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Spatio-temporal characteristics and influencing factors of traditional villages in the Yangtze River Basin: a Geodetector model

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Abstract

The Yangtze River Basin (YRB) is the birthplace of Chinese civilization and is rich in traditional village resources. Studying their spatial distribution characteristics and influencing factors can guide the protection, inheritance, and development of traditional villages in YRB. This study takes 5 batches of 3346 traditional villages in YRB since 2012 as the research object. Using the nearest neighbor index, kernel density analysis, standard deviation ellipse, and Geodetector model, we analyzed the spatial distribution characteristics of traditional villages in YRB and detected their influencing factors. The results show that the distribution of traditional villages in YRB exhibited a spatial pattern of cohesive clusters, forming a high-density area and development center in the junction zone between Guizhou and Hunan provinces and southeast of Anhui Province, and secondary-density areas in Northeast Yunnan Province and east Jiangxi Province. The results of the Geodetector show that the formation of the spatial distribution pattern of traditional villages in YRB is affected by the combined effects of natural and socio-economic factors, among which elevation and NDVI were the main factors, and the interaction of multiple factors showed an enhanced trend. The findings of this study can provide scientific decision-making support for the development and protection of traditional villages in YRB.

Keywords Traditional villages, Spatial distribution characteristics, Influencing factors, Geodetector model, Yangtze River Basin

Introduction

Traditional villages have a long history and are carriers of Chinese traditional culture, with rich historical and cultural value [1]. As modernization, industrialization, and urbanization have accelerated in China in recent years, traditional villages are gradually dying out under the external environment's impact. With the disappearance of traditional villages, as well as the regional history and cultural heritage they carry, they also die out [2, 3]. Traditional villages are also the roots and birthplace of the nation and the origin of its culture. Meanwhile, traditional villages' rich history and culture mean that they can bring economic benefits as important tourism resources [4]. Villages are the carrier for the implementation of China's rural revitalization strategy, and traditional villages, as key areas, should receive sufficient attention for their protection [5]. The protection of traditional villages is the inheritance and protection of traditional culture, and it can also promote the creative transformation of traditional culture and help rural revitalization. Therefore, the preservation of traditional villages is of great

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significance to historical and cultural inheritance, economic development, and rural revitalization. Congratulatively, the Chinese government has published 5 batches of traditional villages since December 2012 and included them in the national strategy for historical and cultural preservation, laying the foundation for the protection of traditional villages. However, regarding the necessity and long-term nature of traditional village protection, there is not yet a perfect law and regulation on traditional villages in China, and the theoretical research on traditional villages lags [6].

Optimizing the spatial distribution characteristics of traditional villages is the essence of preserving traditional villages, which is echoed by the study of the spatial pattern characteristics of traditional villages [7]. Furthermore, the distribution of geographical elements is often spatially regular rather than chaotic, and the optimization of the overall spatial distribution of traditional villages should be approached from a spatial perspective [5, 7]. Simultaneously, the study of the factors influencing the law of geographical differentiation of traditional villages can provide policy reference for corresponding differentiated protection measures [4]. A large number of scholars have conducted in-depth discussions on the spatio-temporal patterns of traditional villages and the factors influencing them. Previous studies on traditional villages mainly focus on the cultural value and connotation of traditional villages [8–11], the layout of traditional villages [12–14], the cultural landscape of traditional villages [15–18], the environmental elements of the formation of traditional villages [19–22], and the tourism development of traditional villages [23–27]. However, most of the studies are mainly qualitative descriptions and case studies, and the research methods are relatively single. Recent years have seen the emergence of digital technologies such as Geographic Information Systems (GIS), City Intelligent Modeling (CIM), and the Internet of Things (IoT), which have taken the study of the preservation and operation of traditional villages to new heights [28–30]. GIS-based research can monitor the spatio-temporal distribution of traditional villages and their influencing factors at multiple scales in sequence, and analyze their geographical differentiation patterns and the evolutionary characteristics of their formation. From the perspective of geography, a series of spatial statistics are used to study the spatio-temporal characteristics of traditional villages, which can quantitatively analyze their geographical differentiation and deterministic influencing factors, and provide spatially differentiated decisions for the conservation of Chinese traditional villages.

Previous studies have mostly focused on large-scale national, provincial, and municipal levels [31–36], and smaller scales such as county and township levels [37–41]. In addition, most studies focus on static spatial distribution, and relatively few studies involve the dynamic evolution process of traditional villages [38–41]. The choice of influencing factors focuses on natural, socio-economic, and ethnocultural factors, and the specific research methods include kernel density analysis, nearest neighbor index, imbalance coefficient, and spatial autocorrelation analysis [38–41]. There are also studies on geographically weighted regression analysis of traditional villages based on grid units [5]. In general, the research on traditional villages mainly qualitative description and then combined with quantitative calculation methods to explore their spatial distribution and influencing factors.

The Yangtze River Basin (YRB) is one of the cradles of Chinese civilization, with a long and splendid history and ethnic culture, and also has many traditional villages as cultural carriers. However, with the construction of the Yangtze River economic belt, traditional villages are facing challenges such as decreasing numbers and backward living conditions of village residents. Therefore, it is typical to choose traditional villages in YRB, the analysis of its spatial distribution characteristics and influencing factors not only contributes to the protection of traditional villages in YRB but also has important reference value for the study of traditional villages in other similar areas. In this study, the spatial analysis method is used to analyze the spatial distribution characteristics of traditional villages, and the Geodetector method is used to detect the formation mechanism of the spatial pattern of traditional villages, which further provides scientific guidance for the development and protection of traditional villages. This study is mainly devoted to (1) determining the spatial distribution characteristics of traditional villages in the YRB and (2) investigating the main factors affecting the spatial distribution of traditional villages in the YRB.

Study area overview and data sources

Study area overview

The YRB straddles three major economic zones in China: the middle, east, and west, and contains 19 provinces, cities, and districts, and 968 county-level administrative regions, with a total area of about 1.8 million km^2, accounting for 18.8% of China's land area (Fig. 1). The terrain in YRB is high in the west and low in the east, and can be roughly divided into five types of landforms: plateau, mountains, basin, hills, and plains from west to east. The birthplace of the YRB (Qinghai-Tibet Plateau) has a plateau mountain climate with strong radiation, a large diurnal temperature range, low temperature, and a long cold season; the rest of the region has a subtropical monsoon climate, with four distinct seasons, high temperature and rainy summer, mild and less rain in winter,

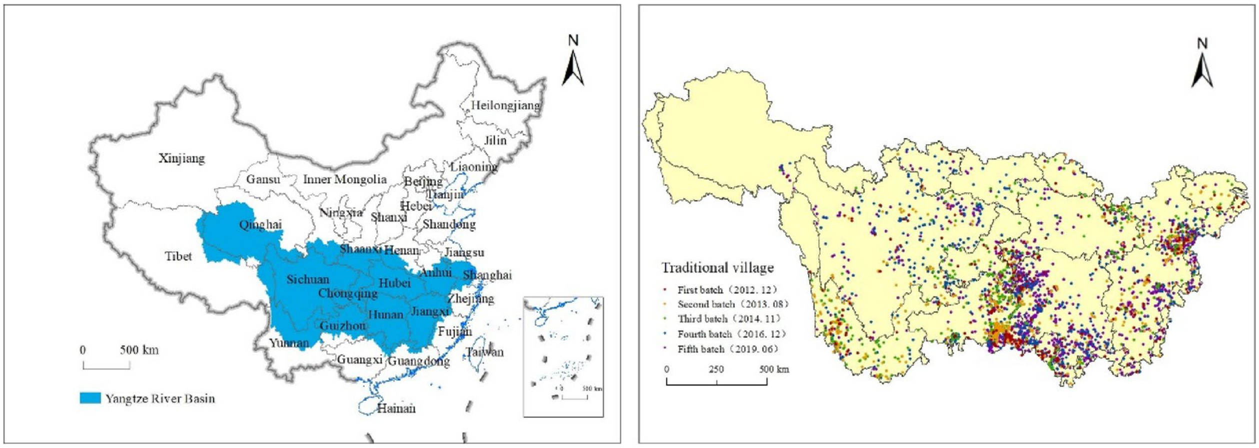

Fig.1 Spatial distribution of 5 batches of traditional villages in YRB

small daily temperature difference, and pleasant climate. Yangtze River is the "Mother River" of China, which has nurtured profound Chinese civilization and formed many traditional villages with values of history, culture, and architectural art. As of June 2019, a total of 3,346 villages in YRB have been selected for the list of Chinese traditional villages, accounting for 49.07% of the total number of Chinese traditional villages. Identifying the spatio-temporal distribution of traditional villages in the YRB and exploration of the formation mechanism of their spatial patterns is very necessary for the development and protection of traditional villages in the YRB.

Data sources

It is difficult to obtain comprehensive, continuous data on the same data platform, so this study synthesizes data from multiple sources. The spatial distribution datasets of 5 batches of Chinese traditional villages used in this study are from the Global Change Science Research Data Publishing System (http://geodoi.ac.cn/WebCn/) [42–44]. The geometric center of traditional villages is extracted by referring to the Baidu map and Google earth image and then extracting village coordinates from the text prompt of the village name or traditional village image. For those where the village cannot be found on the map and no reference image was available, the coordinates of the higher administrative unit where the traditional village is located are used as the geographical coordinates of the village [32]. Furthermore, the sources and descriptions of the spatial data used in this study are shown in Table 1. Unlike other factors, vegetation cover and slope direction need to be obtained by pre-processing NDVI data and DEM data respectively in ArcGIS. Among them, vegetation cover was calculated by the like-element dichotomous model, and slope direction was obtained by calculating the raster surface. Then, we use the spatial analysis module (Spatial Analyst Tools/ Zonal/Zonal Statistics As Table) of ArcGIS software to calculate the values of each influence factor in each grid. The elevation, slope direction, and vegetation cover were averaged for each grid, and the GDP and population were summed over the grid. For rivers and transportation, we calculate

Table 1 Data sources for driving factors

Variables	Data sources	Data format	Description
Elevation	RESDC (http://www.resdc.cn)	GeoTIFF (1000 m-resolution)	Characterization of topographic conditions
Slope direction	RESDC (http://www.resdc.cn)	GeoTIFF (1000 m-resolution)	Characterization of topographic conditions
River	National Geomatics Center of China (https://www.webmap.cn)	Shipfile	Characterization of hydrological conditions
Vegetation cover	RESDC (http://www.resdc.cn)	GeoTIFF (1000 m-resolution)	Characterization of vegetation cover conditions
GDP	RESDC (http://www.resdc.cn)	GeoTIFF (1000 m-resolution)	Characterization of the level of economic development
Population	World pop project (https://www.worldpop.org)	GeoTIFF (1000 m-resolution)	Characterization of population density
Transportation	Gaode Maps (http://www.geodata.cn)	Shipfile	Characterization of traffic conditions

RESDC data center for resources and environment, Chinese Academy of Sciences. *GDP* economy density the total length of rivers and roads within each grid to characterize their conditions.

Methods

Nearest neighbor index and variation coefficient

In this study, the nearest neighbor index method and Tyson polygon variation coefficient method are used to determine the spatial distribution of traditional villages. The nearest neighbor index R is defined as the ratio of the actual nearest neighbor distance $\overline{r_I}$ to the theoretical nearest neighbor distance $\overline{r_E}$ [45]. The equations are:

$$R = \frac{r_I}{r_E} \tag{1}$$

$$\overline{r}_I = \frac{\sum_{n}^{i=1} \gamma_i}{n} \tag{2}$$

$$\overline{r_E} = \frac{1}{2}\sqrt{\frac{s}{n}} \tag{3}$$

where R is the nearest neighbor index; $\overline{r_I}$ is actual nearest neighbor distance; $\overline{r_E}$ is the theoretical nearest neighbor distance; n the is the number of traditional villages in YRB; γ_i is the actual distance between the ith traditional village and its nearest traditional village; S is the total area of YRB. When $R > 1$, it indicates that the spatial distribution pattern of traditional villages in YRB is uniform; when $R < 1$, it is cohesive; when $R = 1$, it is random; and when $R = 0$, it indicates complete concentration [46].

Because the nearest proximity index method has a certain degree of uncertainty in determining the spatial morphology of geographical factors, this study also uses the Tyson polygon coefficient of variation method to conduct a secondary verification of the spatial distribution morphology of traditional villages in YRB. The variation coefficient CV is defined as the ratio of the standard deviation of the Tyson polygon area to the mean value [47]. The equations are:

$$CV = \frac{S_{st}}{S} \times 100\% \tag{4}$$

$$S_{st} = \sqrt{\frac{\sum_{i=1}^{n} (S_i - S)^2}{n}} \tag{5}$$

where CV is the coefficient of variation; S_{st} is the standard deviation of the Tyson polygon area; $\overline{S}$ is the mean of the Tyson polygon area; S_i is the area of the ith Tyson polygon; n is the number of traditional villages in YRB; S is the area of the YRB region. If $CV \leq 33\%$, it indicates that traditional villages in YRB are spatially uniformly distributed; if $33\% < CV < 64\%$, they are randomly distributed; if $CV \geq 64\%$, they are clustered.

Kernel density analysis

In this study, the spatial distribution density of traditional villages is measured by kernel density analysis. Kernel density analysis takes the traditional village element points as the center of the circle, and the density value at the center of the circle is the highest, indicating that the element points are the densest; the farther away from the center of the circle, the lower the density value, indicating that the feature points are sparse [48]. The equations are:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \tag{6}$$

$$h = 0.9 \times min\left(SD, \sqrt{\frac{1}{\ln(2)}} \times D_m\right) \times n^{-0.2} \tag{7}$$

where *f(x)* is the kernel density estimate; n is the number of traditional villages; h is the search radius (bandwidth); $k\left(\frac{x-x_i}{h}\right)$ is the kernel density function; $(x - x_i)$ is the distance value from the estimated value point x to some traditional village point xi; D_m is the median of the distance from the average centroid of traditional villages to each traditional village; SD is the standard distance from the average centroid of traditional villages to each traditional village; min indicates the distance that will be calculated using the smaller one calculated from the two options.

Geographical concentration index

This study uses the geographical concentration index to determine the degree of the spatial distribution of traditional villages in terms of aggregation. The specific calculation equation is:

$$G = 100 \times \sqrt{\sum_{i=1}^{N}\left(\frac{X_i}{T}\right)^2} \tag{8}$$

where G is the geographical concentration index of traditional villages, Xi is the number of traditional villages in the ith county-level administrative region; T is the total number of traditional villages; N is the total number of county-level administrative regions. The value of G is between 0 and 100; the larger G is, the more concentrated the distribution of traditional villages among county-level administrative regions; conversely, the more scattered the distribution of traditional villages is.

Spatial equilibrium degree

To portray the equilibrium of the spatial distribution of traditional villages in YRB, this study introduces the Gini coefficient and Lorenz curve for quantitative description. The Gini coefficient is mainly an important method to analyze the balanced variability of the spatial distribution of research objects in the region. The equations are:

$$Gini = \frac{-\sum_{i=1}^{N} P_i \mathrm{In} P_i}{\mathrm{InN}} \tag{9}$$

$$C = 1 - Gini \tag{10}$$

where $Gini$ denotes the Gini coefficient; P_i denotes the proportion of traditional villages in the ith county-level administrative region to the total number of traditional villages in YRB; N is the number of county-level administrative regions in YRB; C is the degree of equilibrium of the spatial distribution of traditional villages. The Gini coefficient ranges from 0 to 1. The larger the Gini coefficient is, the smaller the C, and the higher the concentration of traditional villages in a certain region; conversely, the more unbalanced the spatial distribution of traditional villages. On this basis, the Lorenz curve was made with the horizontal coordinate of each county-level administrative district and the cumulative percentage of the number of traditional villages in each county-level administrative district as the vertical coordinate. If the arc of the curve is larger, it indicates that the spatial distribution of traditional villages is less balanced.

Standard deviation ellipse

The standard deviation ellipse method of spatial offset degree can reflect the nature of spatial distribution such as centrality, spatial extent, and evolution direction of geographical elements based on parameters such as the center, long and short axes, azimuth, and flatness of the ellipse [49, 50]. In this study, the above method is adopted to measure the degree of offset of traditional villages in YRB in terms of spatial distribution.The equations are:

$$\overline{X} = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \tag{11}$$

$$\overline{Y} = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i} \tag{12}$$

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n} (x_i - X)^2}{n}} \tag{13}$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n} \left(y_i - \overline{Y}\right)^2}{n}} \tag{14}$$

$$\tan\theta = \frac{\left(\sum_{i=1}^{n} \widetilde{x}_l^2 - \sum_{i=1}^{n} \widetilde{y}_l^2\right) + \sqrt{\left(\sum_{i=1}^{n} \widetilde{x}_l^2 - \sum_{i=1}^{n} \widetilde{y}_l^2\right) + 4\left(\sum_{i=1}^{n} \widetilde{x}_l \widetilde{y}_l\right)^2}}{2\sum_{i=1}^{n} \widetilde{x}_l \widetilde{y}_l} \tag{15}$$

where $\overline{X}$ and $\overline{Y}$ are the arithmetic mean center; x_i and y_i are the coordinates of the spatial location of the ith traditional village; $SDEx$ and $SDEy$ are the variance of the long and short axes of the ellipse; θ is the azimuth of the ellipse (the angle of clockwise rotation to the long axis of the ellipse in the due north direction); $\widetilde{x}_l$ and $\widetilde{y}_l$ are the deviation of the coordinates of the spatial location of the traditional village to the mean center. In general, the longer the long semi-axis of the ellipse, the more obvious the directionality of the spatial distribution of traditional villages; the longer the short semi-axis, the greater the dispersion of the spatial distribution of traditional villages; and the azimuth of the ellipse indicates the direction of the main trend of the spatial distribution of traditional villages [49, 50].

Geostatistical analysis

In this study, we introduced various functions of ArcGIS, including overlay analysis, buffer analysis, statistical analysis, and intersection analysis. Specifically, we use superposition analysis to investigate the spatial distribution of traditional villages regarding elevation and slope direction. Buffer analysis was used to study the spatial distribution of traditional villages about rivers (1 km, 5 km, and 10 km buffer zones were established). Statistical analysis was used to study the spatial distribution of traditional villages regarding GDP and population. Finally, we use intersection analysis to investigate the relationship between the spatial distribution of traditional villages and transportation. However, the above methods can only support qualitative analysis, but not quantitative analysis.

Geodetector model

Geodetector is mainly used to detect the spatial differences of geographical elements and analyze their driving forces, including factor detection, interaction detection, risk area detection, ecological detection, etc. [51]. To quantitatively analyze the influence of each influence factor on the spatial layout of traditional villages, we introduced a Geodetector model. This study mainly uses this method to detect the intensity and interaction of the factors that affect the spatial distribution of traditional villages. The specific calculation equation is:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \quad (16)$$

where q denotes the measure of the strength of the effect of an influencing factor and takes a value between 0 and 1. The closer to *1*, the greater the strength of the effect of the influence factor; L is the number of influence factors; N_h and σ_h^2 are the number of cells and variance of the corresponding influence factors; N and σ^2 are the number of cells and variance of the whole, respectively.

Results

Spatial distribution pattern of traditional villages in YRB

The coefficient of variation (*CV*) of the spatial distribution of traditional villages in each batch of YRB was calculated, as shown in Table 2. The results show that although the traditional villages in YRB show cohesive cluster distribution in spatial distribution, the nearest neighbor index (*R*) and the *CV* are different for each batch, which indicates the different degrees of cohesive cluster distribution of different batches of traditional villages. Specifically, the *R* was the largest for the first batch of traditional villages (0.58), followed by the *R* for the fourth batch (0.70), and the smallest for the second batch (0.48). The *CV* was the largest for all batches (404.06%) and the smallest for the first batch (187.23%).

