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SPATIAL PATTERNS AND DRIVING FACTORS OF SPECIALIZED VILLAGES IN THE YANGTZE RIVER ECONOMIC BELT, CHINA

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Abstract: Taking specialized villages in the Yangtze River Economic Belt as the study object, this study uses specialized village data from 2008, 2011, 2014, and 2017, and integrates ArcGIS spatial analysis, the nearest neighbor index, kernel density estimation, spatial autocorrelation, buffer analysis, and GeoDetector to systematically examine the quantity distribution, type structure, spatiotemporal evolution, and influencing factors of specialized villages in the Yangtze River Economic Belt. The results show that: (1) the total number of specialized villages in the Yangtze River Economic Belt remained relatively stable, but significant differences existed across provinces and counties, forming a regional distribution pattern characterized by relatively high concentration in the upper and lower reaches and relatively weaker concentration in the middle reaches. (2) The spatial distribution of specialized villages showed significant spatial clustering, with relatively stable core agglomeration areas mainly located in parts of the Sichuan Basin and central Jiangsu. At the county scale, a spatial differentiation pattern gradually formed, with the Chengdu-Chongqing region and the Yangtze River Delta as the main hot spots, and parts of the central and southwestern mountainous areas as the main cold spots. (3) Specialized villages were mainly distributed in low-elevation and low-slope areas and showed clear river-proximity and road-proximity characteristics, indicating that terrain conditions, river systems, and transport accessibility had important effects on their spatial layout. (4) In terms of type structure, specialized villages in the Yangtze River Economic Belt were dominated by agricultural production-oriented villages, while agriculture-related service-oriented villages showed structural transformation and non-agricultural industry-oriented villages declined markedly. (5) The GeoDetector results indicate that institutional, cultural, technological, and market factors, such as farmers' professional cooperatives, registered trademarks, pollution-free agricultural product certification, green food certification, leading agribusinesses, and agricultural wholesale markets, were important factors influencing the spatial differentiation of specialized villages. Moreover, different factors exhibited significant interaction enhancement effects. The findings provide empirical support for optimizing the spatial layout of specialized villages, promoting rural industrial revitalization, and supporting high-quality agricultural development in the Yangtze River Economic Belt.
Keywords: Specialized villages; Spatiotemporal evolution; Influencing factors; GeoDetector; Yangtze River Economic Belt

1 INTRODUCTION

Agricultural and rural development has long been a central issue in China's economic transformation, regional coordination, and social governance. As the first annual policy statement released by China's central authorities, the 2026 "No. 1 central document" set out a systematic agenda for advancing agricultural and rural modernization and promoting comprehensive rural revitalization, thereby providing an important policy backdrop for understanding current rural industrial development and transformation in China [1]. Against this background, with the continuous advancement of industrialization, urbanization, and population mobility, many rural areas still face persistent challenges such as out-migration, weak industrial foundations, uneven village-level economic development, and insufficient growth in farmers' incomes. How to cultivate distinctive industries based on local resource endowments, strengthen endogenous village development, and promote sustained income growth for rural residents has therefore become an important topic in rural development research [2,3].

Specialized villages represent a typical form of village-level industrial organization that has emerged through the deepening of rural division of labor and market-oriented development in China. They usually refer to rural settlements in which a dominant product or economic activity gives rise to a relatively high degree of specialization, production agglomeration, and market linkages within the village economy [4]. As an important entry point for understanding rural industrial transformation, rural spatial restructuring, and regional disparities in China, specialized villages not only help improve the efficiency of resource allocation, but also play an important role in promoting industrial agglomeration, increasing rural employment and income, and fostering place-based specialty industries [3-5]. Although similar practices have existed elsewhere, the development of specialized villages in China has largely evolved through local resource conditions, institutional environments, and rural transformation practices, and thus exhibits distinctive Chinese characteristics and regional differences [5].

Existing studies on specialized villages have mainly focused on the following five aspects. First, scholars have examined the conceptualization, classification, and basic characteristics of specialized villages [4,6-11]. Second, a substantial body of research has explored their resource endowments, locational conditions, market mechanisms, and institutional environments [11-19]. Third, studies have investigated specialization, industrial upgrading, and transformation pathways in specialized villages [8,20-25]. Fourth, growing attention has been paid to their spatial distribution, agglomeration patterns, and spatiotemporal evolution [9,14,26-35]. Fifth, related studies have also discussed organizational models, market networks, brand building, and relevant theoretical interpretations of specialized village development [7,36-40]. Overall, the existing literature has systematically revealed the economic logic, spatial characteristics, and driving mechanisms of specialized villages, thereby providing an important foundation for understanding rural industrial development and the evolution of rural territorial systems [2].

From the perspective of spatial scale, previous studies have covered counties [10,41], provinces [9,26,42,43], river-basin regions [29,35,44], and the national level [14,45-46]. In terms of methodology, scholars have mainly employed spatial analytical approaches such as nearest-neighbor analysis, kernel density estimation, and spatial autocorrelation to identify the distribution patterns and agglomeration characteristics of specialized villages [3,26,29,35]. These approaches have often been combined with ordinary least squares models [46,47], Logistic models [11,48], and geographically weighted regression to examine the determinants and formation mechanisms of specialized villages [49]. Together, these studies have broadened the research perspective on specialized villages and promoted interdisciplinary integration among rural geography, agricultural economics, and regional development studies.

Despite these advances, there remains room for further improvement in the existing literature. Most studies have focused on typical regions such as Henan Province or on nationwide overviews, whereas systematic research on specialized villages within the Yangtze River Economic Belt, a major national strategic region, remains relatively limited. The Yangtze River Economic Belt spans eastern, central, and western China, and displays substantial intra-regional variation in natural environments, agricultural types, transport conditions, and market contexts. As a result, the formation bases, agglomeration characteristics, and evolutionary mechanisms of specialized villages are likely to exhibit strong regional heterogeneity. Therefore, examining the spatial pattern evolution and influencing factors of specialized villages in the Yangtze River Economic Belt can not only deepen our understanding of the spatial organization of rural industries, but also provide more targeted empirical support for optimizing regional agricultural layouts and promoting rural industrial revitalization [29,35,44].

Against this backdrop, this study takes specialized villages in the Yangtze River Economic Belt as the study object. By integrating nearest-neighbor analysis, kernel density estimation, and spatial autocorrelation, it systematically characterizes their spatial distribution patterns and evolutionary features. It further employs GeoDetector to identify the key factors influencing the spatial distribution of specialized villages and the differences in their effects. Following the analytical framework of “spatial pattern–evolutionary process–driving mechanism,” this study aims to enrich the regional case literature on specialized villages and provide empirical support for optimizing rural industrial layout and advancing rural revitalization in the Yangtze River Economic Belt.

2 DATA AND METHODS

2.1 Study Area

The Yangtze River Economic Belt covers 11 provincial-level regions, namely Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou, with a total area of approximately 2.0523 million km², making it an important strategic development region in China. According to the natural division of the Yangtze River mainstream, the study area can be divided into three sections: upstream, midstream, and downstream. The upper reaches includes Chongqing, Sichuan, Guizhou, and Yunnan; the middle reaches includes Jiangxi, Hubei, and Hunan; and the lower reaches includes Shanghai, Jiangsu, Zhejiang, and Anhui [50]. As shown in Figure 1, the study area exhibits a clear west-to-east descending topographic pattern. The upstream region is characterized by relatively high elevations and pronounced topographic relief; the midstream region features an interwoven distribution of lakes and plains; and the downstream region is marked by low-lying terrain and dense river networks. The Yangtze River mainstream and its major tributaries constitute the core physical geographic framework of the study area and provide an important regional geographic background for analyzing the spatial pattern evolution of specialized villages and their influencing factors.

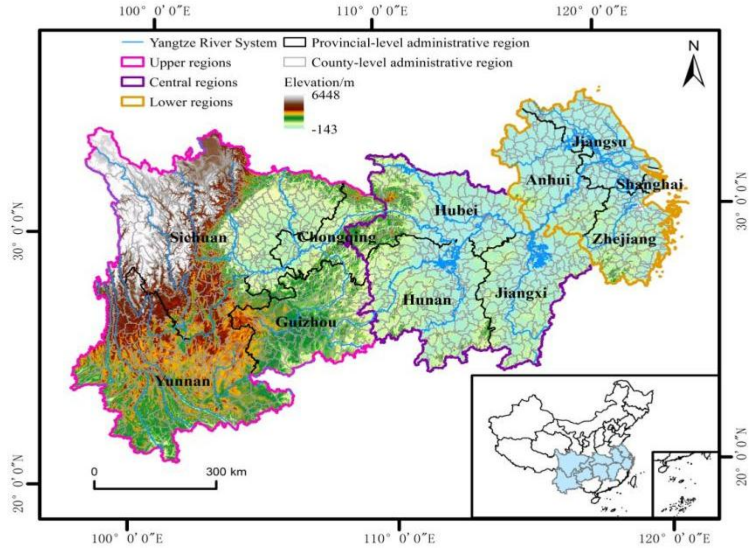

Figure 1 Overview of the Yangtze River Economic Belt Study Area

Note: This figure was produced using standard maps downloaded from the Standard Map Service System of the Ministry of Natural Resources. The main map uses the standard map with approval number GS(2016)1612, and the inset map uses the standard map with approval number GS(2023)2757. The base maps have not been modified. http://bzdt.ch.mnr.gov.cn/

2.2 Data Sources

The data used in this study mainly include spatial data, specialized village data, and county-level socioeconomic data. The spatial data were obtained from the National Earth System Science Data Center of the National Science and Technology Infrastructure Platform, including vector data such as county-level administrative boundaries, provincial boundaries, rivers, road networks, and locations of government seats at different levels, as well as DEM elevation raster data. The specialized village data were derived from the National "One Village, One Product" Statistical Survey System. Based on the rosters of specialized villages and their geographic coordinates for four time points, namely 2008, 2011, 2014, and 2017, a spatial database of specialized villages in the Yangtze River Economic Belt was constructed, and attribute information related to village organization, brand development, market circulation, and quality certification was compiled. County-level socioeconomic data were mainly collected from the China County Statistical Yearbook (2009), the China County Statistical Yearbook (2018), and provincial statistical yearbooks. These data include indicators such as administrative area, cultivated land area, per capita net income of rural residents, highway mileage, per capita GDP, year-end total population, and rural employment. For a small number of missing values in highway mileage, the corresponding prefecture-level city data were used as substitutes.

