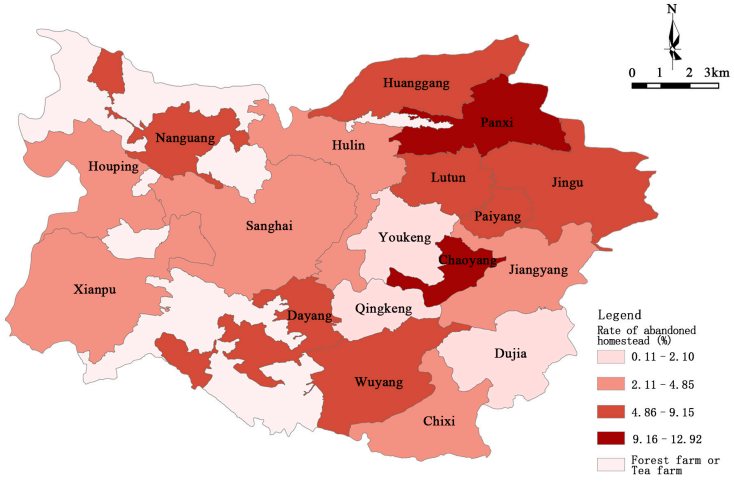

Figure 11. Current situation of abandoned homesteads in 2021.

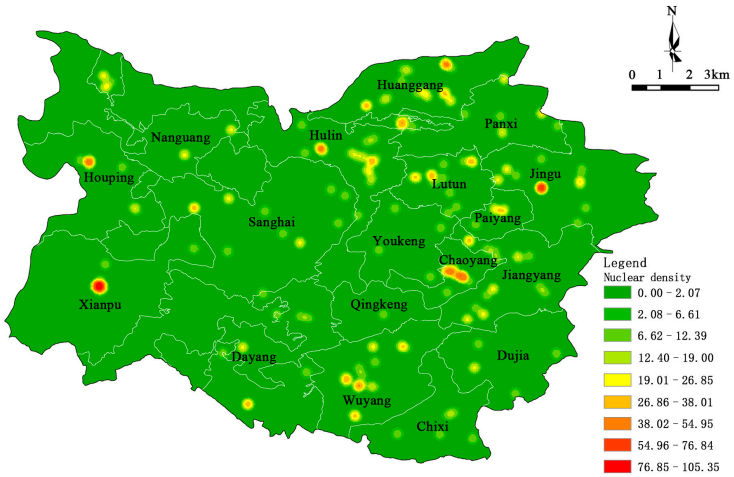

Figure 12. Analysis of the nuclear density of abandoned homestead distribution.

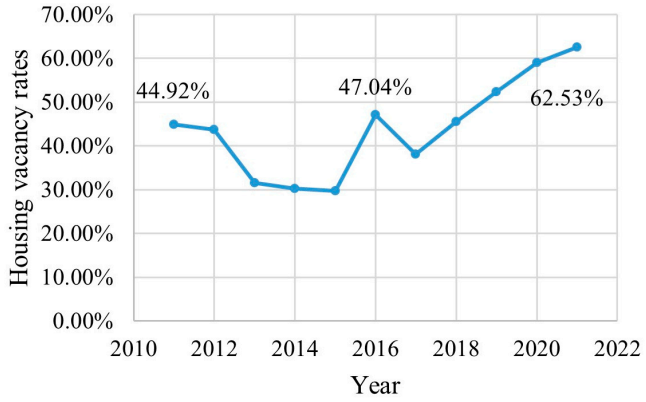

Figure 13. Changes in housing vacancy rates from 2011 to 2021.

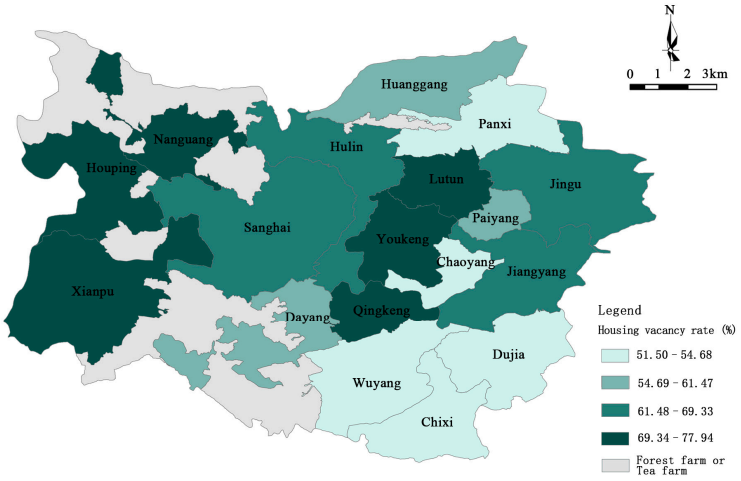

Figure 14. Vacancy rates by village in 2021.

3.5. Composite Shrinkage Index

(1) The degree of shrinkage

The weights of the population, industry, function, and land use indices were determined using the analytic hierarchy process (AHP). Initially, pairwise comparisons were performed to establish a judgment matrix for each index's importance and to calculate their respective weights. Subsequently, the comprehensive shrinkage index for each village was computed through a weighted summation. The resulting range of the comprehensive shrinkage index was between 0.2447 and 0.7988, indicating discernible disparities in shrinkage levels across villages. The comprehensive shrinkage index of 18 administrative villages was inputted into ArcGIS (10.6) software, and the natural breakpoint method was utilized to categorize the shrinkage interval into four levels: relatively contracted ($0.2447 \leq Zt \leq 0.2462$), mildly contracted ($0.2463 \leq Zt \leq 0.4423$), moderately contracted ($0.4424 \leq Zt \leq 0.6125$), and severely contracted ($0.6126 \leq Zt \leq 0.7988$). The relatively contracted villages of Dujia Village and Chixi Village are endowed with typical tourism resources, attracting substantial investment and maintaining stable economic operations. Lightly contracted villages such as Paiyang Village, Hulin Village, Huanggang Village, and seven others account for 39% of the total villages. Moderately contracted villages, including Jingu Village, Jiangyang Village, Xianpu Village, and eight others, represent 44% of the total villages. Nanguang Village stands out as a severely contracted village, experiencing significant declines in population, industry, function, and land use compared to the town's average level. The spatial distribution of the comprehensive shrinkage index for rural areas in Panxi Town is depicted in Figure 15.

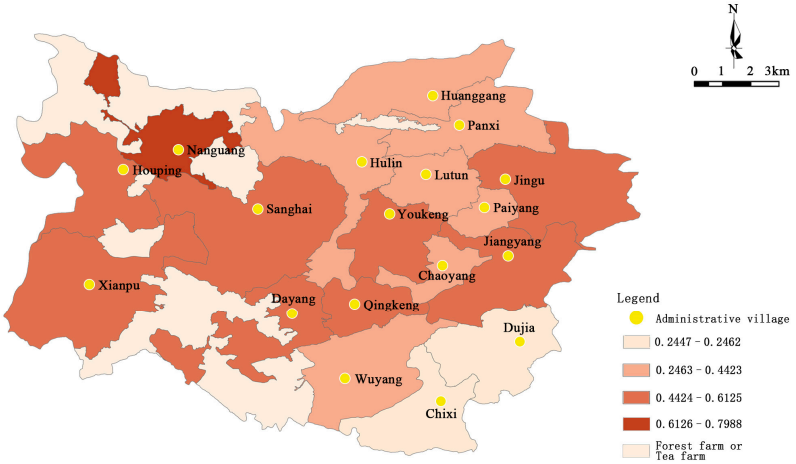

Figure 15. Comprehensive shrinkage index of Panxi villages in 2021.

(2) Shrinkage types

Utilizing a hierarchical classification of shrinkage indices for population, industry, function, and land, with the criterion that a specific index is at the fourth level, villages can be categorized into five types of shrinkage: population-based, industry-based, function-based, land-based, and comprehensive (Table 3).

① Population shrinkage type. The phenomenon of demographic shrinkage is exemplified by Nanguang Village, which represents 5.56% of the total village population. In comparison to other villages, Nanguang Village has experienced a significant decline in both population size and density, leading to a pronounced aging demographic structure. This can be attributed to its location in an economically disadvantaged region with complex topography and inadequate transportation infrastructure, resulting in stagnant industrial development and substantial out-migration.

