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Spatial–temporal evolution and land use transition of rural settlements in mountainous counties

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Abstract

Background Rural settlements are undergoing significant changes under the rapid urbanisation, and understanding their evolution characteristics and surrounding land use will provide a basis for land spatial planning. This study takes Pingnan County, Fujian Province, China as study area, reveals the characteristics of spatial–temporal evolution and surrounding land use transition of settlements during 1985–2020 through landscape metrics, spatial "hot spot" analysis, scale classification statistics, rank-size model, Gini index, land use transition matrix.

Results The results show that: (1) Concerning the size and morphological characteristics, the settlements have witnessed a considerable increase in number and scale while remaining stable in shape. (2) Regarding spatial distribution characteristics, the settlements became more evenly spread, forming three main hotspot clusters. (3) Concerning scale structure characteristics, there are significant differences in scale, growth rates, and polarisation of settlements; the polarisation of large settlements shifted from a marked divergence before 2010 to a more balanced trend after 2010. (4) The land use transition around settlements differed in buffer zones and periods. During 1985–2010, settlement expansion heavily depended on cropland, depleting nearby resources, with an increase of woodland and grassland. During 2010–2020, expansion integrated cropland, woodland, and grassland, with cropland growth mainly encroaching on woodland and grassland.

Conclusions The study's findings are significant for optimising rural settlement structure in mountains and promoting sustainable land resource use.

Keywords Rural settlements, Mountainous settlements, Spatial pattern, Land use change, Rural revitalisation

Introduction

Since China's reform and opening up, rapid urbanisation has occurred, leading to a significant influx of non-agricultural industries and rural populations into cities and towns [1, 2]. In this context, the dynamics between people and land, as well as the structure of rural settlements, have undergone profound transformations. Unfortunately, due to a lack of proactive planning and an imperfect land management system in villages [3], disorderly construction and the emergence of hollow villages have become prevalent issues [4–6]. The lagging and deterioration of rural settlement development have become common challenges during the urbanisation process. It is the consensus of academia and society to scientifically understand the law of rural settlement development, promote the optimisation and reconstruction of rural settlements, and promote the integrated development of urban and rural areas [7, 8].

As an important form of settlement for China's population, mountainous rural settlements face far more

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serious problems than those in the plains. Influenced by the energy gradient, surface fragmentation, spatial heterogeneity and other natural attributes of mountainous areas [9], mountainous settlements are generally small in scale, numerous in number, disorderly in layout, inefficient in land use, and unbalanced and inadequate in economic and social development. These factors present obstacles to the construction of new-type urbanisation, the transformation of rural areas, and the achievement of coordinated development between urban and rural regions [10].

The future of rural settlements is unpredictable, but it can be explored. Scholars from all over the world have conducted extensive research in this field. In terms of methods, early studies commonly collected data from field surveys and field mapping, and qualitatively described relevant characteristics of settlements with theories of typology, morphology, and phenomenology [11]. In recent decades, research has paid more attention to the application of quantitative analysis methods, such as RS, GIS, landscape pattern index, spatial measurement methods, multiple regression, Geodetector, and so on [12, 13]. These methods can objectively and accurately draw conclusions, which are less influenced by subjective judgement, facilitate horizontal comparison, and have a higher degree of credibility. In terms of content, relevant research involves the number, density, scale, and morphology of rural settlements as well as the evolution patterns, influencing factors, driving mechanisms, typology, spatial optimisation, and scenario prediction [14, 15]. For example, Clark et al. explored the spatial distribution characteristics of rural settlements in the remote suburbs of the United States and the factors related to their spatial configuration [16]. Yang et al. explored the spatial distribution characteristics of rural settlements in China during the process of rapid urbanisation and the optimisation of reconstruction patterns [17]. Ristic et al. analyzed the impacts of the spatial distribution characteristics of Serbian rural settlements on the development of the tourism industry [18]. Li et al. explored the evolution direction of the "city–town–village" scale structure of the city of Zhangjiagang, China [19]. At the same time, the evolution of land use around settlements has also aroused widespread interest among scholars. For example, Xie et al. explored the land use change patterns of rural town settlements in Guangdong, China by building sequence alignment method [20]. Zhang et al. explored the land use change trajectories around rural settlement in the karst trough valleys [8]. Huang et al. explored the transition characteristics of agricultural landscape patterns in a watershed of the Three Gorges Reservoir Area, China, especially the transformation between sloping farmland, abandoned land, and orchards [21].

Based on the literature review, it was observed that: (1) previous studies have primarily focused on the more developed regions in eastern China, characterised by active tourism, as well as the lagging regions in central and western China, which benefit from favorable agricultural policies [22]. In contrast, the less developed mountainous regions in southeast China located in the metropolitan fringe area have received relatively less attention in the existing studies. (2) Changes in the settlement system have been overlooked in previous studies. Nevertheless, the settlement is an organic whole composed of various types of settlements, varying in size, function, and environmental characteristics [23]. It is through understanding the interrelationships among different levels of settlements that we can gain a more profound insight into the development and evolution law of the settlements. (3) Prior research has devoted limited attention to the land use dynamics of settlements at the micro-scale and over long time series, instead focusing primarily on land changes across the region [1, 24]. However, settlements occupy a relatively small area in comparison to the total land area within a region, resulting in a limited scope of land affected by the presence of settlements. Thus, conducting a detailed analysis of the land use surrounding settlements will provide a more comprehensive understanding of the implications arising from the evolutionary processes of these settlements. Therefore, it is necessary to pay attention to the multi-dimensional characteristics of mountainous rural settlements located in the metropolitan fringe area in terms of morphology, distribution, and scale, as well as to explore the dynamic changes of land use at the micro-scale, especially settlement expansion and natural land change.

Pingnan County, located in the southeast of China, with hills and mountains widely spread in the territory, is the county with the highest average altitude in Fujian Province. For a long time, a noticeable developmental disparity has persisted between the mountainous towns in southeastern China and coastal first tier cities. Economic factors and urban development have predominantly concentrated in the coastal regions due to their superior locational advantages. However, the industrialisation and urbanisation processes in the inland mountainous areas have lagged behind [25]. As a result of the influence exerted by the coastal areas, the population residing in the mountainous regions has experienced significant decline, leading to intense differentiation and reorganisation of the mountain settlements. The study of human living space in these regions holds significant practical implications for the development of mountainous counties and the revitalisation of rural areas, including villages. As a relatively comprehensive geographical unit encompassing political, economic, and social functions, county serves as an important scale for geographical research [26]. It encompasses a relatively complete settlement system. With these considerations in mind, this paper adopts Pingnan County as the study area and selects key time nodes after China's reform and opening up, namely 1985, 1990, 1995, 2000, 2005, 2010, 2015, and 2020. The aim is to analyse the evolutionary characteristics of rural settlements in Pingnan County through three primary dimensions: settlement size and morphology, settlement spatial distribution, and settlement scale structure. Furthermore, buffer zones of 100 m, 250 m, and 500 m are established around the settlements to investigate the land use transition under the influence of urbanisation.

The main contribution of this research is linked with the multi-objective dimensional feature analysis, and the relationship between settlement expansion and natural land change on the micro-scale, the results of which are of positive significance for optimising the layout of mountainous rural settlements in China's metropolitan fringe area, guiding county land spatial planning work, and promoting rural revitalisation.

Materials and methods

Study area

Pingnan County, located within Ningde City, Fujian Province, China, spans a total area of 1487 km^2 (26°44′–27°10′N, 118°41′–119°13′E) and encompasses 11 townships and 153 administrative villages (Fig. 1). Positioned in the middle section of the Jiufeng Mountain, the county exhibits high topography in the northwest and low topography in the southeast. The region is characterised by medium mountains, low mountains, hills, and valleys, with the average elevation of the entire county being 830 m above mean sea level. Approximately 81% of the county is mountainous, while forest coverage extends to 76.8% of the area, making it to a prototypical inland mountainous county. Pingnan County experiences a central subtropical maritime monsoon climate, characterised by mild winters, moderate summers, significant diurnal temperature variations, and distinct alpine climate characteristics. The region receives abundant rainfall, with annual precipitation reaching 1842.3 mm, while the average annual temperature ranges from 13 to 18 ℃. The county is home to 186 streams of varying sizes, which are divided into two major water systems: Huotong Stream and Gutian Stream. As of November 2020, the permanent population of Pingnan County is 139,800. While the county boasts an excellent natural ecological environment and rich traditional village resources, it has long faced developmental challenges as an underdeveloped mountainous region due to limited transportation infrastructure, inadequate facilities, and labor shortages. In recent years, significant efforts have been made to transform and upgrade the agricultural production

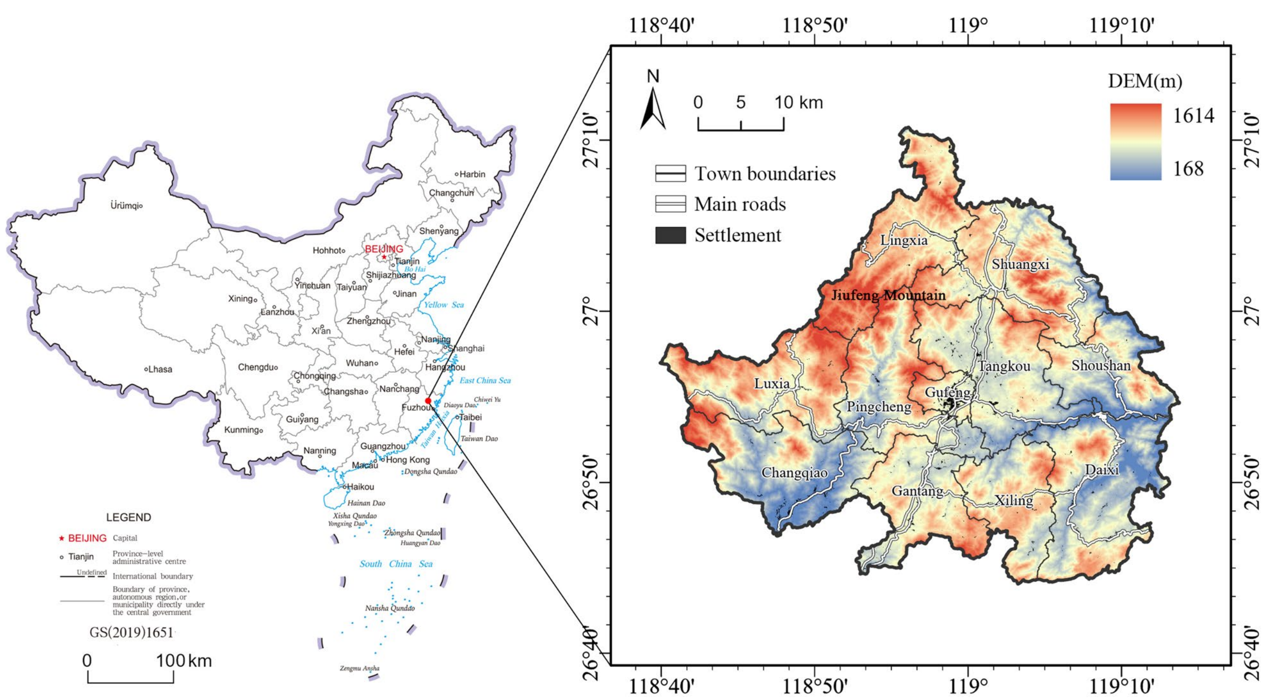

Fig. 1 Location of Pingnan County, China

and industrial structure of Pingnan County. Notably, in 2018, the county successfully withdrew from its designation as a key county for poverty alleviation and development at the provincial level. This makes the study of the evolution of rural settlements in Pingnan County of significant importance.

Data

The research data include: (1) Eight periods of land use data from 1985, 1990, 1995, 2000, 2005, 2010, 2015, and 2020 were obtained from the annual China Land Cover Dataset (CLCD) published by Professors Yang Jie and Huang Xin of Wuhan University. It was produced by the random forest classifier, based on 335709 Landsat images in the Google Earth Engine. The spatial resolution of CLCD is 30 m × 30 m, which has an overall accuracy of 79.31% [27–29]. The reason for selecting CLCD is that it has higher spatial resolution and longer temporal coverage than other datasets. Meanwhile, it is free, open and easy to access. CLCD was utilised to extract impervious patches using ArcGIS Pro software. Built-up land areas, such as traffic roads and large industrial zones, were manually removed to focus specifically on settlement land patches. (2) Regional elevation data were acquired from the 2009 L-band ALOS PALSAR (2006–2011) radar data published by the National Aeronautics and Space Administration (NASA) of the United States. The data were obtained from the Alaska Satellite Facility (ASF) data portal (https://search.asf.alaska.edu). From this source, 12.5 m resolution Digital Elevation Model (DEM) data were extracted. (3) Administrative boundary data for Pingnan County were obtained from two sources: the 1: 250000 national basic geographic database and the 1: 1000000 public version of basic geographic information data (2021) which were published by the National Geographic Information Resources Catalogue Service (https://www.webmap.cn/).

Methods

Landscape metrics

Landscape metrics serve as concise quantitative indicators that provide valuable information regarding the structural composition and spatial arrangement characteristics of a landscape [30]. In this study, various landscape metrics were employed to measure settlements, including the number of patches (NP), total patch area (CA), mean patch size (MPS), maximum patch index (LPI), mean patch shape index (MSI), and mean patch fractal dimension (MPFD) [13] (Table 1).

Spatial "hot spot" analysis (Getis-Ord Gi*)

Spatial "hot spot" detection is employed to assess the presence of statistically significant high and low values in localised areas. This technique allows for the identification of hot spot areas and cold spot areas using regional visualisation methods, followed by an analysis of their local autocorrelation [31]. The Z (Gi*) index serves as a reliable indicator of the distribution of hot and cold spots across the local spatial area. Its calculation is as follows:

$$G_i^* = \sum_{j=1}^{n} W_{ij}(d_i)X_i / \sum_{j}^{n} X_j \tag{1}$$

where $W_{ij}(d)$ is the spatial weight defined based on the distance rule; X_j is the observed value in region j.

Scale classification statistics

Based on the criteria used to classify urban populations and previous research on categorising the scale of urban and rural settlements [32, 33], the study employs Jenks' Natural Break method, which is a data classification method

Table 1 The landscape metrics selected in this study

Landscape pattern index	Description
Number of patches (NP)	NP is the total number of patches
Total class area (CA)	$CA = \sum_{i=1}^{n} a_i$, a_i is the area of patch i
Mean patch size (MPS)	$MPS = \sum_{i=1}^{n} a_i/n$ ai, a_i is the area of patch i, n is the count of patches
Largest path index (LPI)	$LPI = 100a_{max}/A$, a_{max} is the maximum patch area, A is the total patch area and is a simple dominance measurement algorithm
Mean shape index (MSI)	$MSI = 0.5P/\sqrt{\pi A}$, P is the total length of the patch boundary, while A is the total area of the patch. When comparing the shape to that of a circle, a value closer to 1 indicates a greater tendency towards a circular shape
Mean patch fractal dimension index (MPFD)	$MPFD = \sum_{i=1}^{n} \left(\frac{2\ln 0.25P_i}{\ln a_i}\right)/n$, MPFD is the mean settlement fractal dimension, where P_i is the perimeter of patch. a_i is the area of patch i; n is the number of patches. The index serves to assess the complexity and variability of settlement patch boundaries, with larger values indicating a greater intricacy in the shape of the settlement

designed to determine the best arrangement of values into different classes. This method can determine the best classification split point by calculating the degree of discrete data [34]. Then, the study combines the actual situation of the data to comprehensively classify the scale levels of rural settlements and count the changes in the number and scale of rural settlements of different levels.

Rank-size model

The Rank-size model represents the quantitative relationship between urban size and rank, which has undergone continuous refinement and evolution based on empirical relationship [35]. The study employs Zipf's modified Rank-size model to analyse the size distribution of urban settlements within the study area. The model utilises the following fundamental formula:

$$P_r = P_1 r^{-q} \quad (2)$$

By applying the logarithm to both sides of the equation, the expression is transformed into:

$$\ln P_r = \ln P_1 - q \ln r \quad (3)$$

where r is the settlement rank, P_r represents the settlement scale with bit order r, and P_1 is the scale of the first settlement site. The Zipf index, q, is employed to measure the distribution equilibrium of settlement sizes within the county. If $q = 1$, it suggests that the distribution of settlement scales in the study area closely adheres to Zipf's law, with a reasonably balanced distribution of the number of settlements across size classes. If $q > 1$, it indicates a significant disparity in settlement scales within the study area, with larger settlements dominating the system. Conversely, if $q < 1$, it implies a relatively concentrated distribution of settlement scales, with a higher concentration of settlements in the middle ranks and a lack of prominence for larger settlements [36].

Gini index

The urban Gini index is an important indicator developed by Marshall of Canada, in his study of the development and growth of cities of different sizes [37]. It is solved by fitting a constant-form Gini model, which can characterise the degree of agglomeration of the cluster size distribution [38]. Considering that Pingnan County, as a mountainous region, has a large number of small settlements, which are scattered and small in scale, and there is a large scale difference with the county town, the Gini coefficient was chosen in this study to make up for the limitations of the Rank-size model in regression fitting when there is a substantial disparity in settlement scale across regions, which is an effective complementary method [33]. The formula is as follows:

$$G_u = T_u / 2S_u(n - 1) \quad (4)$$

where T_u is the sum of the absolute differences in settlement scale between different settlements in the county; n is the total number of settlements in the county; S_u is the sum of the scale of all settlement sites in the county. The Gini index, G_u, ranges between 0 and 1. A value closer to 0 indicates a more dispersed distribution of settlement sizes, whereas a value closer to 1 suggests a more concentrated distribution. It is commonly accepted that when G_u exceeds 0.6, the scale distribution of settlements is considered highly unbalanced.

Land use transition matrix

The land use transition matrix, derived from Systems Analysis, is a quantitative representation of the transfer of state and condition within a study system. It offers a comprehensive and specific analysis of the quantitative transformation of various land use types and the structure of change. The mathematical expression of the land use transition matrix [39, 40] is as follows:

$$S_{ij} = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} \quad (5)$$

where S is the area; i and j is the land use types at the beginning and end of the study period, respectively. n is the total number of land use types considered. Additionally, S_{ij} is the area transferred from land use type i to land use type j during the study period.

Results

Spatial–temporal evolution of settlements

Size and morphological characteristics of settlements

The study uses the landscape metrics to conduct statistical analysis on the scale and morphology of settlements. The results show (Table 2) that the settlements in Pingnan County show a basic trend of increasing number and scale and stable shape during the evolution process. Between 1985 and 2020, the total number of settlements (NP) in the county witnessed an increase from 359 to 593. However, the growth rate varied, with a slow increase and occasional decreases observed from 1985 to 2010, followed by rapid growth from 2010 to 2020. The total area of settlements (CA) expanded from 160.903 to 911.696 ha. This increase was gradual from 1985 to 2005 but displayed a considerable linear growth pattern from 2005 to 2020. The Mean patch area size (MPS) experienced a rise from 0.448 to 1.537 ha, with rapid growth during the period from 2005 to 2010. The Largest Patch

Table 2 The landscape metrics selected in this study

Year	NP	CA (ha)	MPS (ha)	LPI	MSI	MPFD
1985	359	160.903	0.448	2.263	24.869	1.235
1990	358	167.232	0.467	2.337	24.671	1.238
1995	330	213.229	0.646	4.221	34.563	1.247
2000	344	292.014	0.849	5.881	35.805	1.263
2005	357	273.729	0.767	7.867	53.227	1.275
2010	388	471.735	1.216	9.451	38.577	1.297
2015	476	620.601	1.304	11.731	40.709	1.303
2020	593	911.696	1.537	12.472	32.708	1.346

Index (LPI) saw a rise followed by a decline, with a turning point in 2005. This suggests an increasing proportion of the largest patches prior to 2005, and a large increase in small and medium-sized patches after 2005. The mean settlement shape index (MSI) displayed a gradual increase from 1.235 to 1.346. In contrast, the mean settlement fractal dimension (MPFD) demonstrated an insignificant increase from 1.016 to 1.031, indicating that the rapid expansion of settlement size in the county did not lead to significant changes in its morphological characteristics.

Spatial distribution characteristics of settlements

The study created a 200 m × 200 m grid that covered Pingnan County to calculate the Gi* values of urban and rural settlements in the area from 1985 to 2020, employing Eq. (1) with settlement area as the variable. The results were then classified into four categories: hot spot areas, secondary hot areas, secondary cold areas, and cold spot areas using the geometric spacing method. A distribution map of the county's settlement scale (Fig. 2) was generated. The findings indicate the formation of three major hot spot areas within the Pingnan county, namely the county urban area, Changqiao township, and Shuangxi township. Additionally, secondary hot spot areas have been formed in Luxia township, Lingxia township, Tangkou township, Gantang township, Daixi township, and the vicinity of the county town. Between 1985 and 2000, the hot spot areas remained relatively stable, with only a slight increase in the county urban area. However, from 2000 to 2020, there was rapid growth in both the size of hot spot areas and secondary hot areas, particularly in and around the county urban area. This suggests an increasingly significant spatial clustering characteristic of the county's settlement scale. Over the period of 20 years, sub-hotspot areas displayed a widespread scattering occurrence, especially with a faster growth rate in the last 10 years. This scattering was primarily observed in the county urban areas, around townships, and along major rivers and roads. Overall, the spatial clustering centers were concentrated in the county urban areas and key townships. The spatial distribution of these centers expanded from the county urban areas towards the south and north, gradually becoming more balanced in their distribution pattern.

Scale structure characteristics of settlements

(1) There are substantial variations in the scale and level of settlements, with differing growth rates observed across different levels.

The county's settlements are classified into seven scale classes (Table 3). Between 1985 and 2020, the number of Type I and II of settlements increased from 1 to 6, with their proportion of total scale initially increasing from 24.87% in 1985 to 67.42% in 2005, and then decreasing to 44.23% in 2020. The number of Type III and IV of settlements has increased from 3 to 24, and their land use scale has been consistently expanding year after year, rising from 14.25 to 21.75%. Type I, II, III, and IV of settlements are characterised by their large scale, primarily concentrated in the county center and township areas. Type V and VI of settlements increased from 14 to 97, with their scale share fluctuating around 18.00%. This type of settlement is dominated by central villages. Type VII of settlements, predominantly natural villages, constitute the primary category of settlements in the county. Their number has increased from 341 to 466, but their scale proportion has consistently declined from 42.91 to 14.68%. This indicates a slower growth in the scale of natural villages and a trend towards decentralisation. Overall, there are variations in the growth rates of settlements at different periods and in different scale classes, showing a trend of rapid expansion of large settlements, stable growth of medium-sized settlements, and slow development of small settlements.

(2) The Zipf index showed a steady growth, indicating an increasing polarisation of large settlements, but, still with room for improvement.

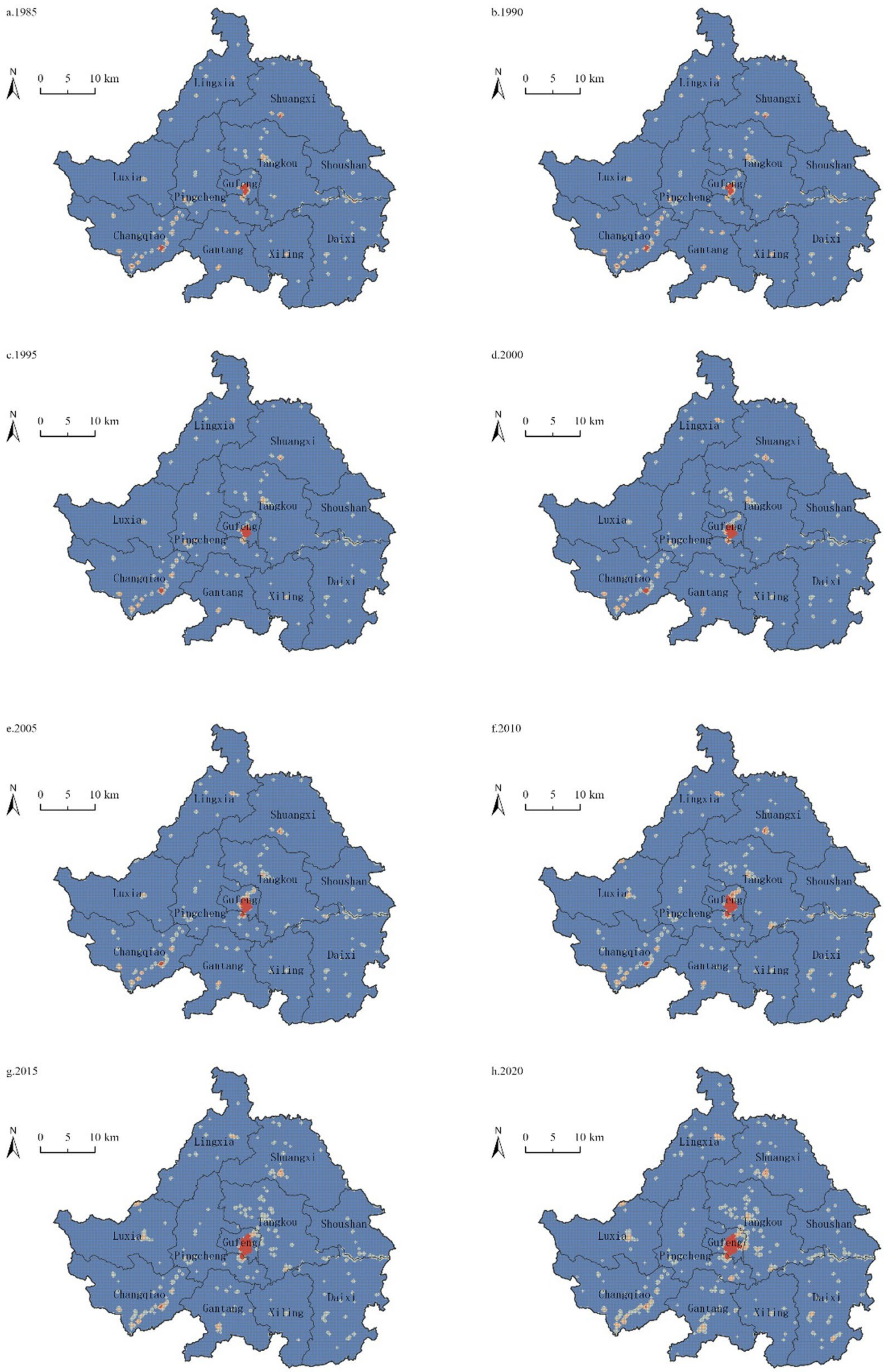

Fig. 2 The change of spatial "hot spot" analysis of settlement of Pingnan Country

Table 3 Scale structure of settlement of Pingnan Country

	Classification (ha)	I (> 25)	II (15–25)	III (8–15)	IV (4–8)	V (2–4)	VI (1–2)	VII (0–1)
1985	Number	1	0	1	2	7	7	341
	Ration (%)	0.28	0.00	0.28	0.56	1.95	1.95	94.99
	Area (ha)	40.01	0	12.98	9.95	19.19	9.72	69.04
	Ration (%)	24.87	0.00	8.07	6.18	11.93	6.04	42.91
1990	Number	1	0	1	2	9	7	338
	Ration (%)	0.28	0.00	0.28	0.56	2.51	1.96	94.41
	Area (ha)	41.26	0	12.98	10.52	25.19	9.26	68.03
	Ration (%)	24.67	0.00	7.76	6.29	15.06	5.54	40.68
1995	Number	1	1	1	4	6	10	307
	Ration (%)	0.30	0.30	0.30	1.21	1.82	3.03	93.03
	Area/ha	73.70	17.94	8.95	18.86	17.5	14.35	61.93
	Ration (%)	34.56	8.42	4.20	8.84	8.21	6.73	29.04
2000	Number	1	2	1	8	3	13	316
	Ration (%)	0.29	0.58	0.29	2.33	0.87	3.78	91.86
	Area (ha)	104.56	37.72	13.36	41.33	9.49	16.73	68.82
	Ration (%)	35.81	12.92	4.58	14.15	3.25	5.73	23.57
2005	Number	1	2	1	7	4	20	318
	Ration (%)	0.28	0.56	0.28	1.96	1.12	5.60	89.08
	Area (ha)	145.7	38.88	8.35	38.18	24.98	27.47	71.87
	Ration (%)	53.23	14.20	3.05	13.95	9.13	10.04	26.26
2010	Number	2	2	2	10	13	22	337
	Ration (%)	0.52	0.52	0.52	2.58	3.35	5.67	86.86
	Area (ha)	207.38	39.49	18.98	56.38	36.61	29.16	83.74
	Ration (%)	43.96	8.37	4.02	11.95	7.76	6.18	17.75
2015	Number	2	1	5	10	12	46	400
	Ration (%)	0.42	0.21	1.06	2.12	2.54	9.75	84.79
	Area (ha)	280.63	22.54	54.46	57.74	33.11	61.82	110.31
	Ration (%)	45.22	3.63	8.78	9.30	5.34	9.96	17.77
2020	Number	3	3	11	13	35	62	466
	Ration (%)	0.51	0.51	1.85	2.19	5.90	10.46	78.58
	Area (ha)	356.08	47.14	124.60	73.64	91.21	85.21	133.81
	Ration (%)	39.06	5.17	13.67	8.08	10.00	9.35	14.68

According to Eqs. (2) and (3), select the county's settlement scale as the dependent variable and the settlement rank as the independent variable. Draw the settlement rank-size curve of Pingnan County from 1985 to 2020 (Fig. 3) to analyse the characteristics of the settlement size structure. The R^2 values for each year exceeded 0.9, indicating that the fitted theoretical values do not differ much from the actual values, and the settlement scale structure basically conforms to the rank-size model. (1) Zipf index showed a gradual increase from 0.858 (< 1) in 1985 to 1.055 (> 1) in 2000 and further to 1.270 in 2020. This suggests that prior to 2000, there were more small and medium-sized settlements in lower orders, with the development of large settlements being less prominent. However, after 2000, large settlements began to dominate, and the difference between them and small and medium-sized settlements increased. The entire process exhibits a growing polarisation of large settlements. (2) The intercept of the fitted equation gradually increased from 1985 to 2020, with values of 11.754, 11.873, 12.256, 12.809, 13.224, 13.850, 14.134, and 15.070, indicating an increase in the size of rural settlements over the study period. Notably, there was a significant increase in the number of settlements with $\ln P_r > 10$, indicating substantial growth in medium and large settlements. (3) Since 2010, the distribution of the top settlements has consistently been below the fitted curve, indicating that the actual values are smaller than the theoretical values. This indicates that although the size of the settlements in the study

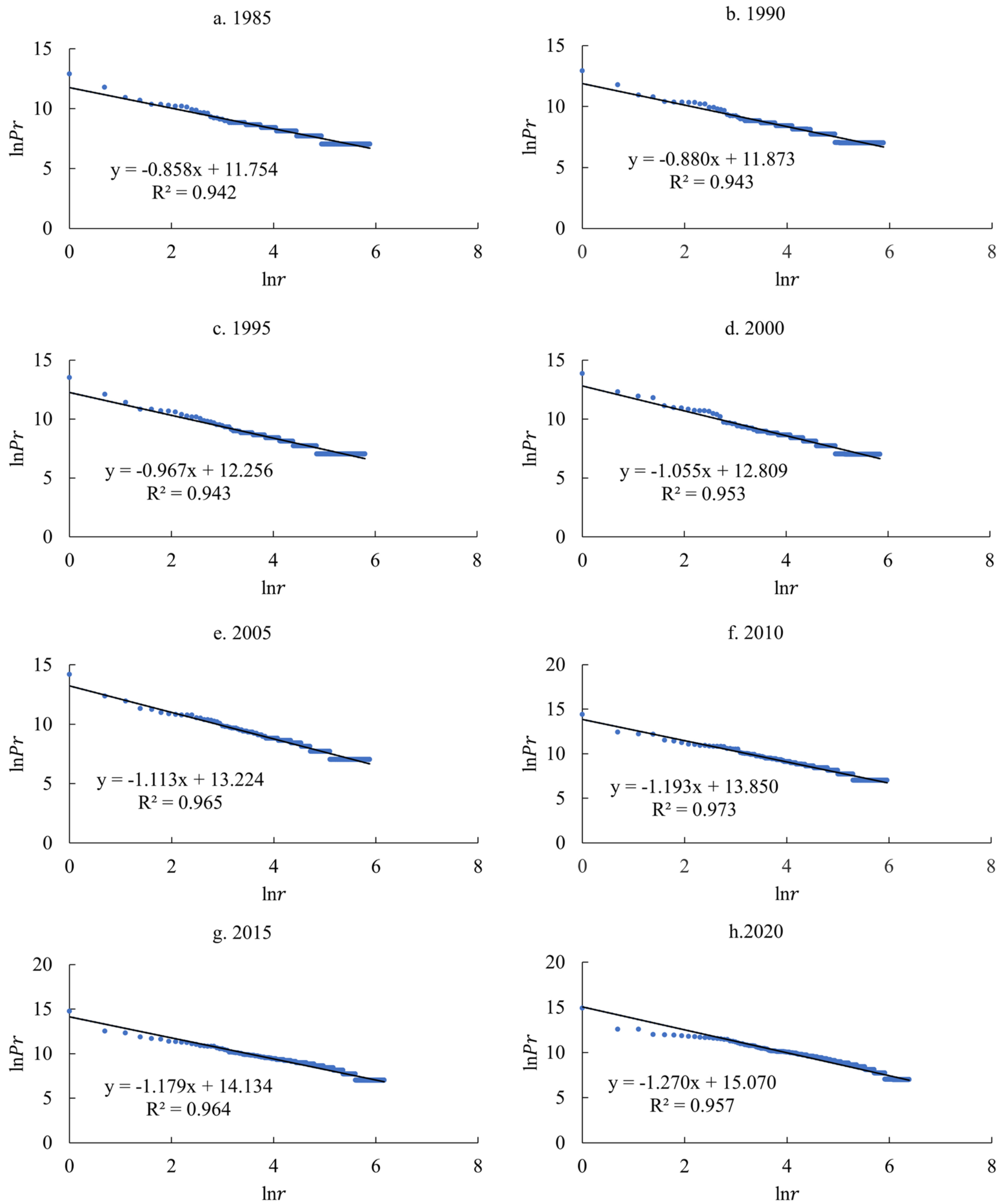

Fig. 3 Rank-size curves of settlement of Pingnan Country

area has increased to varying degrees, the size of the high-rank settlement is small in the overall size distribution, and there is some room for urbanisation in the future [41].

(3) The Gini index had a small value and exhibited an increasing trend, which was later followed by a decreasing trend.

According to Eq. (4), the Gini index G_u (Fig. 4) was calculated for each year and the following observations were made: (1) The Gini index is relatively small, with values below the critical threshold of 0.6 for each year. (2) The

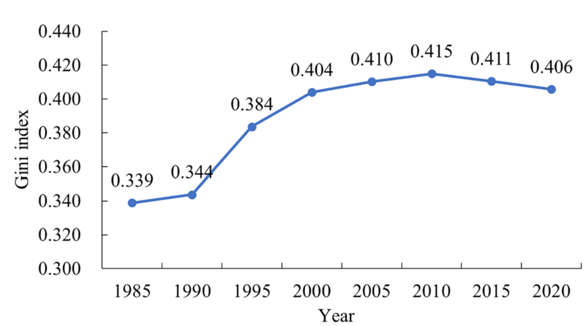

Fig. 4 Gini index of settlement of Pingnan Country during 1985–2020

Gini index initially increased and then decreased, reaching its peak in 2010. This suggests that before 2010, there was significant divergence in the size of settlements, with significant growth in large and medium-sized settlements. However, after 2010, there was a trend towards balanced settlement sizes, with small and medium sized settlements starting to grow. These findings align with the results obtained from the rank-size curve. (3) The higher growth rate of the Gini index from 1990 to 2000 reflects the accelerated urbanisation during the 1990s in the agricultural areas.

Land use transition around settlements

To gain a deeper understanding of the land use changes resulting from the dynamic evolution of rural settlements, this study utilised ArcGIS Pro software to delineate buffer zones of 100 m, 250 m, and 500 m around the settlements. The changes in land use area within these buffer zones were then counted (Table 4). The findings reveal that in terms of spatial dimension, cropland and forest are the primary land use types surrounding the settlements. Within the 100 m buffer zone, the proportions of cropland and forest are nearly equal. As the buffer zone expands to 250 m and 500 m, forest becomes the dominant land use type around the settlements, with grass, shrubs, and water bodies occupying a very small proportion. In the temporal dimension, 2010 is a significant turning point. Between 1985 and 2010, the area of cropland around the settlements consistently decreased, while the area of forest and settlements experienced slow growth. However, between 2010 and 2020, the area of cropland around the settlements began to increase, the area of forest decreased sharply, and the area of settlements witnessed rapid growth.

The study utilised the year 2010 as the turning point to construct the land use transition matrix (Table 5) for the 100 m, 250 m, and 500 m buffer zones, covering the periods of 1985–2010 and 2010–2020.

The findings indicate the following: (1) The evolution of settlement land use within different buffer zones exhibits a consistent pattern. Between 1985 and 2010, cropland was the primary source of land for settlement expansion, accounting for approximately 79.1% of the new settlement land, followed by forest at around 17.8%. However, between 2010 and 2020, the sources of land for settlement expansion became more diversified. Cropland, forest, and grassland played significant roles, accounting for approximately 56.4%, 33.2%, and 10.4% respectively. (2) The evolution of forest, cropland, and grassland within different buffer zones displays variability. Within the 100 m buffer zone, the areas of cropland and forest are similar. Between 1985 and 2010, there was an interchange between cropland and forest, resulting in a slight increase in forest area and an expansion of grassland encroaching on cropland. Between 2010 and 2020, cropland expanded mainly at the expense of woodland, leading to a rapid reduction in forest and grassland areas. Within the 250 m and 500 m buffer zones, forest covers a much larger area compared to other land types. Between 1985 and 2010, there was a substantial forest expansion, accounting for approximately 5% of the total land area, 97% of which was converted from cropland. Consequently, there was a substantial loss of cropland, particularly within the 250 m buffer zone, which underwent conversions primarily to forest, settlement, and grassland. The area covered by grassland experienced exponential growth during this period. Between 2010 and 2020, a significant encroachment of cropland into forest occurred, leading to a substantial increase in the area of cropland. Within the 250 m buffer zone, the cropland expanded by 7.727% of the total area, while within the 500 m buffer zone, it increased by 6.365% of the total area. This encroachment, combined with the expansion of settlements, resulted in a substantial reduction in the forest area. Specifically, within the 250 m buffer zone, the forest decreased by 10.971% of the total area, and within the 500 m buffer zone, it decreased by 7.748% of the total area. Furthermore, there was also a significant decline in the area covered by grassland. (3) The proportion of shrubs and water bodies within the various buffer zones is relatively small, and their area has remained relatively stable without significant changes.

The land use transition of settlements in Pingnan County exhibits variations across different buffer zones and stages. Overall, the settlements continue to expand, and the sources of land for expansion gradually transform from primarily arable land to a combination of cropland, forest, and grassland. Before 2010, the periphery of the settlements experienced a decrease in arable land and an increase in forest land and grassland. However, after 2010, there was an observed trend of increasing arable land and decreasing forest land and grassland in the settlement periphery.

Discussion

Analysis of spatial–temporal evolution of settlements

Pingnan County is currently undergoing rapid urbanisation, with frequent flows of urban and rural factors elements. However, the spatial and temporal evolution of rural settlements and land use transition in this region are more intricate due to the unique geographical and socio-economic characteristics of less developed mountainous areas in southeast China. Over the period from 1985 to 2020, there has been a substantial outflow of Pingnan County's population to coastal cities, resulting in a significant decline from 168389 individuals in 2000

Table 4 Changes of land use area in buffer zones

	Land use	Cropland	Forest	Shrub	Grassland	Water	Settlement
a. Changes of land use area in 100 m buffer zones							
1985	Area (ha)	19331	18314	12	925	41	1424
	Ration (%)	48.27	45.73	0.03	2.31	0.10	3.56
1990	Area (ha)	17588	19977	7	958	37	1480
	Ration (%)	43.92	49.88	0.02	2.39	0.09	3.70
1995	Area (ha)	16420	20501	5	1173	61	1887
	Ration (%)	41.00	51.19	0.01	2.93	0.15	4.71
2000	Area (ha)	15019	20884	6	1490	64	2584
	Ration (%)	37.50	52.15	0.01	3.72	0.16	6.45
2005	Area (ha)	14887	20132	2	1785	96	3145
	Ration (%)	37.17	50.27	0.00	4.46	0.24	7.85
2010	Area (ha)	14415	19292	1	2064	101	4174
	Ration (%)	36.00	48.17	0.00	5.15	0.25	10.42
2015	Area (ha)	16311	16312	0	1819	114	5491
	Ration (%)	40.73	40.73	4.54	0.28	13.71	13.71
2020	Area (ha)	16265	13953	1	1646	115	8067
	Ration (%)	40.61	34.84	0.00	4.11	0.29	20.14
b. Changes of land use area in 250 m buffer zones							
1985	Area (ha)	37330	69976	25	1113	115	1424
	Ration (%)	33.94	63.62	0.02	1.01	0.10	1.29
1990	Area (ha)	33025	74216	11	1141	110	1480
	Ration (%)	30.03	67.48	0.01	1.04	0.10	1.35
1995	Area (ha)	31204	75370	9	1365	148	1887
	Ration (%)	28.37	68.53	0.01	1.24	0.13	1.72
2000	Area (ha)	29669	75886	8	1683	153	2584
	Ration (%)	26.98	69.00	0.01	1.53	0.14	2.35
2005	Area (ha)	28903	75716	3	2030	186	3145
	Ration (%)	26.28	68.84	0.00	1.85	0.17	2.86
2010	Area (ha)	27880	75355	2	2369	203	4174
	Ration (%)	25.35	68.52	0.00	2.15	0.18	3.80
2015	Area (ha)	33547	68576	1	2147	221	5491
	Ration (%)	30.50	62.35	0.00	1.95	0.20	4.99
2020	Area (ha)	36381	63288	4	2021	222	8067
	Ration (%)	33.08	57.54	0.00	1.84	0.20	7.33
c. Changes of land use area in 500 m buffer zones							
1985	Area (ha)	57332	200352	33	1241	190	1424
	Ration (%)	21.83	76.30	0.01	0.47	0.07	0.54
1990	Area (ha)	49025	208610	17	1255	185	1480
	Ration (%)	18.67	79.45	0.01	0.48	0.07	0.56
1995	Area (ha)	46447	210531	13	1460	234	1887
	Ration (%)	17.69	80.18	0.00	0.56	0.09	0.72
2000	Area (ha)	44930	211019	19	1779	241	2584
	Ration (%)	17.11	80.37	0.01	0.68	0.09	0.98
2005	Area (ha)	43239	211768	15	2118	287	3145
	Ration (%)	16.47	80.65	0.01	0.81	0.11	1.20
2010	Area (ha)	42004	211589	14	2463	328	4174
	Ration (%)	16.00	80.58	0.01	0.94	0.12	1.59
2015	Area (ha)	52091	200365	7	2270	348	5491
	Ration (%)	19.84	76.31	0.00	0.86	0.13	2.09

Table 4 (continued)

	Land use	Cropland	Forest	Shrub	Grassland	Water	Settlement
2020	Area (ha)	58593	191399	10	2155	348	8067
	Ration (%)	22.32	72.89	0.00	0.82	0.13	3.07

to 139815 individuals in 2020, representing a decrease of 16.97%, resulting in the abandonment of rural residential areas and the underutilisation of land resources [42]. Despite this, the total area of rural settlements has been steadily increasing, along with a rise in agglomeration. Specifically, regarding the scale and morphology of settlements, there is a basic trend of increasing numbers, expanding scale, and maintaining a stable morphology in Pingnan County. The last decade has witnessed a peak in settlement expansion. In terms of spatial distribution characteristics of the settlements, three significant hot spot areas have emerged within Pingnan County, namely the county urban area, Changqiao Township District, and Shuangxi Township. The phenomenon of population decline and concurrent settlement expansion observed in various regions [43, 44] can be attributed to several factors. (1) Advancements in science and technology have diminished the scale limitations on settlement layouts, allowing for wider expansion into areas characterised by flat terrain, convenient transportation, and economic prosperity [45, 46]. (2) As residents experience steady income growth, they often seek to enhance their quality of life and living conditions by expanding their houses, consequently increasing the overall settlement area [3, 47]. (3) The construction of settlements in mountainous areas is still greatly limited by the topography [48]. Areas with gentle topography are the first choice for settlement construction [49, 50]. Therefore, settlements have formed relatively stable morphological characteristics in the process of laying out the mountains. (4) County urban areas and township centers serve as central sites for regional functions such as markets, science and education, culture and health, as well as consumption and public services [51]. Settlements adjacent to these centers can benefit from their radiation-driven and trickle-down effect, thereby enjoying increased development opportunities [52]. As a result, the settlement in Pingnan County has gradually formed a hotspot area, with the township center serving as its core. Regarding the scale structure characteristics of settlements, significant variations exist among the scale classes of settlements in Pingnan County, with different growth rates for different classes of settlements. Generally, larger settlements tend to expand at a faster rate. Before 2010, the expansion rate of large-scale settlements surpassed that of small-scale settlements, resulting in significant polarisation. However, after 2010, there was an increase in the expansion rate of small and medium-sized settlements, leading to a more balanced scale of settlement. The reasons behind this phenomenon could be attributed to various factors. (1) Before 2010, there was rapid rural urbanisation and extensive expansion of areas with distinct geographical and economic advantages [53]. (2) After 2010, due to the limited area of plains in mountainous regions, the limited resource and environmental carrying capacity determine that such regions are usually not in a position to build large-scale centralised towns. This has made the expansion of large settlements nearly saturated and prevented the development of larger settlements. (3) Small and medium-sized settlements, encouraged by supportive policies, have diversified their businesses based on local conditions, leading to economic growth and expansion of the settlements.

Analysis of land use transition and driving factors

Land use transition around settlements in Pingnan County exhibits variability within different buffer zones and over different time periods. Overall, between 1985 and 2010, arable land served as the primary source of land for settlement expansion. During this period, there was a significant reduction in surrounding arable land, accompanied by a gradual increase in forest and grassland areas. Between 2010 and 2020, the expansion of settlements was supported by cropland, forest, and grassland, with its cropland arable land experiencing growth and encroaching mainly on forest and grassland. Overall, land use transition around settlements is a selective regional development process driven by both natural resource conditions and socio-economic conditions. Natural resource conditions such as climate, topography, river, arable land resources, shape the historical pattern of the settlement. They play a fundamental supporting and limiting role and are characterised by relative stability. While socio-economic conditions more strongly lead the contemporary pattern of settlements, and their characteristics change rapidly in comparison [8, 54], such as demographic changes, economic development, livelihood patterns, farmers' behavior and willingness, Grain for Green policy, Waste land reclamation policy, Targeted Poverty Alleviation policy, and Rural Revitalisation strategy. To expand on this more specifically: (1) The land use transition around mountain settlements exhibits

Table 5 Changes of land use area in buffer zones

		Cropland	Forest	Shrub	Grassland	Water	Settlement	Total	Decrease
a. Land use transformation matrix of 100 m buffer zone between 1985 and 2010 (%)									
2010									
1985	Cropland	30.110	9.121	0.002	3.425	0.140	5.467	48.265	18.155
	Forest	5.663	38.466		0.370	0.007	1.231	45.737	7.271
	Shrub	0.003	0.010		0.008		0.010	0.030	0.030
	Grassland	0.215	0.547		1.351		0.197	2.310	0.959
	Water	0.005	0.027			0.063	0.007	0.102	0.040
	Settlement		0.002			0.042	3.510	3.555	0.045
Total		35.995	48.174	0.002	5.154	0.252	10.423	100.0	
New		5.885	9.708	0.002	3.802	0.190	6.913		
b. Land use transformation matrix of 100 m buffer zone between 2010 and 2020 (%)									
2020									
2010	Cropland	28.259	1.176		1.034	0.037	5.488	35.995	7.736
	Forest	10.911	33.555	0.002	0.477		3.229	48.174	14.619
	Shrub		0.002					0.002	0.002
	Grassland	1.430	0.110		2.600	0.002	1.011	5.154	2.554
	Water	0.010				0.237	0.005	0.252	0.015
	Settlement	0.002				0.010	10.411	10.423	0.012
Total		40.612	34.843	0.002	4.111	0.287	20.144	100.0	
New		12.353	1.289	0.002	1.511	0.050	9.733		
c. Land use transformation matrix of 250 m buffer zone between 1985 and 2010 (%)									
2010									
1985	Cropland	21.283	9.137	0.001	1.442	0.085	1.990	33.938	12.656
	Forest	3.972	59.062		0.142	0.004	0.448	63.628	4.566
	Shrub	0.001	0.015	0.001	0.003		0.004	0.023	0.022
	Grassland	0.090	0.283		0.567	0.001	0.072	1.012	0.445
	Water	0.005	0.017			0.080	0.003	0.105	0.025
	Settlement		0.001			0.015	1.278	1.294	0.016
Total		25.350	68.514	0.002	2.154	0.185	3.795	100.0	
New		4.068	9.453	0.001	1.587	0.105	2.517		
d. Land use transformation matrix of 250 m buffer zone between 2010 and 2020 (%)									
2020									
2010	Cropland	21.720	1.117		0.497	0.019	1.998	25.350	3.631
	Forest	10.687	56.375	0.003	0.274		1.176	68.514	12.140
	Shrub		0.001	0.001				0.002	0.001
	Grassland	0.665	0.052		1.068	0.001	0.368	2.154	1.086
	Water	0.005				0.178	0.002	0.185	0.006
	Settlement	0.001				0.004	3.791	3.795	0.005
Total		33.077	57.544	0.004	1.838	0.202	7.335	100.0	
New		11.357	1.169	0.003	0.770	0.024	3.544		
e. Land use transformation matrix of 500 m buffer zone between 1985 and 2010 (%)									
2010									
1985	Cropland	13.482	6.994	0.000	0.627	0.056	0.840	22.001	8.518
	Forest	2.594	74.038	0.005	0.062	0.004	0.189	76.891	2.854
	Shrub	0.001	0.009	0.000	0.001		0.002	0.013	0.012
	Grassland	0.042	0.149		0.255	0.000	0.030	0.476	0.221
	Water	0.002	0.011			0.059	0.001	0.073	0.014
	Settlement		0.000			0.007	0.539	0.546	0.007
Total		16.121	81.201	0.005	0.945	0.126	1.602	100.0	

Table 5 (continued)

		Cropland	Forest	Shrub	Grassland	Water	Settlement	Total	Decrease
New		2.639	7.163	0.005	0.690	0.067	1.062		
f. Land use transformation matrix of 500 m buffer zone between 2010 and 2020 (%)									
2020									
2010	Cropland	14.092	0.948		0.227	0.011	0.843	16.121	2.029
	Forest	8.094	72.478	0.002	0.130		0.496	81.201	8.723
	Shrub		0.004	0.002				0.005	0.004
	Grassland	0.296	0.023		0.470	0.000	0.155	0.945	0.475
	Water	0.003	0.001			0.121	0.001	0.126	0.005
	Settlement	0.000				0.002	1.600	1.602	0.002
Total		22.486	73.453	0.004	0.827	0.134	3.096	100.0	
New		8.394	0.976	0.002	0.357	0.013	1.496		

a dual character influenced by topography and geomorphology, encompassing both intensification and abandonment transformations. Areas with steep slopes tend to have a stronger ecological orientation, while areas with gentle slopes show a stronger economic orientation [21]. This leads to different land evolution patterns in different areas. (2) Demographic changes, such as the loss of young and middle-aged men from the rural labor force, contribute to an aging and feminisation of the rural labor force. Farmers increasingly rely on non-farm income sources, such as work in urban areas, reducing their dependence on land and increasing the risk of farmland abandonment [55, 56]. (3) Livelihood patterns of Pingnan County have become more diversified. The county has adjusted the industrial structure and promoted industrial upgrading and transformation over the past decade, so that the proportion of the three industries has been adjusted from 21.60% for the tertiary industry, 40.15% for the secondary industry, and 38.25% for the primary industry in 2012, to 15.29%, 34.35%, and 50.36% respectively in 2021. This industrial structure presents a "three, two, one" pattern, that is, the tertiary industry holds the largest share, and the primary industry represents the smallest portion. This industrial adjustment has led to a rapid increase in the living and consumption level of local farmers, providing a solid financial basis for the rational improvement of land resources. As a result, the development mode of the settlement is no longer single orientated, but shifting to industries such as more sophisticated alpine agriculture, green industry, rural cultural tourism and so on. The surrounding land use also shows diversity and compatibility, which also plays a major role in promoting the quality of living space within families and the beautification of the living space and appearance within the village [57]. For example, during this period, with the development of tourism in the mountainous areas, the economy of rural accommodation and catering has developed, and local residents have expanded new settlements in the mountainous areas to accommodate tourists. At the same time, they reclaimed a certain amount of farmland to provide tourists with sightseeing and excursion venues, which has led to the diversification of land use types. (4) Under the influence of various policies, the land use around mountainous settlements exhibits fluctuations in different directions. For instance, under the policy of returning farmland to forest, arable land gradually transformed into forest land before 2010. Coupled with the steady loss of population, a considerable amount of agricultural land is gradually falling into disuse. After 2010, to ensure food security, local governments have begun activities such as reclamation of old villages and " claim one acre of land ". This encouraged farmers' participation in land reclamation for food cultivation, leading to the conversion of some settlements, forest and wastelands into cropland. Simultaneously, the implementation of relevant incentive and subsidy policies, such as incentives for high-standard farmland construction, agricultural machinery subsidies, and subsidies for the reclamation of abandoned land have contributed to an increase in cultivated land area. Under the rural revitalisation strategy, some settlements have developed cultural and creative tourism based on ancient village resources, adopting a transformative development path that involves collaboration between the party government, artists, farmers, ancient villages, and the internet. Cultural and creative base gravitate and flourish around the settlement, fostering population resurgence and contributing to the ongoing expansion of the settlement area. Concurrently, the cropland and forest around the settlement has been further improved.

Compared with plain settlements or other mountain settlements, this kind of mountain settlements located in the metropolitan fringe area has its uniqueness. On one hand, compared with plain areas, the natural environment of mountainous areas has stronger constraints on the settlements. Relevant studies show that in the plains, while the number of settlements increased, the boundaries became irregular and were somehow centralised [58]. However, in the mountainous areas of southwest China and the Loess Plateau, the morphology of the settlements did not change much, indicating that the overall spatial pattern of mountain settlements was generally constrained by the topography [33]. This also establishes the historical spatial pattern of mountain settlements which persists to the present day, and which also limits the expansion of the large-scale settlements in Pingnan County after 2010. On the other hand, compared with other mountain settlements, such as those in the mountainous regions of south-west China and north-west China, this kind of settlement located in the metropolitan fringe area is subject to stronger socio-economic influences. They have a clear tendency to cluster towards county towns or central villages, which is manifested in the continuous outflow of the population from the original settlements towards the central villages or to the more developed cities on the next level. This has led to an increase in the size of central villages and county towns, resulting in the formation of a number of important agglomeration hotspots. At the same time, influenced by the economies of the developed regions, such areas have diversified their livelihood patterns, not only relying on agriculture, but also turning to tourism, industry and other industries, forming a mutually supportive and complementary industrial chain with the developed regions. Therefore, mountain settlements located in the metropolitan fringe area are facing dramatic spatial evolution and modern transformation, and their spatial distribution and evolution patterns are different from those of rural settlements in other regions.

Implications for rural planning

In the next 10 – 20 years, as urbanisation continues in Pingnan County, rural-to-urban migration will remain the dominant population movement trend, further influencing the evolution and development of rural settlements. To promote the optimal reconfiguration of settlement space and enhance land resource utilisation efficiency, the following measures are recommended:

First of all, it is crucial to assess the trend of changes of rural settlements and then build a reasonable and orderly structure and pattern. For a long time, the construction of rural settlements has been basically without planning, approval and management, resulting in a disorderly layout and roughly use of the land [59]. The government and relevant practitioners should give full consideration to the delineation and reorganisation of production and living space of different levels of settlements, integrate broken patches of rural settlements, and reasonably carry out relocation, so as to improve the efficiency of land use. Meanwhile, in rural planning, it is necessary to pay special attention to the towns and large and merged villages, which are the location of major markets and can house larger populations and better accommodate industry in the future [60].

Secondly, the diversified and composite use of land in and around settlements should be advocated. Currently, planning has shifted from incremental planning to inventory or even reduction planning. Rural planning should follow the characteristics of the mixed use of land in rural settlements, taking into account the multiple functions of rural land in terms of production and life, so as to fully release the value and potential of the land. For example, through village planning, a certain piece of land can be used to satisfy the daily lives of residents while at the same time incorporating tourism-related functions, thereby meeting the needs of multiple actors in the context of rural revitalisation.

Thirdly, the advantages of local resources should be promoted, and attractive rural settlements and their surrounding landscapes should be preserved. At present, the phenomenon of "counter-urbanisation" has appeared in the eastern China, which refers to the phenomenon of the urban population's employment, housing, consumption and investment flowing from the city to the suburbs or even the countryside after the development of urbanisation reaches a certain stage [61]. Pingnan County is rich in agricultural resources and ancient villages, which provides an opportunity for the population to move to the countryside. Rural settlements can attract foreign capital through industries such as alpine agriculture and rural cultural tourism, which will help villagers increase their income and promote village regeneration [58]. This will play an important role in decentralised urbanisation.

Finally, emphasis should be placed on the territoriality and diversity of rural settlement landscapes. Over the past thousand years, the Chinese have developed unique settlement landscapes and culture in harmony with nature, which is particularly evident in mountainous areas. However, in the context of rapid urbanisation, many settlements have disappeared, or been replaced by modern Louvre gallery-style buildings [62]. It is urgent to protect the settlements and their surroundings as a holistic heritage. It is the historical responsibility of Chinese civilisation, as one of the oldest and most enduring civilisations in the world, to safeguard these cultural carriers.

Conclusions

This study focuses on Pingnan County as the study area, with the time nodes in 1985, 1990, 1995, 2000, 2005, 2010, 2015, and 2020. Various analytical methods, including landscape metrics, spatial "hot spot" detection, scale classification statistics, rank-size model, Gini index, and land use transition matrix, are employed to reveal the characteristics of spatial and temporal evolution of rural settlements and the transition of surrounding land use in the study area. The findings indicate the following: (1) From 1985 to 2020, regarding the scale and morphological characteristics, the settlements in Pingnan County exhibited a basic trend of growth in both quantity and scale, along with a stable morphology. Notably, the last decade stood out as the peak period of rapid settlement expansion. (2) Concerning the spatial distribution of settlements, Pingnan County has formed three prominent hot spot areas located in the county urban area, Changqiao township, and Shuangxi township. The spatial distribution of the settlement centers has expanded from the county urban area towards the southern and northern regions, resulting in a more balanced distribution pattern. (3) In terms of the scale structure characteristics of settlements, there are noticeable variations in the scale levels, with different growth rates across these levels. Generally, larger settlements exhibit more rapid expansion. The Zipf index of settlements in Pingnan County has grown steadily, and the polarisation of large settlements has increased, but there is still room for improvement. The Gini index of settlements is small, initially showing an increasing trend followed by a decrease. This is reflected in the distinct divergence of settlement scales prior to 2010, and the subsequent trend towards a more balanced scale, with small and medium-sized settlements experiencing growth since 2010. (4) The land use transitions around settlements in Pingnan County exhibit variations across different buffer zones and time periods. From 1985 to 2010, the expansion of settlements primarily resulted in the conversion of cropland, leading to a significant decrease in cropland in the surrounding areas. Meanwhile, there was a gradual increase in forest and grassland. In contrast, between 2010 and 2020, the expansion of settlements involved the conversion of not only cropland but also forest and grassland. Cropland experienced a resurgence in its periphery, while forest and grassland were encroached upon predominantly.

While this study reveals the spatial and temporal evolution of rural settlements and land use transitions in Pingnan County, as well as initiates a discussion on the factors influencing these dynamics, to what extent do these factors' influence on the evolution of settlements and land use? And how did it affect these evolutions? These questions remain unexplored in the current study. In future research, the indicator data of the influencing factors will be further refined to explore the driving mechanisms of settlement evolution in Pingnan County.

Author contributions

SC: conceptualization, methodology, formal analysis, visualization, writing—original draft, writing—review & editing. XW: conceptualization, validation, writing—review & editing, funding acquisition. YQ: visualization, writing—review & editing; QL: supervision, project administration, funding acquisition.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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References

1. Yang R, Liu Y, Long H, Qiao L (2015) Spatio-temporal characteristics of rural settlements and land use in the Bohai Rim of China. J Geog Sci 25:559–572
2. Liu Y, Yang Y, Li Y, Li J (2017) Conversion from rural settlements and arable land under rapid urbanization in Beijing during 1985–2010. J Rural Stud 51:141–150
3. Wang J, Wang X, Du G, Zhang H (2022) Temporal and spatial changes of rural settlements and their influencing factors in Northeast China from 2000 to 2020. Land 11(10):1640
4. Dzanku FM (2019) Food security in rural sub-Saharan Africa: exploring the nexus between gender, geography and off-farm employment. World Dev 113:26–43
5. Jayne TS, Snapp S, Place F, Sitko N (2019) Sustainable agricultural intensification in an era of rural transformation in Africa. Glob Food Sec 20:105–113
6. Govindan K, Loisi RV, Roma R (2016) Greenways for rural sustainable development: an integration between geographic information systems and group analytic hierarchy process. Land Use Policy 50:429–440
7. Bański J, Wesołowska M (2010) Transformations in housing construction in rural areas of Poland's Lublin region—Influence on the spatial settlement structure and landscape aesthetics. Landsc Urban Plan 94(2):116–126
8. Zhang Y, Li Y, Luo G, Bai X, Huang J, Tang F, Yu M (2022) Analysis of the land use dynamics of different rural settlement types in the Karst Trough Valleys of Southwest China. Land 11(9):1572
9. Yingbin F, Hualou L (2020) Progress and prospect of research on spatial reconstruction of rural settlements in mountainous areas of China. Prog Geogr 39:866–879
10. Yu ZW, Xiao LS, Guo QH, He ZC (2016) Mountain county rural settlement landscape pattern change and spatial characteristics in rapid mountain urbanization process in Fujian province. Acta Ecol Sin 36(10):1–11
11. Trewartha GT (1946) Types of rural settlement in colonial America. Geogr Rev 36(4):568–596
12. Li N, Jiang S (2018) Study on spatial pattern of rural settlements in Wuling mountainous area based on GIS. Wireless Pers Commun 102:2745–2757

13. Tian G, Qiao Z, Zhang Y (2012) The investigation of relationship between rural settlement density, size, spatial distribution and its geophysical parameters of China using Landsat TM images. Ecol Model 231:25–36
14. Fitawok MB, Derudder B, Minale AS, Van Passel S, Adgo E, Nyssen J (2020) Modeling the impact of urbanization on land-use change in Bahir Dar City, Ethiopia: an integrated cellular Automata–Markov Chain Approach. Land 9(4):115
15. Salvati L (2013) Urban containment in action? Long-term dynamics of self-contained urban growth in compact and dispersed regions of southern Europe. Land Use Policy 35:213–225
16. Clark JK, McChesney R, Munroe DK, Irwin EG (2009) Spatial characteristics of exurban settlement pattern in the United States. Landsc Urban Plan 90(3–4):178–188
17. Yang R, Xu Q, Long H (2016) Spatial distribution characteristics and optimized reconstruction analysis of China's rural settlements during the process of rapid urbanization. J Rural Stud 47:413–424
18. Ristić D, Vukoičić D, Milinčić M (2019) Tourism and sustainable development of rural settlements in protected areas-Example NP Kopaonik (Serbia). Land Use Policy 89:104231
19. Li Z, Zhang XL, Li H (2019) Evolution characteristics and driving mechanism of urban-rural scale system at county level: a case of Zhangjiagang city, Jiangsu province. J Nat Resour 34(1):140–152
20. Xie S, Zhang W, Zhao Y, Tong D (2022) Extracting land use change patterns of rural town settlements with sequence alignment method. Land 11(2):313
21. Huang M, Li Y, Ran C, Li M (2022) Dynamic changes and transitions of agricultural landscape patterns in mountainous areas: a case study from the hinterland of the Three Gorges Reservoir Area. J Geog Sci 32(6):1039–1058
22. Xi JC, Wang SK, Zhang RY (2016) Restructuring and optimizing production-living-ecology space in rural settlements: a case study of Gougezhuang Village at Yesanpo tourism attraction in Hebei Province. J Nat Resour 31(3):425–435
23. Li XJ, Luo Q (2014) The coordinating ideas of new-form urbanization. China Popul Resour Environ 24:47–53
24. Chen Z, Li Y, Liu Z, Wang J, Liu X (2022) Impacts of different rural settlement expansion patterns on eco-environment and implications in the loess hilly and gully region, China. Front Environ Sci 10:857776
25. Liu Y, Zhou Y, Li Y (2019) Rural regional system and rural revitalization strategy in China. Acta Geogr Sin 74:2511–2528
26. Li Z, Zhang XL, Li H, Yuan Y (2018) Evolution paths and the driving mechanism of the urban-rural scale system at the county level: taking three counties of Jiangsu province as an example. Acta Geogr Sin 73(12):2392–2408
27. Yang J, Huang X (2021) The 30 m annual land cover dataset and its dynamics in China from 1990 to 2019. Earth Syst Sci Data 13(8):3907–3925
28. Huang X, Li J, Yang J, Zhang Z, Li D, Liu X (2021) 30 m global impervious surface area dynamics and urban expansion pattern observed by Landsat satellites: from 1972 to 2019. Sci China Earth Sci 64:1922–1933
29. Huang X, Song Y, Yang J, Wang W, Ren H, Dong M, Li J (2022) Toward accurate mapping of 30-m time-series global impervious surface area (GISA). Int J Appl Earth Obs Geoinform 109:102787
30. Zhang QJ, Fu BJ, Chen LD (2003) Several problems about landscape pattern change research. Scientia Geographica Sinica 23(3):270–275
31. Chen Z, Bai Y, Zhou L (2020) Spatial pattern characteristics and genetic identification of settlements in ecologically fragile areas of alpine mountians: a case study on the Tianzhu Tibetan Autonomous County. Scientia Geographica Sinica 40(24):9059–9069
32. Xu X (1982) The evolution and prediction of China's Urban scale system. J Sun Yat-Sen Univ 03:40–49
33. Yang Y, Li Y, Huang Q, Huang C (2016) Comparison on spatial-temporal dynamics of urban land and population size distribution in China: a case study of the Bohai Rim. Geogr Res 35(09):1672–1686
34. Chen J, Yang ST, Li HW, Zhang B, Lv JR (2013) Research on geographical environment unit division based on the method of natural breaks (Jenks). Int Arch Photogramm Remote Sens Spat Inf Sci 40:47–50
35. Zipf GK (2016) Human behavior and the principle of least effort: An introduction to human ecology. Ravenio Books, New York
36. Li X, Xu J, Hai B (2015) The changing distribution patterns of rural settlements during the process of urbanization: the case of Gongyi (1929–2013), China. Acta Geographica Sinica 70(12):1870–1883
37. Marshall JU (1997) Beyond the rank-size rule: a new descriptive model of city sizes. Urban Geogr 18(1):36–55
38. Arbia G (2001) The role of spatial effects in the empirical analysis of regional concentration. J Geogr Syst 3:271–281
39. Wu LN, Yang ST, Liu XY, Luo Y, Zhou X, Zhao H (2014) Response analysis of land use change to the degree of human activities in Beiluo River basin since 1976. Acta Geogr Sin 69(1):54–63
40. Takada T, Miyamoto A, Hasegawa SF (2010) Derivation of a yearly transition probability matrix for land-use dynamics and its applications. Landscape Ecol 25:561–572
41. Wei C, Zhu J, Li X, Luo P (2017) A rethink of the rank-size rule for rural settlement in traditional agricultural areas: a case study of Zhoukou City. Econ Geogr 37(3):158–165
42. Song W, Chen B, Zhang Y (2014) Land-use change and socio-economic driving forces of rural settlement in China from 1996 to 2005. Chin Geogra Sci 24:511–524
43. Song W, Liu M (2014) Assessment of decoupling between rural settlement area and rural population in China. Land Use Policy 39:331–341
44. Chen C, Gao J, Chen J (2017) Institutional changes, land use dynamics, and the transition of rural settlements in suburban China: a case study of Huishan District in Wuxi city. Habitat Int 70:24–33
45. Long H, Li Y, Liu Y, Woods M, Zou J (2012) Accelerated restructuring in rural China fueled by 'increasing vs. decreasing balance' land-use policy for dealing with hollowed villages. Land Use Policy 29(1):11–22
46. Ma W, Jiang G, Wang D, Li W, Guo H, Zheng Q (2018) Rural settlements transition (RST) in a suburban area of metropolis: Internal structure perspectives. Sci Total Environ 615:672–680
47. Wang J, Zhang Y (2021) Analysis on the evolution of rural settlement pattern and its influencing factors in China from 1995 to 2015. Land 10(11):1137
48. Zhao F, Zhang S, Du Q, Ding J, Luan G, Xie Z (2021) Assessment of the sustainable development of rural minority settlements based on multidimensional data and geographical detector method: a case study in Dehong, China. Socio-Econ Plann Sci 78:101066
49. Sun D, Hong B, Ren P (2022) Spatiotemporal evolution and driving factors of the rural settlements in the mountain-plain transitional zones. Int J Agric Biol Eng 15(2):149–155
50. Shi Z, Ma L, Zhang W, Gong M (2022) Differentiation and correlation of spatial pattern and multifunction in rural settlements considering topographic gradients: evidence from Loess Hilly Region, China. J Environ Manag 315:115127
51. Chen S, Mehmood MS, Liu S, Gao Y (2022) Spatial pattern and influencing factors of rural settlements in Qinba Mountains, Shaanxi Province, China. Sustainability 14(16):10095
52. Li Y, Long H, Liu Y (2015) Spatio-temporal pattern of China's rural development: a rurality index perspective. J Rural Stud 38:12–26
53. Liu H (2006) Changing regional rural inequality in China 1980–2002. Area 38(4):377–389
54. Chen S, Gao M, Zhou Z (2022) Review and prospect of research on settlement adaptation. China City Plann Rev 31(04):28–37
55. Li S, Li X (2017) Global understanding of farmland abandonment: a review and prospects. J Geog Sci 27:1123–1150
56 Rey Benayas JM, Martins A, Nicolau JM, Schulz JJ (2007) Abandonment of agricultural land: an overview of drivers and consequences. CABI Rev. https://doi.org/10.1079/PAVSNNR20072057
57. Zhang B, Zhang R, Jiang G, Cai W, Su K (2023) Improvement in the quality of living environment with mixed land use of rural settlements: a case study of 18 villages in Hebei, China. Appl Geogr 157:103016
58. Li H, Song W (2020) Pattern of spatial evolution of rural settlements in the Jizhou District of China during 1962–2030. Appl Geogr 122:102247
59. Ren Y, Yansui L, Hualou L, Chengyi CHEN (2015) Spatial-temporal characteristics of rural residential land use change and spatial directivity identification based on grid in the Bohai Rim in China. Geogr Res 34(6):1077–1087

60. Tan M, Li X (2013) The changing settlements in rural areas under urban pressure in China: patterns, driving forces and policy implications. Landsc Urban Plan 120:170–177
61. Li H, Song W (2020) Evolution of rural settlements in the Tongzhou District of Beijing under the new-type urbanization policies. Habitat Int 101:102198
62. Gong J, Jian Y, Chen W, Liu Y, Hu Y (2022) Transitions in rural settlements and implications for rural revitalization in Guangdong Province. J Rural Stud 93:359–366

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