2.3 Research Methods

This study, based on the ArcGIS 10.8, employs the nearest neighbor index, kernel density estimation, and buffer analysis to measure and analyze the spatial pattern of specialized villages in the Yangtze River Economic Belt and its evolutionary characteristics. It further applies the GeoDetector factor detector model to identify the key driving factors affecting the formation and development of specialized villages and to reveal differences and dynamic changes in the explanatory power of these factors.

2.3.1 Nearest neighbor index

The nearest neighbor index measures the spatial distribution of point features against the benchmark of a random distribution [51]. It is commonly used to analyze point data distributed in space. The formula is as follows:

$$NNI = \frac{\overline{d}_{min}}{E(d_{min})} = \frac{\overline{d}_{min}}{1/2\sqrt{n/A}} \tag{1}$$

where *NNI* denotes the nearest neighbor index; n represents the number of point features, which in this study refers to the number of specialized village samples within the study area; and *A* denotes the area of the study region. $\bar{d}_{\min}$ is the mean nearest-neighbor distance among specialized villages, while $E(d_{\min})$ is the theoretical nearest-neighbor distance under a spatially random distribution. When NNI > 1, the point features tend to be more dispersed overall. When NNI < 1, the point features exhibit spatial clustering. When NNI = 1, the point features follow a random distribution pattern.

2.3.2 Kernel density estimation

Kernel density estimation can reflect differences in the spatial density of geographic events within a given spatial range. It assumes that the density of specialized villages is positively correlated with their probability of occurrence [52]. In this study, this method is used to analyze the spatial density characteristics of specialized villages in the Yangtze River Economic Belt. The formula is as follows:

$$f_t(s) = \frac{1}{\pi r^2}\sum_{i=1}^{n} K(d_{is}/r) \tag{2}$$

where t denotes the year; f_t(s) represents the kernel density estimate at location s in year t; r is the bandwidth; n is the number of specialized villages; d_{is} is the shortest distance from specialized village i to location s; and $K(r)$ denotes the kernel function used in the kernel density estimation.

2.3.3 Spatial autocorrelation

Spatial autocorrelation analysis is mainly used to identify spatial dependence and clustering characteristics of geographic features. In this study, specialized village point data were aggregated to county-level administrative units to generate the variable of the number of specialized villages at the county level. Spatial autocorrelation analysis was then conducted at the county scale. First, Global Moran's I was used to test whether the number of specialized villages in county-level units within the Yangtze River Economic Belt exhibits overall spatial autocorrelation. On this basis, Optimized Hot Spot Analysis was further applied to identify statistically significant hot spots and cold spots in the number of specialized villages [53]. The formula for Global Moran's I is as follows:

$$I = \frac{n}{S_0}\frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i-\bar{x})(x_j-\bar{x})}{\sum_{i=1}^{n}(x_i-\bar{x})^2} \tag{3}$$

where n denotes the number of county-level administrative units; xi and x_j represent the number of specialized villages in county-level administrative units i and j, respectively; $\bar{x}$ is the mean number of specialized villages across all county-level administrative units, w_{ij} denotes the spatial weight between county-level administrative units i and j; and $S_0=\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}$. When Moran's I is significantly greater than 0, the number of specialized villages at the county level shows positive spatial autocorrelation, indicating that county-level units with similar numbers of specialized villages tend to cluster. When Moran's I is significantly less than 0, county-level units with large differences in the number of specialized villages tend to be adjacent. When Moran's I is close to 0, the overall spatial distribution of the number of specialized villages at the county level tends to be random.

Optimized Hot Spot Analysis can automatically determine the analysis scale and identify statistically significant hot spots and cold spots in the number of specialized villages at the county level [54]. Its standardized statistic can be expressed as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij}x_j - \bar{X}\sum_{j=1}^{n} w_{ij}}{S\sqrt{\frac{n\sum_{j=1}^{n} w_{ij}^2 - \left(\sum_{j=1}^{n} w_{ij}\right)^2}{n-1}}} \tag{4}$$

where

$\bar{X} = \frac{1}{n}\sum_{j=1}^{n} x_j$,

and

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \bar{X}^2} \tag{5}$$

where x_{ij} denotes the number of specialized villages in county-level administrative unit j; w_{ij} represents the spatial weight between county-level administrative units i and j; n denotes the number of county-level administrative units; and $\bar{X}$ and S are the mean and standard deviation of the number of specialized villages across all county-level administrative units, respectively. When the Z-score corresponding to G_i^* is significantly positive, the county-level unit and its neighboring units are identified as a high-value cluster of specialized villages, namely a hot spot. When the Z-score is significantly negative, they are identified as a low-value cluster of specialized villages, namely a cold spot. If the Z-score is not statistically significant, the county-level unit and its surrounding area do not form a significant local cluster.

2.3.4 GeoDetector

GeoDetector is a statistical method used to identify spatially stratified heterogeneity and its driving factors. It can measure the explanatory power of influencing factors on the spatial differentiation of geographic phenomena and has been widely applied in fields such as ecological environment, hydrology and meteorology, socioeconomic studies, and regional development [55]. In line with the study objectives of this study, factor detection and interaction detection are employed to analyze the influencing factors and their interactions underlying the spatial differentiation of the number of specialized villages at the county level in the Yangtze River Economic Belt. The factor detector model is expressed as follows:

$$q_{X,U} = 1 - \frac{1}{h\sigma_U^2}\sum_{l=1}^{L} h_{X,l}\,\sigma_{U_{X,l}}^2 \tag{6}$$

where $q_{x,u}$ denotes the explanatory power of influencing factor x on the spatial differentiation of the number of specialized villages at the county level; h is the total number of county-level units in the study area; $h_{x,l}$ represents the number of county-level units in the l-th subregion; σ_U^2 is the overall variance of the study area; and $\sigma_{U_{x,l}}^2$ is the variance of the l-th subregion. The value of $q_{x,u}$ ranges from 0 to 1. A larger value indicates stronger explanatory power of the factor for the spatial differentiation of the number of specialized villages.

The results of interaction detection can be interpreted by comparing the *q* value after factor overlay with the *q* values of individual factors. When $q(X_1 \cap X_2)$ is smaller than the lower *q* value of the two individual factors, the interaction is classified as nonlinear weakening. When it falls between the two individual *q* values, it is classified as single-factor weakening. When it is greater than the larger *q* value of the two individual factors, it indicates two-factor enhancement. When it equals $q(X_1)+ q(X_2)$, the two variables are independent. When it is greater than $q(X_1)+ q(X_2)$ the interaction shows nonlinear enhancement. Continuous influencing factors are discretized before being entered into the model.

3 RESULTS

3.1 Quantity Distribution and Type Structure of Specialized Villages in the Yangtze River Economic Belt

3.1.1 Interprovincial differences in quantity distribution and regional gradient characteristics

At the provincial level, the number of specialized villages in the Yangtze River Economic Belt shows significant interprovincial differences (Table 1). Sichuan Province consistently maintained the highest number of specialized villages, accounting for 33.4% of the total number in the Yangtze River Economic Belt in 2017, making it the province with the highest concentration of specialized villages in the region. Anhui, Jiangsu, Jiangxi, and Hubei also had relatively large numbers of specialized villages, whereas Shanghai had the fewest, with only four in both 2011 and 2014. From 2008 to 2017, the changing trends of specialized village numbers varied markedly across provinces. Sichuan and Jiangsu showed steady growth, with average annual growth rates of 7.98% and 6.30%, respectively. Anhui, Jiangxi, Yunnan, and Chongqing exhibited an increase followed by a decline, with relatively limited fluctuations overall. Hunan, Hubei, and Guizhou showed a decline followed by an increase, while Zhejiang experienced a continuous decrease. Overall, at the provincial scale, specialized villages in the Yangtze River Economic Belt were characterized by "high concentration in a few provinces and differentiated temporal changes across most provinces."

At the regional level, the number of specialized villages showed clear gradient differences among the upstream, midstream, and downstream regions (Table 2). In 2008, 2011, 2014, and 2017, the numbers of specialized villages in the upstream region were 5,001, 5,631, 5,666, and 5,655, respectively, with an average share of 39.96%. The corresponding numbers in the midstream region were 3,589, 3,766, 3,593, and 3,659, with an average share of 28.67%. In the downstream region, the numbers were 3,924, 4,061, 4,216, and 4,041, with an average share of 31.35%. These results indicate that specialized villages were mainly concentrated in the upstream and downstream regions, while the midstream region accounted for a relatively lower proportion, forming a regional distribution pattern characterized by "relatively high concentration in the upstream and downstream regions and a relatively weaker concentration in the midstream region."

This distribution pattern is closely related to regional resource endowments, agricultural foundations, market conditions, and development environments. The upstream region has diverse ecological resources, and its mountainous, hilly, and plateau landscapes provide a diversified natural basis for the development of specialty agriculture. In some areas, relatively abundant labor resources and lower agricultural production costs also facilitate the clustering of specialized villages based on local specialty resources. The downstream region has a stronger economic foundation, higher levels of agricultural technology, stronger market organization capacity, and better transport accessibility. Strong urban consumer demand for high-quality and branded agricultural products has promoted the development of specialized villages toward scaling, branding, and market orientation. In contrast, although the midstream region is rich in plains and lake resources, its capacity for specialty industry cultivation, brand building, and market organization remains relatively insufficient, resulting in a lower proportion of specialized villages than in the upstream and downstream regions. Overall, the quantity distribution of specialized villages in the Yangtze River Economic Belt is the result of the combined effects of resource endowments, industrial foundations, market demand, and regional development levels.

Table 1 Provincial-Level Distribution of Specialized Villages in the Yangtze River Economic Belt

Year	Sichuan	Yunnan	Chongqing	Guizhou	Hunan	Hubei	Jiangxi	Jiangsu	Zhejiang	Anhui	Shanghai	Total
2008	3272	337	388	1004	514	1599	1476	1840	873	1201	10	12514
2011	3985	573	443	630	460	1143	2163	2272	602	1183	4	13458
2014	4493	449	338	386	85	1347	2161	2313	423	1476	4	13475
2017	4461	462	273	459	314	1281	2064	2352	248	1427	14	13355

Note: Data sources from China County Statistical Yearbook (2009, 2018) and the One Village One Product Survey System.

Table 2 Statistics of Specialized Villages in the Upper, Middle, and Lower Reaches of the Yangtze River Economic Belt

Year	Upper Reaches	Middle Reaches	Lower Reaches	Total
2008	5001	3589	3924	12514
2011	5631	3766	4061	13458
2014	5666	3593	4216	13475
2017	5655	3659	4041	13355

Note: The upper reaches include Sichuan, Yunnan, Chongqing, and Guizhou; the middle reaches include Hunan, Hubei, and Jiangxi; the lower reaches include Jiangsu, Zhejiang, Anhui, and Shanghai.

3.1.2 Intercounty differences in quantity distribution and spatial distribution patterns

At the county level, the number of specialized villages in the Yangtze River Economic Belt showed significant differences. In 2017, Yuechi County in Sichuan Province had the largest number of specialized villages, reaching 300. The number of counties without specialized villages reached its peak in 2014. From 2008 to 2017, the average number of specialized villages in counties with specialized villages increased from 15.3 to 19.9, indicating a certain expansion trend in counties where specialized villages already existed, although intercounty differences remained pronounced.

Considering the large differences in the number of specialized villages across counties, this study used the geometric interval method for classification. Since a relatively large number of counties had no specialized villages, these counties were classified separately as the "no specialized villages" category. The remaining counties were divided into five levels—"low," "relatively low," "medium," "relatively high," and "high"—using 3, 9, 25, and 66 as classification thresholds. Based on this classification, ArcGIS 10.8 was used to map the county-level spatial distribution of specialized villages in 2008, 2011, 2014, and 2017 (Figure 2).

In terms of changes across classes, from 2008 to 2017, the number of counties in the "high" category increased from 29 to 44, showing a continuous upward trend, although their overall proportion remained relatively low. The numbers of counties in the "relatively high" and "low" categories remained relatively stable. The proportions of counties in the "medium" and "relatively low" categories continued to decline, while the number of counties in the "none" category fluctuated markedly, reflecting a certain degree of instability in the cultivation of specialized villages in some counties.

Spatially, the county-level distribution of specialized villages showed a pattern of "local clustering and peripheral dispersion." Counties in the "high" and "relatively high" categories were mainly distributed in the Chengdu-Chongqing region, the middle reaches of the Yangtze River, and the Yangtze River Delta, and tended to cluster along the Yangtze River mainstream and major transport corridors. Counties in the "medium" category were mainly distributed in the Sichuan Basin, Jianghan Plain, Dongting Lake Plain, Poyang Lake Plain, and downstream areas along the Yangtze River, showing clear transitional characteristics. Counties in the "relatively low," "low," and "none" categories were more commonly found in mountainous or peripheral areas, such as the western Sichuan Plateau, northwestern Yunnan Plateau, mountainous areas of Guizhou, western Hubei, southwestern Hunan, southern Jiangxi, southwestern Zhejiang, and western Anhui.

Overall, the county-level distribution of specialized villages in the Yangtze River Economic Belt was not characterized by balanced diffusion. Instead, specialized villages tended to cluster in areas along the Yangtze River, areas with better transport accessibility, and areas with stronger agricultural foundations, while they were relatively sparse in remote mountainous areas, high-altitude regions, and some ecologically fragile areas. This suggests that county-level specialized village development is influenced not only by agricultural resource endowments, but also by terrain conditions, transport accessibility, market linkages, and regional industrial foundations.

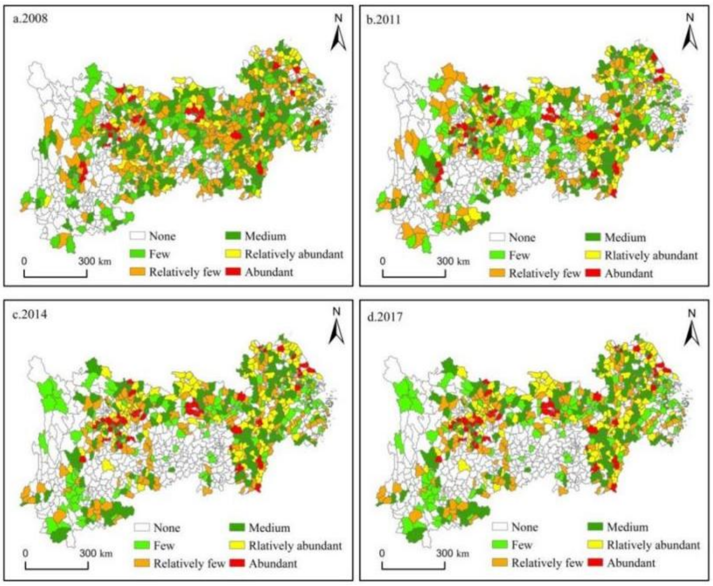

Figure 2 Schematic Map of the Number of specialized villages in the Yangtze River Economic Belt at the County Level

Note: Yangtze River Delta Science Data Center, National Earth System Science Data Center, National Science & Technology Infrastructure of China (https://www.geodata.cn/data/datadetails.html?dataguid=124662254116753&docid=16639)

3.1.3 County-level spatial clustering and spatial differentiation characteristics

(1)Global spatial autocorrelation analysis

Based on ArcGIS 10.8, this study conducted a global spatial autocorrelation test on the number of specialized villages at the county level in the Yangtze River Economic Belt from 2008 to 2017 (Table 3). The results show that Moran's I values were greater than 0 in all years, and all Z-values were statistically significant. This indicates a significant positive spatial correlation in the number of specialized villages at the county level. In other words, high-value counties tended to be adjacent to other high-value counties, while low-value counties tended to be adjacent to other low-value counties. The spatial pattern of specialized villages was therefore not randomly formed, but exhibited clear spatial clustering characteristics.

From a temporal perspective, Moran's I increased overall from 0.1285 in 2008 to 0.1874 in 2017. Although the value in 2017 was slightly lower than that in 2014, the overall trend still indicates an increase, suggesting that the county-level spatial clustering degree of specialized villages in the Yangtze River Economic Belt generally strengthened during the study period.

Table 3 Global Spatial Autocorrelation Coefficients of Specialized Villages at the County Level in the Yangtze River Economic Belt

Year	2008	2011	2014	2017
Moran's *I*	0.1285	0.1314	0.1897	0.1874
Z-value	14.623	15.053	21.670	21.400

(2)Optimized Hot Spot Analysis

The results of Optimized Hot Spot Analysis show that the number of specialized villages at the county level in the Yangtze River Economic Belt presented a clear spatial differentiation pattern of hot spots and cold spots. The spatial extent of both hot spot and cold spot clusters generally expanded over time, indicating increasingly significant spatial clustering. At the 99% confidence level, hot spot and cold spot counties accounted for a relatively large number of county-level units, and both showed an evolutionary trend from scattered local patches toward contiguous clusters. Based on Figure 3, the spatial clustering characteristics at the 99% confidence level are analyzed below.

From 2008 to 2017, the numbers of hot spot counties were 200, 233, 305, and 299, respectively. In 2008, hot spots were mainly formed in the Chengdu-Chongqing region and some counties in Hubei, but their spatial extent was relatively limited and they had not yet formed an obvious contiguous pattern. In 2011, hot spots around the Wuhan metropolitan area weakened, while the hot spot area in the Chengdu-Chongqing region expanded markedly and gradually became contiguous. Meanwhile, a new hot spot cluster emerged in Jiangxi. By 2014, the hot spot area in the Yangtze River Delta had expanded significantly and, together with the Chengdu-Chongqing region, formed an east-west hot spot pattern for specialized village development in the Yangtze River Economic Belt. Both the spatial scale and statistical significance of hot spots further increased. In 2017, the hot spot pattern remained generally stable, with the main hot spots still concentrated in the Chengdu-Chongqing region and the Yangtze River Delta, and no substantial change in spatial structure was observed.

From 2008 to 2017, the numbers of cold spot counties were 144, 215, 360, and 352, respectively. In 2008, cold spots were mainly scattered in central Yunnan and central Hunan, with a relatively small spatial extent and no continuous distribution pattern. In 2011, the cold spot area in central Yunnan and southwestern Guizhou expanded markedly, while cold spots in central Hunan continued to extend. At the same time, scattered cold spots appeared in the southern wing of the Yangtze River Delta, indicating a shift from local block-like distribution to multiple expanding cold spot areas. In 2014, cold spots became more contiguous, and a relatively large low-value clustering belt gradually formed across central Yunnan, southwestern Guizhou, central Hunan, and central Jiangxi. The cold spot area reached a phased peak, suggesting a significant strengthening of low-value spatial clustering. In 2017, the cold spot pattern in southwestern and south-central China remained largely stable, while cold spots in the southern wing of the Yangtze River Delta weakened. Overall, a relatively stable spatial differentiation pattern characterized by "hot spots in the east and west, and cold spots in parts of the central and southwestern regions" had formed.

Overall, the number of specialized villages at the county level in the Yangtze River Economic Belt showed significant spatial clustering and regional differentiation. Hot spots were mainly concentrated in the Chengdu-Chongqing region and the Yangtze River Delta, while cold spots were mainly distributed in mountainous or relatively peripheral areas, such as central Yunnan, southwestern Guizhou, central Hunan, and central Jiangxi. In general, during the study period, specialized villages in the Yangtze River Economic Belt gradually formed a spatial differentiation pattern with the Chengdu-Chongqing region and the Yangtze River Delta as the main hot spots, and parts of the central and southwestern mountainous areas as the main cold spots.

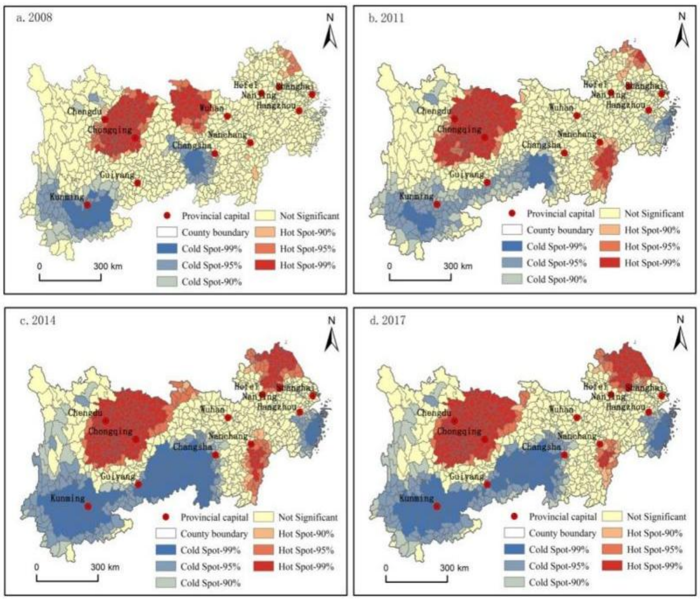

Figure 3 Hot Spot Analysis of the Number of specialized villages at the County Level in the Yangtze River Economic Belt

Note: Yangtze River Delta Science Data Center, National Earth System Science Data Center, National Science & Technology Infrastructure of China (https://www.geodata.cn/data/datadetails.html?dataguid=124662254116753&docid=16639)

3.1.4 Type structure and evolutionary characteristics of specialized villages

A statistical analysis of the type structure of specialized villages in the Yangtze River Economic Belt (Table 4) shows that, from 2008 to 2017, the type structure was characterized by the absolute dominance of agricultural production-oriented villages and the relative contraction of agriculture-related service-oriented and non-agricultural industry-oriented villages. Agricultural production-oriented specialized villages consistently occupied the dominant position, accounting for 96.51% in 2017, indicating that agricultural production remained the core foundation for specialized village development in the Yangtze River Economic Belt. The number of agriculture-related service-oriented villages declined slightly, but their internal structure changed significantly, with rapid growth in leisure agriculture and marked shrinkage in traditional processing and marketing types. Non-agricultural industry-oriented specialized villages experienced the largest decline, reflecting insufficient development momentum in this category and the need to further enhance industrial diversification and integration. Overall, the type structure of specialized villages in the Yangtze River Economic Belt showed an evolutionary pattern of "dominance of agricultural production-oriented villages, transformation of service-oriented villages, and contraction of non-agricultural industry-oriented villages."

Table 4 Distribution of Specialized Villages Types in the Yangtze River Economic Belt , 2008–2017

Year	Agricultural Production Type	Agricultural Service Type	Non-agricultural Industry Type	Total
2008	11883	293	338	12514
2011	12859	312	287	13458
2014	12940	302	233	13475
2017	12889	270	196	13355

Note: Agricultural production type includes crop, livestock, aquaculture, and forestry; Agricultural service type includes processing, distribution, and leisure agriculture; Non-agricultural industry type refers to industrial activities.

(1)Agricultural Product Production-Oriented Specialized Villages

The internal structure of agricultural product production-oriented specialized villages in the Yangtze River Economic Belt was dominated by planting-related product types, showing an evolutionary pattern in which the dominance of planting continued to strengthen while other types fluctuated relatively (Table 5). From 2008 to 2017, the number of planting-related product types increased from 8,329 to 9,761, and their share rose from 70.1% to 75.7%, indicating that the core position of planting in agricultural product production-oriented specialized villages was further strengthened. The number of animal husbandry-related product types first increased and then declined, reaching 1,863 in 2011 before gradually falling to 1,582 in 2017. Aquatic product types showed an overall fluctuating downward trend, with relatively stable scale but insufficient growth. Forestry product types fluctuated markedly, with a certain rebound in 2017 compared with 2011. Other agricultural product types were relatively small in number but showed a slight upward trend. Overall, agricultural product production-oriented specialized villages in the Yangtze River Economic Belt remained dominated by planting, while animal husbandry, aquatic products, forestry, and other types were relatively underdeveloped. The degree of industrial diversification still needs to be improved. In the future, on the basis of consolidating the advantages of planting, differentiated development of specialized villages related to animal husbandry, aquatic products, forestry, and other specialty agricultural products should be promoted to further optimize the industrial structure of specialized villages.

Table 5 Distribution of Agricultural Production Subtypes in Specialized Villages, 2008–2017

Year	Crop Production	Livestock	Aquaculture	Forestry	Other agricultural products	Total
2008	8329	1775	782	965	32	11883
2011	9557	1863	692	712	35	12859
2014	9680	1660	728	838	34	12940
2017	9761	1582	682	772	91	12889

Note: Crop production includes cereals and vegetables; Livestock includes pigs, cattle, and poultry; Aquaculture includes freshwater products; Forestry includes timber and forest products; Other agricultural products include specialty crops.

(2)Agriculture-Related Service-Oriented Specialized Villages

From 2008 to 2017, agriculture-related service-oriented specialized villages in the Yangtze River Economic Belt showed clear internal structural transformation (Table 6). Agricultural product processing was once an important component of this type, with the number remaining above 100 from 2008 to 2014, but it dropped sharply to 21 in 2017, indicating a marked contraction of traditional processing activities. The number of agricultural product marketing-oriented specialized villages continued to decline, falling to zero in 2017. In contrast, leisure agriculture-oriented specialized villages continued to grow, increasing from 72 in 2008 to 193 in 2017, making it the fastest-growing type among agriculture-related service-oriented specialized villages. Other agriculture-related service types fluctuated and did not form a stable growth trend.

Overall, agriculture-related service-oriented specialized villages are undergoing a structural transformation from “processing and marketing-oriented” development toward “leisure and experiential” development. This reflects the coexistence of weakening traditional agriculture-related service momentum and growing demand for leisure agriculture.

Table 6 Classification Statistics of Agriculture-related Service-oriented Specialized Villages in the Yangtze River Economic Belt, 2008–2017

Year / Type	2008	2011	2014	2017
Agricultural Product Processing	159	145	133	21
Agricultural Product Distribution	12	22	5	0
Agritourism	72	101	130	193
Other Agriculture-Related Services	50	44	34	56
Total	**293**	**312**	**302**	**270**

(3)Non-Agricultural Industry-Oriented Specialized Villages

From 2008 to 2017, non-agricultural industry-oriented specialized villages in the Yangtze River Economic Belt showed an evolutionary pattern of continuous decline in quantity and increasing structural concentration (Table 7). The total number of this type decreased from 338 to 196, a decline of more than 40%, making it the most significantly shrinking category among the three types of specialized villages. From the perspective of internal structure, except for the “other non-agricultural industries” category, which maintained a relatively high number and increased to 135 in 2017, traditional subtypes such as arts and crafts, construction materials, hardware and electrical products, resource recycling, and transportation all showed downward trends, with some subtypes even temporarily falling to zero.

Overall, non-agricultural industry-oriented specialized villages in the Yangtze River Economic Belt had relatively insufficient development momentum. Their internal structure became increasingly dependent on the “other non-agricultural industries” category, while the diversity of subtypes declined. This indicates that specialized village development in the region remained dominated by agriculture-related industries, and the transformation, upgrading, and continuous cultivation of non-agricultural industry-oriented specialized villages still need to be further strengthened.

Table 7 Classification Statistics of Non-agricultural Industry-oriented Specialized Villages in the Yangtze River Economic Belt, 2008–2017

Year / Type	2008	2011	2014	2017
Handicrafts and Gifts	25	20	22	10
Apparel and Accessories	14	15	18	11
Stationery and Educational Supplies	23	9	8	5
Plastic Products	4	9	5	8
Household Goods	25	16	31	7
Construction Materials	40	34	27	10

Year / Type	2008	2011	2014	2017
Hardware and Electrical Supplies	46	30	17	3
Packaging and Printing	7	0	3	0
Transportation	22	13	11	5
Resource Recycling	31	19	5	2
Other Non-Agricultural Industries	101	122	86	135
Total	**338**	**287**	**233**	**196**

3.2 Spatial Pattern Evolution of Specialized Villages in the Yangtze River Economic Belt

3.2.1 Spatial clustering pattern

Based on the ArcGIS 10.8, this study applied the nearest neighbor index to analyze the spatial distribution of specialized villages in the Yangtze River Economic Belt from 2008 to 2017 (Table 8). The results show that the nearest neighbor index was less than 1 in all years, the Z-scores were all lower than −2.58, and the P-values were all less than 0.01. These results indicate that the spatial distribution of specialized villages in the Yangtze River Economic Belt significantly deviated from randomness and exhibited a clear spatial clustering pattern.

From a temporal perspective, the average observed distance decreased from 3.97 km in 2008 to 3.64 km in 2017 and was consistently much lower than the expected average distance under random distribution. The nearest neighbor index decreased from 0.50 in 2008 to 0.46 in 2014 and then slightly increased to 0.47 in 2017, but it remained at a low level overall. This suggests that the spatial clustering of specialized villages in the Yangtze River Economic Belt generally strengthened during the study period, with specialized villages becoming increasingly concentrated in core areas. This result provides a basis for further identifying core agglomeration areas and their spatial evolution characteristics.

Table 8 Nearest Neighbor Index of Specialized Villages in the Yangtze River Economic Belt, 2008–2017

Year	Average observed distance /km	Expected average distance /km	NNI	Z-value	P-value	Area of the study area /km²
2008	3.97	7.93	0.5	-106.92	0.00	3149437.41
2011	3.73	7.73	0.48	-114.97	0.00	3219030.31
2014	3.6	7.74	0.46	-118.63	0.00	3221483.01
2017	3.64	7.74	0.47	-117.19	0.00	3197295.97

3.2.2 Spatial distribution density and core agglomeration areas

To further identify the core agglomeration areas of specialized villages in the Yangtze River Economic Belt, this study conducted kernel density estimation using specialized village point data for 2008, 2011, 2014, and 2017 (Figure 4). The results show that the maximum kernel density values for the four years were 0.0309, 0.0369, 0.0398, and 0.0402 villages/km², respectively, showing an generally upward trend. This indicates that the concentration degree of high-density agglomeration areas continued to increase.

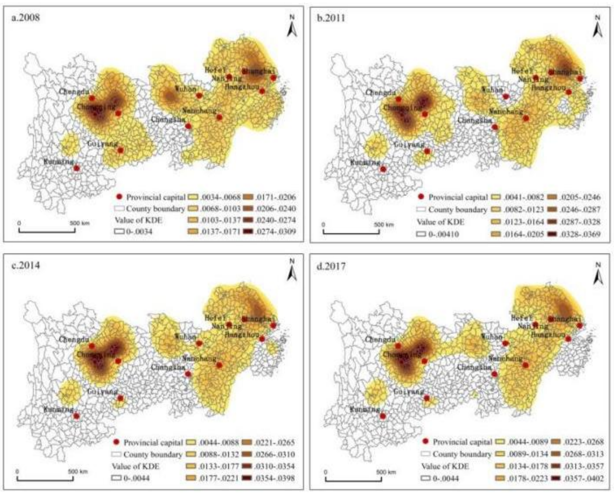

Figure 4 Distribution Map of Estimated Kernel Density for Location Distribution of Specialized Villages in the Yangtze River Economic Belt(2008-2017).

Note: Yangtze River Delta Science Data Center, National Earth System Science Data Center, National Science & Technology Infrastructure of China (https://www.geodata.cn/data/datadetails.html?dataguid=124662254116753&docid=16639)

In terms of core distribution areas, the high-density areas of specialized villages remained relatively stable from 2008 to 2017. They were mainly located in the southeastern Sichuan Basin and northeastern Sichuan in the upstream region, as well as parts of central Jiangsu in the downstream region. Specifically, the upstream core areas were mainly concentrated in Zigong, Neijiang, Meishan, Guang'an, and surrounding counties in Sichuan Province. The downstream core areas were mainly distributed in Taizhou, Yancheng, and neighboring counties in Jiangsu Province. These areas had concentrated numbers of specialized villages and strong spatial continuity, making them the main core agglomeration areas of specialized village development in the Yangtze River Economic Belt.

Secondary core areas showed both relative stability and dynamic change. Relatively stable secondary core areas were mainly located in Yichang in Hubei Province, northern Jiangxi, and southwestern Jiangxi. Areas with more obvious changes mainly appeared in Guiyang and Anshun, which showed a certain degree of clustering in the early stage but gradually weakened over time. Central Anhui and eastern Hubei had relatively low kernel density values, while most other areas in the upstream and midstream regions had kernel density values close to zero.

Overall, the spatial distribution of specialized villages in the Yangtze River Economic Belt showed significant uneven agglomeration. Core areas were mainly concentrated in parts of the Sichuan Basin and central Jiangsu, while secondary core areas were relatively scattered and showed phased changes. This indicates that specialized village development is jointly influenced by regional agricultural foundations, transport conditions, market linkages, and the cultivation of local specialty industries.

3.2.3 Terrain-related distribution characteristics

From the perspective of elevation distribution, specialized villages in the Yangtze River Economic Belt were mainly concentrated in low-elevation areas (Table 9). From 2008 to 2017, areas below 200 m had the largest number of specialized villages, accounting for approximately 45% of the total on average. The number of specialized villages in the 200–500 m elevation range increased overall, rising from 3,414 in 2008 to 4,146 in 2017. The numbers in the 500–1,000 m, 1,000–1,500 m, and 1,500–2,000 m elevation ranges changed relatively little. Specialized villages above 2,000 m were relatively few, accounting for approximately 1.92% of the total on average, and there were almost no specialized villages above 5,000 m. Overall, specialized villages in the Yangtze River Economic Belt were highly concentrated in low-elevation and gentle-terrain areas, suggesting that such areas have more obvious advantages in agricultural production conditions, transport accessibility, and population concentration.

Spatially, specialized villages below 200 m were mainly distributed in the middle and lower Yangtze River plains, including Hubei, eastern Hunan, Jiangxi, Jiangsu, and Anhui. Those in the 200–500 m elevation range were mainly located in the Sichuan Basin, the hilly areas of southern Jiangxi, and the low hilly areas of southern Anhui. Areas above 500 m were more commonly found in eastern Yunnan-Guizhou Plateau, the western margin of the Sichuan Basin, and the eastern Yunnan Plateau, where the number of specialized villages declined markedly. This indicates that elevation conditions impose clear constraints on the spatial distribution of specialized villages, and low-elevation areas are more conducive to their formation and agglomeration.

From the perspective of slope distribution, the number of specialized villages in the Yangtze River Economic Belt decreased significantly as slope increased (Table 10). From 2008 to 2017, areas with slopes below 5° accounted for an absolute majority of specialized villages, with an average share of about 87.5%. Among them, the 0°–0.5° slope range had the largest number of specialized villages, accounting for approximately 41.62% on average. The numbers in the 0.5°–2° and 2°–5° slope ranges were relatively stable, with average shares of approximately 28.15% and 17.60%, respectively. In contrast, the number of specialized villages in the 15°–35° slope range was relatively small, with only 43 in 2008, indicating that steep terrain strongly restricts the formation and development of specialized villages.

Spatially, specialized villages in the 0°–2° slope range were mainly distributed in the Sichuan Basin, the eastern Hubei Plain, Anhui, and Jiangsu. Those in the 2°–15° slope range were mainly distributed in western Sichuan, Yunnan, and Guizhou, where hilly and mountainous terrain is more common. Overall, plains, low hills, and gentle slopes are the main suitable terrain types for the formation and development of specialized villages in the Yangtze River Economic Belt, whereas specialized villages are relatively sparse in high-elevation, steep-slope, and fragmented-terrain areas.

Table 9 Statistics of Specialized Villages in Different Elevation Zones of within the Yangtze River Economic Belt

Altitude(m)	2008	2011	2014	2017
0-200	5877	5990	6149	5953
200-500	3414	3853	4132	4146
500-1000	1955	2074	1799	1897
1000-1500	796	876	675	678
1500-2000	333	390	390	381
2000-3000	119	234	291	262
3000-4000	17	39	37	35
4000-7213	3	2	2	3

Note: Altitude levels represent the elevation of village locations.

Table 10 Statistics of Specialized Villages in Different Slope Zones of the Yangtze River Economic Belt

Slope (°)	2008	2011	2014	2017
0-0.5	5240	5503	5656	5586
0.5-2	3614	3719	3793	3758
2-5	2289	2478	2283	2248
5-15	1327	1687	1641	1665
15-35	43	71	102	98

Note: Slope levels represent the average slope of village locations.