② Industrial shrinkage type. The villages of Nanguang and Qingkeng are examples of industrial shrinkage, representing 11.11% of the total village population. These communities are predominantly engaged in traditional rice cultivation, exhibiting a sluggish pace in terms of industrial transition and advancement. The significant emigration of young and middle-aged individuals has exacerbated the issue of an aging farming population, leading to a relatively high rate of abandoned farmland [39]. Furthermore, the considerable distance between the primary residential areas and farmland poses an inconvenience for agricultural activities, contributing to farmland abandonment.

③ Functionally contracted type. The category of functionally contracting villages encompasses Nanguang Village, Xianpu Village, Sanghai Village, Dayang Village, Wuyang Village, and Jingu Village, constituting 33.33% of the total village count. These communities have witnessed varying degrees of decline in the utilization of educational and medical facilities due to population reduction. Spatially speaking, the development of rural functions is intertwined with the village–town hierarchy system; as the distance from the town or central village increases, so does the extent of the abandoned public building and space. The proximity between two central villages may result in shared service facilities and severe functional shrinkage in one center.

④ Land use shrinkage type. Villages experiencing land shrinkage, such as Nanguang Village, Panxi Village, and Lutun Village, collectively account for 16.67% of the total village count. These villages demonstrate two distinct spatial characteristics: firstly, due to population outflow, significant areas of residential land lay vacant, or houses remain unoccupied, resulting in an overall decline in environmental quality [40]. Secondly, influenced by location and industrial development, a discrepancy arises between declining population levels and increasing demand for shrinkage land [41]. This leads to internal hollowing within the villages and the disorderly expansion of shrinkage land on the outskirts, ultimately diminishing the overall land use efficiency.

⑤ Comprehensive shrinkage type. The comprehensive shrinkage type refers to a scenario in which all demographic, industrial, functional, and land use indicators contract without any specific index showing a significant decline, as exemplified by Nanguang Village. In such communities, there has been a sharp decrease in the population, predominantly comprising elderly individuals who have been left behind. The industrial sector has experienced severe deterioration, while housing infrastructure has been dilapidated. It is highly probable that these villages will transform into abandoned settlements in the foreseeable future.

Table 3. Identification of problem areas in Panxi Town.

Problem Type	Specific Tillage	The Proportion of
Population shrinkage type	Nam Quang Village	5.56%
Industrial shrinkage type	Nanguang Village, Qingkeng Village	11.11%
Functional shrinkage type	Nanguang Village, Xianpu Village, Songhai Village,	33.33%
Land use shrinkage type	Nanguang Village, Panxi Village, Lutun Village	16.67%
Composite shrinkage type	Nam Quang Village	5.56%

4. Discussion

(1) The temporal dimension exhibits an accelerated feature in the shrinkage of rural space. Time-series data on the shrinkage of population, industries, functions, and land use in rural areas indicate an accelerating trend in the shrinkage of various elements within these regions. The curves depicting the proportion of permanent residents, the aging index of employed persons, and the vacancy rate of houses demonstrate clear downward or upward trends. As of 2021, China's urbanization rate has stood at 64.7%, signifying that it is still undergoing rapid urbanization according to established developmental patterns [42]. Consequently, there has been a notable increase in the speed at which rural populations are migrating to urban areas. This ongoing process has led to a continued intensification in the shrinkage of rural spatial elements under the influence of urbanization development; this is expected to remain a primary trend in rural development for some time [43]. The current constriction of rural space represents a significant obstacle to its revitalization efforts. Therefore, reconfiguring rural spatial resources and steering rural development toward quality have become paramount priorities for achieving high-quality rural development.

(2) The shrinkage of rural spaces exhibits heterogeneous characteristics in terms of geographical dimensions. Analysis of rural spatial shrinkage indices reveals spatial disparities, with villages located farther from the central township exhibiting more pronounced shrinkage characteristics, while those in closer proximity display milder features. Remote mountainous areas with complex terrain and inadequate infrastructure experience significant population outflows, leading to evident spatial shrinkage. Conversely, villages near the central township benefit from job opportunities, better education, healthcare services, and improved transportation conditions, resulting in less conspicuous shrinkage characteristics. The geographical heterogeneity of rural spatial shrinkage provides a foundation for village relocation and settlement consolidation to achieve spatial restructuring [44,45]. In remote rural areas, gradually promoting village mergers and infrastructure sharing to establish a pivotal "center village" represents an effective approach to achieving spatial integration.