Spatial distribution density

The results of kernel density are shown in Fig. 2. It can be seen that the batch 1 traditional villages formed 2 significant density cores, one located in the border area of Guizhou Province, Hunan Province, and Guangxi Zhuang Autonomous Region, the other in the border area of Anhui Province and Jiangxi Province, and several sub-level density cores scattered throughout the YRB. Compared with batch 1, the density cores in the border area of Guizhou Province, Hunan Province, and Guangxi Zhuang Autonomous Region were reduced in scope, and the other density cores in the border area of Anhui Province and Jiangxi Province were reduced to the dense cores of the next level. Batch 3 traditional villages form three notable density cores: the first has the largest extent located in the border area of Guizhou Province, Hunan Province, and Chongqing City, the second in the southeastern area of Anhui Province, and the third in the northeastern area of Yunnan Province. The Batch 4 traditional villages mainly have two significant density cores, one located in the border area of Guizhou Province and Hunan Province and the other in the southeastern area of Anhui Province, in addition to numerous sub-level density cores distributed in various parts of the basin, especially in the northeastern area of Sichuan Province and Jiangxi Province. Compared with batch 4, batch 5 has a reduced range of density cores located in the border area of Guizhou and Hunan provinces, and the density cores located in the southeastern area of Anhui Province are unchanged, in addition to a significant reduction of sub-level density cores. Comparing the kernel density maps of these 5 batches of traditional villages, we can find that the first batch of traditional villages laid the general pattern of the spatial distribution of traditional villages in YRB, and the subsequent 4 batches of traditional villages supplemented and improved the first batch, finally forming 2 significant density cores in the junction zone between Guizhou and Hunan provinces and southeastern Anhui Province, the spatial distribution pattern of traditional villages in YRB with the northeast of Yunnan Province and the east of Jiangxi Province as the secondary density core.

Geographical concentration

The results of the geographic concentration index of traditional villages in YRB are shown in Table 3, where *Ga* indicates the geographic concentration index of traditional villages in YRB under uniform distribution among county-level administrative regions. It can be seen that the geographic concentration indices (*G)* in the actual situation are all greater than the geographic

Table 2 Nearest neighbor index and coefficient of variation of traditional villages in YRB

Batch	Nearest neighbor index (*R*)	Coefficient of Variation (*CV*) (%)	Distribution pattern
All batches	0.55	404.06	cohesive clusters
First batch (2012.12)	0.58	187.23	cohesive clusters
Second batch (2013.08)	0.48	239.81	cohesive clusters
Third batch (2014.11)	0.54	224.09	cohesive clusters
Fourth batch (2016.12)	0.57	215.21	cohesive clusters
Fifth batch (2019.06)	0.52	298.92	cohesive clusters

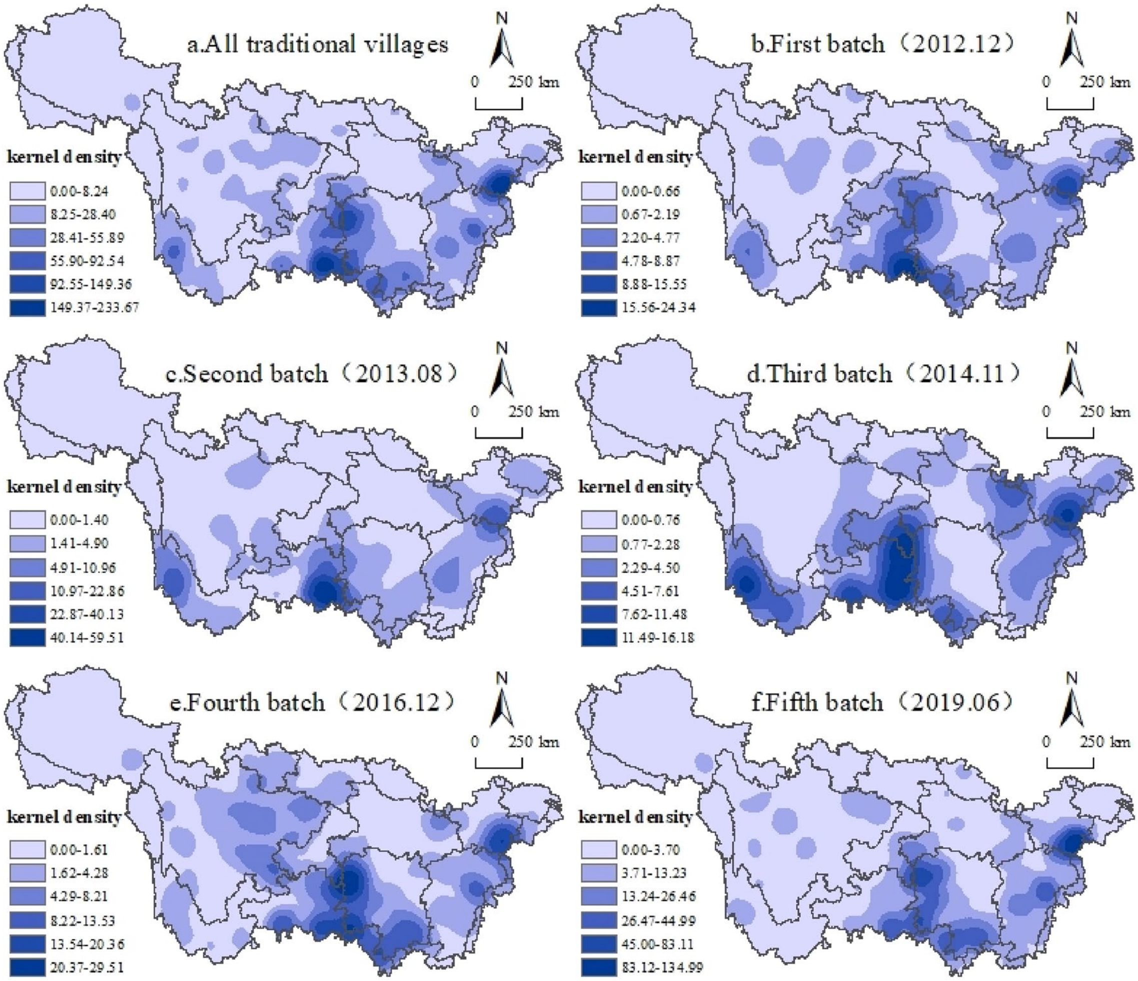

Fig. 2 Kernel density of traditional villages in YRB

Table 3 Geographical concentration index of the spatial distribution of traditional villages in YRB

Batch	Actual geographical concentration index (*G*)	Geographical concentration index under balance distribution (*Ga*)
All batches	8.37	3.21
First batch (2012.12)	16.49	
Second batch (2013.08)	15.88	
Third batch (2014.11)	9.74	
Fourth batch (2016.12)	8.64	
Fifth batch (2019.06)	11.94	

concentration indices (*Ga)* under the uniform distribution, which indicates that the spatial distribution of traditional villages in YRB is not uniform among the county-level administrative regions. The *G* is not the same among batches of traditional villages, for example, the first batch of traditional villages has the largest *G* value of 16.49 compared with other batches, which indicates that the spatial distribution of traditional villages in different batches varies among county-level administrative regions in the study area.

Degree of spatial equilibrium

To quantitatively describe the inbalance of the spatial distribution of traditional villages in YRB, this study

Table 4 Gini coefficient and distribution balance degree of traditional villages in YRB

Batch	Gini coefficient	Distribution balance degree
All batches	0.82	0.18
First batch (2012.12)	0.66	0.34
Second batch (2013.08)	0.65	0.35
Third batch (2014.11)	0.72	0.27
Fourth batch (2016.12)	0.77	0.23
Fifth batch (2019.06)	0.74	0.26

calculates the *Gini* coefficient and the degree of equilibrium *C* of traditional villages in YRB in each county-level administrative region, and the results are shown in Table 4. The results show that the Gini coefficient is from smallest to largest in batch 2, batch 1, batch 3, batch 5, batch 4, and all batches, and the corresponding degree of equilibrium *C* is decreasing in order. This indicates that the spatial distribution of traditional villages in YRB in the corresponding batches is more unbalanced. The arc size of the Lorenz curve of the spatial distribution of traditional villages in YRB also verifies the above conclusion (Fig. 3).

Degree of spatial excursion

Moreover, this study used the spatial statistics tool of ArcGIS to analyze the degree of spatial offset of traditional villages in YRB, and the results are shown in Fig. 4 and Table 5. The spatial distribution center of traditional villages in YRB is mainly located in the northwestern part of Hunan Province, among which the batch 2 and batch 3 traditional villages fall at the junction of Hunan, Chongqing, and Guizhou provinces, which indicates that the traditional villages in YRB are mainly located in Hunan Province with a small degree of offset. The standard ellipse flatness of the spatial distribution of each batch of traditional villages is from batch 4, batch 5, batch 1, batch 2, and batch 3 in descending order, which indicates that the corresponding batches of traditional villages in YRB have increasingly clear directional rows in spatial distribution, and the distribution range is also larger. From the azimuthal size of the standard ellipse parameter, the spatial distribution of traditional villages in different batches is more consistent in terms of directionality. The azimuth of the standard deviation ellipse is closest to that of batch 5, which indicates that the direction of the spatial distribution of batch 5 traditional villages is close to that of the whole; the long semi-axis, short semi-axis, and flatness are closest to that of batch 1, which indicates that the directionality and dispersion of the spatial distribution of batch 1 traditional villages are similar to that of the whole.

Analysis of factors influencing the spatial distribution

The spatial distribution of traditional villages is affected by different factors, such as topography and terrain, regional economic conditions, population density, and

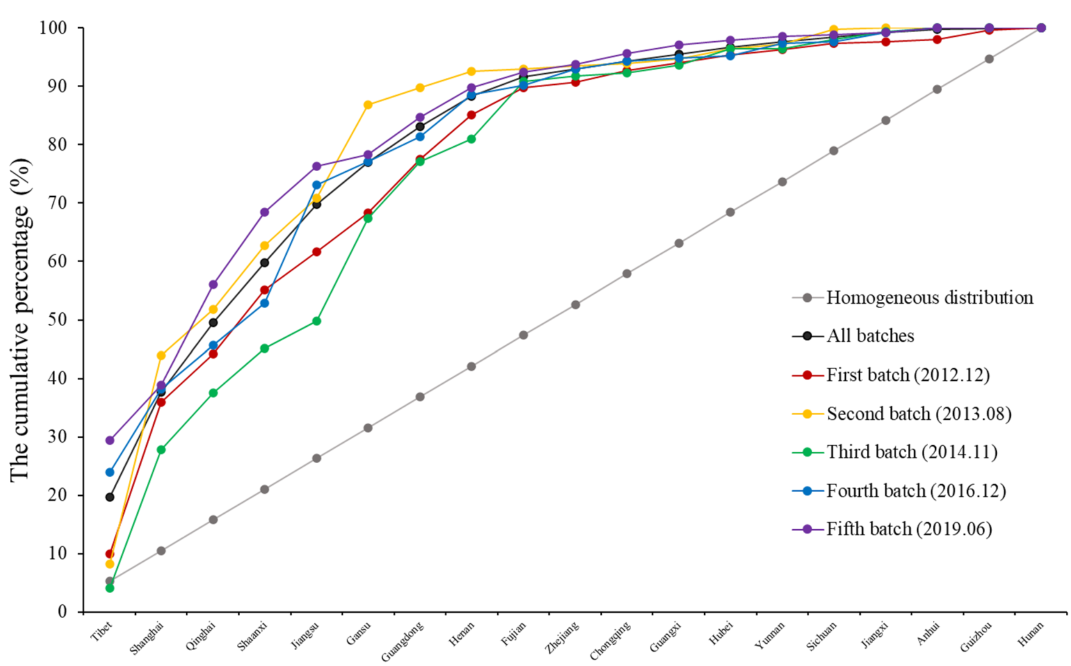

Fig. 3 Lorentz curve of the spatial distribution of traditional villages in YRB

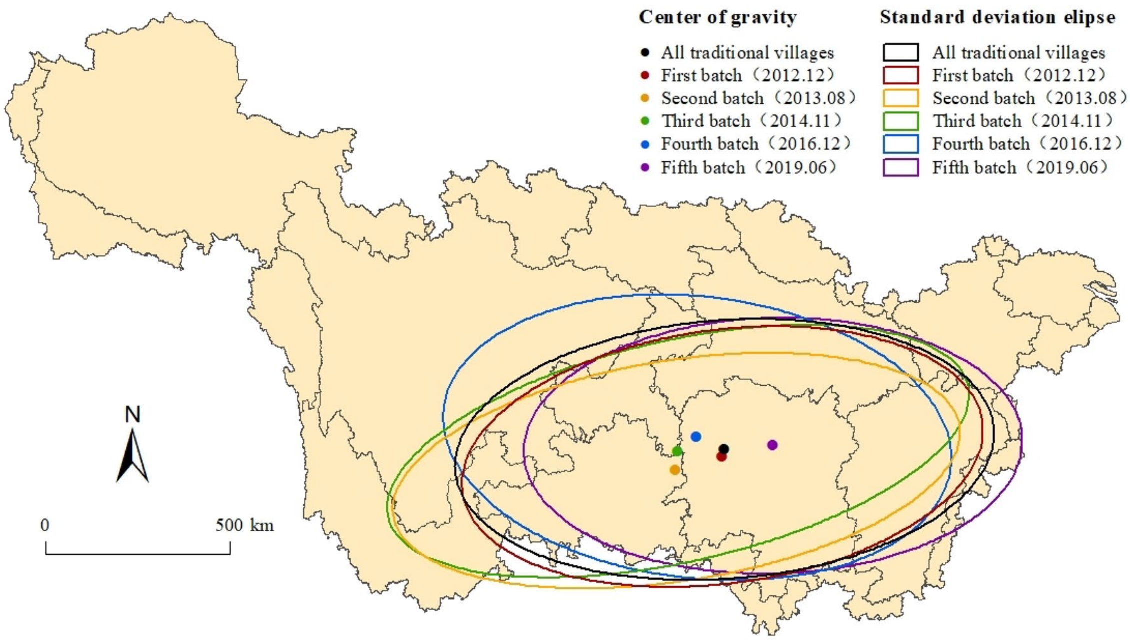

Fig. 4 Standard deviation ellipse of the spatial distribution of traditional villages in YRB

Table 5 Parameters of standard deviation ellipse of the spatial distribution of traditional villages in YRB

Batch	Long axis of ellipse/km	Short axis of ellipse/km	Azimuth angle	Oblateness
All batches	731849.01	349731.96	82.65°	0.5221
First batch (2012.12)	710493.62	342882.03	79.47°	0.5174
Second batch (2013.08)	776391.63	298258.029	78.11°	0.6158
Third batch (2014.11)	804687.58	299217.86	74.34°	0.6282
Fourth batch (2016.12)	691229.71	380870.02	93.69°	0.4490
Fifth batch (2019.06)	675415.51	345902.84	85.59°	0.4879

traffic conditions [34–37]. Integrating previous research results and based on the availability of data, this study selects 7 factors, including elevation, slope direction, river, vegetation cover, GDP, population, and transportation, starting from both natural and socioeconomic aspects. At the same time, the intensity of each influencing factor on the spatial distribution of traditional villages was calculated by Geodetector.

Figure 5 shows that the traditional villages in YRB are mainly located in Anhui, Jiangxi, Hunan, and Guizhou provinces in the eastern part of the YRB, where the elevation is relatively low, and to a lesser extent in Sichuan and Yunnan provinces in the western part of the YRB. The statistical results show that most of the villages are located between 200 and 2000 m in elevation, and the data of traditional villages located in low hill/plain areas (<500 m), low mountain/hill areas (500–1000 m) and middle and high mountain area (1000–2000 m) are 1884, 865, and 321 respectively, accounting for 56.31%, 25.85%, and 9.59% respectively. The results show that traditional villages are mainly concentrated in low mountain/hill areas below the elevation range of 2000 m, which is consistent with the results of previous studies [31], indicating that suitable elevation is an essential condition for the formation and protection of traditional villages.

Table 6 results show that the proportion of traditional villages in YRB is higher in the northwest, west, and southwest directions, accounting for 43.81% of the total; if classified by yin and yang slopes, the number of traditional villages with yang slopes (90–270°) is 1686, accounting for 50.39% of the total; the mean and median slope directions of all traditional villages are about 200°. The above results indicate that the sunny slopes are more suitable for the distribution of traditional villages, which is also consistent with the traditional Chinese culture of "sitting in the north and facing south".

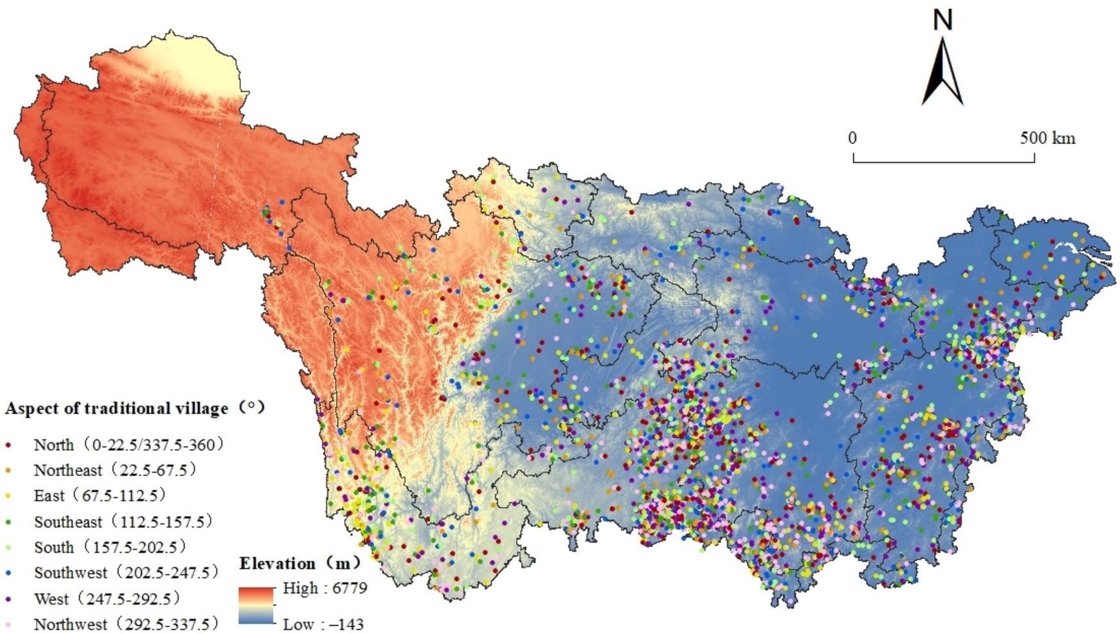

Fig. 5 The relationship among the spatial distribution of traditional villages, elevation, and aspects in YRB

Table 6 Statistical table about the aspect of traditional villages in YRB

Aspect	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Range/°	0–22.5/337.5–360	22.5–67.5	67.5–112.5	112.5–157.5	157.5–202.5	202.5–247.5	247.5–292.5	292.5–337.5
Number/Percentage	439/13.12%	295/8.82%	342/10.22%	352/10.52%	452/13.51%	465/13.90%	485/14.49%	516/15.42%

The results of river show that there are 632 traditional villages distributed in the 1 km radius, accounting for 18.89% of the total; in the 5 km radius, there are 1517 traditional villages distributed, accounting for 45.34% of the total. Within a 10 km radius, there are 2375 traditional villages, accounting for 70.98% of the total.

The statistical results of vegetation cover degree showed that the vegetation cover of the area where the traditional villages were located ranged from 0.08 to 0.9, and the average vegetation cover was about 0.78. There were 2858 traditional villages with vegetation cover of no less than 0.70, accounting for 85.42%, which indicated that the high vegetation cover areas with a better ecological environment were helpful for the siting of traditional villages (Fig. 6).

With the help of the ArcGIS platform, we counted the GDP of the YRB where the traditional villages are located, and its average value is 11,416,500 yuan/km^2, which is much lower than the average value of 15,928,100 yuan/km^2 of the YRB. If less than 75% of the GDP of the YRB (11,946,100 yuan/km^2) is considered an underdeveloped area, the number of traditional villages is 2619, accounting for 77.85%, which indicates that traditional villages in YRB are mainly located in places with weaker economic development.

We counted the population density of the area where the traditional villages are located in YRB, and its mean value is 226.23 persons/km^2, which is higher than the population density of 160.68 persons/km^2 in YRB; meanwhile, we found that the median population density of the traditional villages is 170.89 persons/km^2, which is different from the mean value of 226.23 persons/km^2, indicating that lower population density is beneficial to the retention of traditional villages. The above results indicate that the YRB has an inherent advantage in terms of the population density for the formation of traditional villages.

This study uses Gaode Map 2020 national urban road dataset and ArcGIS platform to dissect the YRB into 5 km*5 km grids, totaling 95,572, and calculates the road length of each grid to represent the traffic density, and the traffic density of the area where its YRB traditional

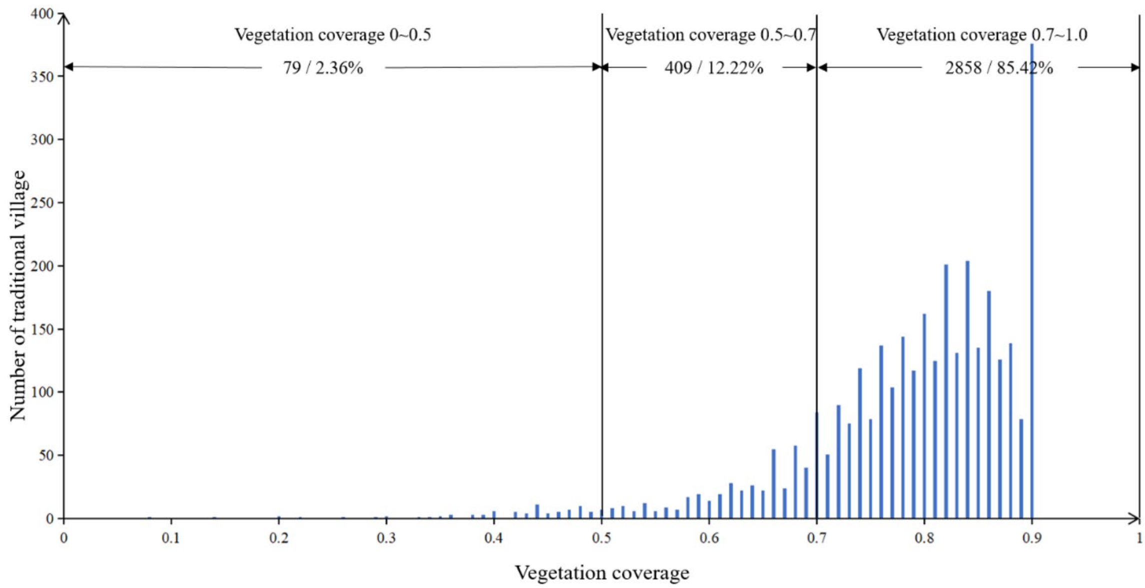

Fig. 6 Number of traditional villages in YRB under different vegetation coverage

villages are located. The results show that the traffic density in YRB is 0–21.94 km/km^2, while the maximum traffic density in the area where traditional villages are located is only 10.69 km/km^2, and the traffic density of 154 traditional villages is 0, which indicates that there is no direct access to convenient roads within 1 km of the area, revealing that the traffic accessibility of traditional villages is poor, but the indirect protection of traditional villages has played a good role.

Comparison of factors influencing the spatial distribution of traditional villages

The results of the above analysis show that the elements affect the spatial distribution of traditional villages, and to quantitatively analyze the strength of each influencing factor, this study takes the number of traditional villages in the unit grid as the dependent variable and each influencing factor as the independent variable and uses Geodetector to quantitatively calculate the strength of their effects. Firstly, the YRB is divided into 10 km*10 km grids, totaling 24,299, of which 2149 grids have traditional villages; secondly, the ArcGIS platform is used to count the values or average values of traditional villages and each influencing factor in each grid (Table 7); subsequently, the natural breakpoint method is used to discretize them into 5 levels concerning previous studies; finally, Geodetector software was used to calculate the intensity of each influencing factor on the traditional villages in YRB (Table 7).

The explanatory power of each factor on the spatial differentiation of traditional villages from strong to weak is elevation, vegetation cover, traffic, slope direction, water system, GDP, and population. Among them, elevation and vegetation cover are the main factors influencing the spatial distribution of traditional villages in YRB, followed by traffic, slope direction, water system, and other secondary factors. The explanatory power of natural factors such as elevation and

Table 7 Geodetect results of spatial differentiation of traditional villages in YRB

Dependent variable	Index	Index descriptions	Value
Y—Number of traditional villages(per 100km^2)	X_1—average elevation (m)	The average elevation per grid	0.037150
	X_2—average aspect (°)	The average aspect per grid	0.007763
	X_3— density of hydrographic net (km/100km^2)	Length of river per grid	0.001557
	X_4—vegetation coverage	Vegetation coverage per grid	0.024474
	X_5—GDP (ten thousand yuan /100km^2)	The total GDP per grid	0.001011
	X_6—population (per 100km^2)	The population per grid	0.000677
	X_7—transportation (km/100km^2)	Length of road per grid	0.013153

vegetation cover is more significant, indicating that elevation and vegetation cover has the strongest influence on the spatial differentiation of traditional villages in YRB.

In ancient societies, where agriculture was the mainstay, the factors considered in selecting village sites were mainly high-quality arable land, sufficient and clean water sources, excellent natural environment, and few natural disasters, thus mountainous and hilly areas with a relatively high elevation and high vegetation cover were more suitable for traditional village sites than plain areas in some aspects. Transportation is the factor that has the greatest impact on traditional villages among socio-economic factors, the higher the accessibility of a region, the more frequent the communication with the outside world, and the greater the influence on the local culture, thus the lower the accessibility is, the better the preservation and continuation of traditional villages. Comparing the natural factors and socioeconomic factors, the former has more influence on the spatial distribution of traditional villages, indicating that natural factors are the main reason for the location of traditional villages and the main factor for the preservation of traditional villages.

The interactions between different influencing factors are shown in Table 8, which shows that natural and socio-economic factors combine to impact the formation of the spatial pattern of traditional villages, and all of them are multi-factor interactions showing the phenomenon of effect enhancement. The intensity of the effect of the enhancement between different factors on their traditional villages varies, for example, the two factors of the maximum synergistic intensity are elevation and population, and the two factors of the minimum synergistic intensity are GDP and population.

Conclusion and discussion

Discussion

This study analyzes the spatial distribution characteristics of traditional villages in the YRB based on the data and ArcGIS platform, and qualitatively analyzes the relationship between their spatial distribution and natural and socio-economic factors. On this basis, Geodetector model is used to calculate the action intensity of different influencing factors, and the spatial distribution pattern and formation reasons of traditional villages in YRB are further understood. The specific results are as follows: the calculation results of the nearest neighbor index and coefficient of variation show that the traditional villages in YRB are distributed in cohesive clusters in space, but the degree of cohesive clusters distribution of each batch of traditional villages is different; the results of kernel density analysis show that the traditional villages in YRB form 2 significant density cores in the intersection of Guizhou Province and Hunan Province and southeastern Anhui Province in spatial distribution, and northeastern Yunnan Province and eastern Jiangxi Province; the results of the geographical concentration index show that the spatial distribution of traditional villages in the Yangtze River valley is uneven among county-level administrative regions, and the concentration degree of spatial distribution among different batches of traditional villages is different; Gini coefficient, equilibrium degree C, and Lorenz curve jointly show and verify that the equilibrium degree of different batches of traditional villages is different; the results of spatial deviation analysis show that the spatial distribution center of traditional villages in YRB is mainly in the northwest of Hunan Province, and the spatial distribution direction and scope are consistent.

Qualitative analysis of the influencing factors shows that the natural factors in the area where the traditional

Table 8 Main interaction factors and associated changes

Interaction factors	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	0.037150	/	/	/	/	/	/
X_2	0.044392[a]	0.007763	/	/	/	/	/
X_3	0.039348[b]	0.009501[b]	0.0015576	/	/	/	/
X_4	0.046889[a]	0.029668[a]	0.026169[b]	0.024474	/	/	/
X_5	0.041303[b]	0.009223[b]	0.003065[b]	0.024880[a]	0.001011	/	/
X_6	0.055767[b]	0.009376[b]	0.003725[b]	0.027683[b]	0.001088[a]	0.000677	/
X_7	0.047431[a]	0.020514[a]	0.015050[b]	0.0330452[a]	0.014241[a]	0.024564[b]	0.013153

The interaction factor detection results (q-values),

[a] Two-factor enhancements, and

[b] Nonlinear enhancements

villages are spatially distributed are mainly below 2000 m above sea level, sunny slopes, within 10 km from rivers, and high vegetation coverage; for socioeconomic factors, the traditional villages are mainly distributed in areas with low GDP, low population density, and poor accessibility.

The calculation results of the Geodetector show that elevation and vegetation coverage are the main factors that affect the spatial distribution of traditional villages in YRB, followed by traffic, slope direction, water system, and other secondary factors. The interaction between different influencing factors shows that natural and socioeconomic factors jointly promote the formation of the spatial pattern of traditional villages in YRB.

Factors influencing the spatial pattern of traditional villages

As one of the important natural factors of traditional villages, elevation plays a decisive role in the topography and terrain of the location of traditional villages. Differences in elevation lead to differences in temperature, precipitation, sunlight radiation, and other conditions in traditional villages at different elevation, thus making the structure and ways of villages distinctive [6]; secondly, the increase in elevation leads to an increase in the degree of topographic relief, which leads to a decrease in the accessibility of villages and a lower degree of communication between traditional villages and the outside world, which is beneficial to the preservation of traditional villages and the protection of their cultural heritage. The slope direction of the mountainous area where traditional villages are located has a great influence on the intensity of solar radiation and sunshine duration, and is an important reference element for the location of traditional villages, so the slope direction is also one of the important factors affecting the spatial distribution of traditional villages [6]. Water is a necessity for human life, so traditional villages are generally formed within a specific range of rivers. Human settlements in general are built near water, and this spatial characteristic near water is directly related to the traditional Chinese concept of settlement layout [52]. In general, areas with better ecological environments are more suitable for the formation and development of traditional villages [5], and vegetation cover can reveal the difference between good and bad ecological environments to some extent [5]. Generally speaking, a greater vegetation cover represents a better ecological environment [5].

The difference in regional economic development levels has a certain degree of connection to the preservation and retention of traditional villages. Generally speaking, the lower the level of economic development, the more the number of traditional villages is relative, the reason is mainly that the backward economic development will make transportation and other infrastructure construction slower, thus creating the necessary conditions for the retention of traditional villages. The population is the basis for the formation of traditional villages, but the development of the times has led to the migration of densely populated areas to cities, which has led to a decrease in the number of traditional villages and even their extinction. Therefore, the analysis of the population density of traditional villages is of great significance for their preservation and retention. Transportation is a precondition for the development of a region, and if the traditional villages are weakly accessible, they are not easily affected by the external environment, which plays an important role in their preservation and development.

Policy implications

In the process of urbanization, the extinction of many traditional villages has brought irreparable damage to traditional Chinese history and culture, cultural diversity and regional cultural ecology have been greatly affected, so how to preserve traditional villages is a challenging task. Most of the traditional villages in the Yangtze River valley are in areas with low traffic accessibility, socioeconomic backwardness, and good ecological environment, and spatial differentiation of traditional villages is strongly affected by natural factors, similar to the spatial distribution of traditional villages in the Yellow River basin, which is also the birthplace of Chinese civilization [53]. Under the current social and economic background, traditional villages are easily affected and destroyed by the external environment. Therefore, the protection and development of traditional villages in the Yangtze River valley should be determined comprehensively according to the specific conditions of each region. The results of this study can provide a policy reference for the differentiated conservation of traditional villages.

From the geographical differentiation of traditional villages, they are mainly concentrated in the middle and lower reaches of the Yangtze River basin because of the healthy ecological environment and high level of economic development in these areas. In the upper reaches, most of the traditional villages are concentrated in less economically developed areas and ecologically fragile areas, while the population of these traditional villages is scattered and the resident population is mainly elderly and children, which lacks development vitality. For the traditional villages that are gradually dying out, we should give full play to their cultural advantages, set up special funds to develop rural tourism, drive the employment of young people in the area, and promote the return of the population to these villages. Meanwhile, traditional villages have significant spatial clustering characteristics, and their development and utilization should take into account the complementary advantages of neighboring villages to maximize their value. In assessing traditional villages, a broader perspective should be taken, as artificial division often brings about the fragmentation of traditional villages in the region. The development of protected areas for traditional villages may be the solution.

The study also found that elevation and vegetation have a greater influence on the formation of the spatial pattern of traditional villages, and the synergistic effect of elevation and population is also stronger. Site conditions such as elevation cannot be changed, but vegetation can be artificially altered. As mentioned above, strengthening the ecological construction of existing traditional villages, developing rural tourism, and promoting population return can also be important means to regulate the spatial distribution pattern of traditional villages. Starting from its influencing factors, optimizing the spatial distribution of traditional villages and giving full play to their cultural and economic spatial spillover effects will not only enhance their cultural inheritance but also further prevent traditional villages from dying out.

The establishment of traditional village protection system

The development and conservation of traditional villages should be considered from three aspects: life, production, and ecology. Traditional villages often have multi-functional characteristics such as economic function, social and cultural function, and ecological function. This also corresponds to the three aspects of production, life, and ecology. Traditional villages have formed distinctive patterns and characteristics over a long period of time, and have evolved under the exogenous pull of socioeconomic development.

From the production perspective, the industrial display model should be developed. Relying on the surrounding cities and towns to develop the traditional village economy using industrial display conditions, villagers participate in the industrial display services comprehensively and effectively. Through government intervention, social capital intervention enables local villagers to benefit from industrial development and increases the opportunities for self-development, thus realizing sustainable protection and development of traditional villages.

From the perspective of life, the protection of traditional villages should not only be rooted in the deep local vernacular culture, but also in the form of innovative development. Relying on the rich cultural heritage of traditional villages, the organic connection between the conservation elements is established through heritage conservation, and conservation is based on the whole. In addition, the systematic conservation and utilization of villages can be realized by deeply exploring the organic integration of traditional village original appearance conservation and folk culture.

Finally, under the ecological perspective, ecological restoration of traditional villages needs to be adhered to. As mentioned above, vegetation restoration can significantly affect the spatial pattern of traditional villages. Traditional villages should focus on the harmonious symbiosis with the natural environment. Since ancient times, China has been influenced by the idea of heaven-and-man combination, forming an ecological only of harmonious coexistence between man and nature. In the process of developing and protecting traditional villages, we should control the limits of artificial expansion, optimize the spatial structure, pay attention to ecological perception, and enhance ecological resilience.

Author contributions

WC: conceptualization, methodology, software, formal analysis; LY: writing-review and editing, data curation; JW: writing-original draft, data curation; JW: data curation; GW: data curation; JB: data curation; JZ: writing-review and editing; ZL: writing-review and editing. All authors read and approved the final manuscript.

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Availability of data and materials

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

Declarations

Competing interests

The authors declare that they have no competing interests.

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