3.2.4 River-proximity distribution characteristics

Rivers play an important role in shaping the spatial distribution of specialized villages. On the one hand, rivers provide stable water resources for agricultural production and rural life. On the other hand, riverine areas often have favorable terrain, soil, and transport conditions, which are conducive to the production of specialty agricultural products and the formation of specialized villages. Based on ArcGIS 10.8, this study constructed 15 km multi-level buffer zones with an interval of 1 km for rivers of Grade 5 and above in the Yangtze River Economic Belt to analyze the spatial relationship between specialized villages and rivers.

The results show that in 2008, 2011, 2014, and 2017, the numbers of specialized villages located within 15 km of rivers were 10,393, 10,841, 10,903, and 10,747, respectively, accounting for 83.05%, 80.55%, 80.91%, and 80.47% of the total number of specialized villages in the Yangtze River Economic Belt in the corresponding years. This indicates that most specialized villages were distributed near rivers and had a clear spatial dependence on the river system.

In terms of buffer distance, the number of specialized villages reached its maximum within the 1 km buffer zone in all years, with 1,291, 1,260, 1,250, and 1,206 villages, respectively. As the distance from rivers increased, the number of specialized villages generally declined. This suggests that specialized villages in the Yangtze River Economic Belt tended to be located close to rivers, and that water accessibility, flat river-valley terrain, and transport conditions along rivers jointly influenced their spatial layout.

Overall, specialized villages in the Yangtze River Economic Belt showed a clear river-proximity pattern, and riverine areas served as important spatial carriers for their formation and development. This finding suggests that the optimization of specialized village layout and the development of specialty agriculture should take into account the coordination between river system conditions, resource utilization along rivers, and ecological protection.

3.2.5 Road-proximity distribution characteristics

Road transport conditions are important locational factors influencing the formation and development of specialized villages. Road networks affect not only the transport costs and market accessibility of agricultural products, but also the circulation of agricultural inputs, industrial organization linkages, and the scale development of specialized villages. Based on ArcGIS 10.8, this study constructed 15 km multi-level buffer zones with an interval of 1 km for national roads, provincial roads, and county roads in the Yangtze River Economic Belt to analyze the spatial relationship between specialized villages and transport corridors.

The results show that from 2008 to 2017, the spatial distribution of specialized villages in the Yangtze River Economic Belt exhibited a clear orientation toward transport corridors. A relatively large number of specialized villages were distributed around national roads, provincial roads, and county roads, with the largest number located within the 1 km buffer zone. As the buffer distance increased, the number of specialized villages generally decreased, indicating a clear road-proximity clustering pattern.

Different types of roads played different roles. National and provincial roads had strong spatial guiding effects on the distribution of specialized villages, mainly by supporting interregional agricultural product circulation and market linkages. County roads directly connected rural settlements and agricultural production spaces within counties, thereby playing an important role in daily production organization and product transport. During the study period, the clustering of specialized villages along county roads gradually strengthened, suggesting that county-level transport networks played an increasingly important supporting role in specialized village development.

Overall, the spatial layout of specialized villages in the Yangtze River Economic Belt was closely related to the transport network, showing a road-proximity clustering pattern jointly supported by national, provincial and county roads. Transport accessibility not only affects the locational choice of specialized villages, but also promotes their evolution from scattered point distribution toward axial agglomeration.

3.3 Influencing factors of spatial differentiation of specialized villages in the Yangtze River Economic Belt

Considering the natural conditions, economic foundation, market environment, technological support, institutional construction, and cultural branding related to the formation and development of specialized villages in the Yangtze River Economic Belt, this study selects 17 county-level indicators for GeoDetector analysis. Natural factors include elevation (X_1) , precipitation (X_2), and river network density (X_3). Economic foundation factors include road network density (X_4), per capita cultivated land area (X_5), rural employees (X_6), per capita GDP (X_7), and per capita net income of farmers (X_8). Market scale is represented by agricultural wholesale markets (X_9). Quality certification factors include pollution-free product certification (X_{10}), green food certification (X_{11}), and organic food certification (X_{12}). Institutional construction factors include leading agribusinesses (X_{13}) and farmers' professional cooperatives (X_{14}). Cultural branding factors include registered trademarks (*X_{15}*), provincial-level or higher famous-brand products (X_{16}), and geographical indication products (*X_{17}*).

Table 11 Indicators and Classification Criteria for GeoDetector analysis

Factor	Level 1district	Level 2district	Level 3district	Level 4district	Level 5district	Level 6district	Level 7district	Level 8district
X_1	≤200	200~500	500~1000	1000~1500	1500~2000	2000~3000	3000~4000	≥4000
X_2	≤800	800~1200	＞1200	—	—	—	—	—
X_3	≤0.01	0.01~0.02	0.02~0.03	0.03~0.05	0.05~0.06	0.06~0.09	0.09~0.14	＞0.14
X_4	≤0.35	0.35~0.65	0.65~0.91	0.91~1.2	1.2~1.5	1.5~1.92	1.92~2.87	＞2.87
X_5	≤0.03	0.03~0.04	0.04~0.06	0.06~0.08	0.08~0.12	0.12~0.19	0.19~0.37	＞0.37
X_6	≤8.7	8.7~14.4	14.4~20.2	20.2~27.7	27.7~37	37~48.35	48.35~63.74	＞63.74
X_7	≤0.66	0.66~0.98	0.98~1.34	1.34~1.94	1.94~3.23	3.23~5.83	5.83~10	＞10
X_8	≤0.28	0.28~0.37	0.37~0.46	0.46~0.57	0.57~076	0.76~1.03	1.03~2.03	＞2.03
X_9	≤1	1~4	4~9	9~14	14~19	19~25	25~36	＞36
X_{10}	≤2	2~6	6~12	12~20	20~29	29~39	39~62	＞62
X_{11}	≤1	1~4	4~8	8~13	13~21	21~32	32~46	＞46
X_{12}	0	0~2	2~4	4~7	7~10	10~15	15~22	＞22
X_{13}	≤2	2~6	6~11	11~17	17~23	23~36	36~57	＞57
X_{14}	≤4	4~9	9~17	17~26	26~36	36~52	52~90	＞90
X_{15}	≤2	2~6	6~12	12~20	20~30	30~41	41~60	＞60
X_{16}	≤1	1~4	4~7	7~11	11~16	16~24	24~54	＞54
X_{17}	0	0~2	2~6	6~10	10~14	14~23	23~49	＞49

Note: "~" means the left end is excluded and the right end is included; "—" indicates that the corresponding category is not applicable.

Since GeoDetector requires independent variables to be input as categorical or stratified variables, all influencing factors were discretized before analysis. Specifically, elevation was classified into eight levels according to China's geomorphic regionalization standard [56]. Precipitation was divided into three categories—≤800 mm, 800 - 1200 mm, and >1200 mm—based on the precipitation characteristics of the study area and with reference to China's climatic regionalization scheme [57]. Other county-level indicators were discretized using the natural breaks method in ArcGIS 10.8 to improve the comparability of variables in spatial detection. The classification criteria for all indicators are shown in Table 11.

To reveal changes in the influencing factors of spatial differentiation of specialized villages at different stages, this study selected 2008 and 2017 for GeoDetector analysis. In the full-region analysis, to reduce the interference of low-frequency samples on the model results, 622 county-level units with more than two specialized villages were included in the model for 2008. For 2017, to enhance cross-period comparability, 440 county-level units with more than two specialized villages in both 2017 and 2008 were included in the model. Considering the substantial differences in natural environment, industrial foundation, and development conditions among the upstream, midstream, and downstream regions of the Yangtze River Economic Belt, this study further conducted regional analysis. In the regional analysis, all county-level units with specialized villages were included in the model. Specifically, in 2008, 301, 263, and 234 county-level units were included in the upstream, midstream, and downstream regions, respectively; in 2017, the corresponding numbers were 275, 196, and 175, ensuring the representativeness of the regional results.

3.3.1 Full-region analysis of influencing factors

The factor detection results show that, in both 2008 and 2017, the core factors influencing the spatial differentiation of specialized villages across the Yangtze River Economic Belt were mainly concentrated in institutional construction, cultural branding, quality certification, and market scale (Table 12). Among them, farmers' professional cooperatives (X_{14}) ranked first in explanatory power in both years, with the q-value increasing from 0.7403 in 2008 to 0.7861 in 2017. Registered trademarks (X_{15}) also showed strong explanatory power, with the q-value increasing from 0.4566 to 0.5159. Pollution-free product certification (X_{10}), green food certification (X_{11}), leading agribusinesses (X_{13}), and agricultural wholesale markets (X_9) also demonstrated relatively strong explanatory power. In contrast, natural factors such as elevation, precipitation, and river network density, as well as some economic foundation indicators, generally had lower q-values, indicating that the spatial differentiation of specialized villages in the Yangtze River Economic Belt was more strongly influenced by human and economic factors such as organizational development, branding, quality certification, and market conditions.

The interaction detection results indicate that, in both 2008 and 2017, the explanatory power of major interacting factors was higher than that of individual factors, and the interaction types were mainly bi-factor enhancement and nonlinear enhancement (Tables 13 and 14). In 2008, the top six interaction combinations in the full region were all centered on farmers' professional cooperatives. Strong interactions were observed between farmers' professional cooperatives and provincial-level or higher famous-brand products, registered trademarks, geographical indication products, leading agribusinesses, and pollution-free product certification, indicating a clear synergistic effect among institutional organization, branding, technology, and market entities. In 2017, interactions between farmers' professional cooperatives and green food certification, river network density, leading agribusinesses, geographical indication products, road network density, and pollution-free product certification became prominent. This suggests that the spatial distribution of specialized villages shifted from being driven primarily by institutional organization toward a joint mechanism involving institutions, technology, markets, transport, and resource conditions.

Overall, the dominant mechanism shaping the spatial differentiation of specialized villages in the Yangtze River Economic Belt has gradually shifted from constraints imposed by natural conditions and basic economic conditions toward the combined effects of institutional organization, brand building, quality certification, and market systems. Farmers' professional cooperatives remained the most important explanatory factor, indicating that the level of organization is a key foundation for the formation, agglomeration, and sustained development of specialized villages. The increasing explanatory power of branding and quality certification factors suggests that specialized village development is gradually shifting from quantity expansion toward quality improvement and enhanced market competitiveness.

3.3.2 Regional heterogeneity of influencing factors

(1)Upstream Region. The core factors influencing the spatial differentiation of specialized villages in the upstream region were mainly concentrated in institutional construction, cultural branding, and quality certification. In 2008, the most influential factors were farmers' professional cooperatives (0.7753), registered trademarks (0.4933), pollution-free product certification (0.4756), provincial-level or higher famous-brand products (0.3475), agricultural wholesale markets (0.3268), and leading agribusinesses (0.2842). In 2017, farmers' professional cooperatives still ranked first, with a q-value of 0.7815, while registered trademarks, pollution-free product certification, green food certification, leading agribusinesses, and agricultural wholesale markets also showed relatively strong explanatory power. These results indicate that the spatial differentiation of specialized villages in the upstream region was jointly influenced by cooperative organizations, brand building, quality certification, and market foundations.

The interaction detection results show that high-explanatory interaction combinations in the upstream region were still mainly centered on farmers' professional cooperatives. In 2008, strong interactions were found between farmers' professional cooperatives and road network density, provincial-level or higher famous-brand products, registered trademarks, river network density, rural employees, and geographical indication products. In 2017, farmers' professional cooperatives formed strong interactions with green food certification, river network density, leading agribusinesses, rural employees, provincial-level or higher famous-brand products, and geographical indication products.

This indicates that the development of specialized villages in the upstream region relies not only on institutional support such as cooperatives, but also increasingly on quality certification, brand building, labor foundations, and natural resource conditions. With intensifying market competition, specialized villages in the upstream region need to further improve their level of organization, branding, and standardization to strengthen the transformation capacity of local specialty agricultural resources.

(2)Midstream Region. The spatial differentiation of specialized villages in the midstream region also showed strong institutional and branding effects. In 2008, farmers' professional cooperatives (0.7633), registered trademarks (0.5321), leading agribusinesses (0.4992), pollution-free product certification (0.4564), green food certification (0.3548), and provincial-level or higher famous-brand products (0.3307) had relatively strong explanatory power. In 2017, the explanatory power of farmers' professional cooperatives further increased to 0.8704, while registered trademarks, pollution-free product certification, leading agribusinesses, green food certification, and provincial-level or higher famous-brand products remained among the leading factors. This suggests that the distribution of specialized villages in the midstream region was mainly affected by cooperative organizations, brand building, quality certification, and the driving role of leading agribusinesses.

The interaction detection results show that in 2008, the top six high-explanatory interaction combinations in the midstream region all showed bi-factor enhancement. These combinations mainly involved farmers' professional cooperatives interacting with green food certification, registered trademarks, leading agribusinesses, provincial-level or higher famous-brand products, pollution-free product certification, and agricultural wholesale markets. In 2017, interactions between farmers' professional cooperatives and per capita GDP, river network density, leading agribusinesses, pollution-free product certification, rural employees, and agricultural wholesale markets became more prominent. This indicates that the development of specialized villages in the midstream region initially relied more on the synergistic effects of institutional, branding, technological, and market factors, while later increasingly reflected the importance of county-level economic foundations, human resources, and natural conditions.

Therefore, the midstream region should further enhance county-level economic support capacity, improve industrial chains, and strengthen the market competitiveness of specialty agricultural products while consolidating cooperative organizations and brand systems.

(3)Downstream region. The spatial differentiation of specialized villages in the downstream region was jointly influenced by institutional organization, brand building, quality certification, and market conditions. In 2008, farmers' professional cooperatives (0.7678), leading agribusinesses (0.5867), registered trademarks (0.5812), pollution-free product certification (0.5363), agricultural wholesale markets (0.5122), and green food certification (0.3994) showed strong explanatory power. In 2017, the explanatory power of farmers' professional cooperatives increased to 0.9194, while registered trademarks reached 0.6286; pollution-free product certification, agricultural wholesale markets, leading agribusinesses, and green food certification also maintained relatively high explanatory power. These results indicate that the spatial differentiation of specialized villages in the downstream region was closely associated with market systems, organizational networks, brand building, and technical standards.

The interaction detection results show that in 2008, the top six high-explanatory interaction combinations in the downstream region mainly reflected bi-factor enhancement between farmers' professional cooperatives and provincial-level or higher famous-brand products, agricultural wholesale markets, registered trademarks, organic food certification, rural employees, and pollution-free product certification. In 2017, interactions between farmers' professional cooperatives and pollution-free product certification, agricultural wholesale markets, river network density, per capita cultivated land area, green food certification, and per capita GDP became prominent. This suggests that, under conditions of relatively high marketization and a strong industrial foundation, specialized villages in the downstream region gradually shifted from joint institutional, market, and brand-driven development toward a composite mechanism in which institutional organization coordinates quality certification, market circulation, resource conditions, and economic foundations.

Overall, specialized villages in the downstream region already have relatively strong market and brand foundations. However, as their scale expands, factors such as water system conditions, cultivated land resources, and county-level economic development increasingly influence their spatial layout. Therefore, the downstream region should continue to strengthen cooperative organizations, leading agribusinesses, brand certification, and market systems while also considering resource and environmental constraints and land-use efficiency, thereby promoting high-quality and sustainable development of specialized villages.

Table 12 GeoDetector Factor Detection Results for 2008 and 2017

Influencing Factor	Yangtze River Economic Belt		Upstream		Midstream		Downstream	
	2008	2017	2008	2017	2008	2017	2008	2017
X_1	0.0210	0.0286	0.0997	0.1689	0.0196	0.0201	0.0056	0.0170
X_2	0.0110	0.0035	0.0133	0.0123	0.0391	0.0014	0.0042	0.0713
X_3	0.0164	0.0265	0.0351	0.0600	0.0545	0.0360	0.0414	0.0464
X_4	0.0341	0.0209	0.0960	0.0482	0.0192	0.0279	0.0254	0.1249
X_5	0.0057	0.0389	0.0318	0.0670	0.0139	0.0124	0.0176	0.0708
X_6	0.0452	0.0857	0.0906	0.1356	0.0525	0.0428	0.1166	0.2216
X_7	0.0112	0.0164	0.0265	0.0181	0.0495	0.1630	0.0372	0.0275
X_8	0.0175	0.0056	0.0762	0.0266	0.0293	0.0312	0.0595	0.0345
X_9	0.3020	0.2643	0.3268	0.3358	0.2770	0.2652	0.5122	0.5200
X_{10}	0.4426	0.4341	0.4756	0.5339	0.4564	0.5493	0.5363	0.5532
X_{11}	0.2513	0.3251	0.2227	0.4311	0.3548	0.4087	0.3994	0.3335
X_{12}	0.0811	0.0339	0.0422	0.0323	0.2379	0.1265	0.1512	0.1879
X_{13}	0.3548	0.3034	0.2842	0.3782	0.4992	0.4363	0.5867	0.5191
X_{14}	0.7403	0.7861	0.7753	0.7815	0.7633	0.8704	0.7678	0.9194
X_{15}	0.4566	0.5159	0.4933	0.5889	0.5321	0.5808	0.5812	0.6286
X_{16}	0.3068	0.2103	0.3475	0.3170	0.3307	0.3252	0.3384	0.2281
X_{17}	0.1997	0.1242	0.2402	0.2066	0.2634	0.3003	0.2414	0.1570

Table 13 GeoDetector Interaction Detection Results in 2008

Sort	Yangtze River Economic Belt	Upstream	Midstream	Downstream
1	$X_{14}\cap X_{16}$=0.8114,BE	$X_{14}\cap X_{4}$=0.8635,BE	$X_{14}\cap X_{11}$=0.8817,BE	$X_{14}\cap X_{16}$=0.8510,BE
2	$X_{14}\cap X_{15}$=0.8036,BE	$X_{14}\cap X_{16}$=0.8512,BE	$X_{14}\cap X_{15}$=0.8621,BE	$X_{14}\cap X_{9}$=0.8460,BE
3	$X_{14}\cap X_{17}$=0.7930,BE	$X_{14}\cap X_{15}$=0.8391,BE	$X_{14}\cap X_{13}$=0.8478,BE	$X_{14}\cap X_{15}$=0.8413,BE
4	$X_{14}\cap X_{13}$=0.7860,BE	$X_{14}\cap X_{3}$=0.8347,NE	$X_{14}\cap X_{16}$=0.8419,BE	$X_{14}\cap X_{12}$=0.8411,BE
5	$X_{14}\cap X_{10}$=0.7844,BE	$X_{14}\cap X_{6}$=0.8332,BE	$X_{14}\cap X_{10}$=0.8324,BE	$X_{14}\cap X_{6}$=0.8392,BE
6	$X_{14}\cap X_{4}$=0.7795,NE	$X_{14}\cap X_{17}$=0.8277,BE	$X_{14}\cap X_{9}$=0.8231,BE	$X_{14}\cap X_{10}$=0.8388,BE

Note: NE denotes nonlinear enhancement, and BE denotes bi-factor enhancement.

Table 14 GeoDetector Interaction Detection Results in 2017

Sort	Yangtze River Economic Belt	Upstream	Midstream	Downstream
1	$X_{14}\cap X_{11}$=0.8773,BE	$X_{14}\cap X_{11}$=0.9012,BE	$X_{14}\cap X_{7}$=0.9440,BE	$X_{14}\cap X_{10}$=0.9445,BE

Sort	Yangtze River Economic Belt	Upstream	Midstream	Downstream
2	$X_{14}∩X_3$=0.8644,NE	$X_{14}∩X_3$=0.8861,NE	$X_{14}∩X_3$=0.9235,NE	$X_{14}∩X_9$=0.9439,BE
3	$X_{14}∩X_{13}$=0.8616,BE	$X_{14}∩X_{13}$=0.8854,BE	$X_{14}∩X_{13}$=0.9131,BE	$X_{14}∩X_3$=0.9417,BE
4	$X_{14}∩X_{17}$=0.8582,BE	$X_{14}∩X_6$=0.8823,BE	$X_{14}∩X_{10}$=0.9081,BE	$X_{14}∩X_5$=0.9412,BE
5	$X_{14}∩X_4$=0.8364,NE	$X_{14}∩X_{16}$=0.8766,BE	$X_{14}∩X_6$=0.9070,BE	$X_{14}∩X_{11}$=0.9400,BE
6	$X_{14}∩X_{10}$=0.8342,BE	$X_{14}∩X_{17}$=0.8741,BE	$X_{14}∩X_9$=0.9054,BE	$X_{14}∩X_7$=0.9397,BE

Note: NE denotes nonlinear enhancement, and BE denotes bi-factor enhancement.

4 DISCUSSIONS AND FUTURE RESEARCH

4.1 Conclusions

Taking specialized villages in the Yangtze River Economic Belt as the study object, this study systematically examined their quantity distribution, spatial pattern evolution, type structure, and driving factors from 2008 to 2017 by using the nearest neighbor index, kernel density estimation, spatial autocorrelation, Optimized Hot Spot Analysis, buffer analysis, and GeoDetector. The main conclusions are as follows.

(1) The quantity distribution of specialized villages in the Yangtze River Economic Belt shows significant interprovincial differences and regional gradient characteristics. At the provincial scale, Sichuan, Jiangsu, Jiangxi, Anhui, and Hubei had relatively large numbers of specialized villages, while Shanghai had the fewest. Overall, specialized villages showed a pattern of “high concentration in a few provinces and differentiated changes across most provinces.” From the perspective of upstream, midstream, and downstream regions, specialized villages were mainly concentrated in the upstream and downstream regions, while the midstream region accounted for a relatively lower proportion, forming a regional distribution pattern of “relatively high concentration in the upstream and downstream regions and relatively weaker concentration in the midstream region.” At the county scale, specialized villages showed a pattern of “local clustering and peripheral dispersion.” High-value counties were mainly distributed in the Chengdu-Chongqing region, parts of the middle reaches of the Yangtze River, and the Yangtze River Delta, whereas low-value and non-distribution counties were more concentrated in remote mountainous areas, high-elevation regions, and some ecologically fragile areas.

(2) The spatial pattern of specialized villages in the Yangtze River Economic Belt exhibits significant clustering and a certain degree of stability. The nearest neighbor index results show that, from 2008 to 2017, the nearest neighbor index values of specialized villages were all less than 1 and passed the significance test, indicating that their spatial distribution significantly deviated from randomness and showed a clear clustering pattern. Kernel density estimation further reveals that high-density core areas were mainly concentrated in parts of the Sichuan Basin in the upstream region and central Jiangsu in the downstream region, while secondary core areas were located in Yichang of Hubei, northern Jiangxi, and southwestern Jiangxi. Global spatial autocorrelation and Optimized Hot Spot Analysis indicate that the number of specialized villages at the county level had significant positive spatial autocorrelation. Hot spots were mainly concentrated in the Chengdu-Chongqing region and the Yangtze River Delta, while cold spots were mainly distributed in mountainous or relatively peripheral areas such as central Yunnan, southwestern Guizhou, central Hunan, and central Jiangxi. Overall, a spatial differentiation pattern of “hot spots in the east and west, and cold spots in parts of the central and southwestern regions” was formed.

(3) Terrain, river systems, and transport conditions play important roles in shaping the spatial layout of specialized villages. Terrain analysis shows that specialized villages were mainly distributed in low-elevation and low-slope areas. Areas below 200 m in elevation and with slopes less than 5° were the most concentrated zones, indicating that plains, low hills, and gentle slopes are more conducive to the formation and development of specialized villages. Buffer analysis shows that the number of specialized villages decreased as the distance from rivers and roads increased, presenting clear river-proximity clustering and road-proximity clustering characteristics. Rivers provide water resources for agricultural production and rural life, while favorable terrain and soil conditions along rivers also support the production of specialty agricultural products. Roads improve market accessibility, reduce transport costs, and strengthen industrial linkages, thereby providing important support for the formation and expansion of specialized villages.

(4) The type structure of specialized villages in the Yangtze River Economic Belt shows an evolutionary pattern characterized by the dominance of agricultural production-oriented villages, the transformation of agriculture-related service-oriented villages, and the contraction of non-agricultural industry-oriented villages. From 2008 to 2017, agricultural product production-oriented specialized villages consistently occupied the dominant position, with planting-related product types accounting for the highest proportion and showing a continuously strengthened role. The total number of agriculture-related service-oriented villages changed only slightly, but their internal structure underwent marked adjustment: leisure agriculture-oriented villages continued to grow, while traditional processing and marketing types shrank significantly. Non-agricultural industry-oriented villages declined substantially, and their internal structure became more concentrated. These results suggest that specialized village development in the Yangtze River Economic Belt remains dominated by agriculture-related industries, while industrial chain extension, service function expansion, and non-agricultural industrial integration still need to be improved.

(5) The spatial differentiation of specialized villages is jointly influenced by institutional organization, brand building, quality certification, market systems, and regional development foundations. The GeoDetector results show that farmers’

professional cooperatives are the most stable and core factor explaining the spatial differentiation of specialized villages in the Yangtze River Economic Belt. Registered trademarks, pollution-free agricultural product certification, green food certification, leading agribusinesses, and agricultural wholesale markets also show strong explanatory power. Interaction detection indicates that the effects of different factors are mainly characterized by bi-factor enhancement and nonlinear enhancement, suggesting that specialized village development is not driven by a single factor but by the synergy of institutions, technology, markets, branding, and resource conditions. Regionally, the upstream region highlights the role of institutional organization, quality certification, and specialty resource transformation; the midstream region increasingly depends on county-level economic foundations and human resources in addition to institutional and branding effects; and the downstream region reflects a composite mechanism jointly driven by institutions, markets, technology, branding, and resource conditions.

4.2 Prospects and Future Research

This study systematically analyzed the spatial pattern evolution and influencing factors of specialized villages in the Yangtze River Economic Belt from the perspectives of multi-scale spatial analysis and GeoDetector. However, several aspects still require further improvement.

First, due to data availability, this study mainly selected four time points—2008, 2011, 2014, and 2017—for analysis, and did not include the latest data after 2017. As a result, it cannot fully capture the new changes in the spatial pattern and industrial structure of specialized villages since the further implementation of the rural revitalization strategy. Future research may incorporate more recent and continuous time-series data to reveal long-term evolutionary trends and stage-specific changes in specialized villages.

Second, the influencing factor system in this study mainly covers natural environment, economic foundation, market scale, technological level, institutional construction, and cultural branding. However, factors such as policy support intensity, rural governance capacity, social network linkages, digitalization level, and e-commerce development have not been sufficiently considered. Future studies may integrate questionnaire surveys, field interviews, enterprise and cooperative data, and online platform data to enrich the influencing factor system and improve the explanatory power for the formation mechanisms and development paths of specialized villages.

Third, this study mainly conducted analysis at the provincial, regional, and county scales. Although it reveals the overall spatial pattern and county-level differentiation characteristics of specialized villages in the Yangtze River Economic Belt, it does not sufficiently explore village-level micro differences, industrial chain organization, or cross-regional spatial spillover effects. Future research may further extend the analysis to the village or community scale and combine spatial econometric models, social network analysis, and industrial chain analysis to deepen the understanding of the spatial evolution mechanisms and regional linkages of specialized villages.

Finally, this study focuses more on the quantity distribution and spatial influencing factors of specialized villages, while the analysis of development quality, industrial upgrading capacity, farmer income effects, and sustainable development performance remains limited. Future research may combine the spatial pattern of specialized villages with industrial integration, brand value, household income, ecological constraints, and rural governance performance to further evaluate the comprehensive role of specialized villages in rural industrial revitalization and regional coordinated development, thereby providing more targeted policy support for the optimized layout and high-quality development of specialized villages in the Yangtze River Economic Belt.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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