

Spatio-temporal Evolution of Spatial Accessibility of Traditional Chinese Villages in Guangdong Province and Its Determinants

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ABSTRACT: Taking 263 traditional Chinese villages in Guangdong Province as the study sites and spatial accessibility as the core focus, this study employs ArcGIS, the GWR model, web-crawling techniques, and other modern geographical analytical tools to provide an in-depth analysis of the spatio-temporal evolution, processes, and determinants of spatial accessibility in traditional villages to conduct an integrated qualitative-quantitative analysis. Furthermore, the GWR model is applied to examine the local effects and spatial spillovers of these determinants. The findings indicate that: (1) From the Song to the Qing dynasties, the point-axis progressive development pattern of historical accessibility and historical routes is distinct. It generally extends outward from Guangzhou along six major axes. (2) At present, spatial accessibility shows a concentric, stepwise decline from the Pearl River Delta toward the surrounding areas. (3) The traditional settlement concepts of “living with mountains and waters” and the practical needs of “transportation and commerce” have become key determinants of spatial accessibility. (4) GWR regression analysis shows that among the determinants, the effect of elevation on accessibility weakens in concentric layers from the Pearl River Delta toward the surrounding areas; river density shows clear inter-municipal clusters of positive and negative values; and the influence of road-network density varies considerably across municipalities, and the regression coefficients increase outward from central Guangdong. Differences in spatial accessibility thus shape divergent pathways for preservation and revitalization.

KEYWORDS: traditional villages; spatial accessibility; Guangdong Province; determinants; GWR model

Introduction

From December 2012 to June 2019, the Ministry of Housing and Urban-Rural Development, the Ministry of Culture and Tourism, and other authorities designated five batches totaling 6,819 traditional Chinese villages, of which 263 are located in Guangdong Province (hereinafter referred to as “traditional villages in Guangdong Province”). The traditional villages in Guangdong are primarily

composed of settlements associated with the Guangfu, Hakka, and Chaoshan Han Chinese cultural groups, accounting for about 88% of the total, reflecting the deep integration of Central Plains culture and Lingnan culture. In addition, a small number of minority villages are found in areas such as Lianzhou City, Qingyuan.

Research on traditional villages in China initially focused on topics such as atypical architecture, folk customs,

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and organizational systems. In recent years, the application of theories and methods from cultural anthropology, cultural geography, cultural ecology, and spatial sociology has substantially expanded and deepened research into the spatial dimensions of traditional villages. Major areas of focus include [1-15]: spatial morphology and regional reconstruction (XI Jianchao et al., 2014; LI Hongbo et al., 2015), spatial distribution and driving mechanisms (FENG Yafen et al., 2017; KANG Jingyao et al., 2016), spatial production and social change (ZHANG Jingxiang et al., 2014; GUO Wen et al., 2015; YANG Guiqing et al., 2016), production-living-ecological space and human settlements (WANG Yuncai et al., 2011; LI Bohua et al., 2018), and spatial memory and cultural revitalization (LