

Article

Multidimensional Evaluation of Traditional Villages in Jiangnan Region, China: Spatial Pattern, Accessibility and Driving Factors

Yi Zhang ^{1,2}, Zheng Tian ¹, Jiacheng Du ¹ and Shibo Bi ^{1,*}

¹ School of Design Art & Media, Nanjing University of Science and Technology, Nanjing 210094, China; yiz@njjust.edu.cn (Y.Z.); ztian@njjust.edu.cn (Z.T.); jcdu@njjust.edu.cn (J.D.)

² Qinglan Project "Excellent Teaching Team in Jiangsu Province in 2021", Nanjing 210094, China

* Correspondence: bshibo@163.com; Tel.: +86-13720898259

Abstract: Assessment of the spatial distribution and accessibility of traditional villages is closely related to their development. However, the impacts of spatial heterogeneity on the accessibility of traditional villages remain largely unknown. A total of 644 national-level traditional villages in the Jiangnan region were used to explore the spatial heterogeneity impact with a geographically weighted regression (GWR) model. We found: (1) spatially, the villages exhibit a predominant aggregation distribution pattern with significant local spatial disparities ($R < 1$, $p < 0.01$), predominantly originating from the Song and Ming dynasties (59.21%). Their clustering shifts from northeast to southwest, with over 70% of the villages located on slopes ranging from 0° to 20° and within 1 km of water. (2) The accessibility of these villages is generally low, with 85.66% being accessible within 200 ~ 300 min; it decreases concentrically outwards from Changzhou and exhibits clustering autocorrelation characteristics (Moran's $I > 0$, $Z > 2.58$). (3) Road network density, elevation, and slope are significantly correlated with accessibility ($p < 0.05$), demonstrating pronounced spatial heterogeneity in their effects, with these factors collectively explaining approximately 85% of the accessibility levels. These findings provide a basis for comprehensive planning and categorized strategies for traditional villages.

Keywords: traditional villages; spatiotemporal pattern; accessibility; driving factors; spatial heterogeneity



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1. Introduction

As early settlements rich in both tangible and intangible cultural assets, traditional villages hold immense historical, cultural, scientific, artistic, and socioeconomic significance and are marked by distinct regional cultural identities [1]. The rapid pace of urbanization poses a significant threat to these heritage sites [2]. Notably, over 1.1 million villages in China vanished from 1991 to 2012 [3], a trend that has garnered attention from global bodies such as the United Nations Educational Scientific and Cultural Organization (UNESCO) and the International Council on Monuments and Sites (ICOMOS) [4]. To address these challenges, a total of 8155 traditional Chinese villages were listed in six batches by March 2023. Furthermore, the establishment of regions such as Jiangnan (Jixi County in Anhui Province and Wuzhong District in Jiangsu Province) as concentrated and contiguous protection and utilization demonstration zones for traditional villages further highlights the importance of protecting this cultural heritage [5,6].

Recent interdisciplinary research in fields such as history, geography, architecture, and ecology has significantly enhanced our understanding of traditional villages, with a particular emphasis on spatial studies [7–10]. These studies primarily encompass four themes: the evolution and development of these villages [10,11], their valuation and assessment [7,9], preservation strategies and utilization models [12,13], and adaptation to modernization [14,15]. Notably, Fu et al. studied the heritage value of traditional dwellings

in Xiangxi [7], and Li et al. and Liu et al. studied the spatial distribution of traditional villages in Hunan and Henan provinces, respectively [3,16].

Methodologically, the shift from qualitative methods such as literature analysis, fieldwork, and case studies to quantitative approaches has been pivotal [17–19]. The integration of geographic information systems (GISs) has enabled the application of advanced techniques such as kernel density analysis and spatial correlation and regression analyses [20–22]. These methods have significantly contributed to a macroregional comprehension of the spatiotemporal patterns in village spaces [23–25]. A key field of focus is the examination of the distribution characteristics and driving factors of traditional villages [16,23,26,27]. For instance, Chen et al. investigated the spatial distribution patterns and determinants of traditional villages in China [23], while Liu et al. utilized ArcGIS to analyze the spatial characteristics of 275 villages in Henan Province [16]. Chen et al. and Gao et al. investigated the spatial distribution factors in the Yangtze and Yellow river basins [26,27]. These studies, especially at the administrative and basin scales, offer critical insights into the spatial formation mechanisms of villages, with a specific focus on spatial localization [10,26].

However, compared with the inherent characteristics of spatial location, exploring the accessibility of village spaces and its influencing factors can provide more direct guidance for the protection and development of villages [28,29]. To this end, methods such as the grid cost-weighted distance algorithm [30] and the minimum cumulative resistance (MCR) model [29] have been used to evaluate the accessibility of traditional villages. However, these methods fall short in real-time dynamic monitoring of village accessibility. Recent advances in web spider technology, such as the Octopus Web Data Collector, commonly employed in urban flooding hazards [31] and climate change studies [32], offer potential solutions to this limitation. Moreover, existing studies often utilize global spatial analysis methods [29,30], such as simple linear regression or ordinary least squares (OLS), to assess the global spatial impacts of accessibility factors such as topography. However, there is a significant gap in understanding the local spatial effects of these factors. Furthermore, recognizing traditional villages as reservoirs of regional culture [1] and examining them within the framework of cultural zoning—a concept that transcends administrative boundaries [33]—has emerged as a vital perspective in spatial studies of these traditional villages.

The Jiangnan region of China, a culturally and geographically distinct area, boasts a long history with numerous traditional villages that are rich in cultural heritage and have been well preserved [34]. Research in this area has predominantly concentrated on detailed studies of specific villages. For instance, Cheng et al. investigated the spatial features of traditional villages in Huizhou, southern Anhui, including notable sites such as Hongcun, Nanping, and Xidi [35]. Chen et al. and Wang et al. explored the spatial characteristics and dynamics of Dongcun Village in Suzhou and Chengkan Village in Huizhou, respectively [1,36]. Despite these valuable contributions, there is a lack of a macroregional perspective on Jiangnan's traditional villages, posing a challenge for the development of comprehensive regional conservation strategies.

In summary, while there has been extensive research on the spatial dimensions of traditional villages, it reveals certain gaps. First, previous studies are often limited to administrative scales such as national, provincial, and city levels, as well as river basin scales [16,26,27]. There is a lack of research focusing on cultural districts that transcend administrative boundaries, such as the Jiangnan region. Second, there is a relative dearth of research on the accessibility assessment of traditional villages and their influencing factors [29,30]. Moreover, their analysis of overall accessibility impacts without addressing local spatial differences fails to lay the groundwork necessary for providing differentiated protection strategies. Third, previous studies on traditional villages in the Jiangnan region often focused on studies of typical villages and lacked a more macroscopic perspective for an in-depth investigation of the accessibility of traditional villages and their influencing factors.

In response, GIS spatial analysis was utilized to assess the spatiotemporal patterns and accessibility of traditional villages in the Jiangnan region. Overlay analysis and global (OLS) and local spatial regression (GWR) models were employed to dissect the global and local spatial characteristics of factors influencing the accessibility of traditional villages in Jiangnan, and a classified protection strategy was proposed for these villages. The key research questions include the following: (1) What are the distribution characteristics and evolutionary patterns of traditional villages in Jiangnan? (2) How is the accessibility of these villages characterized? (3) Which factors influence this accessibility, and do these impacts exhibit spatial heterogeneity? How do these impacts vary across global and local spatial dimensions? Finally, this study employs a combined quantitative and qualitative analytical approach to uncover the key factors related to the accessibility and distribution patterns of traditional villages, with a focus on analyzing the spatial heterogeneity characteristics of accessibility impacts. This study provides theoretical and practical guidance for the categorized protection and revitalization of traditional villages in Jiangnan, while also offering methodological references for the accessibility assessment of traditional villages in other regions.

2. Date and Methodology

2.1. Study Area

The Jiangnan region, one of the cradles of Chinese farming civilization, is situated in the Yangtze River Delta region of China, a region distinguished by its unique geographical and cultural characteristics. This research focused on the Taihu Lake Basin, which encompasses 19 cities across southern Jiangsu, northern Zhejiang, southern Anhui, and Shanghai [37] (Figure 1), spanning an area of approximately 137,100 km². These areas exhibit significant similarities in aspects such as production, lifestyle, customs, architecture, and art [38]. Meanwhile, Jiangnan is marked by distinct historical, regional, and cultural features, hosting a multitude of traditional villages of high conservation, developmental, and research significance. With the introduction of relevant national policies in recent years, it has become a crucial area for the protection and development of traditional villages in China.

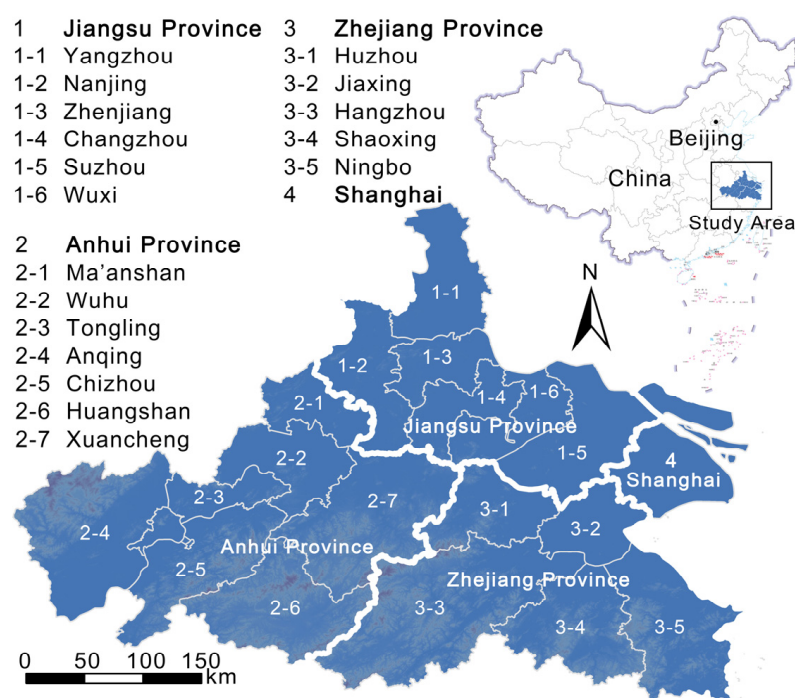


Figure 1. Study area (1, 2, 3, and 4 represent the provinces/municipalities of the Jiangnan area).

2.2. Data Source and Preprocessing

The traditional villages in this study are derived from the six releases of the “Chinese Traditional Villages List” published by the Chinese government (<https://www.mohurd.gov.cn>) (accessed on 15 July 2023). The establishment dates of these villages were determined using various documentary sources, including local records, gazetteers, and historical records from Anhui, Zhejiang, Jiangsu provinces, and Shanghai. Three criteria for determining the dates are as follows. (1) The founding dates explicitly recorded in documents; (2) the earliest historical relics found in the villages; (3) the inferences based on modern archaeological discoveries [39]. A total of 644 villages with clearly established dates were selected for this study. Accordingly, the formation periods of traditional villages in the Jiangnan region were categorized into five eras: the pre-Song, Song, Yuan, Ming, and Qing dynasties. The geographical coordinates for each village were obtained using Google Earth (<https://maplocation.sjfkai.com>) (accessed on 18 July 2023) and adjusted to calculate their spatial locations. Additionally, the elevation DEM data required for the study were sourced from the SRTMDEM data available at <http://www.gscloud.cn> (accessed on 22 July 2023), with a spatial resolution of 30 m × 30 m. The spatial data for water systems and road networks were obtained from the latest vector data provided by the National Geomatics Center of China (<https://www.ngcc.cn>) (accessed on 22 July 2023). The current accessibility database is based on the shortest driving times obtained in real time from Baidu Maps (<https://map.baidu.com>) (accessed on 30 July 2023).

2.3. Methodology

2.3.1. Research Framework

A combined quantitative and qualitative approach was adopted to comprehensively explore the spatiotemporal patterns of the distribution, accessibility, and impact factors of traditional villages in Jiangnan (Figure 2). (1) The spatiotemporal distribution pattern. Specifically, the distribution state (aggregation or dispersion) was determined using the nearest neighbor index, imbalance index, and kernel density analysis. Furthermore, the standard deviation ellipse analysis method was used to investigate the spatiotemporal evolution of the founding years of traditional villages in Jiangnan [40]. (2) The accessibility of these villages was quantified with web-scraping technology. It is further visualized by the kriging method. (3) The influencing factors of accessibility were revealed through overlay analysis, correlation, and regression analyses. First, as a qualitative analysis method in our study, overlay analysis was used to determine the overall relationship between accessibility and variables such as elevation, slope, proximity to water systems, and road network density. Second, Pearson correlation analysis is employed to diagnose potential associations between explanatory variables (influencing factors) and the dependent variable (accessibility). On this basis, a global spatial regression model between the dependent and explanatory variables is established using ordinary least squares (OLS). Third, spatial autocorrelation analysis is utilized to examine the presence of spatial autocorrelation in accessibility. Then, local regression models are constructed using geographically weighted regression (GWR), revealing the impacts of spatial heterogeneity on accessibility caused by various factors. Finally, an in-depth examination of the global and local spatial characteristics of the factors influencing the accessibility of villages in Jiangnan was conducted by comparing the results obtained with OLS and GWR. This methodology culminated in a comprehensive framework for evaluating the spatiotemporal patterns of traditional villages, integrating both qualitative and quantitative techniques. Based on this framework, categorized development strategies for traditional villages in Jiangnan were proposed.

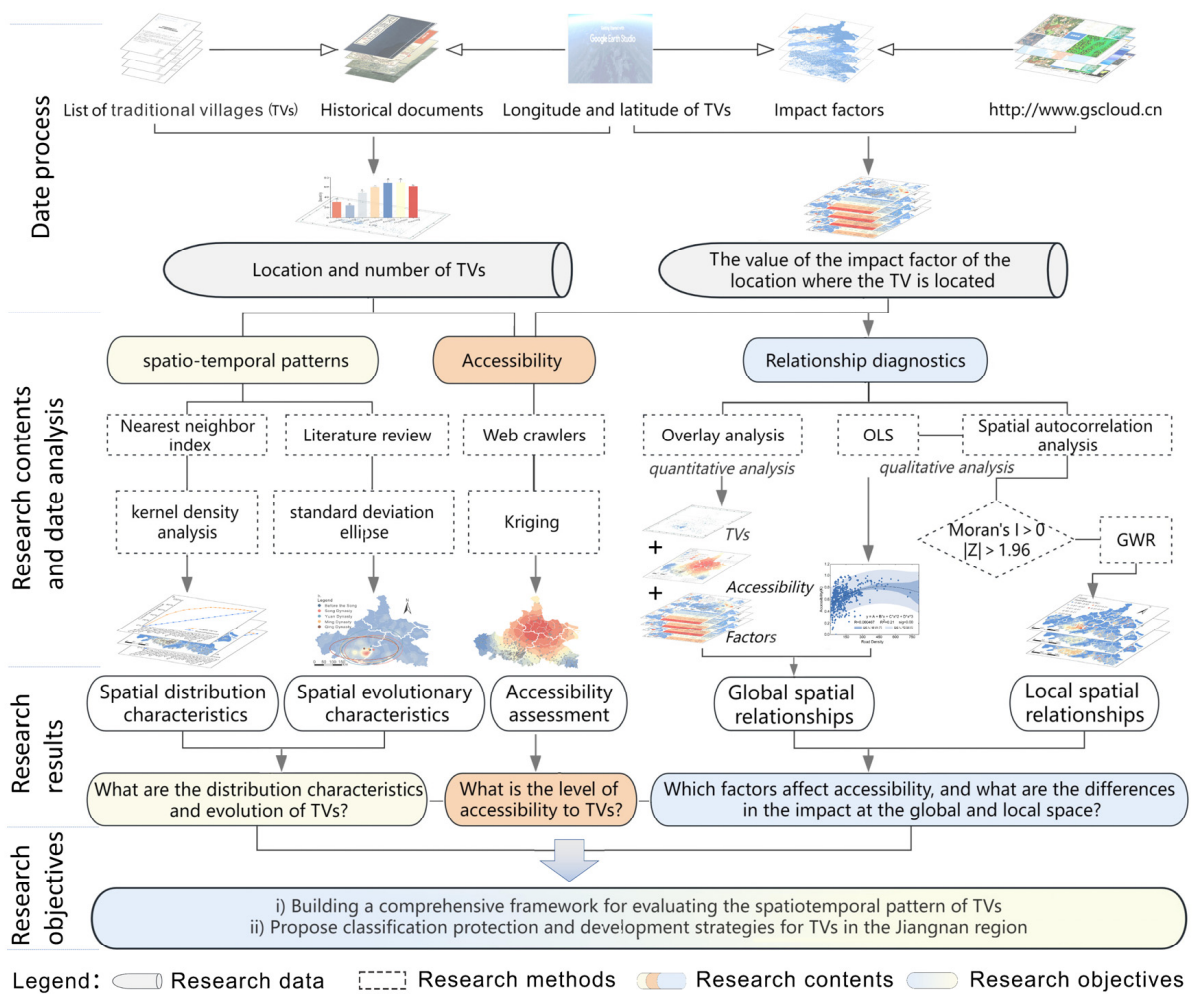


Figure 2. Research framework.

2.3.2. Research Methods

(1) Nearest neighbor index

The nearest neighbor index (R) is an important indicator used to measure the type of spatial distribution, reflecting the aggregation or random or dispersion distribution status of traditional villages, and is calculated by Equation (1).

$$R = \frac{\bar{r}_1}{r_E} = 2\sqrt{D} \quad (1)$$

where R represents the nearest neighbor index, r_1 represents the actual average nearest neighbor distance between traditional villages, r_E represents the theoretical average nearest neighbor distance between traditional villages, and D is the point density. When $R = 1$, the distribution of villages is random. When $R > (<) 1$, the distribution of traditional villages is aggregated or dispersed.

(2) Imbalance index

The imbalance index, denoted by S , is used to measure the balance degree of traditional villages in local space and is calculated by Equation (2). The value of S ranges from 0 to 1, with a value closer to 0 indicating a more balanced spatial distribution of traditional villages and a value closer to 1 indicating a less balanced spatial distribution.

$$S = \frac{\sum_{i=1}^n M_i - 50(n+1)}{100 \cdot n - 50(n+1)} \quad (2)$$

where S represents the imbalance index, n represents the number of prefecture-level cities in Jiangnan, and M_i represents the cumulative percentage of the ratio of the number of traditional villages in each city to the total number, ranked in descending order.

(3) Kernel density estimation

This method is used to calculate the spatial distribution density (P_v) and road network density (P_r) of traditional Jiangnan villages. It searches for the number of traditional villages/roads within a certain radius of any traditional village/road and then calculates the density within that range. The higher the value is, the greater the density value, which is calculated by Equation (3).

$$P = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{X - X_i}{h}\right) \quad (3)$$

where p is the kernel density of the sample, n is the number of traditional villages or road networks, K is the kernel function, h is the bandwidth ($h > 0$), and $(X - X_i)$ represents the distance from the estimated point X to the sample point X_i .

(4) Standard deviational ellipse analysis

Standard deviational ellipse analysis (SDE) is a spatial statistical method used to reveal the direction, center of gravity, and dispersion of the spatial distribution of traditional villages [41]. The main parameters include the center of gravity, ellipse area, azimuth, and the long axis (X) and short axis (Y). The center of gravity represents the location of village aggregation, the area represents the spatial distribution range, the azimuth represents the main trend of the distribution direction, and the ratio of the X -axis to the Y -axis is called the flatness rate. The larger (smaller) the flatness rate is, the stronger (weaker) the directionality of the distribution of traditional villages; that is, the greater the dispersion. This part was calculated using ArcGIS 10.8.

(5) Accessibility analysis

Accessibility is used to measure the ease of access to traditional villages. The “Octoparse Web Data Extractor” network crawler technology is used to obtain more accurate accessibility levels through real-time measurements [42]. The accessibility of traditional villages is calculated using Equations (4) and (5) and further processed through the kriging interpolation method for grid data calculations.

$$K_j = \frac{\sum_{i=1}^n E_{ij}}{n} \quad (4)$$

$$K = \frac{\frac{\text{Max}K_j - K_j}{1 \leq j \leq m}}{\frac{\text{Max}K_j - \text{Min}K_j}{1 \leq j \leq m} - \frac{\text{Min}K_j - K_j}{1 \leq j \leq m}} \quad (5)$$

where K_j represents the spatial accessibility of traditional village j , measured in minutes (minute, min); n refers to the number of cities; E_{ij} represents the shortest distance from traditional village j to city i ; and K represents the standardized numerical value of the spatial accessibility of a traditional village (K_j), with a larger K value indicating stronger accessibility.

(6) Overlay analysis

Overlay analysis is a qualitative analysis method of overlapping two or more raster layers of factors within the same area to analyze their relationships. Our study overlays the raster layers of traditional village distribution and accessibility values with the raster layers of elevation (DEM), hydrological distribution, and road network distribution to analyze the distribution, accessibility, and potential associations between these factors. They were calculated with ArcMap 10.8 software.

- (7) Global (ordinary least squares, OLS) and local (geographic weighted regression, GWR) spatial regression analysis

Quantitative analysis methods, namely, OLS and GWR, were utilized to examine the spatial relationships between the accessibility of traditional villages in Jiangnan and various influencing factors. OLS was utilized to quantify overall spatial relationships (Equation (6)), while spatial heterogeneity was addressed with GWR, which calculates local regression coefficients (LRCs) between accessibility and each influencing factor in local spaces (Equation (7)). These coefficients indicate how accessibility is variably influenced by different factors in specific local contexts [43]. Positive (negative) LRC values indicate a positive (negative) correlation in local spaces, with larger (smaller) $|LRC|$ values signifying stronger (weaker) effects [44]. Prior to GWR analysis, spatial autocorrelation of accessibility was assessed using ArcMap 10.8 to determine the presence of spatial dependencies.

$$y_i = b + \sum_{k=1}^n a_k x_{ik} + \varepsilon_i \quad (6)$$

where y_i is the accessibility value of traditional villages; b is a constant term; $k = 1, 2, \dots, n$, represents influencing factors; x_{ik} is the data of the k -th influencing factor in village i ; and ε_i is the error term.

$$Y_i = \beta_0(U_i, V_i) + \sum_m \beta_m(U_i, V_i) X_{im} + \varepsilon_i \quad (7)$$

where Y_i is the accessibility of a traditional village at location i , and X_{im} is the value of the m -th influencing factor at this location i . The coordinates of location i are represented by (U_i, V_i) . The intercept of the regression equation at any given point is expressed as $\beta_0(U_i, V_i)$, while $\beta_m(U_i, V_i)$ reflects the regression value of the m -th factor at that specific location i . The variable m is the total number of factors in the model, and ε_i is the error term at location i .

3. Results

3.1. Spatiotemporal Distribution and Evolution of Traditional Villages in Jiangnan

3.1.1. Spatial Distribution Characteristics

As of March 2023, the Jiangnan region encompasses 644 national-level traditional villages (Table 1). The nearest neighbor index (R -value) of 0.54 indicated a highly significant aggregation in the spatial distribution of these villages ($R < 1$, $P < 0.01$) (Figure 3a). However, there is a notable imbalance in distribution across various municipal areas ($S = 0.74 < 1$). A considerable number of traditional villages are found in southern Anhui and northern Zhejiang, whereas fewer are located in southern Jiangsu and Shanghai. At the municipal scale, the Lorenz curve (Figure 3b) shows that traditional villages are mainly distributed in Huangshan City, Xuancheng City, and Hangzhou (more than 70% of the total traditional villages), with Huangshan accounting for the highest number of villages (310, representing 41.18%). This is followed by Xuancheng and Hangzhou, with 85 and 65 villages, accounting for 12.94% and 9.89%, respectively. Conversely, cities such as Yangzhou, Changzhou, Huzhou, and Ma'an Shan have lower numbers of national-level traditional villages (fewer than 5).

Figure 4 shows the spatial pattern of the distribution of traditional villages via nuclear density analysis (represented by P_v). A significant difference in the spatial density of traditional villages in Jiangnan is observed, characterized by a pattern of “small-scale clusters within a larger-scale dispersion”. Specifically, the highest-density cluster is located in the northeastern part of Huangshan and the southwestern part of Xuancheng, with kernel density values ranging between 393.38 and 1139.89. The secondary high-density area is primarily concentrated in the central region of Huangshan (P_v : 151.99~393.37). Additionally, varying scales of lower-density clusters are found in regions such as the western part of Xuancheng, the southwestern area of Suzhou City, and the northeastern sector of Zhenjiang (P_v : 22.36~151.98). Other areas, including Anqing, Ningbo, and Shaoxing, exhibit more dispersed distributions of traditional villages.

Table 1. Number and distribution of traditional villages in Jiangnan.

Province/City	Number	Percentage	Province/City	Number	Percentage
1 Jiangsu Province	58	9.01%	2 Anhui province	450	69.87%
1-1 Yangzhou	3	0.47%	2-1 Ma'anshan	1	0.16%
1-2 Nanjing	5	0.78%	2-2 Wuhu	2	0.31%
1-3 Zhenjiang	9	1.40%	2-3 Tongling	6	0.93%
1-4 Changzhou	3	0.47%	2-4 Anqing	22	3.42%
1-5 Suzhou	27	4.19%	2-5 Chizhou	28	4.35%
1-6 Wuxi	11	1.71%	2-6 Huangshan	304	47.20%
			2-7 Xuancheng	82	12.73%
3 Zhejiang Province	136	21.12%			
3-1 Huzhou	6	0.93%	4 Shanghai	5	0.78%
3-2 Jiaxing	5	0.78%			
3-3 Hangzhou	64	9.94%			
3-4 Shaoxing	29	4.50%			
3-5 Ningbo	32	4.97%	Total	644	100%

Note: Percentage refers to the proportion of traditional villages in a province/city relative to the total number of traditional villages in the Jiangnan region of China.

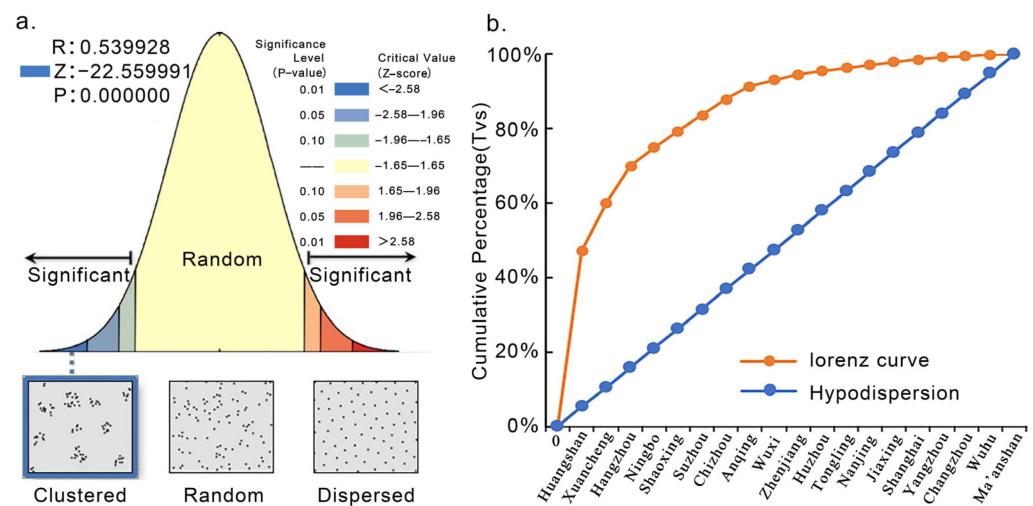


Figure 3. (a) The results of the nearest point index of traditional villages in Jiangnan. The figure shows that the spatial distribution of traditional villages in Jiangnan is highly significantly clustered ($R = 0.54 < 1$, $p = 0.00 < 1$). (b) Lorentz curve distribution map of traditional villages in Jiangnan. The X-axis represents the names of the cities in Jiangnan, and the Y-axis represents the cumulative proportion of traditional villages.

3.1.2. Spatial and Temporal Evolution Characteristics of Traditional Village Distribution

Significant differences in the spatiotemporal evolution of the distribution of traditional villages in Jiangnan were visualized via standard deviational ellipse analysis (Figure 5). Generally, the aggregation orientation of traditional villages in different dynasties demonstrated a trajectory that was initially northeastward and then shifted southwestward, centered around the intersection of southern Xuancheng and northeastern Huangshan (118.79° E, 30.10° N) (Figure 5b).

Specifically, the barycenter of the village distribution exhibited minor fluctuations during the research period, spanning approximately 0.3° east–west and approximately 0.08° north–south. Additionally, in terms of the ellipse area and orientation angle, the spatial range of traditional village distribution initially expands and then contracts, predominantly aligning in a southwest–northeast direction. The overall orientation angle changes by 3.01° , averaging an increment of 0.75° per founding period. Notably, the Yuan Dynasty records the largest change in orientation angle (77.37°) and the widest spatial distribution (ellipse area value of 5.80 km^2). Finally, the standard deviation ellipse eccentricity decreased from

0.48 to 0.40 and then increased to 0.64 from the pre-Song to the Yuan and Qing dynasties, indicating that the degree of dispersion in the spatial distribution of traditional villages decreased and then increased over time (Figure 5a).

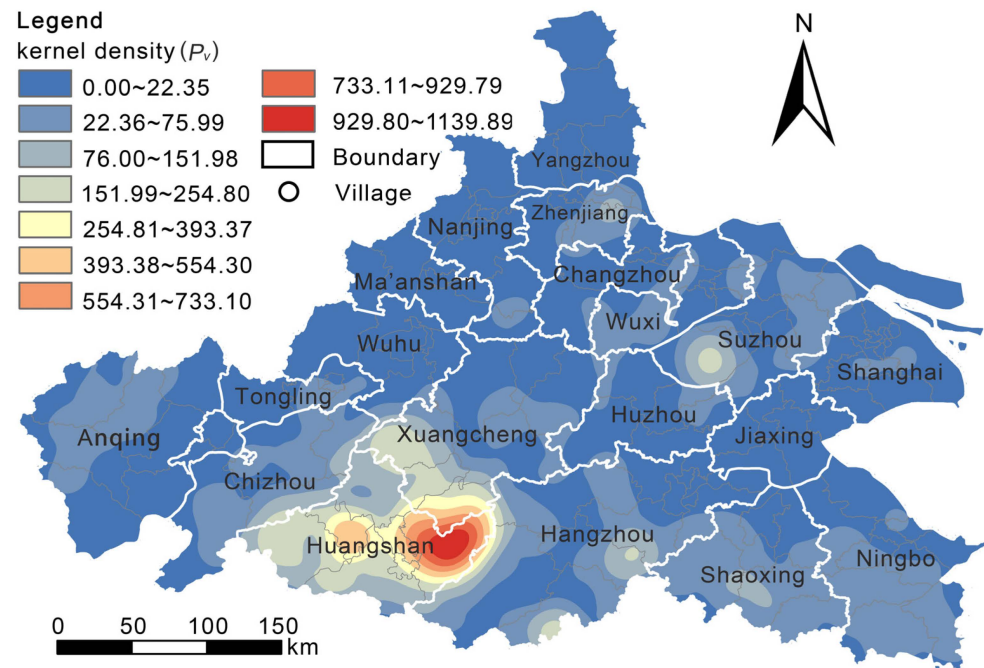


Figure 4. Nuclear density analysis of traditional villages in the Jiangnan region. Areas closer to red indicate a denser distribution of traditional villages, with Huangshan having the densest distribution of traditional villages.

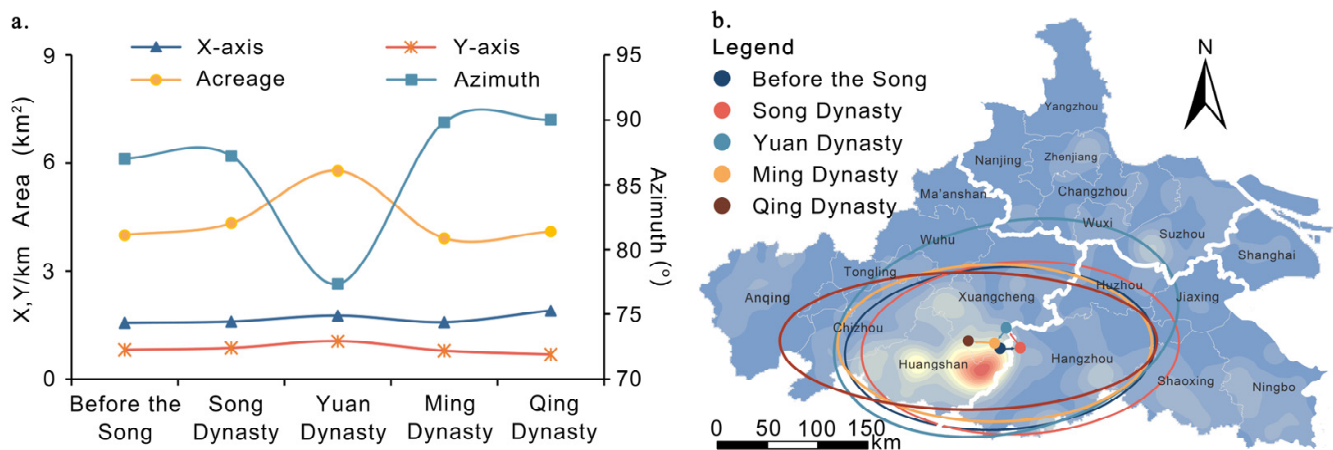


Figure 5. (a) The results of the standard deviation ellipse analysis of Jiangnan traditional villages in different periods. In the figure, the horizontal axis shows different dynasties of village establishment; the left vertical axis represents the X-axis (km), Y-axis (km), and area (km²); and the right vertical axis indicates the azimuth angle (°). (b) The spatial centroids of traditional Jiangnan villages in different dynasties. They reflect the core locations where traditional villages were concentrated in different periods.

3.2. Assessment of Accessibility of Traditional Villages in Jiangnan

In the study area, traditional village accessibility displays a concentric distribution pattern, with higher accessibility in the central regions and lower accessibility in the peripheral areas (Figure 6). The 20 traditional villages, including the 10 villages with

the highest accessibility and 10 with the lowest accessibility, are presented in Table 2. The overall accessibility level of traditional villages in the study area is relatively low, with significant local spatial variations. Specifically, the average accessibility level of traditional villages is 0.64 (i.e., 224.65 min), with 85.66% of the villages falling within an accessibility range of 0.34 to 0.73 (i.e., 200~300 min). The gap between the lowest and highest accessibility levels of traditional villages is 253.37 min. Villages located in the southern Jiangsu region (Wuxi, Changzhou, Nanjing) exhibit greater accessibility, while those located in Anqing and southern Ningbo exhibit comparatively lower accessibility. This suggests substantial potential spatial variations in the influence of different factors on the accessibility of traditional villages in the study area (the detailed analysis was conducted in Section 4.2), indicating the importance of optimizing strategies for accessibility in local spaces.

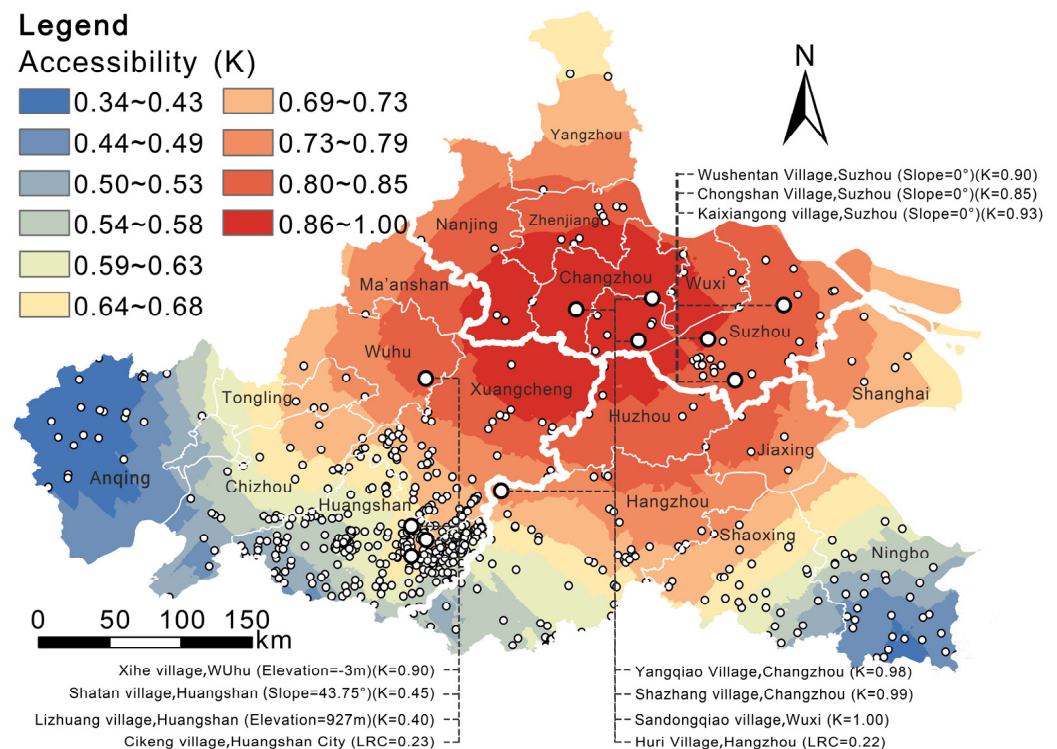


Figure 6. The distribution pattern of accessibility of traditional villages. Areas closer to red (blue) indicate greater (poorer) accessibility of traditional villages in that region. The enlarged dots shown in the figure represent the typical villages mentioned in Sections 3.3.1 and 4.4.

Table 2. Spatial accessibility and ranking of traditional villages in Jiangnan.

Ranking	Traditional Village	Accessibility	Ranking	Traditional Village	Accessibility
1	Sandongqiao Village, Wuxi	1.0000	635	Jincheng Village, Anqing	0.2530
2	Shazhang Village, Changzhou	0.9923	636	Wuhe Village, Anqing	0.2459
3	Yangqiao Village, Changzhou	0.9892	637	Dongmenyu Village, Ningbo	0.2287
4	Fangzhuang Village, Wuxi	0.9840	638	Geyuan Village, Anqing	0.2196
5	Qiqiao Village, Nanjing	0.9774	639	Dianqian Village, Anqing	0.2092
6	Shitouzhai Village, Nanjing	0.9771	640	Mayuan Village, Anqing	0.1685
7	Jiaodu Village, Wuxi	0.9753	641	Zhentianqiao Village, Anqing	0.1323
8	Baoyan Village, Zhenjiang	0.9715	642	Jinying Village, Anqing	0.1147
9	Zhuling Village, Wuxi	0.9699	643	Longtanzhai Village, Anqing	0.0870
10	Zhangjia Village, Nanjing	0.9680	644	Liao Village, Anqing	0.0000

Note: The greater the accessibility value is, the greater the accessibility of the area. The left column and the right column represent the 10 traditional villages with the highest and worst accessibility, respectively. For example, if the ranking is 1 or 635, the accessibility ranks first or 635th out of 644 villages.

3.3. Overlay Analysis of Accessibility and Influencing Factors in Traditional Villages

The spatial accessibility of traditional villages is influenced by a variety of natural and social factors [30,45]. Based on existing research and specific to the Jiangnan region, elevation, slope, proximity to water systems, and road network density were selected as key factors. ArcMap 10.8 software facilitated the analysis of potential interrelations.

3.3.1. Relationships between Elevation, Slope, and Accessibility

The topography of Jiangnan, characterized by higher elevations in the south and lower elevations in the north, exhibits significant variation (Figure 7a). The terrain is classified into plains (<200 m), hills (200 m to 500 m), and mountains (>500 m). Generally, as elevation increases, the number of traditional villages and their accessibility levels tend to decrease (Figures 6 and 7). Predominantly, 363 villages (56.37%) are situated in plains, showing a broad range of accessibility levels (K : 0.34 to 1.00) (Figures 6 and 7a-1). In contrast, villages in hilly and mountainous areas, primarily located in southern Anhui and northern Zhejiang, constitute 39.44% and 4.19%, respectively, and generally exhibit lower accessibility levels (K : 0.34 to 0.68) (Figures 6 and 7a-2,a-3). In addition, the highest-elevation village is Lizhuang Village in Huangshan City (elevation = 927 m, K = 0.40), while the lowest is Xihelaojie Village in Wuhu City (elevation = −3 m, K = 0.90), showing significant variations in elevation and accessibility (Figure 6). Overall, lower accessibility levels of villages are generally observed at higher elevations (Figures 6 and 7).

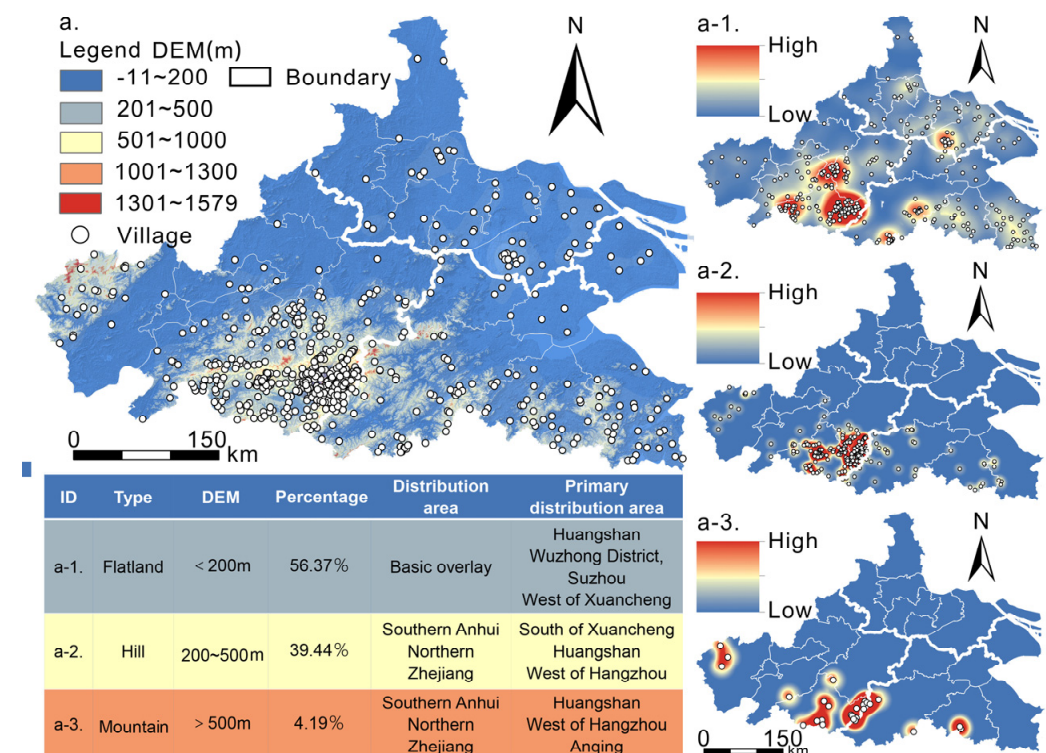


Figure 7. (a) The overlay analysis results of traditional villages and elevation. (a-1,a-2,a-3) represent the spatial distributions of traditional villages at elevations less than 200 m, 200~500 m, and greater than 500 m, respectively. Areas closer to red indicate a greater and denser number of traditional villages within that range. Their specific information is presented in the table.

In terms of slope, traditional villages in the Jiangnan region are located on slopes between 0° and 43.75° , with an average of 10.98° . Generally, as the slope increases, the number of villages and their accessibility levels decrease (Figures 6 and 8). The majority of villages (79.5%) are situated on slopes of 0° to 20° , with 56.52% located on inclines below 10° (Figures 6 and 8a-1,a-2). Additionally, 14.75% and 5.75% of villages are found on slopes

of 20° to 30° and above 30° , respectively, mainly in Huangshan and northern Zhejiang, which generally exhibit lower accessibility levels (K : 0.34 to 0.58) (Figures 6 and 8a-3,a-4). The village with the steepest slope (slope = 437.75) is Shatan Village in Huangshan City ($K = 0.45$), while Kaixiangong Village in Suzhou ($K = 0.93$) and Wushentan Village ($K = 0.90$) have the lowest slopes (slope = 0°). In general, there are lower accessibility levels on steeper slopes of villages (Figures 6 and 8).

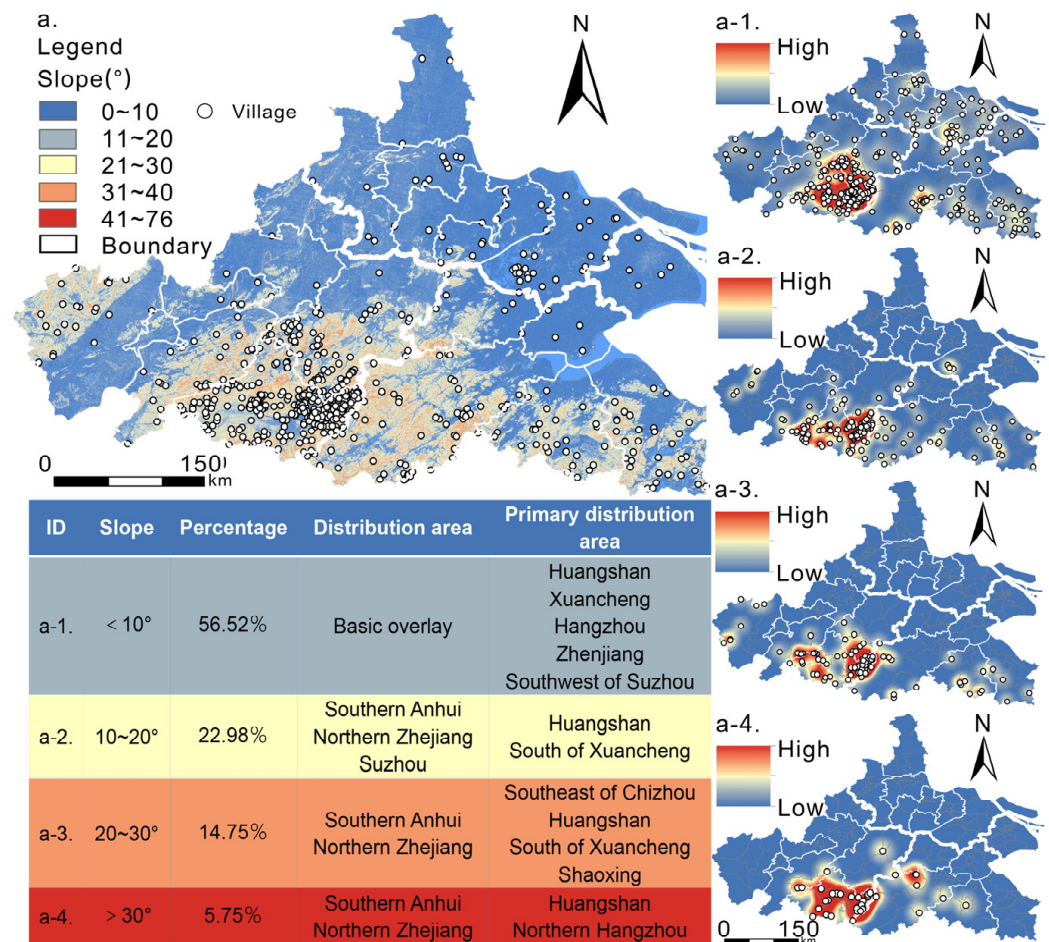


Figure 8. (a) The overlay analysis results of traditional villages and slopes. (a-1,a-2,a-3,a-4) represent the spatial distribution maps of traditional villages for slopes less than 10° , 10° ~ 20° , 20° ~ 30° , and greater than 30° , respectively.

3.3.2. Relationship between Proximity to Water Systems and Accessibility

The average distance of traditional villages from water systems is approximately 0.75 km. As the distance to the nearest water system increases, there is a decrease in the number of villages, but no significant pattern in accessibility level change is observed (Figures 6 and 9). Specifically, the majority of villages (74.07%) are within 1 km of water systems, predominantly in southern Anhui (Huangshan, Xuancheng), with relatively lower accessibility levels (K : 0.34 to 0.68) (Figures 6 and 9a-1,a-2). Beyond the 1.0 km to 2.0 km range, the number of villages significantly decreased (17.70%), with only 53 villages (8.23%) located more than 2 km away, primarily in Suzhou, Zhenjiang, and Huangshan (Figures 6 and 9a-3,a-4). In other words, there is no significant correlation between the accessibility of traditional villages and proximity to water systems.

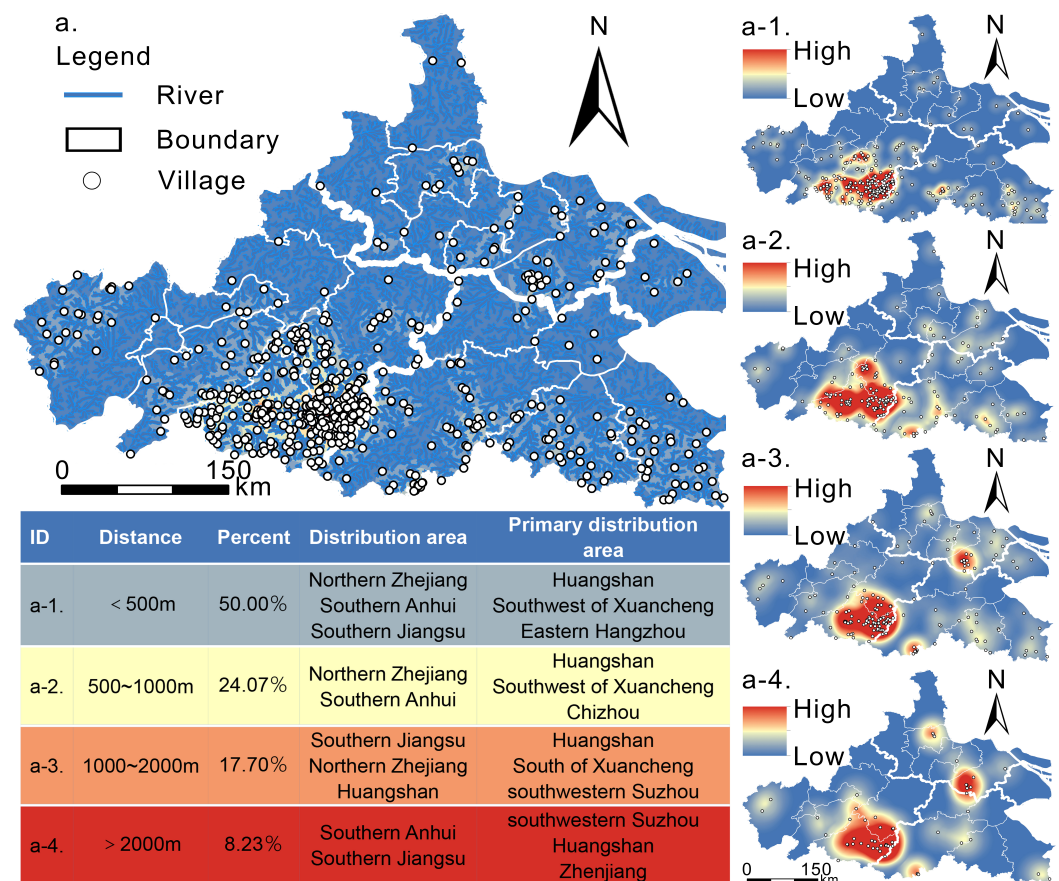


Figure 9. (a) The results of the overlay analysis of traditional villages and water systems. (a-1,a-2,a-3, a-4) represent the spatial distributions of traditional villages located at distances less than 0.5 km, 0.5~1 km, 1~2 km, and more than 2 km from water systems, respectively.

3.3.3. Relationship between Road Network Density and Accessibility

The values of the road network density in the study area decreased from northeast to southwest and were categorized into four levels based on density values: 1st level (P_r : 0.11 to 130.46), 2nd level (P_r : 130 to 279.44), 3rd level (P_r : 279.45 to 474.97), and 4th–5th level (P_r : 474.98 to 1187.26). First, more than 90% of traditional villages are located in areas with 1st- and 2nd-level road network density, mainly in Huangshan and northern Zhejiang, where accessibility levels are generally lower (K : 0.34 to 0.68) (Figures 6 and 10a-1,a-2). Second, 5.75% and 1.40% of the villages are found in the 3rd- and 4th–5th-level road network areas, respectively, which generally show higher accessibility levels (K : 0.74 to 1.00) (Figures 6 and 10a-3,a-4). In addition, cities such as Anqing, Chizhou, and Xuancheng, which have lower road network densities (P_r : 0.11 to 279.44), generally have lower accessibility levels (K : 0.34 to 0.79). However, cities such as Nanjing, Shanghai, and Hangzhou, which have higher road network densities (P_r : 279.45 to 1187.26), generally have higher accessibility levels (K : 0.80 to 1.00). In summary, villages in areas with higher road network density tend to have better accessibility levels (Figures 6 and 10).

