


## Article

# Spatial–Temporal Evolution, Impact Mechanisms, and Reclamation Potential of Rural Human Settlements in China

Duan Ran , Qiyu Hu \* and Zhanlu Zhang \*

School of Public Administration and Policy, Renmin University of China, Beijing 100872, China; randuan@ruc.edu.cn

\* Correspondence: huqiyu9@163.com (Q.H.); zhangzhanlu@ruc.edu.cn (Z.Z.)

**Abstract:** In China’s pursuit of modernization, the government has introduced the rural revitalization strategy to combat rural decline, foster balanced urban–rural development, and reduce the urban–rural gap. Rural human settlements, as key components of this strategy, play a vital role. This paper examines the types and characteristics of human–earth relationships within rural settlements, emphasizing their significance. Using national land use and population census data, we analyze the spatiotemporal evolution of rural settlements at the county level, investigating landscape pattern changes, assessing the degree of coupling coordination between rural population and settlements, categorizing relationship types and features, and estimating the potential for remediation. Our findings reveal a growing trend in the scale of rural human settlements, particularly sourced from arable land, with significant expansions observed in the North China Plain and Northeast Plain, indicating potential for farmland reclamation and village consolidation. Landscape patterns of rural human settlements exhibit increased fragmentation, complex shapes, and aggregation. We categorize the utilization of rural human settlements into two types, each with four distinct features: human–land coordination is observed in regions characterized by either a higher rural population and larger rural settlement areas, or lower rural population and smaller rural settlement areas. Human–land trade-offs are evident in areas where there is either a higher rural population and smaller rural settlement areas, or lower rural population and larger rural settlement areas. This provides valuable insights for the Chinese government’s context-specific implementation of the rural revitalization strategy. It also serves as an experiential reference for the governance of rural human settlements in other developing countries.



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**Keywords:** rural human settlements; human–earth system; spatial and temporal evolution; impact mechanisms; cultivated land reclamation; China

## 1. Introduction

With urbanization and industrialization, rural decline has emerged as a global challenge [1,2]. The United States, Canada, Sweden, Australia, and Japan, among others, have either experienced or are currently experiencing rural decline [3–7]. Since the reform and opening-up, following rapid urbanization and industrialization, China’s urbanization rate has risen from 17.92% in 1978 to 65.22% in 2022. A significant number of people in rural areas have migrated to cities, and the decline in the countryside is one of the challenges that must be addressed in China’s journey toward modernization [6]. According to historical experiences of modernization worldwide, failure to appropriately handle the relationships between workers and peasants, as well as between urban and rural areas, can lead to the unemployment of peasants, their influx into civilian areas of cities, difficulties or declines in the rural economy, hindrance or reversal of industrialization and urbanization processes, and, worse still, the emergence of social instability [8,9]. To promote the coordinated development of urban and rural areas, the sustainable development of villages, and the improvement of rural habitats, the Chinese Government has proposed a rural revitalization strategy. Rural human settlements are not only crucial spaces for

farmers' production and daily life, but also serve as a significant spatial foundation for the strategic objectives of rural revitalization. In the context of rural revitalization, this study focuses on identifying the evolving characteristics of rural human settlements and the spatial differentiation features of various human–earth relationships in China. The aim is to contribute valuable insights for the implementation of this strategy and, in turn, to contribute to the nation's path toward modernization. The innovation in this paper lies in its foundation on the theory of human–earth relationships, putting forth and refining two types and four features of the human–earth relationships of rural human settlements to address the shortcomings of existing theories. Additionally, it explores the spatial differentiation features of human–earth relationships in China's rural human settlements at the county scale. The aim is to provide a reference for the Chinese government for conducting rural revitalization tailored to local conditions under different features. Rural areas in many parts of the world have undergone significant demographic, socio-economic, spatial, and functional transformations. In response to the issues within rural environments, foreign scholars have successively proposed expressions such as rural decline, community destruction, the “dying” of rural communities, marginalized communities, and the “hollowing out” of villages [2,10,11]. Rural decline may lead to issues such as economic recession, reduced employment opportunities, declining agricultural potential, population aging and decline, and deteriorating quality of life. These problems may exacerbate and potentially become deeply entrenched [12–14]. Since 1949, China's urban–rural relations have been characterized by four main stages, namely urban–rural segmentation, urban–rural duality, urban–rural balance, and rural–urban integration [15,16]. Since the beginning of the 21st century, China has implemented various macro-strategies, such as balanced urban–rural development, new rural construction, urban–rural integration, and new-type urbanization, aimed at addressing the issues related to “agriculture, rural, and farmers”, and narrowing the urban–rural gap, but the overall progress and effectiveness have been inconclusive, with some contradictions and problems continuing to exacerbate [17]. In the development process, the characteristic of “the prosperity of cities and the decline of rural areas” emerges as a result of the imbalance in urban and rural developments [18]. In other words, rural areas are facing issues such as population loss, land abandonment, businesses hollowing, and the phenomenon of rural ailments [19,20]. Furthermore, an increasing trend is observed in the continuous migration of rural populations [21], particularly the second generation of farmers, who are settling in urban areas without returning to their hometowns [16]. This has led to critical issues in rural areas [22], including a shortage of agricultural labor [23,24], businesses decline [25], aging rural populations [26], abandoned housing [27], environmental pollution [28,29], and the abandonment of arable land [30,31].

Rural human settlements, as a crucial component of the rural regional system, refers to the spatial units where rural populations reside and engage in activities [32]. In China, rural human settlements exhibit characteristics such as a large total area, small average area, and scattered distribution [33,34]. In rural human settlements in China, there exist issues such as extensive land use [35], inefficient utilization [36], and the unorganized spread encroaching on arable land [37], as highlighted by various studies [38,39].

China's urban and rural developments have witnessed a dual increase in construction land in both areas, and the challenges stemming from urbanization, including an irrational internal structure, low-density distribution of urban and rural construction land, and environmental deterioration, which are important issues for land use change and land use optimization [40,41]. While there has been a notable increase in rural construction land in China, concerted efforts by the government have significantly improved the rural human environment. However, the current state of rural human environments remains concerning. Pollution in rural ecological environments is primarily linked to residential pollution from the daily lives of rural residents. The indiscriminate discharge of wastewater with low treatment rates [42] and the improper disposal of rural domestic waste, with low collection and treatment rates, are prevalent issues. The predominant methods for handling rural domestic waste still involve mixed landfilling and incineration [43,44]. In some rural

areas, the continued use of pit latrines and open-air toilets poses a risk of pollution to the surrounding soil and water environments [42,45]. In addressing urban–rural imbalances during urbanization, countries, like the United States, France, Japan, and South Korea, have committed substantial resources to promote rural development, balance businesses and population distribution, alleviate urban challenges, narrow urban–rural gaps, and protect the ecological environment, resulting in successful efforts and the establishment of a situation marked by coordinated urban and rural developments, fostering the sustained progress of rural areas [46,47]. How to achieve coordinated urban–rural development is one of the important governance goals of the Chinese government. In pursuit of this objective, the Chinese government has introduced the Rural Revitalization Strategy to address the inadequate and imbalanced development between urban and rural areas. The 20th National Congress of the Communist Party of China introduced by the Chinese government will steadily promote the revitalization of businesses, talent, culture, ecosystems, and organizations in the countryside. In line with this, the Chinese government has inaugurated the National Rural Revitalization Administration to facilitate the implementation of the rural revitalization strategy. The rural human settlement serves as a fundamental construction element in the strategy for rural revitalization and the reduction in urban–rural disparities. Against the backdrop of modernization in China, exploring the human–earth relationship between rural residents and rural human settlements holds significant implications for rural revitalization and the integrated development of urban and rural areas.

The initiation of reform and opening-up has fueled a continual concentration of rural population, land, capital, and production factors in urban areas, resulting in profound transformations in rural human settlements, encompassing changes in scale, layout, structure, and other facets of land use in rural human settlements [37,48]. Domestic and international scholars have undertaken research on rural human settlements, examining perspectives such as spatiotemporal evolution [33,49], land use structure [50,51], and spatial layout [52,53]. Some scholars have explored the changing dynamics of rural human settlements in China, noting a distinctive trend of “the rural population is decreasing while rural human settlements are expanding”, where the continual outmigration of rural populations coincides with an expansion in the scale of rural human settlements [54,55]. Some researchers have found that the utilization of rural human settlements exhibits characteristics of seasonal and long-term vacancies [56], and even abandonment [57]. On the foundation of the original residential land structure, new land use types, such as rural industrial land, commercial and tourism land, public service land, and large-scale livestock and poultry farming land, have gradually emerged [58–61]. In terms of the layout, there is a gradual concentration toward roads, rivers, and low-altitude areas [34,62]. On the methodological front, research on rural human settlements has employed various approaches, such as RS/GIS spatial analysis [63,64], social surveys [65], regression analysis [48], kernel density estimation [66], geographic detectors [67], and landscape pattern analysis [68]. At the scale level, the existing research predominantly focuses on regional studies at various scales, including provincial [69], municipal [70], county [71], village [67], and other levels [72]. Some researchers have found that, in the rural areas of China, where the rural homestead system predominates, there are systemic issues leading to a phenomenon of “the rural population decreasing while rural human settlements are expanding”. These issues include: members of rural collective economic organizations obtaining rural homestead use rights for free [73]; poor government management and insufficient supervision; high management costs and risks [74]; collective ownership of homesteads by rural farmers’ organizations, which is challenging to realize at the economic level [75]; a lack of economic and legal awareness in rural areas, making it challenging to enforce homestead management systems [76]; the utilization of homestead land conflicts with legal provisions and the challenging implementation of planning [77]; and the absence of a mechanism for compensation upon exit, leading to a psychological tendency to “prefer leaving land idle rather than allowing others to use it” [72,78,79].

In summary, the existing research has made significant progress in understanding the spatiotemporal evolution, land use structure, spatial layout, optimization, and driving mechanisms of rural human settlements at various scales. However, current studies fall short of supporting the enhancement of rural human settlement quality in the context of rural revitalization. What are the types and features of human–earth relationships in rural human settlements in China? What are the driving mechanisms between different types and features? There is currently no systematic review or research at the national level on the spatial aspects of rural human settlements. Such research can contribute to comprehensive planning for rural construction and environmental improvement at the national level, providing valuable experiences for rural human settlement governance in other developing countries.

This paper studies the current state and driving mechanisms of rural human settlements in China, exploring the quality of utilization of these settlements following the development of urbanization and industrialization and the current state of human–earth coupling. Drawing on the theory of human–earth systems, different human–earth relationship types and features in the Chinese context are proposed. Additionally, problem-oriented policy suggestions for homestead system reform are presented, aiming to provide a scientific basis for future policies related to homestead system reform, farmland protection, land reclamation, and food security in China. To accomplish this, the study utilizes national land use data from 2000, 2005, 2010, 2015, and 2020, along with data from the seventh national population census. It analyzes the spatiotemporal evolution characteristics of rural human settlements at the county level, examines landscape pattern changes, measures the coupling coordination between rural populations and rural human settlements, and summarizes the types and features of human–earth relationships. The study also estimates the remediation potential of rural human settlements in China. Section 1 of the paper provides an introduction to the research and a review of studies on rural human settlements. Section 2 outlines the theoretical framework, while Section 3 details the data sources and research methods. Section 4 presents the spatiotemporal evolution characteristics, changes in land use types, landscape pattern changes, coupling coordination between rural populations and rural human settlements, and the spatial distribution characteristics of human–earth relationships four features. Section 5 discusses the driving mechanisms of human–earth relationship features, the remediation potential of rural human settlements, policy suggestions based on the research findings, as well as the limitations of the study and future research directions. Section 6 presents the research conclusions of this paper.

## 2. Theoretical Framework

The human–earth relationship is a dynamic structure based on a specific geographical region in the Earth’s surface layer, where individuals and the land interact and interconnect with each other in a particular area [80]. In the rapid processes of urbanization and industrialization in China, the agricultural population has evolved into a structure comprising semi-urbanized rural registered residents and rural registered residents [81,82]. A rural human settlement is shaped and influenced by social, economic, and cultural resources and the environment in the rural context [83,84]. It is a crucial material space for people’s production and life activities [17]. Under the combined influence of multiple factors, rural human settlements undergo corresponding changes. As the spatial carrier of a rural human settlement, land exhibits changes in land use, reflecting the outcomes and dynamics of the human–earth system [15,53] (Figure 1). Human beings, driven by their needs and resource endowments, utilize land resources to generate products and services, thereby creating various land use types with closely related functional characteristics, resulting in a rural composite space with interconnected functions, such as production, living, and ecology [85].

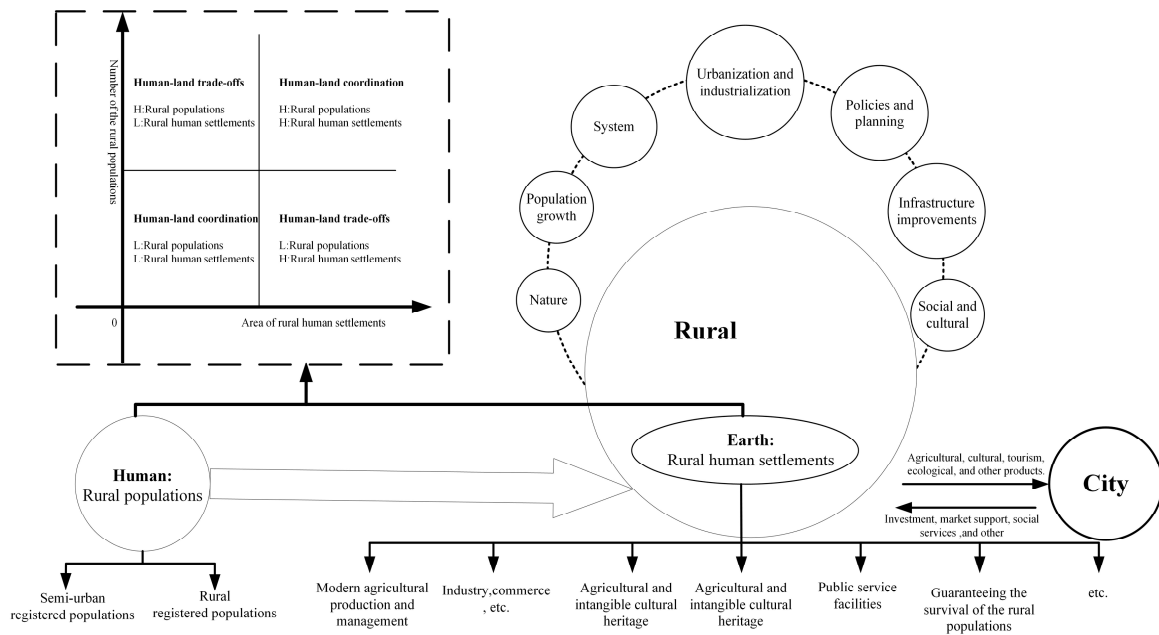


Figure 1. Territorial rural human settlements analysis framework.

The functions of rural human settlements have evolved from traditional, single, residential purposes to multifunctional roles, including production, living, and ecological aspects [86,87]. The original land use functional structure provided by rural human settlements no longer meets the needs of rural development, as continuous upgrades in rural production and lifestyle, as well as changes in industrial structure, have led to the disappearance of certain land use functions in villages [61,86,87]. With the increasing impact of human activities on land use, the human–earth relationship has become one of the important theories for studying changes in land use [88]. Rural areas, influenced by urbanization and industrialization, are exhibiting signs of decline, posing challenges that need to be addressed in the modernization process of China. The issue of rural decline is a crucial aspect that requires a resolution. Rural living space, serving as a comprehensive carrier for rural society, economy, culture, resources, and the environment, plays a significant role in the revitalization of rural areas and the achievement of harmonious urban–rural development [15,84]. With the development of the social economy, the overall features of human–land relationships in rural human settlements in China exhibit the characteristics of a “decrease in rural population and an increase in rural human settlement” [54,55]. However, constrained by resources and the development of social economy, different regions have evolved different types and characteristics in the utilization of rural human settlements within the context of human–earth relationships. This paper, based on the concept of human–earth relationships, posits the existence of two types and four features in China’s rural human settlements, namely, human–land coordination and human–land trade-offs (Figure 1). Human–land coordination involves scenarios in which there is a correlation between a higher rural population and a larger area of rural human settlements, or a lower rural population and a smaller area of rural human settlements. On the other hand, human–land trade-offs pertain to situations in which there is a balance between a higher rural population and a smaller area of human settlements, or a lower rural population and a larger area of rural human settlements.

The spatial evolution of rural human settlements can be considered as a process influenced by the combined effects of natural, social, economic, and institutional factors [89–91]. Natural factors, such as altitude, slope, and climate, impact the spatial distribution of land use in rural human settlements [63]. The processes of industrialization and urbanization, along with changes in rural socio-economic structures during these processes, also play a significant role [55]. Institutional factors, including the dualistic urban–rural system, house-

hold registration system, and the linkage between urban–rural construction land increase and decrease [89,92], contribute to the complex evolution of rural human settlements.

Natural conditions and population growth are the primary driving forces behind the expansion of rural human settlements [33,48]. Specifically, regions characterized by a flat terrain, pleasant climate, fertile soil, low altitude, and suitable precipitation provide ideal conditions for crop growth and create a favorable living environment for the population. Since 1978, China's total population has increased from 0.962 billion to 1.412 billion in 2020, mainly due to the growth of the rural registered population or semi-urbanized rural registered population. This population growth has led to the rapid expansion of rural human settlements, meeting basic housing needs. In areas with favorable geographical conditions for agricultural production, the distribution of rural human settlements is mainly influenced by the increase in population size. These regions are not only rich in resources, but also provide convenience for agriculture and population habitation. Therefore, China's rural human settlements are not only a result of population growth, but also a product influenced by natural geographical conditions.

Since the initiation of economic reforms and opening-up policies in 1978, China has experienced rapid urbanization and industrialization, with a significant portion of the rural population contributing to the nation's modernization efforts. The research indicates that rural population migration exhibits characteristics of “not leaving hometown but leaving farmland”, “leaving hometown and leaving farmland”, and “leaving hometown but not leaving farmland” [93]. China's urbanization has chosen a development path prioritizing low-cost, high-efficiency industries [94], with the urbanization rate increasing from 17.92% in 1978 to 65.22% in 2022. However, structural disparities exist within urbanization, giving rise to both “urbanization” and “semi-urbanization”, resulting in the categorization of rural populations into “semi-urban” registered residents and rural registered residents. The former group works and lives in cities, but faces restrictions due to household registration systems and other institutional limitations [88], preventing them from enjoying urban services on an equal footing [81,82]. In the population of semi-urbanized rural registered residents, rural land and homesteads play a crucial role in providing basic social security for farmers. Many “semi-urbanized” farmers find it challenging to establish themselves in cities, resulting in a pattern of “not leaving the hometown but not leaving the land”. During the urbanization process, these farmers improve rural housing by obtaining non-agricultural income in cities, contributing to the expansion of rural human settlements [33]. Simultaneously, some rural laborers who have “left the hometown and left the farmland” undergo transformation in cities, enjoying corresponding benefits. With the improvement of rural infrastructure, there is a trend of some individuals willing to return to the village to build or renovate houses. The government, in the process of urbanization, has retained the rights of farmers in rural areas, allowing this segment of the population to qualify for building or renovating houses in the village. In China, there exists a significant number of implicit transaction markets, especially in economically developed coastal regions, despite legal prohibitions on the buying and selling of homesteads and their economic use [75].

In the context of the growth of rural human settlements in China, traditional village culture has demonstrated significant influences on individuals and society [95,96]. Rooted in deeply in the Chinese culture, this tradition forms a noticeable reverse attraction in response to the pressures of urban living. Urban residents are inclined to seek a rural lifestyle, characterized by the fresh air, tranquility, and a connection to traditional values, as an escape from the hustle and pollution of urban environments. Influenced by this cultural shift, some individuals choose to migrate to rural areas, reveling in the pastoral landscapes and pursuing traditional rural living experiences. This cultural influence is one of the reasons behind the existence of the implicit market for homesteads [96]. Simultaneously, some individuals in a state of “semi-urbanization”, facing bleak prospects in urban livelihoods, are also drawn to rural traditions. They exhibit a willingness to return to the countryside and engage in agricultural-related work. This return not only expresses an acknowledgment of traditional culture, but also reflects a deliberate choice

for an agricultural lifestyle. Therefore, rural traditions play a positive and profound role in guiding people toward choosing a rural life, making the countryside a symbolic, ideal living environment for certain individuals.

With the continuous improvement of rural infrastructure, including roads, water supply, electricity, gas, and internet facilities, the gap in infrastructure between rural and urban areas is gradually narrowing [97–99]. As a result, many people, including those in semi-urbanized and urbanized populations, choose to build new houses or renovate existing ones in rural areas, leading to the use of a significant amount of high-quality arable land for housing construction. The research indicates that, since the opening-up and reform policies, there has been a noticeable improvement in rural housing quality, living conditions, and increased housing space [100,101]. This reflects the positive aspects of rural development, but also presents challenges to the protection of arable land.

In the revitalization of rural areas in China, rural human settlements play a crucial role by providing tangible space for agricultural modernization, the preservation of rural culture, social security, and business development. The land structure is gradually shifting from a single type to a diversified one, encompassing rural industries, commercial and tourism services, infrastructure, public services, and large-scale farming [60]. In the pursuit of coordinated urban–rural development, the government advocates and fully leverages the decisive role of the market in allocating resources to promote rural products that meet urban demands. Fueled by urbanization and industrialization, there is an increasing demand from urban residents for rural products, creating a market for rural economic, cultural, and ecological products. For example, the rural football league in Rongjiang, Guizhou, contributes to the export of village soccer culture, fostering multi-sectoral development, increasing villagers' income, and driving comprehensive rural revitalization.

### 3. Materials and Methods

#### 3.1. Data Sources

The land use/cover maps in 2000, 2005, 2010, 2015, and 2020 include 6 primary categorized land use types and 25 secondary categorized land use types, with a cell size of 30 m × 30 m, from the Resource and Environmental Sciences and Data Center, Chinese Academy of Sciences (<https://www.resdc.cn>, accessed on 5 June 2022). The six primary land use/cover types are: cropland, woodland, grassland, water body, built-up land, and unused land. Built-up land includes urban build-up land, rural settlements, and other construction land. The data pertaining to the rural population were obtained from China's seventh population census. Administrative boundary data were obtained from the National Basic Geographic Information Center (<http://www.ngcc.cn/ngcc/>, accessed on 5 June 2022). The total population data for China in 1978 and 2020 were sourced from the China Statistical Yearbook (<http://www.stats.gov.cn/sj/ndsj/>, accessed on 15 October 2023). The urbanization rate of China in 1978 was from the China Statistical Yearbook, and the urbanization rate in 2022 was from the 2022 Statistical Bulletin of China's National Economic and Social Development (<http://www.stats.gov.cn/sj/ndsj/>, accessed on 15 October 2023). Hong Kong, Macau, and Taiwan were excluded from the analysis in this paper, focusing solely on mainland China.

#### 3.2. Methods

##### 3.2.1. Mean Center Change and Standard Deviational Ellipses

The mean center change is a spatial analysis technique used to investigate changes in the central location of a set of geographic features over time [102]. The method involves calculating the mean center of a set of features at two or more points in time, and then comparing the resulting mean centers to determine how they have shifted. It is commonly used in fields such as urban planning, environmental science, and sociology to study changes in the spatial distribution of various phenomena. It can assist us in gaining an understanding of the changing patterns of rural human settlements in this study. The utilization of standard deviation ellipses is a prevalent method for examining spatial distri-

bution characteristics and temporal trends of elements [103]. In this study, we employed the standard deviation ellipse analytical approach to elucidate the spatial attributes and evolutionary patterns exhibited by rural human settlements in the context of China. This analytical methodology encompasses key parameters, including rotation angle, area, as well as the lengths of the long and short axes. Specifically, the long and short axes of the ellipse function as indicators, respectively, of the degree of dispersion observed in rural human settlements along the principal and secondary axes. Simultaneously, the rotation angle conveys the primary direction of the rural settlement distribution, while the calculated ellipse area serves as a metric for quantifying the level of spatial concentration among rural human settlements. Please refer to ArcGIS 10.8 software for details about these two tools.

### 3.2.2. Landscape Pattern Metrics

Landscape metrics are frequently used methods for quantitatively describing regional landscape pattern changes [104]. With reference to existing studies [17,62,68,86], we selected the patch density (PD), landscape shape index (LSI), and aggregation index (AI) components of the landscape pattern metrics to analyze the changes in the landscape pattern of rural human settlements. Table 1 contains a list of each of the chosen landscape metrics, and the landscape metrics were calculated in Fragstats4.2.1 [105] (<https://www.fragstats.org/>, accessed on 5 June 2022). Please refer to Fragstats4.2.1 software for more details on the five metrics.

**Table 1.** The landscape metrics selected in this study.

Abbr	Metrics	Range	Units
PD	Patch Density	PD > 0, constrained by cell size. PD is ultimately constrained by the grain size of the raster image, because the maximum PD is attained when every cell is a separate patch.	Number per 100 hectares
LSI	Landscape Shape Index	LSI ≥ 1, without limit. LSI = 1 when the landscape consists of a single square patch of the corresponding type; LSI increases without a limit as the landscape shape becomes more irregular and/or as the length of the edge within the landscape of the corresponding patch type increases.	None
AI	Aggregation Index	0 ≤ AI ≤ 100. AI equals 0 when the patch types are maximally disaggregated (i.e., when there are no similar adjacencies); AI increases as the landscape is increasingly aggregated and equals 100 when the landscape consists of a single patch. AI is undefined and reported as “N/A” in the “basename”.land file if each class consists of a single cell (and hence is undefined).	Percent

### 3.2.3. Land Use Transition Matrix

The land use matrix, which defines the transition among various land use types at the beginning and end of a period of time, is crucial for analyzing the change in land types in a region [106]. The equation is as follows:

$$L = \begin{bmatrix} L_{11} & L_{12} & \cdots & L_{1j} \\ L_{21} & L_{22} & \cdots & L_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ L_{i1} & L_{i2} & \cdots & L_{ij} \end{bmatrix} \quad (1)$$

where  $L$  represents the area,  $L_{ij}$  indicates the area in transition from landscape  $i$  to  $j$  at the beginning and end of a period of time.

### 3.2.4. Hot-Spot Analysis

The hot-spot analysis tool identifies statistically significant spatial clusters of high values (hot spots) and low values (cold spots). We used this tool to analyze the distribution characteristics of statistical significance in the changes in the PD, LSI, and AI of rural human settlements, as well as the changes in the areas of rural human settlements. Please refer to Arc Gis 10.8 software for the details of the hot-spot analysis tool.

### 3.2.5. Coupling Coordination Degree

The model of coupled coordination degree was employed to gauge the extent of coordinated development among various systems or system components [107]. In this paper, we utilized a coupled coordination degree model to assess the level of coordination between rural populations and rural human settlements. The initial step involved normalizing the data for rural populations and rural human settlements. The coupling coordination degree is calculated as follows:

$$C = \frac{\sqrt{U_1 U_2}}{U_1 + U_2} \quad (2)$$

$$T = \sum_1^n \omega_i U_i \quad (3)$$

$$D = \sqrt{C \times T} \quad (4)$$

where  $D$  refers to the value of the coupling coordination degree, and it ranges from 0 to 1;  $U_1$  refers to the rural populations;  $U_2$  refers to the area of rural human settlements;  $C$  refers to the degree of coupling between subsystems;  $T$  refers to the overall coordination level between subsystems; and  $\omega$  is the weighting coefficient, with values of 0.6 for rural populations and 0.4 for rural human settlements, to reflect the people-centered philosophy. Based on previous research, we categorized the degree of coupled coordination between rural populations and rural human settlements in China into five levels (Table 2).

**Table 2.** The degree of coupling coordination.

CCD Range	CCD-Level Subsystem
$0 < D \leq 0.2$	Seriously unbalanced development
$0.2 < D \leq 0.4$	Slightly unbalanced development
$0.4 < D \leq 0.6$	Slightly balanced development
$0.6 < D \leq 0.8$	Moderately balanced development
$0.8 < D \leq 1$	Highly balanced development

### 3.2.6. Spatial Autocorrelation

Spatial autocorrelation analysis represents a prominent spatial statistical methodology employed to investigate the interrelationships among attributes in neighboring geographical locations. This methodology is typically categorized into two distinct categories: global spatial autocorrelation and local spatial autocorrelation [108]. In this research, we utilized both global and local spatial autocorrelations to identify the spatial characteristics of the coupling coordination degrees between rural populations and settlements across different counties. To explore the spatial autocorrelation between two variables, Anselin, et al. [109] introduced the bivariate spatial autocorrelation method. In this study, we applied this method to assess the spatial correlation between rural populations and rural human settlements. To facilitate this analysis, we employed Queen neighboring spatial weights.

## 4. Results

### 4.1. The Spatial and Temporal Characteristics of Rural Human Settlements

#### 4.1.1. Characteristics of Changes in the Overall Size of Rural Human Settlements

The data in Table 3 showcase the area of rural human settlements in China over a span of two decades. They reveal a consistent trend of gradual expansion, with the area

increasing from 126,924.11 km<sup>2</sup> in 2000 to 144,736.46 km<sup>2</sup> in 2020. Examining the annual changes in the area of rural human settlements, Table 4 provides valuable insights into the dynamics of rural settlement areas in China from 2000 to 2020. From 2000 to 2020, the overall change rate is calculated to be 14.03%, indicating a notable increase in the spatial extent of rural human settlements during this period. Analyzing the period-wise changes presented in Table 4, several patterns emerge. Firstly, during the initial five-year period (2000–2005), the area of rural human settlements experiences a growth rate of 2.33%, corresponding to an absolute change of 2951.93 km<sup>2</sup>. This indicates a relatively modest expansion in rural settlement areas. Subsequently, from 2005 to 2010, the rate of expansion accelerates to 6.85%, with an absolute change of 8893.64 km<sup>2</sup>. From 2010 to 2015, the growth rate decreases slightly to 2.51%, resulting in an absolute change of 3488.51 km<sup>2</sup>. While the expansion remains positive, the rate of increase decelerates compared to the previous period. Finally, between 2015 and 2020, the growth rate further declines to 1.74%, with an absolute change of 2478.27 km<sup>2</sup>. This period exhibits the slowest rate of expansion, indicating a potential stabilization or saturation of rural settlement areas. In summary, the data indicate an overall growth in the area of rural human settlements in China from 2000 to 2020. The period-wise analysis suggests a varying pace of expansion, with the highest growth observed from 2005 to 2010.

**Table 3.** The area of rural human settlements in China from 2000 to 2020. (Unit: km<sup>2</sup>).

Year	2000	2005	2010	2015	2020
Rural human settlements area	126,924.11	129,876.03	138,769.68	142,258.20	144,736.46

**Table 4.** The area change in and growth rate of rural human settlements in China from 2000 to 2020. (Unit: km<sup>2</sup>, %).

Period	2000–2005	2005–2010	2010–2015	2015–2020	2000–2020
Area change	2951.93	8893.64	3488.51	2478.27	17,812.35
Growth rate	2.33%	6.85%	2.51%	1.74%	14.03%

#### 4.1.2. Characteristics of Changes in Rural Human Settlements across Four Regions in China

Table 5 shows the rural settlement areas for China East, China Central, China West, and China Northeast at five-year intervals. The data reveal distinct patterns of rural development in each region. China East experiences continuous and robust growth, expanding from 46,077.81 km<sup>2</sup> in 2000 to 54,438.61 km<sup>2</sup> in 2020. China Central also demonstrates steady growth, with the rural settlement area increasing from 35,328.99 km<sup>2</sup> to 39,001.88 km<sup>2</sup> over the same period. In contrast, China West exhibits fluctuations in rural settlement areas. Although it peaks at 30,952.20 km<sup>2</sup> in 2015, the region sees a slight decline, reaching 30,364.06 km<sup>2</sup> in 2020. China Northeast displays steady growth, increasing from 19,049.44 km<sup>2</sup> in 2000 to 20,931.92 km<sup>2</sup> in 2020. China East has the largest total rural settlement area, followed by China Central and China West. China Northeast has the smallest rural settlement area, but it still shows consistent growth over the studied period.

**Table 5.** The areas of rural human settlements in the four regions of China from 2000 to 2020.

Year	2000	2005	2010	2015	2020
China East	46,077.81	47,396.81	50,258.78	51,963.95	54,438.61
China Central	35,328.99	35,962.28	37,656.86	38,651.79	39,001.88
China West	26,467.87	27,409.00	30,252.20	30,946.34	30,364.06
China Northeast	19,049.44	19,107.95	20,601.84	20,696.11	20,931.92

The data presented in Table 6 provide a comprehensive analysis of the area change in and growth rates of rural human settlements in the four regions of China from 2000 to 2020.

China East experiences continuous growth in rural settlement areas, with the highest increase of 2861.97 km<sup>2</sup> occurring from 2005 to 2010, contributing to an overall growth rate of 18.14% over the two decades. The total area change in China East during this period is 8360.79 km<sup>2</sup>. Similarly, China Central demonstrates consistent growth, with the highest increase of 1694.58 km<sup>2</sup> recorded from 2005 to 2010, resulting in an overall growth rate of 10.40% and a total area change of 3672.89 km<sup>2</sup>. China West exhibits varying growth rates, peaking with an increase of 2843.20 km<sup>2</sup> from 2005 to 2010, but experiencing a decline of −582.28 km<sup>2</sup> from 2015 to 2020. The overall growth rate for China West is 14.72%, and the total area change during the entire period is 3896.19 km<sup>2</sup>. China Northeast displays steady growth, with the highest increase of 1493.89 km<sup>2</sup> occurring from 2005 to 2010, leading to an overall growth rate of 9.88% and a total area change of 1882.47 km<sup>2</sup>.

**Table 6.** The area change in and growth rate of rural human settlements in the four regions of China from 2000 to 2020. (Unit: km<sup>2</sup>, %).

Period	2000–2005	2005–2010	2010–2015	2015–2020	2000–2020
China East	1319.00	2861.97	1705.17	2474.66	8360.79
China Central	633.29	1694.58	994.93	350.08	3672.89
China West	941.13	2843.20	694.14	−582.28	3896.19
China Northeast	58.51	1493.89	94.27	235.80	1882.47
China East	2.86%	6.04%	3.39%	4.76%	18.14%
China Central	1.79%	4.71%	2.64%	0.91%	10.40%
China West	3.56%	10.37%	2.29%	−1.88%	14.72%
China Northeast	0.31%	7.82%	0.46%	1.14%	9.88%

#### 4.1.3. Characteristics of Changes in Rural Human Settlements within Thirteen Urban Agglomerations

Tables 7 and 8 present an overview of the areas occupied by rural human settlements within the thirteen major urban agglomerations in China over a span of two decades, from 2000 to 2020. The thirteen urban agglomerations are as follows: South-Central Liaoning Urban Agglomerations (SCLUAs), Shandong Peninsula Urban Agglomerations (SPUAs), Mid-Yangtze River Urban Agglomerations (MYRUAs), Harbin–Changchun Urban Agglomerations (HCUAs), Chengdu–Chongqing Urban Agglomerations (CCUAs), Yangtze River Delta Urban Agglomerations (YRDUAs), ZhongYuan Urban Agglomerations (ZYUAs), Beibu Gulf Urban Agglomerations (BGUAs), Guanzhong Plain Urban Agglomerations (GZPUAs), Hohhot–Baotou–Ordos–Yulin Urban Agglomerations (HBOYUAs), Pearl River Delta Urban Agglomerations (PRDUAs), Lanzhou–Xining Urban Agglomerations (LXUAs), and Beijing–Tianjin–Hebei Urban Agglomerations (BTHUAs).

**Table 7.** The areas of rural human settlements in the thirteen urban agglomerations of China from 2000 to 2020. (Unit: km<sup>2</sup>).

Year	2000	2005	2010	2015	2020
SCLUA	4215.98	4223.97	5091.44	5120.28	5228.33
SPUA	14,504.09	14,860.47	15,354.04	15,529.44	15,724.68
MYRUA	6034.06	6275.96	6379.61	6348.38	6417.37
HCUA	9521.84	9512.86	9558.52	9575.71	9509.98
CCUA	1800.40	2036.09	2145.21	2178.46	2328.53
YRDUA	10,743.39	11,618.54	12,479.42	13,392.34	13,774.45
ZYUA	23,159.48	23,417.78	24,306.68	24,928.16	25,633.11
BGUA	3350.42	3303.61	3301.37	3319.71	3461.94
GZPUA	2919.30	3121.04	3427.69	3521.52	3499.33
HBOYUA	2325.10	2415.28	2530.81	2556.82	2512.20
PRDUA	2100.00	2065.02	1448.87	1450.71	1620.70
LXUA	1064.57	1110.71	1162.40	1226.34	1174.84
BTHUA	9915.19	10,068.21	11,949.48	12,521.48	13,475.16

**Table 8.** The area change in and growth rate of rural human settlements in the thirteen urban agglomerations of China from 2000 to 2020. (Unit: km<sup>2</sup>, %).

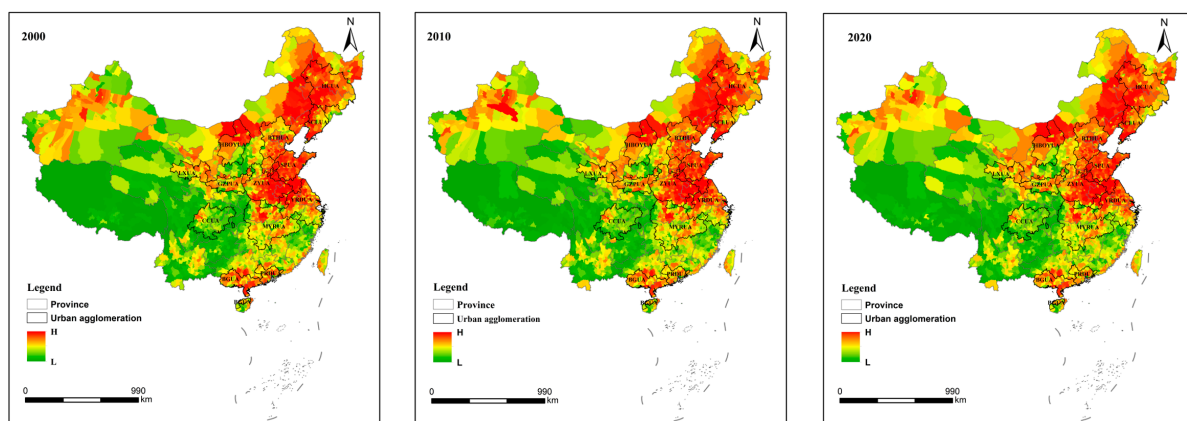
Period	2000–2005	2005–2010	2010–2015	2015–2020	2000–2020
SCLUA	7.99	867.46	28.84	108.05	1012.35
SPUA	356.38	493.57	175.40	195.24	1220.59
MYRUA	241.90	103.66	−31.23	68.99	383.31
HCUA	−8.97	45.65	17.19	−65.72	−11.85
CCUA	235.69	109.12	33.25	150.08	528.13
YRDUa	875.15	860.88	912.92	382.10	3031.06
ZYUA	258.30	888.91	621.47	704.95	2473.63
BGUA	−46.81	−2.24	18.34	142.22	111.52
GZPUA	201.74	306.65	93.83	−22.19	580.03
HBOYUA	90.18	115.53	26.01	−44.63	187.10
PRDUA	−34.98	−616.15	1.84	169.99	−479.30
LXUA	46.14	51.69	63.94	−51.50	110.27
BTHUA	153.02	1881.27	572.01	953.68	3559.97
SCLUA	0.19%	20.54%	0.57%	2.11%	19.36%
SPUA	2.46%	3.32%	1.14%	1.26%	7.76%
MYRUA	4.01%	1.65%	−0.49%	1.09%	5.97%
HCUA	−0.09%	0.48%	0.18%	−0.69%	−0.12%
CCUA	13.09%	5.36%	1.55%	6.89%	22.68%
YRDUa	8.15%	7.41%	7.32%	2.85%	22.00%
ZYUA	1.12%	3.80%	2.56%	2.83%	9.65%
BGUA	−1.40%	−0.07%	0.56%	4.28%	3.22%
GZPUA	6.91%	9.83%	2.74%	−0.63%	16.58%
HBOYUA	3.88%	4.78%	1.03%	−1.75%	7.45%
PRDUA	−1.67%	−29.84%	0.13%	11.72%	−29.57%
LXUA	4.33%	4.65%	5.50%	−4.20%	9.39%
BTHUA	1.54%	18.69%	4.79%	7.62%	26.42%

The total rural settlement area across most of the agglomerations increased from 2000 to 2020, except for HCUAs and PRDUAs, indicating the continuous expansion of rural human settlements within these regions. In the year 2020, rural human settlements within ZYUAs, SPUAs, YRDUAs, and BTHUAs collectively spanned an expanse exceeding 10,000 km<sup>2</sup>, with respective areas of 25,633.11 km<sup>2</sup>, 15,724.68 km<sup>2</sup>, 13,774.45 km<sup>2</sup>, and 13,475.16 km<sup>2</sup>.

Tables 7 and 8 show that, between 2000 and 2020, the rural settlement areas in BTHYAs expanded from 9915.19 km<sup>2</sup> to 13,475.16 km<sup>2</sup>, marking an increase of 3559.97 km<sup>2</sup> and a cumulative growth rate of 26.42%. In parallel, YRDUAs witnessed a rise in rural settlement areas from 10,743.39 km<sup>2</sup> to 13,774.45 km<sup>2</sup>, reflecting an augmentation of 3031.06 km<sup>2</sup> and a cumulative growth rate of 22.00%. In the same vein, ZYUAs experienced an enlargement in rural settlement areas from 23,159.48 km<sup>2</sup> to 25,633.11 km<sup>2</sup>, showcasing a growth of 2473.63 km<sup>2</sup> and a cumulative growth rate of 9.65%. Similarly, SPUAs recorded an increment in rural settlement areas from 14,504.09 km<sup>2</sup> to 15,724.68 km<sup>2</sup>, representing an increase of 1220.59 km<sup>2</sup> and a cumulative growth rate of 7.76%. Additionally, SCLUAs observed an augmentation in rural settlement areas, expanding from 4215.98 km<sup>2</sup> to 5228.33 km<sup>2</sup>, signifying a growth of 1012.35 km<sup>2</sup> and a cumulative growth rate of 19.36%. The analysis conducted for different time periods indicates fluctuating rates of expansion, with the most substantial growth identified between 2005 and 2010 (Table 3). Table 8 shows that, between 2005 and 2010, the rural settlement areas in BTHUAs, ZYUAs, SCLUAs, and YRDUAs experienced growth rates of 18.69%, 3.80%, 20.54%, and 7.41%, respectively, with each expanding by over 800 km<sup>2</sup> to reach areas of 1881.27 km<sup>2</sup>, 888.91 km<sup>2</sup>, 867.46 km<sup>2</sup>, and 860.88 km<sup>2</sup>. Remarkably, the BTHUA stands out, consistently and significantly expanding its rural settlement area, culminating in an impressive cumulative growth of 26.42% over the entire span from 2000 to 2020.

#### 4.1.4. Characteristics of Rural Human Settlements Changing at the County Scale

In Figure 2, we illustrate the spatial arrangement of rural human settlements at the county level in China. This visualization effectively depicts the distribution of rural human settlements across the country's landscape from the perspective of the three major tiers of China's terrain and topography. The areas with a higher concentration of rural human settlements are primarily located in China's North China Plain, Middle and Lower Yangtze River Plains, and Northeast Plain, and these regions fall within China's third tier of terrain and topography. Predominantly situated on China's plains, these areas' altitudes do not exceed the 500 m above sea level mark. The combination of factors, including even terrain, topography, fertile soil, abundant water resources, a robust economy, and a significant population, significantly influenced the distribution of rural human settlements at the county level in China, with a pronounced concentration observed within these specific regions. In the second tier of China's terrain and topography, the regions with a higher concentration of rural human settlements are mainly located in central and southeastern Inner Mongolia, the Sichuan Basin, central Shaanxi, Ningxia, parts of northern Xinjiang, the Hexi Corridor in Gansu, and the southeastern parts of Yunnan. In the first tier of China's terrain and topography, rural human settlements are less well-distributed; the reason are that the terrain and topography of these areas, dominated by plateaus and mountains unsuitable for the construction of large cities, feature altitudes ranging between 3000 and 4000 m, low temperatures at high elevations, reduced oxygen levels, and predominantly alpine, cold, and harsh climates, collectively making them unsuitable for human habitation.

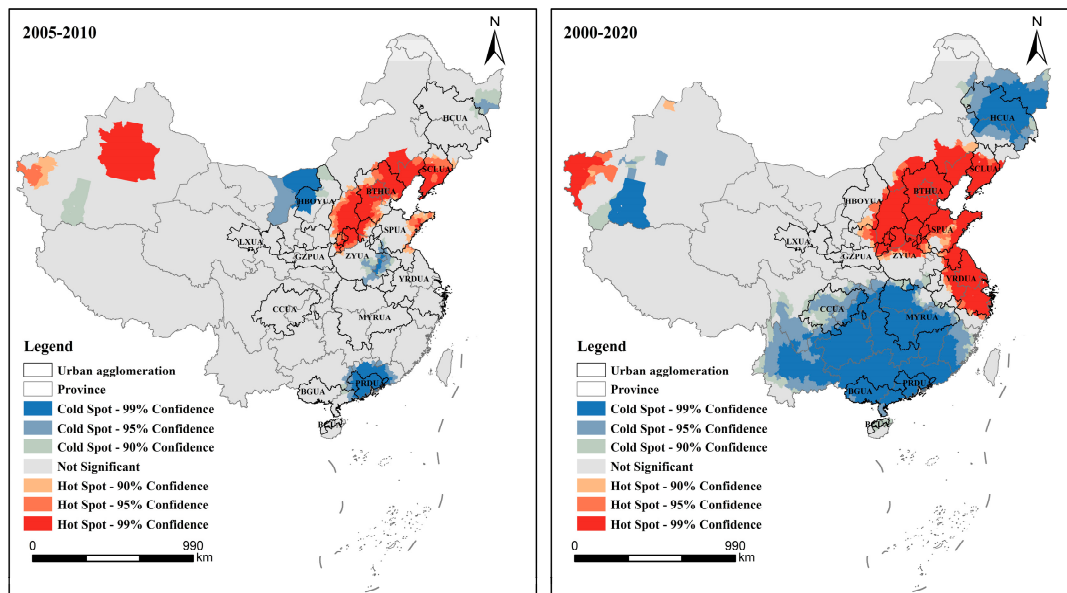


**Figure 2.** Spatial distribution of rural human settlements in China in 2000, 2010, and 2020.

Figure 2 visualizes the spatial distribution of rural human settlements in China. However, it is necessary to further analyze the spatial changes in rural human settlements across China. This analysis aimed to determine the regional distributions of increases and decreases in rural human settlements. To achieve this, we employed the ArcGIS hot-spot analysis tool to identify hot spots and cold spots of changes in rural human settlements throughout China (Figure 3). The hot-spot analytical method can identify areas with a high- or low-value clustering of changes in rural human settlements, and it can effectively represent the spatial distribution characteristics of these changes. This allowed us to effectively examine the spatial distribution of the changing characteristics of rural human settlements in China.

We incorporated the alterations in rural human settlements that occurred between 2005 and 2010, prompted by this study's discovery of an 8893.64 km<sup>2</sup> increase in China's rural settlement area (Table 3) during the 2005–2010 period. Consequently, a comprehensive analysis of the spatial distribution characteristics of these changes becomes essential for the 2005–2010 period. From 2000 to 2020 (Figure 3, 2000–2020), the hot spots of urban agglomerations experiencing a change in China's rural human settlements are BTHUAs, YRDUAs, SPUAs, SCLUAs, and the northern parts of ZYUAs, while the cold spots of urban

agglomerations experiencing a change in China's rural human settlements are MYRUAs, CCUAs, BGUAs, and PRDUAs. The hot-spot provinces are mainly in the north, including Shanxi, Hebei, Tianjin, Beijing, Shandong, Jiangsu, Shanghai, etc. The cold-spot provinces, on the other hand, are mainly in the south, including Hubei, Chongqing, Jiangxi, Hunan, Guizhou, Yunnan, Guangxi, Guangdong, Fujian, Heilongjiang, etc.

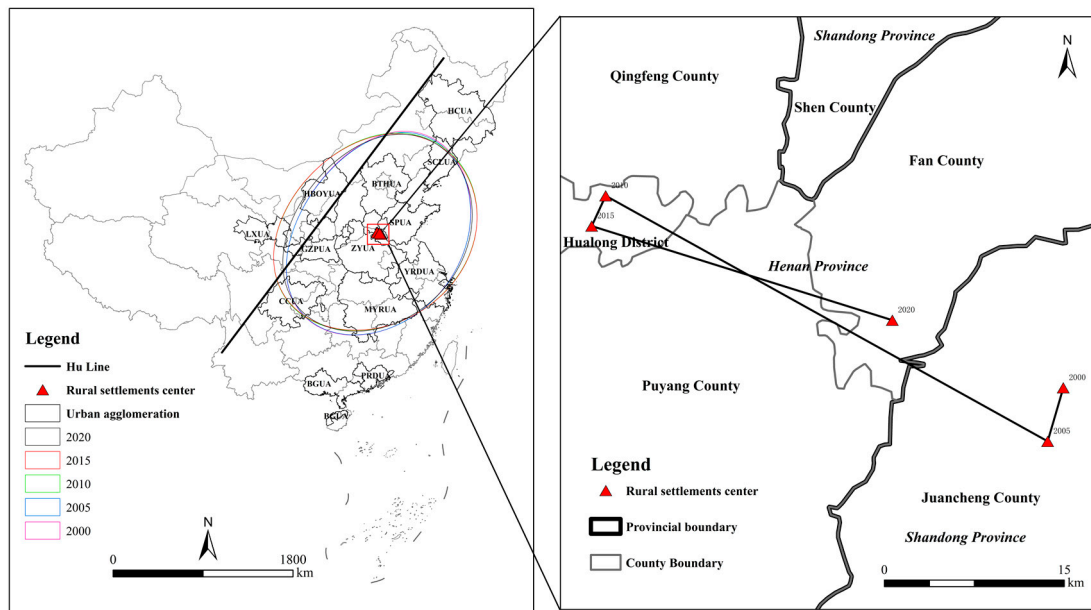


**Figure 3.** Hot-spot analysis of changes in rural human settlements in China in 2005–2010 and 2000–2020.

During the period from 2005 to 2010 (Figure 3 2005–2010), China's rural settlement changes exhibit hot spots in BTHUAs, SCLUAs, certain segments of SPUAs, the north-eastern smaller segments of GZPUAs, and the northern smaller segments of ZYUAs. Conversely, the cold spots in urban agglomerations undergoing rural settlement changes were identified as PRDUAs, smaller parts of HBOYUAs, and smaller sections of ZYUAs. In terms of provincial-level regions, from 2005 to 2010, the hot spots of changes in China's rural human settlements were observed in the north, such as Beijing, Tianjin, Hebei, Shanxi, and Liaoning, etc. On the other hand, the cold spots of changes were noticeable in the south, such as Guangdong and Guangxi, and in the north, such as parts of central Inner Mongolia. Additionally, cold spots were observed in central regions, including portions of Henan and sections of Anhui.

#### 4.2. Direction of Distribution of Rural Human Settlements

We utilized central migration and standard deviation ellipses to assess the evolving characteristics of scale, quality, and spatial patterns within rural human settlements across China for the years 2000, 2010, 2015, and 2020. We generated spatial distributions for the central and spatial standard deviation ellipses of rural human settlements at the county scale (Figure 4). Furthermore, we extracted information on the attribute changes in the standard deviation ellipses (Table 7), including area (Shape\_Area), long axis (XStdDist), short axis (YStdDist), and rotation angle. The size of the standard deviation ellipse was set to a standard deviation that encompassed approximately 68% of the total number of centers of mass in the surrounding counties with rural human settlements centered on the National Center for Rural human settlements.



**Figure 4.** Standard deviational ellipses and central migration of rural human settlements. Note: the Hu Line, alternatively known as the Heihe–Tengchong Line or Aihui–Tengchong Line, was initially termed the “Aihui–Tengchong Line” by Chinese geographer Hu Huanyong (1901–1998) in 1935 for demarcating China’s population density, with subsequent renamings due to changes in place names.

Table 9 presents information concerning the characteristics of the standard deviation ellipses from 2000 to 2020. The lengths of the long axes of the ellipses for the five periods are notably greater than the lengths of the short axes, indicating a distinct directional characteristic; this demonstrates that the center of rural human settlements in China exhibits a more pronounced dispersion in the southwest–northeast direction as opposed to the northwest–southeast direction. The rotation angle ranges from 61.6612 to 74.0216 degrees, indicating an orientation of 61.6612 to 74.0216 degrees east of north; this demonstrates the prevailing southwest–northeast distribution pattern of rural human settlements in China. The length of the long axis of the ellipse exhibited fluctuations across different years: the longest, at 11.9213 radians, was recorded in 2010, followed by 11.8860 radians in 2015, 11.3557 radians in 2000, and 11.3453 radians in 2020. The shortest measurement, 11.2968 radians, occurred in 2005. These varying lengths reflect the differences in the degree of dispersion among Chinese rural human settlements along the southwest–northeast direction, with greater lengths indicating a more pronounced dispersion. It is evident that 2010 demonstrates the highest distribution disparity among China’s rural human settlements in the southwestern–northeastern direction, while 2005 shows the least disparity. Furthermore, the entirety of the 2000–2020 period displays a discernible dispersion pattern along the southwestern–northeastern axis. The varying lengths of the short axes of the ellipses across different years also indicate varying degrees of dispersion among rural human settlements in China along the northwest–southeast direction, with the greatest disparity in 2015, the smallest in 2005, and an overall trend of a widening fluctuation in the degree of dispersion during the 2000–2020 period. This indicates that the degree of dispersion of Chinese rural human settlements in the southwest–northeast and northwest–southeast directions is higher in 2010 compared to other years, while the lowest degree of dispersion in these two directions can be observed in 2005. Furthermore, the degree of dispersion of Chinese rural human settlements along these two directions increased from 2000 to 2020. From 2000 to 2015, the rotation angle increased each year, ranging from 61.6612 degrees to 74.0216 degrees. This indicates a shift in the direction of the ellipse toward the east, suggesting a corresponding shift in the development direction of China’s rural human settlements. However, in 2020, the rotation angle decreased to 67.3227 degrees, signifying a shift in the direction of development of China’s rural human settlements toward the north.

Overall, the direction of development of Chinese rural human settlements shifted toward the east from 2000 to 2020. The largest ellipse area measured 307.7993 radians in 2010, followed by 306.3462 radians in 2015, 283.1775 radians in 2020, and 282.1796 radians in 2000. The smallest ellipse, at 280.1388 radians, was observed in 2005. These measurements suggest that the degree of aggregation of rural human settlements is complex and variable in 68% of the counties. Different years exhibit distinct characteristics of agglomeration, with 2005 displaying a higher degree of agglomeration than other years, 2010 showing the lowest degree, and the overall degree of agglomeration decreasing from 2000 to 2020.

**Table 9.** Standard deviation ellipses information. (Unit: radian).

Year	Shape_Area	XStdDist	YStdDist	Rotation (Unit: Degree)
2000	282.1796	11.3557	7.9102	61.6612
2005	280.1388	11.2968	7.8940	62.1553
2010	307.7993	11.9213	8.2190	73.3285
2015	306.3462	11.8860	8.2046	74.0216
2020	283.1775	11.3453	7.9455	67.3227

Table 9 and Figure 4 depict the results of the standard deviation ellipse analysis, illustrating that the distribution direction of Chinese rural human settlements aligns with the Hu Line. This alignment indicates that this direction represents the primary distribution pattern of Chinese rural human settlements. Figure 4 shows the centers of rural human settlements in the country are situated in Juancheng County, Shandong Province (2000 and 2005); Hualong District, Henan Province (2010 and 2015); and Fan County, Henan Province (2020). Throughout the entire period, the center of rural human settlements in China shifts toward the northwest, indicating a shift in the center of rural human settlements sizes in that direction, and a trend of size change in rural human settlements in this direction that outpaces that in other directions. The migration trajectory of rural settlement centers in China exhibits diverse trends, shifting toward the southwest (2000–2005), northwest (2005–2010), northeast (2010–2015), and southeast (2015–2020), thereby highlighting the intricate and fluctuating nature of rural settlement scales across the country. In regard to the distance of migration for rural settlement centers in China, the longest migration distance occurred in 2005–2010, followed by 2015–2020, then 2000–2005, with the shortest being in 2005–2010; this suggests that the distribution pattern of rural settlement sizes has undergone varying degrees of change in different directions and time periods. During the period from 2005 to 2010, not only did the size of China’s rural human settlements undergo the most substantial change (Table 3), but the spatial distribution (Figure 4) also shows a notable migration distance toward the northwest; this suggests that the trend of change in rural human settlements toward the northwest direction exceeds that in other directions during this period.

#### 4.3. Characteristics of Changing Landscape Patterns in Rural Human Settlements

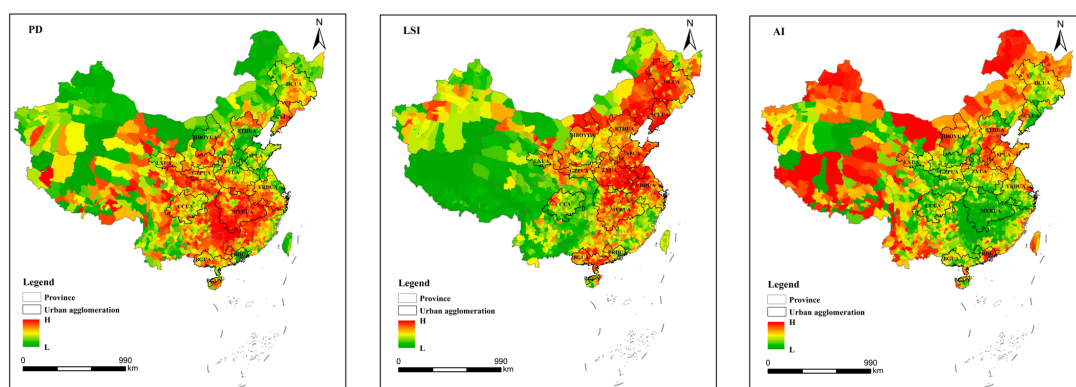
Table 10 presents the values associated with the average of the PD, LSI, and AI for each individual period spanning the years 2000 to 2020. Over the interval spanning from 2000 to 2020, there is discernible evidence of a gradual decrement in the PD, dwindling from 8.11 to 7.37. The information presented in Table 3 indicates a consistent expansion of rural human settlements in China from 2000 to 2020. Hence, there is a noticeable pattern of increasing fragmentation among China’s rural human settlements from 2000 to 2020. The LSI increased from 19.39 in 2000 to 19.34 in 2010, followed by a decrease to 19.16 in 2020. These data illustrate an initial upward trend followed by a downward trend, while still maintaining an overall increasing trend from 2000 to 2020. During this period, there is evidence of an increase in the LSI, with a rise from 18.39 in the year 2000 to 19.16 in 2020. This progression implies a gradual enhancement in the complexity of rural settlement shapes throughout this timeframe. The AI declines from 90.02 in 2000 to 90.01 in 2005, followed by a rise to 90.43 in 2020. This pattern demonstrates a sequential shift, featuring a

modest initial decrease, followed by an increase, indicating an overall upward trend from 2000 to 2020—starting at 90.02 in 2000 and reaching 90.43 in 2020. This suggests that the increase in the total area (Table 3) and fragmentation of rural human settlements in China are accompanied by an increasing trend of change in spatial aggregation.

**Table 10.** The average of the PD, LSI, and AI in 2000–2020.

Year	PD	LSI	AI
2000	8.11	18.39	90.02
2005	8.02	18.77	90.01
2010	7.98	19.34	90.09
2015	7.74	19.26	90.30
2020	7.37	19.16	90.43

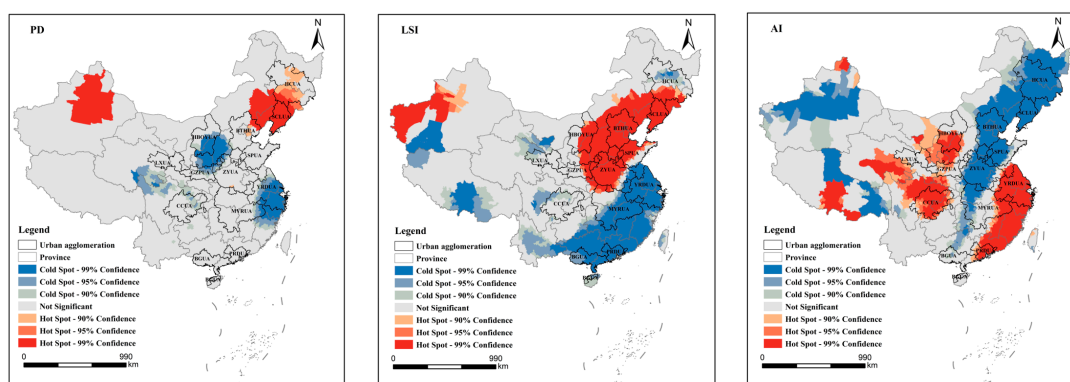
In order to visually analyze the spatial distribution of landscape patterns in rural human settlements across China in 2020, we created plots that depicted the spatial distributions of the PD, LSI, and AI in counties, as illustrated in Figure 5. As depicted in Figure 5 (PD), regions with higher PD values for rural human settlements in China are predominantly concentrated in and around MYRUAs, with the western distribution primarily focusing on territories such as Gansu, Guangxi, Shaanxi, and Sichuan, and sporadic occurrences in the northeast. As illustrated in Figure 5 (LSI), the urban agglomerations in China exhibiting intricate landscape utilization shapes of rural human settlements comprise ZYUAs, SPUAs, YRDUAs, MYRUAs, BTHUAs, SCLUAs, HCUAs, and BGUAs. Rural human settlements in China exhibiting a high degree of landscape utilization complexity are predominantly situated in the North China Plain and Northeast China Plain. As illustrated in Figure 5 (AI), the spatial aggregation of rural human settlements in China exhibits various distribution patterns. China's regions with a higher spatial aggregation of rural human settlements encompass SPUAs, HBOYUAs, most parts of BTHUAs, parts of PRDUAs, and other regions. Areas with an elevated spatial aggregation of rural human settlements encompass western China, such as Xinjiang, Tibet, Qinghai, Yunnan, and Inner Mongolia, as well as the Yangtze River Delta and Pearl River Delta in the Eastern Region. It is worth noting that the spatial aggregation of rural residence sites in the central regions of Hunan, Jiangxi, and Hubei is low.



**Figure 5.** Spatial distribution of the PD, LSI, and AI in China in 2020.

The preceding section examined the temporal changes and spatial distribution characteristics of the landscape pattern indices (PD, LSI, and AI) within rural human settlements in China; it is now imperative to conduct an in-depth analysis of the spatial change characteristics of these indices. The hot-spot analytical method can identify areas with a high- or low-value clustering of changes in the PD, LSI, and AI in rural human settlements in 2000–2020, and it can effectively represent the spatial distribution characteristics of these changes. As shown in Figure 6 (PD), areas with hot spots of PD index changes in rural

human settlements are distributed across SCLUAs, some parts of HCUAs, and a few areas within BTHUAs, the southeastern region of Inner Mongolia, some parts of Xinjiang. Conversely, areas identified as cold spots, in terms of changes in the PD index of landscape patterns within rural human settlements, are distributed across YRDUAs, HBOYUAs, northern Shaanxi, western Shanxi, parts of Qinghai, and Zhejiang and its bordering regions. As depicted in Figure 6 (LSI), areas exhibiting hot spots of the landscape pattern LSI in rural human settlements are distributed in northern urban agglomerations, such as BTHUAs, SCLUAs, ZYUAs, SPUAs, HBOYUAs, etc. Conversely, areas identified as cold spots are located in the southeast coastal areas, including YRDUAs, PRDUAs, BGUAs, MYRUAs, etc. This pattern is observed in provinces such as Guangdong, Fujian, Zhejiang, Jiangsu, etc. As illustrated in Figure 6 (AI), the urban agglomerations with hot-spot AI changes in the landscape pattern of rural human settlements are distributed in YRDUAs, PRDUAs, CCUAs, the majority of HBOYUAs, and some parts of MYRUAs, while the cold-spot urban agglomerations are prevalent in most areas of BTHUAs, SCLUAs, HCUAs, ZYUAs, and SPUAs. For provinces, hot spots are distributed across Fujian, Ningxia, certain areas of Qinghai, and other regions, while cold-spot areas are distributed across certain parts of Tibet, certain parts of Inner Mongolia, and parts of Xinjiang. As illustrated in Figure 6 (AI), urban agglomerations with hot-spot AI changes in the landscape pattern of rural human settlements are distributed in YRDUAs, PRDUAs, CCUAs, the majority of HBOYUAs, and some parts of MYRUAs, while cold-spot urban agglomerations are prevalent in most areas of BTHUAs, SCLUAs, HCUAs, ZYUAs, and SPUAs. At the provincial level, hot spots are distributed across Fujian, Ningxia, certain areas of Qinghai, and other regions, while cold-spot areas are found in certain parts of Tibet, certain parts of Inner Mongolia, and parts of Xinjiang.



**Figure 6.** Hot-spot analysis of changes in the PD, LSI, and AI in rural human settlements in China from 2000 to 2020.

#### 4.4. Transfer Matrix for Land Use Types in Rural Human Settlements

Table 11 shows the types of land use changes in rural human settlements in China from 2000 to 2020. From the perspective of change in other land use types to rural human settlements, we can observe that the primary land use types for rural human settlements from 2000 to 2020 are cropland, grassland, and woodland, with areas of 38,219.31 km<sup>2</sup>, 2864.77 km<sup>2</sup>, and 2481.04 km<sup>2</sup>, respectively, while 1004.10 km<sup>2</sup> of urban built-up land is transformed into rural human settlements. The period of highest cropland conversion into rural human settlements is 2005–2010, accounting for the largest area of 29,795.52 km<sup>2</sup>, followed by 2015–2020 with 14,384.56 km<sup>2</sup>, while the smallest conversion area occurs in 2000–2005, covering 4860.02 km<sup>2</sup>. The peak period for the conversion of grassland into rural human settlements was between 2005 and 2010, encompassing the largest area of 2696.06 km<sup>2</sup>, succeeded by 2015–2020 with 1652.97 km<sup>2</sup>, while the smallest conversion area was observed from 2000 to 2005, covering 307.26 km<sup>2</sup>. From 2005 to 2010, there was a peak in the conversion of woodland into rural human settlements, encompassing the largest area

of 1905.96 km<sup>2</sup>, followed by 2015–2020 with 1162.92 km<sup>2</sup>, whereas the smallest conversion area was noted in 2010–2015, covering 304.03 km<sup>2</sup>. Between 2015 and 2020, the largest urban built-up land conversion into rural human settlements took place, covering an area of 2273.58 km<sup>2</sup>, followed by 2005–2010 with 819.46 km<sup>2</sup>, while the smallest conversion area was observed in 2000–2005, covering 15.51 km<sup>2</sup>. From the perspective of change in rural human settlements to other land use types, we can observe that the highest conversion of rural human settlements to other land use types during the period 2000–2020 is cropland, covering an area of 18,966.81 km<sup>2</sup>, followed by urban build-up land with an area of 5953.94 km<sup>2</sup>, and woodland with an area of 1163.60 km<sup>2</sup>. The highest conversion of rural human settlements to cropland took place between 2005 and 2010, encompassing an area of 19,902.13 km<sup>2</sup>, exceeding the area of change in 2000–2020, followed by 2015–2020 with an area of 11,320.89 km<sup>2</sup>, while the smallest conversion occurred from 2000 to 2005, covering 1075.60 km<sup>2</sup>. Between 2005 and 2010, the most significant conversion of rural human settlements into urban built-up land occurred, spanning an extensive area of 5597.05 km<sup>2</sup>, followed by 2015–2020 with an area of 1648.09 km<sup>2</sup>, while the smallest conversion took place from 2010 to 2015, covering 357.60 km<sup>2</sup>. Overall, the primary types of land use change in rural human settlements in China are the conversion of cropland to rural human settlements, the transformation of rural human settlements to cropland, and the conversion of rural human settlements to urban build-up land.

**Table 11.** Land use change types in rural human settlements in China in 2000–2020. (Unit: km<sup>2</sup>).

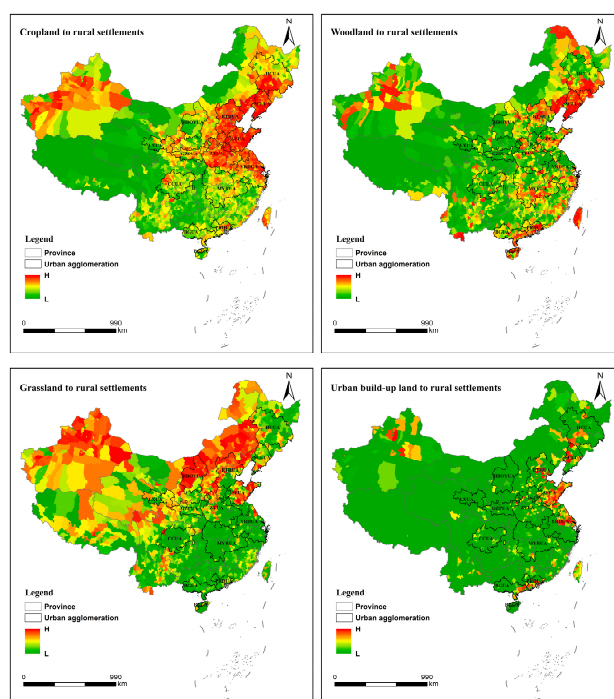
Land Use Change Types	2000–2005	2005–2010	2010–2015	2015–2020	2000–2020
1-52	4860.02	29,795.52	5127.87	14,384.56	38,219.31
2-52	328.43	1905.96	304.03	1162.92	2481.04
3-52	307.26	2696.06	353.95	1652.97	2864.77
4-52	175.59	440.27	86.49	483.80	715.85
51-52	15.51	819.46	33.84	2273.58	1004.10
53-52	35.78	655.59	40.88	966.87	655.13
6-52	34.54	2268.80	108.95	474.00	706.18
52-1	1075.60	19,902.13	1851.47	11,320.89	18,966.81
52-2	127.39	1077.91	143.05	1118.38	1163.60
52-3	101.12	1374.58	108.08	1482.30	906.10
52-4	65.53	529.65	58.19	387.45	614.80
52-51	1316.32	5597.05	357.60	1648.09	5953.94
52-53	57.42	756.17	80.54	928.55	950.74
52-6	18.62	407.43	22.83	1962.28	183.51

Note: 1: cropland; 2: woodland; 3: grassland; 4: water body; 51: urban built-up land; 52: rural human settlements; 53: other construction land; 6: unused land. The code before “-” represents the land use type in the base period, and the code after “-” represents the land use type in the final period.

For a comprehensive analysis of the spatial distribution concerning the transformation of different land use types into rural human settlements, we generated a spatial distribution of the conversion of other land use types into rural human settlements in 2000–2020 (refer to Figure 7). From Figure 7 (cropland to rural human settlements), it is evident that the urban agglomerations in China, which have converted cropland into rural human settlements, are primarily situated in North and Northeast China Plains, and parts of Xinjiang. These regions, characterized by advanced infrastructure, higher income levels, and robust economic activities, represent the more socio-economically developed areas of the country. They often feature thriving businesses, better educational and healthcare facilities, and a higher standard of living compared to other parts of the nation. The increase in Xinjiang is attributed to the Chinese government’s substantial investment in the socio-economic development of the region, including infrastructure projects, educational initiatives, and efforts to boost economic growth.

Based on Figure 7 (woodland to rural human settlements), it is clear that Chinese urban agglomerations that transformed woodland into rural human settlements are predominantly located in SCLUAs, PRDUAs, certain parts of BTHUAs, sections of HCUAs, portions of SPUAs, fewer areas of ZYUAs, minor sections of MYRUAs, limited parts of

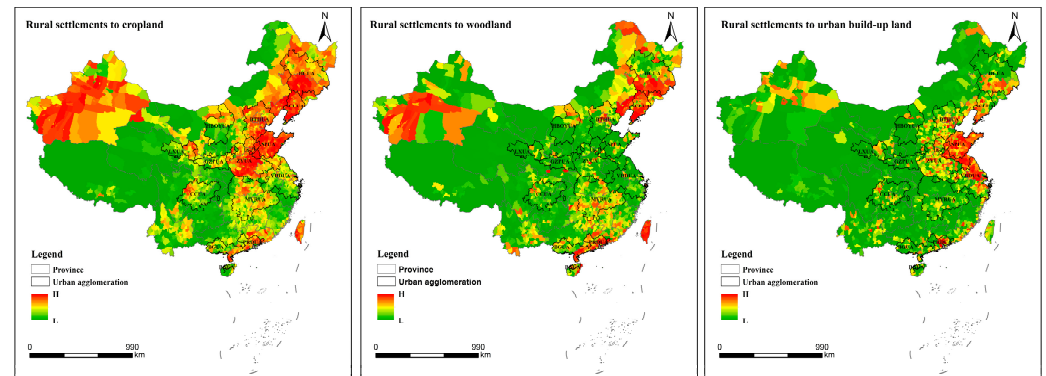
YRDUAs, and several other regions. Regarding the provinces, this distribution is predominantly noticeable in Liaoning, Jilin, Beijing, some areas of Hebei, segments of Guangdong, portions of Shandong, sections of Hunan, parts of Jiangxi, sections of Hainan, and parts of Xinjiang, and other regions. From Figure 7 (grassland to rural human settlements), it is evident that the Chinese urban agglomerations that converted grassland into rural human settlements are primarily situated in HBOYUAs, SPUAs, the majority of BTHUAs, portions of LXUAs, segments of GZPUAs, limited sections of ZYUAs, and various other regions. In terms of the provinces, the distribution is mainly in the northern provinces, such as Inner Mongolia, Xinjiang, Shandong, Shanxi, Hebei, Ningxia, Qinghai, and Gansu. These places constitute the primary distribution of important grassland land types in the country. From Figure 7 (urban build-up land to rural human settlements), it is evident that Chinese urban agglomerations, which converted urban build-up land into rural human settlements, are predominantly situated in SPUAs, sections of YRDUAs, portions of BTHUAs, segments of SCLUAs, parts of HCUAs, sections of PRDUAs, and various other regions.



**Figure 7.** Spatial distribution of the conversion of other land use types into rural human settlements in China from 2000 to 2020.

In order to conduct a thorough analysis of the spatial distribution related to the conversion of rural human settlements into different land use types, we produced a spatial distribution map depicting the conversion of various land use types into rural human settlements from 2000 to 2020 (see Figure 8). From Figure 8 (rural human settlements to cropland), it is apparent that Chinese urban agglomerations, which have transformed rural human settlements into cropland, are primarily located in the northern regions, such as HCUAs, SCLUAs, BTHUAs, SPUAs, and ZYUAs. In terms of the provinces, this distribution is predominantly observed in Xinjiang and Inner Mongolia. Based on Figure 8 (rural human settlements to woodland), it is evident that the Chinese urban agglomerations that have converted rural human settlements into woodland are mainly situated in SCLUAs, PRDUAs, sections of HCUAs, and diverse other regions. In terms of the provinces, this distribution is chiefly observed in parts of Xinjiang, etc. Based on Figure 8 (rural human settlements to urban build-up land), it is evident that Chinese urban agglomerations that have transformed rural human settlements into urban build-up land are primarily concentrated in SPUAs, sections of YRDUAs, parts of BTHUAs, segments

of SCLUAs, sections of HCUAs, and various other regions. In terms of the provinces, this distribution is predominantly observed in Shandong, Jiangsu, Liaoning, Jilin, etc. These regions are the most dynamic in terms of socio-economic development in the country, characterized by flourishing industries and robust economic activities.



**Figure 8.** Spatial distribution of rural settlement conversions into other land use types in China from 2000 to 2020.

#### 4.5. Provincial Classification of Rural Human Settlements in 2000 and 2020

In this section, we explore the characteristics of structural changes in the rural settlement areas of China's provincial-level regions (Table 12). The areas of rural human settlements in 2000 and 2020 in all counties were averaged arithmetically and then divided into five categories based on 1/2, 1, 2, and 3 times the mean value, as follows:  $0.00 < x \leq 0.09$ ,  $0.09 < x \leq 0.17$ ,  $0.17 < x \leq 0.34$ ,  $0.34 < x \leq 0.52$ , and  $x > 0.52$  (Unit:  $\text{km}^2$ ). Table 12 shows that the majority of rural human settlements in most provinces have an area structure dominated by the  $0.00\text{--}0.09 \text{ km}^2$  range, followed by  $0.09\text{--}0.17 \text{ km}^2$ . In 2000, most of the provinces with more than 60% of rural human settlements are in the  $0.00\text{--}0.17 \text{ km}^2$  range, except for the following: Heilongjiang (59.84%), Xinjiang (48.69%), Inner Mongolia (44.77%), Hebei (43.31%), Beijing (40.63%), and Tianjin (36.32%). The provinces with more than 50% of rural human settlements in the  $0.00\text{--}0.09 \text{ km}^2$  range are as follows: Hunan (82.78%), Jiangxi (78.09%), Sichuan (71.85%), Hubei (64.99%), Gansu (63.88%), Tibet (63.64%), Zhejiang (63.32%), Guizhou (60.83%), Guangxi (59.96%), Qinghai (59.62%), Shaanxi (58.69%), Hainan (58.64%), Shanghai (54.81%), Chongqing (52.94%), Shanxi (52.43%), and Anhui (50.51%). The following provinces have over 25% of their rural human settlements in the  $0.09\text{--}0.17 \text{ km}^2$  range: Heilongjiang (31.93%), Ningxia (30.71%), Fujian (29.71%), Jilin (29.56%), Anhui (29.14%), Shandong (29.11%), Yunnan (28.97%), Inner Mongolia (28.07%), Liaoning (27.67%), Henan (26.57%), Guangdong (25.71%), Hebei (25.55%), and Shaanxi (25.20%). In 2020, most of the provinces with more than 60% of rural human settlements are in the  $0.00\text{--}0.17 \text{ km}^2$  range, except for the following: Hebei (51.76%), Tianjin (49.1%), Inner Mongolia (44.94%), and Xinjiang (44.75%). The provinces with more than 50% of rural human settlements in the  $0.00\text{--}0.09 \text{ km}^2$  range are as follows: Hunan (82.03%), Jiangxi (76.81%), Sichuan (69.52%), Hubei (63.65%), Gansu (62.61%), Zhejiang (60.29%), Qinghai (59.16%), Guangxi (58.86%), Hainan (57.46%), Guizhou (56.86%), and Shaanxi (51.56%). The following provinces have over 25% of their rural human settlements in the  $0.09\text{--}0.17 \text{ km}^2$  range: Heilongjiang (30.3%), Yunnan (29.76%), Jilin (29.07%), Anhui (28.86%), Fujian (27.76%), Inner Mongolia (27.57%), Shandong (27.46%), Shaanxi (27.27%), Ningxia (26.99%), Liaoning (26.81%), Xinjiang (26.01%), and Guangdong (25.89%). Between 2000 and 2020, the proportion of rural human settlements with an area between 0.00 and  $0.09 \text{ km}^2$  significantly increased in areas such as Beijing (25.67%), Tianjin (15.4%), Hebei (12.87%), Liaoning (9.26%), and Henan (5.6%), while it notably decreased in Tibet (−21.93%), Shaanxi (−7.13%), Xinjiang (−6.96%), Shanghai (−4.84%), and Shanxi (−4.76%).

**Table 12.** Statistics of the size structure of rural human settlements in China's 31 provincial-level regions in 2000 and 2020. (Unit: %).

Province	Year	0.00 < x ≤ 0.09	0.09 < x ≤ 0.17	0.17 < x ≤ 0.34	0.34 < x ≤ 0.52	x > 0.52	Province	Year	0.00 < x ≤ 0.09	0.09 < x ≤ 0.17	0.17 < x ≤ 0.34	0.34 < x ≤ 0.52	x > 0.52
Beijing	2000	18.93%	21.71%	26.92%	13.36%	19.08%	Hubei	2000	64.99%	21.17%	9.56%	2.23%	2.05%
	2020	44.60%	16.32%	16.34%	7.58%	15.16%		2020	63.65%	21.82%	9.88%	2.39%	2.27%
	Change value	25.67%	-5.39%	-10.58%	-5.78%	-3.92%		Change value	-1.34%	0.65%	0.32%	0.16%	0.21%
Tianjin	2000	14.61%	21.71%	30.05%	15.86%	17.77%	Hunan	2000	82.78%	12.21%	3.93%	0.70%	0.39%
	2020	30.01%	19.09%	22.74%	11.15%	17.00%		2020	82.03%	12.57%	4.13%	0.78%	0.48%
	Change value	15.40%	-2.61%	-7.30%	-4.71%	-0.77%		Change value	-0.74%	0.36%	0.21%	0.08%	0.09%
Hebei	2000	17.77%	25.55%	30.24%	13.02%	13.43%	Guangdong	2000	49.48%	25.71%	15.68%	4.37%	4.76%
	2020	30.64%	21.13%	22.92%	10.89%	14.43%		2020	49.58%	25.89%	15.15%	4.09%	5.29%
	Change value	12.87%	-4.42%	-7.32%	-2.13%	1.00%		Change value	0.10%	0.18%	-0.53%	-0.28%	0.53%
Shanxi	2000	52.43%	20.84%	17.15%	5.70%	3.88%	Guangxi	2000	59.96%	22.51%	11.88%	3.11%	2.54%
	2020	47.67%	21.95%	17.79%	6.53%	6.06%		2020	58.86%	23.02%	12.16%	3.18%	2.77%
	Change value	-4.76%	1.11%	0.64%	0.83%	2.18%		Change value	-1.09%	0.51%	0.28%	0.07%	0.23%
Inner Mongolia	2000	16.70%	28.07%	32.65%	12.09%	10.49%	Hainan	2000	58.64%	24.22%	12.06%	2.97%	2.10%
	2020	17.37%	27.57%	32.25%	12.02%	10.79%		2020	57.46%	23.55%	11.81%	3.87%	3.32%
	Change value	0.67%	-0.50%	-0.41%	-0.07%	0.30%		Change value	-1.19%	-0.68%	-0.25%	0.90%	1.21%
Liaoning	2000	36.95%	27.67%	21.10%	7.29%	6.99%	Chongqing	2000	52.94%	23.60%	13.82%	4.56%	5.07%
	2020	46.20%	26.81%	16.98%	5.20%	4.81%		2020	49.15%	23.73%	13.98%	6.09%	7.05%
	Change value	9.26%	-0.86%	-4.12%	-2.09%	-2.18%		Change value	-3.79%	0.13%	0.16%	1.53%	1.97%
Jilin	2000	42.88%	29.56%	19.50%	4.89%	3.16%	Sichuan	2000	71.85%	16.80%	7.45%	2.06%	1.84%
	2020	44.80%	29.07%	18.40%	4.55%	3.18%		2020	69.52%	16.79%	8.29%	2.33%	3.08%
	Change value	1.91%	-0.49%	-1.10%	-0.34%	0.02%		Change value	-2.33%	-0.01%	0.84%	0.27%	1.23%
Heilongjiang	2000	27.92%	31.93%	26.82%	7.63%	5.71%	Guizhou	2000	60.83%	23.26%	12.06%	2.29%	1.56%
	2020	31.81%	30.30%	25.23%	7.08%	5.58%		2020	56.86%	23.87%	12.45%	3.62%	3.20%
	Change value	3.89%	-1.63%	-1.59%	-0.54%	-0.12%		Change value	-3.96%	0.61%	0.38%	1.33%	1.64%
Shanghai	2000	54.81%	22.39%	12.80%	3.43%	6.57%	Yunnan	2000	32.96%	28.97%	23.52%	7.75%	6.81%
	2020	49.97%	19.42%	13.37%	4.98%	12.25%		2020	31.53%	29.76%	23.47%	7.78%	7.47%
	Change value	-4.84%	-2.97%	0.57%	1.56%	5.68%		Change value	-1.43%	0.79%	-0.05%	0.03%	0.66%
Jiangsu	2000	45.33%	24.90%	17.49%	6.00%	6.27%	Tibet	2000	63.64%	20.25%	11.36%	3.10%	1.65%
	2020	42.85%	24.37%	17.74%	6.40%	8.64%		2020	41.71%	24.61%	17.80%	7.50%	8.38%
	Change value	-2.48%	-0.53%	0.25%	0.40%	2.37%		Change value	-21.93%	4.36%	6.44%	4.41%	6.72%
Zhejiang	2000	63.32%	23.99%	9.72%	1.89%	1.08%	Shaanxi	2000	58.69%	25.20%	11.83%	2.57%	1.70%
	2020	60.29%	22.37%	10.62%	2.85%	3.87%		2020	51.56%	27.27%	14.52%	3.64%	3.01%
	Change value	-3.03%	-1.62%	0.90%	0.96%	2.79%		Change value	-7.13%	2.07%	2.69%	1.07%	1.31%
Anhui	2000	50.51%	29.14%	14.91%	3.38%	2.05%	Gansu	2000	63.88%	23.68%	9.38%	1.86%	1.19%
	2020	49.68%	28.86%	14.91%	3.67%	2.88%		2020	62.61%	23.65%	9.72%	2.20%	1.81%
	Change value	-0.84%	-0.28%	0.00%	0.29%	0.83%		Change value	-1.27%	-0.03%	0.34%	0.34%	0.62%
Fujian	2000	46.20%	29.71%	16.21%	4.37%	3.50%	Qinghai	2000	59.62%	23.80%	12.05%	2.73%	1.80%
	2020	44.83%	27.76%	16.37%	5.09%	5.94%		2020	59.16%	23.69%	11.58%	2.94%	2.64%
	Change value	-1.37%	-1.95%	0.16%	0.72%	2.44%		Change value	-0.46%	-0.11%	-0.48%	0.21%	0.84%
Jiangxi	2000	78.09%	15.63%	5.14%	0.84%	0.30%	Ningxia	2000	48.70%	30.71%	15.24%	3.33%	2.02%
	2020	76.81%	16.18%	5.26%	1.04%	0.72%		2020	49.66%	26.99%	15.20%	3.95%	4.20%
	Change value	-1.28%	0.55%	0.12%	0.20%	0.41%		Change value	0.96%	-3.72%	-0.04%	0.61%	2.18%
Shandong	2000	32.28%	29.11%	24.03%	8.05%	6.53%	Xinjiang	2000	25.71%	22.98%	25.58%	11.59%	14.15%
	2020	34.21%	27.46%	23.32%	7.61%	7.41%		2020	18.74%	26.01%	29.58%	11.45%	14.23%
	Change value	1.92%	-1.66%	-0.71%	-0.44%	0.88%		Change value	-6.96%	3.03%	4.00%	-0.14%	0.08%
Henan	2000	44.04%	26.57%	19.07%	5.81%	4.50%							
	2020	49.64%	23.56%	16.76%	5.29%	4.76%							
	Change value	5.60%	-3.02%	-2.31%	-0.53%	0.25%							

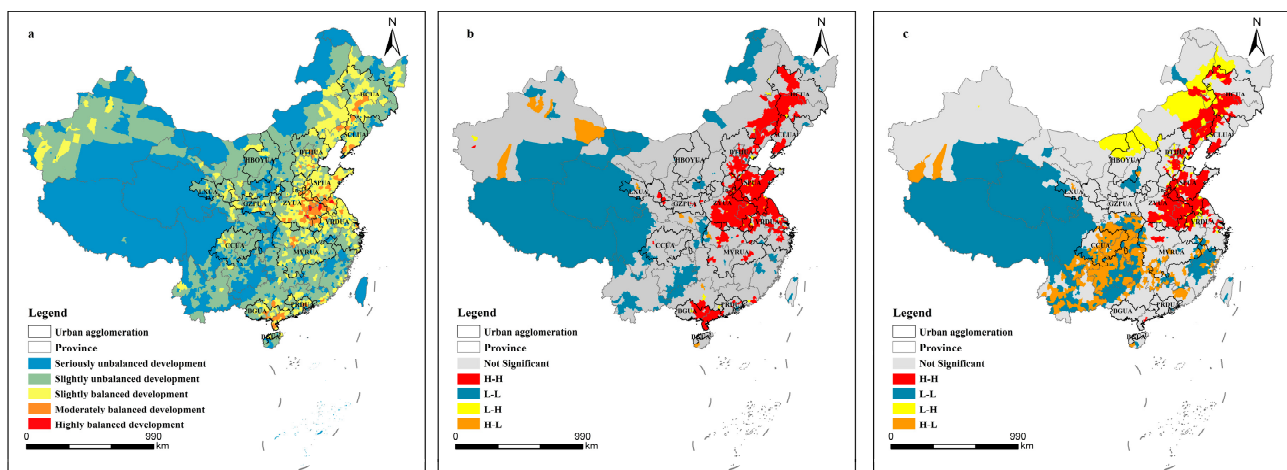
Note: the redder the color, the larger the value; the bluer the color, the smaller the value; x indicates areas of rural human settlements.

The top ten provinces in terms of provincial population, according to the 2020 China Statistical Yearbook, were Guangdong, Shandong, Henan, Jiangsu, Sichuan, Hebei, Hunan, Zhejiang, Anhui, and Hubei. Various provinces exhibited distinct structural characteristics. In 2000, for instance, Hunan and Sichuan had a remarkably high proportion in the 0.00–0.09 km<sup>2</sup> range, accounting for 82.78% and 71.85%, respectively, while Hubei, Zhejiang, and Anhui were dominated by proportions in the 0.00–0.09 km<sup>2</sup> and 0.09–0.17 km<sup>2</sup> ranges, which accounted for 64.99%, 63.32%, and 50.51%, and 21.17%, 23.99%, and 29.14%, respectively, with their combined sum exceeding 80%. Guangdong, Jiangsu, and Henan were dominated by proportions in the 0–0.09 km<sup>2</sup> and 0.09–0.17 km<sup>2</sup> ranges, and they also exhibited higher proportions in the 0.17–0.34 km<sup>2</sup> range, ranging from 15% to 20%, with percentages of 15.68%, 17.49%, and 19.07%, respectively. Shandong's share in the ranges of 0–0.09 km<sup>2</sup>, 0.09–0.17 km<sup>2</sup>, and 0.17–0.34 km<sup>2</sup> was even more than that of other provinces, with 32.28%, 29.11%, and 24.03%, respectively. Conversely, Hebei was marked by a predominant percentage in the 0.17–0.34 km<sup>2</sup> range (30.24%) and the 0.09–0.17 km<sup>2</sup> range (25.55%), along with a relatively even distribution across the 0.00–0.09 km<sup>2</sup> range (17.77%), the 0.34–0.52 km<sup>2</sup> range (13.02%), and areas greater than 0.52 km<sup>2</sup> (13.43%). In 2020, in Hunan and Sichuan, within the range of 0.00–0.09 km<sup>2</sup>, there were variations of –0.74% and –2.33%, respectively, with percentages of 82.03% and 69.52%. However, in the range of 0.09–0.17 km<sup>2</sup>, the percentage change was –2.33%. These data suggest that, despite the gradual trend toward aggregation in the area structure of rural human settlements in Hunan and Sichuan, a significant level of dispersion persists in both regions. Hubei, Zhejiang, and Anhui are predominantly characterized by proportions within the 0.00–0.09 km<sup>2</sup> and 0.09–0.17 km<sup>2</sup> ranges, all of which experienced varying degrees of decline, except for Hubei's proportion in the 0.09–0.17 km<sup>2</sup> range. Within the ranges of 0.00–0.09 km<sup>2</sup> and 0.09–0.17 km<sup>2</sup>, these three provinces saw respective value changes of –1.34%, –3.03%, and –0.84%, and 0.65%, –1.62%, and –0.28%. Their shares within these ranges were 63.65%, 60.29%, and 49.68%, and 21.82%, 22.37%, and 28.86%, respectively. Additionally, Hubei, Zhejiang, and Anhui observed varying degrees of growth in the proportion exceeding 0.17 km<sup>2</sup>, indicating a trend toward rural settlement agglomeration, albeit not very pronounced. Guangdong, Henan, and Jiangsu predominantly featured shares within the 0.00–0.09 km<sup>2</sup> and 0.09–0.17 km<sup>2</sup> ranges, with Henan displaying more variability in the 0.00–0.09 km<sup>2</sup> range. The proportions for these areas in the 0.00–0.09 km<sup>2</sup> and 0.09–0.17 km<sup>2</sup> ranges were 49.58%, 49.64%, and 42.85%, and 25.89%, 23.56%, and 24.37%, with corresponding value changes of 0.10%, 5.60%, and –2.48%, and 0.18%, –3.02%, and –0.53%. The rise in Guangdong's proportion within the 0.00–0.09 km<sup>2</sup> and 0.09–0.17 km<sup>2</sup> ranges, alongside the decline in other ranges, suggests an increase in the dispersion of rural human settlements in this area compared to the year 2000. Henan experienced a notable increase in the 0.00–0.09 km<sup>2</sup> range and varying decreases in other ranges, signaling an upward trend in rural settlement dispersion in the region. Jiangsu moved toward reduced fragmentation and increased aggregation. In Shandong, the proportion within the 0.00–0.09 km<sup>2</sup> range increased by 1.92% compared to 2000, whereas the proportion within the 0.09–0.34 km<sup>2</sup> range decreased compared to 2000. Furthermore, the proportion exceeding 0.52 km<sup>2</sup> increased by 0.53%, indicating a rising level of dispersion in rural human settlements in Shandong. Hebei experienced greater changes than the other provinces, including a 12.87% increase in the 0.00–0.09 km<sup>2</sup> range, a 7.32% decrease in the 0.17–0.34 km<sup>2</sup> range, and a 4.42% decrease in the 0.09–0.17 km<sup>2</sup> range compared to 2000. These data suggest that rural settlement dispersion in Hebei has increased significantly compared to 2000. The top ten provinces in terms of provincial GDP, according to the 2020 China Statistical Yearbook, are Guangdong, Jiangsu, Shandong, Zhejiang, Henan, Sichuan, Fujian, Hubei, Hunan, and Shanghai. Here, we only analyzed Fujian and Shanghai; the analysis for the other provinces has already been completed. In 2000 and 2020, Fujian and Shanghai predominantly exhibited shares in the 0.00–0.09 km<sup>2</sup> and 0.17–0.34 km<sup>2</sup> ranges. During this period, Fujian's share in the 0.00–0.09 km<sup>2</sup> range decreased from 46.20% to 44.83%, a decline of 1.37%, while Shanghai's share in the same range decreased from 54.81%

to 49.97%, a decrease of 4.84%. In the 0.17–0.34 km<sup>2</sup> range, Fujian’s share declined by 1.95%, from 46.20% to 29.71%, and Shanghai’s share dropped by 2.97%, from 22.39% to 19.42%. Both Fujian and Shanghai experienced varying degrees of increase in percentages greater than 0.34 km<sup>2</sup>. These findings indicate an increasing trend of rural settlement dispersion in Fujian and Shanghai, coupled with a decrease in aggregation.

#### 4.6. Coupling Coordination Degree between Rural Populations and Rural Human Settlements

Figure 9a illustrates the spatial distribution of the degree of coupling coordination between rural populations and rural human settlements at the county level in China for the year 2020. It is evident that the degree of coupling coordination between rural populations and rural human settlements in China exhibits a distinct spatial distribution pattern. The balance between rural populations and rural human settlement development was categorized into three levels: slight, moderate, and high balance. Conversely, unbalanced development was categorized into two levels: serious and slight unbalance. Areas of balanced development were primarily found in the North China Plain, the Northeast Plain, the middle and lower reaches of the Yangtze River, and other regions across China. A highly balanced development of rural populations and rural human settlements was primarily observed in Linquan, Qiao Cheng and Yongqiao in Anhui Province, and Shuyang in Jiangsu Province. When examining urban agglomerations, a moderately balanced development between rural populations and rural human settlements was predominantly observed within the ZYUAs, SPUAs, BGUAs, MYRUAs, SCLUAs, HCUAs, and BTHUAs. Serious imbalances in rural populations and rural human settlement development were most notably observed in Tibet, Qinghai, western Sichuan, southeastern and northeastern Xinjiang, southeastern Guizhou, as well as in smaller areas of northwestern Guangxi, western and northeastern Inner Mongolia, and various other regions.



**Figure 9.** Spatial distribution map (a) and LISA cluster map (b) of the coupling coordination degree between rural populations and rural human settlements in 2020. BiLISA cluster map (c) for rural populations and rural human settlements in 2020.

To examine whether there was spatial dependence in the coordinated interaction between rural populations and rural human settlements, we employed global spatial autocorrelation. This analysis can provide insights into spatial relationships and patterns that may exist within the coordinated interaction between rural populations and rural human settlements. The Moran’s I value for the degree of coupling coordination between rural populations and rural human settlements in 2020 was 0.5558, indicating a significant positive spatial autocorrelation. The following four types of spatial clusters were evaluated: H-H, L-L, L-H and H-L. In a given geographic area, H-H signifies that locations with a high-value rural population and rural human settlement coupling coordination are encircled by neighboring locations with equally high values, L-L indicates that low-value

locations are surrounded by low-value ones, while L-H denotes that low-value locations are surrounded by high-value ones, and H-L indicates that high-value locations are surrounded by low-value ones.

Figure 9b shows the LISA cluster map of the coupling coordination degree between rural populations and rural human settlements in 2020. H-H cluster areas are observed in North China Plain, Northeast Plain, and other regions. L-L cluster areas are found in the Tibetan Plateau, parts of the Yunnan–Guizhou Plateau, and other regions. We employed a bivariate spatial autocorrelation to investigate the spatial clustering relationship between rural populations and rural human settlements. In 2020, a bivariate Moran's I value of 0.2583 revealed a significant positive spatial autocorrelation between rural populations and rural human settlements. Figure 9c depicts the BiLISA cluster map for rural populations and rural human settlements in the year 2020. The spatial agglomeration between rural population and rural human settlement area can be categorized into four types: H-H, L-L, L-H, and H-L. In a geographic area, H-H shows high-value rural populations and settlements, L-L signifies a low value for both, L-H indicates low-value populations amid high-value settlements, and H-L represents high-value populations surrounded by low-value settlements. H-H cluster areas can be observed in North China Plain, Northeast Plain, and other regions. L-L cluster areas can primarily be found in Tibet, Qinghai, western Sichuan, northern Fujian, parts of Yunnan and Guizhou, southwestern Guangxi, northern Shaanxi, with sporadic occurrences in other regions. L-H cluster areas are sporadically distributed in the north, such as Inner Mongolia, Heilongjiang, Jilin, Liaoning, Hebei, Beijing, Shandong; central areas, such as Henan and Anhui; and the east, such as Jiangsu and Zhejiang. L-H cluster areas are mainly distributed in the north, such as Inner Mongolia, Heilongjiang, Jilin, Liaoning, Hebei, Beijing, and Shandong; sporadically in the central region, such as Henan and Anhui; and sporadically in the east, such as Jiangsu and Zhejiang. H-L cluster areas are primarily in the southwest, such as Chongqing, Sichuan, Yunnan, Guizhou, Guangxi, Hunan, Jiangxi, and other regions.

## 5. Discussion

### 5.1. Mechanisms Influencing Changes in Rural Human Settlements

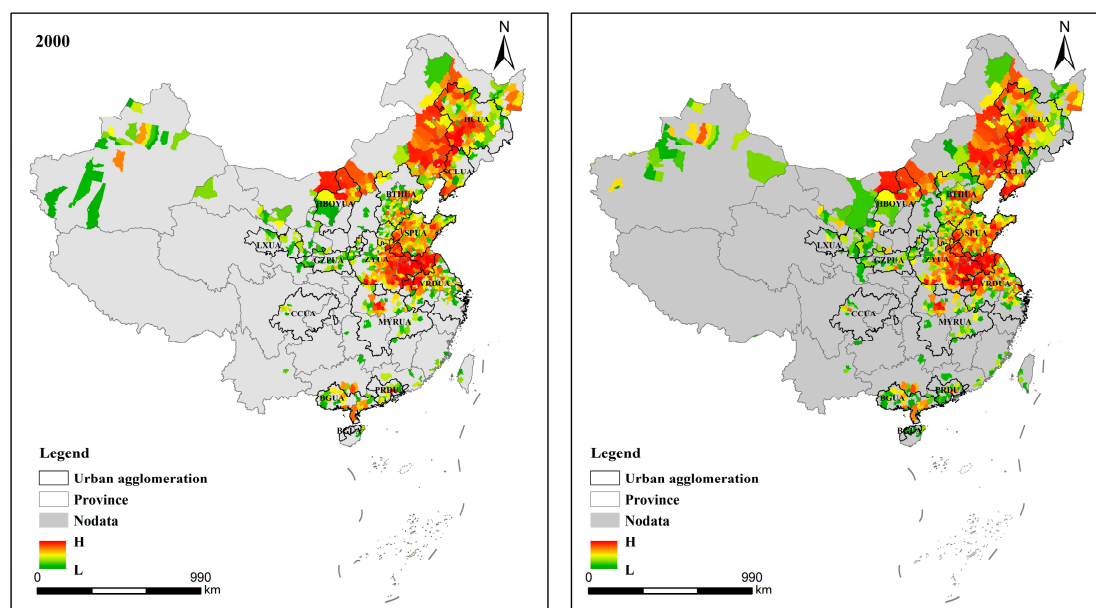
The expansion of rural human settlements exhibits regional variations in China. In developed eastern coastal areas (Figure 3), population mobility is a significant factor contributing to this expansion, particularly driven by the influx of people attracted to urban areas, leading to a demand for affordable rental housing. The expansion of rural human settlements in suburban areas reflects the economic function of homestead land. Additionally, the policy of linking the increase and decrease in urban and rural construction land has resulted in the transformation of a considerable amount of rural human settlements into cultivated land (Table 10). The areas where construction land is urgently needed are mainly distributed in economically developed regions, primarily in urban clusters such as HCUAs, SCLUAs, BTHUAs, SPUAs, and ZYUAs. In economically underdeveloped areas, the primary driver of the expansion of rural human settlements is the manifestation of the social security function of homestead land. In the process of urban development, individuals acquire non-agricultural income in urban areas and use it to build or expand homes in their rural homesteads, while the original homestead land remains unused. This phenomenon reflects the complex interactions between urban and rural areas in terms of population, economy, culture, and institutions, giving rise to diverse features of development in rural human settlements.

Figure 9c displays spatial distribution maps for two types and four features: high rural population and a large area of rural human settlements, high rural population and a small area of rural human settlements, low rural population and a large area of rural human settlements, as well as low rural population and a small area of rural human settlements. Natural and geographical factors play a decisive role in the distribution of rural human settlements and population growth. The flat terrain, favorable climate, fertile soil, low altitude, and suitable precipitation in the North China Plain and Northeast China Plain

contribute to the predominance of the “high rural population and a large area of rural human settlements” feature in these regions. Additionally, being located in the south-eastern coastal areas of China, these regions have experienced better urbanization and industrialization, further reinforcing the prevalence of the “high rural population and a large area of rural human settlements” feature. On the other hand, areas where the “low rural population and a small area of rural human settlements” feature is predominant often face less favorable natural and geographical conditions. These areas are mainly distributed in the Qinghai–Tibet Plateau and Yunnan–Guizhou Plateau, characterized by challenging terrains with mountainous landscapes. The “low rural population and a large area of rural human settlements” feature is distributed mainly in Inner Mongolia and Heilongjiang, where there is a severe issue of excessive per capita rural human settlements (Figure 2). These regions also suffer from widespread rural human settlement land waste [110,111], despite having a relatively small rural registered population. Conversely, the “high rural population and a small area of rural human settlements” feature is prevalent in the southwestern regions, particularly in Chongqing, Sichuan (excluding the Sichuan Basin), Yunnan, Guizhou, and Guangxi. These provinces have a higher rural registered population, and their terrain is predominantly mountainous and hilly, with a limited availability of land resources. While natural and geographical factors limit population size and, to some extent, influence the scale rural human settlements, other factors should not be overlooked. The dual urban–rural system, policies and planning, social culture, and other factors play significant roles in the disorderly growth and chaotic layout of rural human settlements.

### 5.2. Spatial Distribution of Cropland Reclamation Potential Patterns

Figure 2 shows the spatial distribution characteristics of rural human settlements in China in 2000 and 2020. The results show that the North China Plain and the North-east China Plain are the main regions where rural human settlements are concentrated. However, there are issues with the utilization of homestead land in China, including inefficient use, waste, vacancy, uncontrolled expansion, and chaotic layout. Therefore, this study calculated the potential for farmland reclamation and village consolidation. The calculation method involved first determining the difference between the area of rural human settlements in county-level areas in 2000 and 2020 and the national average in 2020. Subsequently, negative and zero values were removed, and a spatial distribution map was generated (Figure 10). From Figure 10, it can be observed that the potential for cultivated land reclamation and village consolidation is mainly concentrated in the North China Plain and Northeast China Plain, covering regions such as Shandong, Henan, Anhui, Jiangsu, Liaoning, Jilin, Heilongjiang, and parts of Inner Mongolia. These areas are also the primary distribution regions of China’s cultivated land resources and major grain-producing areas [112]. Characterized by fertile soil, flat terrain, abundant precipitation, mild climate, and concentrated farmland resources, these regions are of significance for supplementing China’s insufficient cultivated land resources. In the context of China’s ongoing urbanization and industrialization, coupled with a declining birth rate, this study suggests that implementing village consolidation and cultivated land reclamation in these regions would not only align with demographic trends, but also contribute positively to enhancing rural living environments, reducing rural environmental pollution, and promoting coordinated urban–rural development.



**Figure 10.** Spatial distribution map of reclamation potential of cropland in China in 2000 and 2020.

### 5.3. Policies and Recommendations

In China, the rural homestead system is the primary management system for rural human settlements. Rural homestead reform is a significant initiative that involves multiple crucial domains, such as political stability, social security, economic property, and food security [113]. The Chinese government explores the concept of “separating the three rights”—ownership, qualification, and use—of rural homestead. This involves implementing collective ownership of rural homestead, safeguarding the qualification rights of rural homestead farmers, and securing property rights to farmers’ rural homestead and houses. The reform also involves granting reasonable flexibility to the use rights of rural homestead and farmers’ houses. Grounded in China’s status as a major agricultural and rural population nation, the rural homestead system plays a crucial role in social security and contributes to the stability of rural society. The emphasis on safeguarding the qualification rights of rural homestead farmers is essential for ensuring their livelihoods. Simultaneously, it enables the realization of usufructuary property rights to rural homestead, leading to an increase in farmers’ property income [73,114]. By optimizing the rural homestead system, China aims to achieve sustainable development in rural society and promote an improvement in the living standards of farmers.

In 2017, the Chinese government introduced the Rural Revitalization Strategy, aiming to promote integrated urban–rural development, modernize agriculture and rural areas, and enhance relevant policies and mechanisms. The reform of the three rights of the rural homestead system not only can improve the utilization efficiency of the rural homestead system, promote integrated urban–rural development, and provide support for attracting capital and talent, but can also utilize idle homestead land for the development of rural tourism, agricultural product processing, and other businesses, providing necessary land elements. This can increase the economic benefits for farmers, improve their living standards, and expand their rights, perfecting capabilities such as mortgage, transfer, and withdrawal. This helps safeguard the property income of homestead land and contributes to maintaining rural social stability. The Ministry of Agriculture and Rural Affairs drafted the “Interim Measures for the Administration of Rural Homesteads (Draft for Solicitation of Opinions)”, strengthening the management of rural homestead land. According to this proposal, township (town) governments are responsible for the approval and supervision of homestead land, as well as real-estate registration. This refinement of homestead land management is conducive to addressing issues such as extensive use, resource waste, idle land, disorderly expansion, and chaotic land layout during the utilization of homestead land.

In summary, with the advancement of urbanization and industrialization, the spatial disparities between the economic and social security functions of homestead land have become increasingly pronounced. Therefore, in the reform process, it is essential to tailor rational policies to local conditions, prioritizing the reinforcement of social security functions before promoting economic development. Only through such an approach can the stability of farmers be ensured and their property rights effectively safeguarded.

#### 5.4. Limitations and Future Work

This study, based on the theory of human–earth relationship, posited the existence of two types and four features in the human–earth relationship of rural human settlements in China. It extensively explored their characteristics, such as spatiotemporal evolution, land use type changes, and landscape pattern variations. Through a quantitative analysis, the coupling coordination between landscape pattern variations and rural population was assessed, and the potential of amalgamating villages for the reclamation of arable land was calculated. Furthermore, we identified the distribution characteristics of the two types and four features in the human–earth relationship of rural human settlements in China and provided preliminary insights into the driving mechanisms behind the development and changes in rural human settlements. This offers valuable references for the formulation of policies related to rural homestead reform, arable land reclamation, and village consolidation by the government. However, due to limitations in the data and methods, this study has shortcomings. The large-scale land use data may have interpretation and accuracy issues, making it challenging to comprehensively identify rural human settlements. Although we discussed human–earth relationships at a national macro-level, in-depth research using micro-scale methods, such as field surveys, is needed. Further investigation is also required to reveal the spatial differences and driving mechanisms of the two types and four features in rural human settlements. In future research, we will continue to focus on these features differences and their driving mechanisms in human–earth relationships. The phenomenon of the detachment of rural registered populations from the registered residence is also a factor to consider in our future research.

## 6. Conclusions

(1) Currently, rural human settlements in China are experiencing a trend where the rural population is decreasing while rural human settlements are expanding. Different regions are exhibiting changing relationships between rural populations and rural human settlements, focusing on two types and four features in China’s rural human settlements, namely, human–land coordination and human–land trade-offs. Human–land coordination involves scenarios in which there is a correlation between a higher rural population and a larger area of rural human settlements, or a lower rural population and a smaller area of rural human settlements. On the other hand, human–land trade-offs pertain to situations in which there is a balance between a higher rural population and a smaller area of human settlements, or a lower rural population and a larger area of rural human settlements.

(2) Natural and geographical factors play a significant role in the spatial distribution of these different features. The “high rural population and a large area of rural human settlements” feature is primarily found in the North China Plain and the Northeast China Plain. The “low rural population and a small area of rural human settlements” feature is prevalent in the Qinghai–Tibet Plateau, with the Yunnan–Guizhou Plateau being another significant area. The “low rural population and a large area of rural human settlements” feature is sporadically distributed, with Inner Mongolia and Heilongjiang being the main areas. The “high rural population and a small area of rural human settlements” feature is predominantly observed in the southwestern regions, such as Chongqing, Sichuan (outside the Sichuan Basin), Yunnan, Guizhou, and Guangxi.

(3) Despite significant developments in rural human settlements due to government efforts, challenges, such as the encroachment on prime farmland, rural hollowing, and poor living environments, persist. The ongoing processes of urbanization and industrial-

ization in China have led to substantial changes in population and age structures, with an increasing aging population and a continuous decline in the birth rate. This dynamic will bring about new features and structures in rural human settlements. To address these challenges, government should tailor initiatives to the specific circumstances of different periods and regions. This includes promoting the reclamation of farmland and the construction of projects for village consolidation. Simultaneously, there should be active efforts in constructing rural living environments, enhancing infrastructure, and providing public services. Facilitating the orderly flow of factors between urban and rural areas and promoting the movement of various products from villages to cities, spanning agriculture, businesses, culture, ecology, and livability, will contribute to achieving coordinated urban–rural development. With the guidance of the Chinese government and the comprehensive influence of social, economic, cultural, policy, resource, and environmental factors, it is anticipated that rural human settlements will witness the realization of agricultural modernization and large-scale operations. Significant progress is expected in food security and farmland protection, leading to a marked improvement in living environments. Ultimately, Chinese rural areas are poised to become beautiful villages characterized by thriving businesses, social etiquette and civility, a pleasant living environment, and prosperous lives.

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**Data Availability Statement:** The land use/cover maps in 2000, 2005, 2010, 2015, and 2020 include 6 primary categorized land use types and 25 secondary categorized land use types, with a cell size of 30 m × 30 m, from the Resource and Environmental Sciences and Data Center, Chinese Academy of Sciences (<https://www.resdc.cn>, accessed on 5 June 2022). The data pertaining to the rural population is were obtained from China’s seventh population census.

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