(3) Rural shrinkage involves complex interactions and driving mechanisms among its constituent elements. The primary driver of rural shrinkage is rapid urbanization, which facilitates the migration of rural populations to urban areas [46], resulting in a net outflow from rural regions and giving rise to two intertwined vicious cycles:

The first cycle involves "population outflow-industrial shrinkage". Urbanization-driven population movements, predominantly comprising young individuals, lead to a severe shortage of rural labor and impede industrial growth. With an aging and female-dominated workforce lacking essential technical skills, farming methods, and innovative organizational management practices, industrial development stagnates and loses its dynamism. This shrinkage in industry, coupled with low efficiency, fails to generate employ-

ment opportunities or provide the necessary income for young people's livelihoods, further accelerating their exodus [47]. Consequently, population outflow exacerbates industrial shrinkage in a self-reinforcing loop [48,49].

The second cycle encompasses "population outflow-inadequate service facilities". Population emigration, particularly among younger demographics, significantly reduces the number of school-age children in villages. This results in insufficient demand for educational amenities, such as kindergartens and primary schools. Inadequate demand subsequently impacts the supply and quality enhancement of educational facilities. Insufficient provision hinders access to quality education for eligible children, compelling young people to relocate to urban areas seeking superior educational resources—further intensifying population outflows. Analogous challenges are evident across medical care facilities, as well as cultural and sports amenities within these communities [50,51]. Thus, a detrimental feedback loop emerges between population decline and the undersupply of rural services.

In summary, the cascading effects stemming from urbanization-induced rural depopulation manifest spatially through overall scale reduction, imbalanced human-land relationships, and wastage of spatial resources [52–54]. Redefining human-land dynamics within rural settings while implementing strategic downsizing represents an imperative pathway forward for future transformations in these locales.

5. Conclusions

This study employs typical rural areas as exemplars and discloses the characteristics of rural spatial shrinkage in terms of population, industry, function, and land by establishing an assessment model. Regarding population, the ratio of permanent residents keeps declining, there are varying degrees of dissociation between people and land, and the population density is diluted. Concerning industry, the utilization efficiency of cultivated land is low, the abandoned area is constantly rising, the labor force is aging, and the driving force for agricultural development is insufficient. With respect to function, the number of rural schools is constantly decreasing, the scope of facility services continues to decline, and the educational function of a large number of villages in the central and western regions has completely withdrawn. The number of health clinics shows a significant downward trend, and the rural three-level health service system has completely contracted. In terms of land, there exists a phenomenon of abandoned homesteads, especially in remote villages where the abandonment of homesteads is severe. The vacancy rate of houses has increased, and some natural villages have become uninhabited. The majority of the current research on rural spatial shrinkage is predicated on the individual characteristics of rural shrinkage, such as the shrinkage of population and land, that of economic industry, or that of public service facilities. Nevertheless, the research results of this paper reveal the main characteristics of rural spatial shrinkage from multiple perspectives and provide a basis for rural space governance.

The limitations of this study are twofold. Firstly, in this paper, eight assessment indicators were selected based on the degree of importance. Nevertheless, these eight indicators are unable to describe the characteristics of rural spatial shrinkage comprehensively. Rural spatial shrinkage is also manifested in social and cultural aspects. Owing to the constraints of data acquisition and quantitative expression, social and cultural assessment indicators were not incorporated into the model system. Secondly, this study concentrated on analyzing the temporal and spatial characteristics of population, industry, function, and land shrinkage. However, research on the interactions among various elements was inadequate, and there were limitations in analyzing the mechanism of rural spatial shrinkage. Therefore, future research should enhance the assessment index system based on a more practical basis and quantitatively analyze the interaction relationship among various elements, thereby more accurately and reasonably analyzing the characteristics and mechanism of rural spatial shrinkage.

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