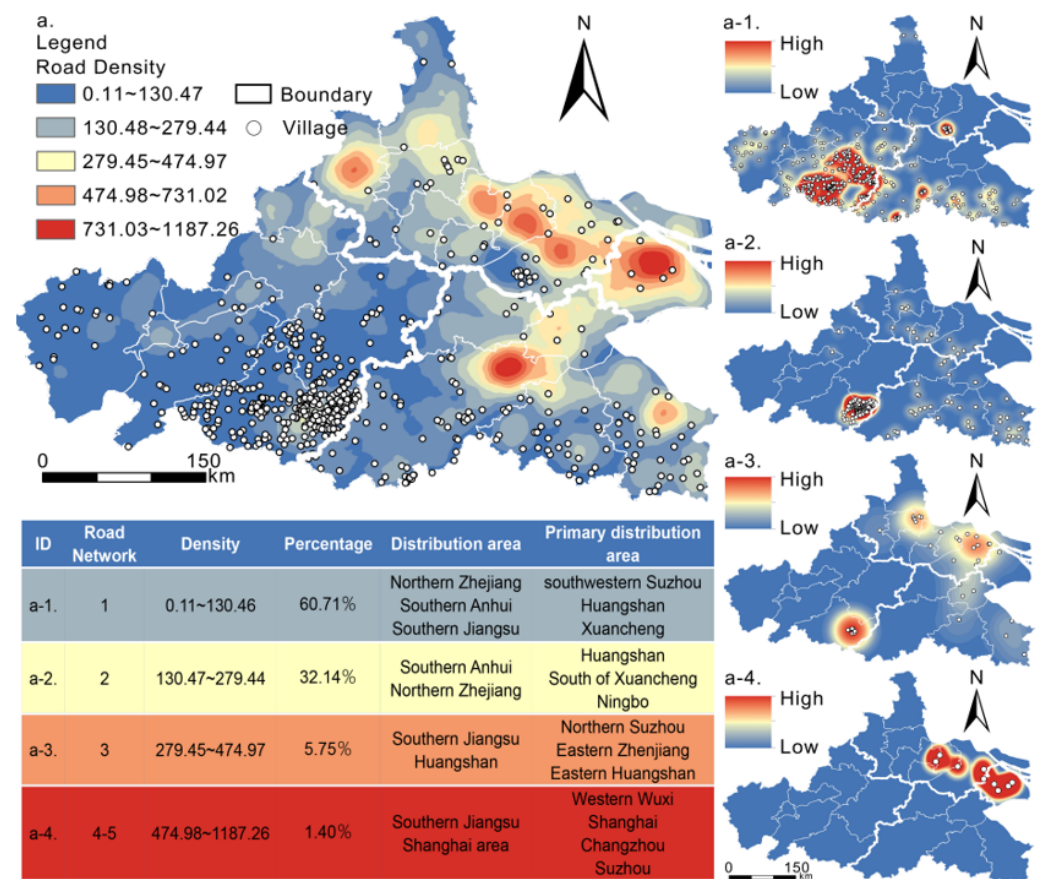


Figure 10. (a) The results of the overlay analysis of traditional villages and road network density. (a-1,a-2,a-3,a-4) represent the distributions of traditional villages at the 1st, 2nd, 3rd, and 4th levels of road network density, respectively.

4. Discussion

4.1. Results of the Global Spatial Regression (OLS) Analysis

A global spatial regression model was developed for traditional villages in Jiangnan, with village accessibility level as the dependent variable (Y) and four explanatory variables: elevation (X_1), slope (X_2), distance to the nearest water system (X_3), and road network density (X_4). The analysis indicated significant correlations between village accessibility and three factors: road network density, elevation, and slope. Specifically, road network density shows a significant positive correlation with accessibility, while elevation and slope exhibit a negative correlation (Table 3). These three factors have a threshold effect on the accessibility levels of Jiangnan's traditional villages (Figure 11). Namely, when the road density is less than 500 km/km^2 , village accessibility increases with increasing road density. However, when the elevation (slope) reaches approximately 200 m (10°), the rate of decrease in accessibility begins to plateau, and at 600 m (35°), accessibility rapidly decreases. The distance to water systems, however, did not demonstrate a significant correlation. Based on these findings, a local spatial regression model using GWR was constructed to further explore the spatial heterogeneity of the effects of these three factors on the accessibility of traditional villages in Jiangnan.

Table 3. OLS results of the accessibility and driving factors of traditional villages in Jiangnan.

Parameters	Coefficient	T Value	p Value	Standard Deviation	VIF
intercept	0.633537	46.774889	0.000000 **	0.013544	-----
X ₁	−0.000244	−5.157562	0.000003 **	0.000047	1.837890
X ₂	−0.001557	−2.259577	0.023197 *	0.000689	1.667096
X ₃	0.000014	1.754615	0.099943	0.000008	1.067676
X ₄	0.000467	8.376407	0.000000 **	0.000056	1.155800
R ²			0.255825		
Adjusted R ²			0.251167		
Jarque–Bera Test			131.313146		
AICc			−731.026794		

Note: * $p < 0.05$, ** $p < 0.01$ (* and ** indicate that variables are significantly correlated at the 95% and 99% confidence intervals, respectively).

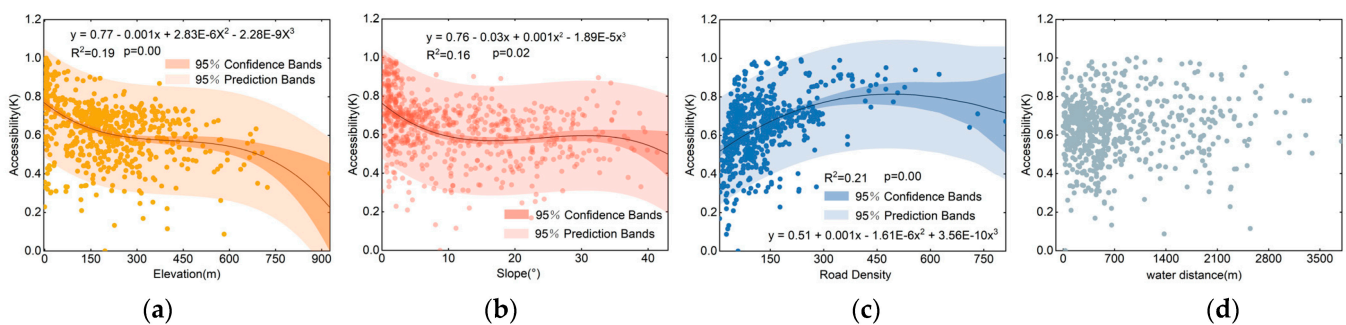


Figure 11. Fitting equation between elevation (a), slope (b), road network density (c), and distance to the water system (d) and accessibility. Elevation (a) and slope (b) were negatively correlated with accessibility ($r < 0$, $p < 0.05$), road network density (c) was positively correlated with accessibility ($r > 0$, $p < 0.05$), and distance to a water system (d) was not significantly correlated with accessibility.

4.2. Local Spatial Regression (GWR) Analysis Results

The premise of spatial heterogeneity research is that the dependent variable (accessibility in this study) exhibits spatial autocorrelation characteristics [46]. A significant spatial clustering autocorrelation characteristic was observed in the accessibility of traditional villages in the study area (Moran's $I = 0.67 > 0$, $Z = 3.55 > 2.58$) (Figure 12a), suggesting significant potential spatial heterogeneity in the impact of each factor on the accessibility of traditional villages. Consequently, a local spatial regression model for the relationship between traditional village accessibility and its influencing factors was developed. The results indicated that the local spatial regression model, calculated based on GWR, more effectively revealed the influence of factors on accessibility. Specifically, compared to the OLS model, which explained approximately 26% of the accessibility levels, the GWR model significantly improved the R^2 value, with a significant decrease in the bandwidth and AIC_C values, and the three factors collectively explained approximately 80% of the variability in accessibility levels in traditional villages ($R^2 = 0.85$), confirming significant spatial heterogeneity in their impacts (Table 4).

Table 4. Parameters of the local spatial regression model between accessibility and driving factors.

Parameters	Bandwidth	AIC _C	Sigma	R ²	Adjusted R ²
value	154,505.68	−1598.87	0.067	0.85	0.82

Note: The smaller the bandwidth and AIC_C values are and the larger the R^2 value is, the greater the fit of the model.

The local spatial heterogeneity impacts of elevation, slope, and road network density on accessibility are demonstrated in Table 5 and Figure 12b–d. First, the average absolute LRC values of each factor indicate their overall contributions to accessibility in the study

area [47]. We found that road network density presented the greatest overall contribution ($|LRC|_{\text{average}} = 0.18$), followed by slope ($|LRC|_{\text{average}} = 0.13$) and elevation ($|LRC|_{\text{average}} = 0.04$). Furthermore, by integrating both the positive and negative LRC values with their spatial distributions, the impacts of the three factors on accessibility are categorized into two groups: (1) the LRC values of elevation and slope exhibit a decreasing trend from southwest to northeast (Figure 12a–b). The areas of the two factors positively correlated with accessibility ($LRC > 0$) accounted for more than 87.89% and 67.55%, respectively, indicating a predominantly positive correlation. In terms of specific spatial distribution, elevation is mainly distributed in high-density clusters of northeastern Huangshan City and southwestern Xuancheng City, signifying notable internal homogeneity characteristics of its impacts on accessibility. Slope is more widely distributed across the study area, excluding Huangshan City. (2) The LRC of road network density displays an increasing trend from northwest to southeast (Figure 12c), with 84.16% of the area exhibiting a negative correlation ($LRC < 0$), indicating a predominantly negative impact, especially in southern Anhui Province, such as Huangshan and Xuancheng City

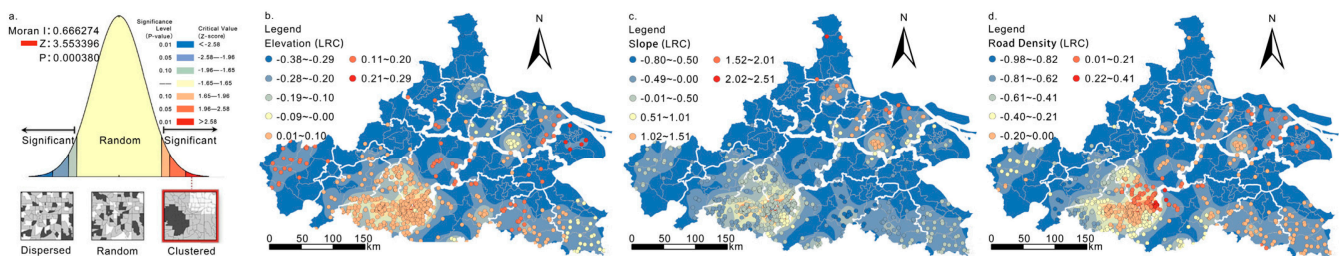


Figure 12. (a) The results of spatial autocorrelation calculations for the accessibility of traditional villages; (b–d) show the spatial distributions of LRC values indicating the impacts of elevation, slope, and road network density on accessibility, respectively. Traditional villages (represented by dots) that are closer to red (blue) indicate a positive (negative) correlation with accessibility in that area.

Table 5. Five-quintile observation table of the LRC of the three influencing factors.

Influencing Factors	Minimum Value	Upper Quintile	Median	Lower Quintile	Maximum Value	Average	Test
Elevation	−0.38	0.02	0.04	0.06	0.24	0.04	0.00
Slope	−0.80	−0.07	0.09	0.26	2.01	0.13	0.02
Road density	−0.98	−0.29	−0.15	−0.04	0.23	−0.18	0.00

Note: The LRC average reflects the overall level of the impact of the three factors on accessibility, and the higher the value is, the stronger the overall impact.

4.3. Comparison of Overlay Analysis, OLS Regression, and GWR Results

The distance to water systems is a critical factor influencing the accessibility of traditional villages [10]. However, the relationship between this factor and accessibility remains a subject of debate. For instance, Zuo et al. observed no significant correlation between them in the Wuling Mountain area of Hubei Province [48], whereas Ma and Huang identified a notable negative correlation between them with a focus on the middle reaches of the Yangtze River [49]. The disparities in these findings are partly attributable to the selection of study areas and to the limitations inherent in quantitative analysis methods. This is supported by our study. Specifically, the results of our OLS model indicated that there was no distinct correlation between distance to water systems and village accessibility (Table 3), corroborating the findings of Zuo et al. [48]. In contrast, overlay analysis revealed that more than 70% of traditional villages in Jiangnan are distributed within 1 km of water systems, signifying a typical settlement pattern near water (Figure 9a,b), which is more consistent with the geographical characteristics of the dense water network in the Jiangnan region and consistent with findings reported by Xiao et al. [50].

It is important to note the potential limitations of quantitative analysis methods such as OLS and simple linear correlation in specific studies, as potential relationships between the subjects of study are likely to be overlooked, which means that the conclusions drawn solely from OLS quantitative analyses warrant re-examination [20–22]. Additionally, the GWR model, beyond considering global spatial relationships, enabled the examination of spatial heterogeneity in the impacts of these factors on accessibility. We identified significant variations in the influence of each factor on the accessibility of traditional villages (Section 4.2), laying the groundwork for developing differentiated conservation strategies for these villages.

4.4. Categorized Development Strategies Based on Accessibility Assessment

Accessibility and its influencing factors are significant for the protection and development of traditional villages [28]. Based on an assessment of accessibility and its influencing factors, categorized development strategies for the Jiangnan region are proposed.

On the one hand, villages with well-developed road networks (P_r : 474.98~1187.26) and high accessibility, such as Sandongqiao Village ($K = 1.00$), Shazhang Village ($K = 0.99$), and Yangqiao Village ($K = 0.98$) (Figure 6), can significantly benefit from developing cultural tourism as a strategic approach to promote the integrated development of “culture, tourism, and agriculture” [51]. Excellent transportation conditions serve as a basis for implementation in these villages. This strategy involves establishing concentrated and contiguous protection and utilization demonstration areas and exploring pathways for the protection and development of traditional villages. Importantly, the implementation of this strategy inevitably necessitates the development of tourism resources, such as distinctive natural landscapes, historical sites, and unique cultural attributes. Hence, it is critical to avert the potential risks of over commercialization to these assets.

On the other hand, villages with poorer accessibility but high developmental potential can indirectly improve accessibility by constructing local transport routes. This approach maintains the integrity and unique culture of traditional villages while attracting more development opportunities, offering prospects for village protection, heritage preservation, and industrial structure optimization. For instance, improvements in road network grades significantly enhance the accessibility of villages such as Huri Village (LRC = 0.22), Zhongcun Village, and Cikeng Village (LRC = 0.23) (Figure 6).

In summary, good accessibility enhances the interaction between traditional villages and the outside world, promoting cultural integration and balancing the protection and development of traditional villages. Therefore, region-specific policies and strategies for concentrating, categorizing protection, and revitalizing traditional villages should be provided according to local conditions.

5. Conclusions

Jiangnan, a typical geographical and cultural region in China, is home to a wide distribution of traditional villages. However, the spatiotemporal pattern and accessibility of these villages have not been thoroughly revealed. The aim of our study was to assess the spatiotemporal pattern, accessibility, and spatial heterogeneity impacts of factors on the accessibility of traditional villages in Jiangnan, thereby laying a foundation for categorized protection strategies. Our key contributions are as follows:

(1) Spatially, most of these villages, primarily established during the Song and Ming dynasties, demonstrated a clustered distribution pattern around the eastern area of Huangshan but showed a significant imbalance in local spatial distribution ($R = 0.54 < 1$, $p < 0.01$; $S = 0.74 < 1$). The distribution and geographical context of traditional villages are closely intertwined, as evidenced by the fact that a predominant majority (79.5%) are located on slopes ranging from 0° to 20° , more than three-quarters (74.07%) are situated within 1 km of water systems, and more than half (56.37%) are found in plains.

(2) Regarding the spatial pattern of accessibility, a significant spatial clustering autocorrelation characteristic was observed in the accessibility of traditional villages (Moran's

$I = 0.67 > 0$, $Z = 3.55 > 2.58$), with a gradually decreasing trend of a “higher level in central areas, lower in peripheral areas” in the study area. Regional variability in accessibility levels was notable and predominantly low (averaging 224.65 min), with 85.66% of traditional villages having accessibility levels between 0.34 and 0.73 (equivalent to 200 ~ 300 min). This highlights the necessity of categorized optimization of spatial accessibility for traditional villages in the Jiangnan region.

(3) Regarding the influencing factors of accessibility, significant correlations between village accessibility and road network density, elevation, and slope were revealed ($p < 0.05$). The impacts of the three factors on accessibility demonstrated notable spatial heterogeneity. Specifically, they collectively explained approximately 85% of the variability in the accessibility levels of traditional villages ($GWR/R^2 = 0.85$). In a single-factor analysis, the local spatial influence intensity of the three factors exhibited significant differences, with the first evidence of the following ranking: road network density ($|LRC| = 0.18$) > slope ($|LRC| = 0.13$) > elevation ($|LRC| = 0.04$). The other evidence is the spatial distribution pattern of local influence visualized by LRC values. Specifically, the influence of elevation and slope on accessibility from southwest to northeast presented decreasing and increasing trends, respectively, and the influence of road network density increased from northwest to southeast. This indicates that optimization strategies for accessibility of traditional villages vary across specific spatial locations.

Despite these results, our study has certain limitations. First, the factors influencing the accessibility of traditional villages are varied. Based on previous research, our focus was primarily on topography, water systems, and road networks. Future research should encompass a broader range of factors for more precise accessibility assessments. Second, while our focus was on the correlation between accessibility and its driving factors, we also identified potential connections between distribution patterns, accessibility, and the drivers of accessibility in Section 3.3, which may constitute an avenue for future research.

Nevertheless, our finding of the spatial heterogeneity impact lay a theoretical foundation for the protection and development of traditional villages in Jiangnan. More significantly, we offered a perspective on studying traditional villages from a cultural zoning perspective and provided a methodological reference for re-evaluating studies that have overlooked the spatial heterogeneity of factors affecting traditional village accessibility and spatial distribution.

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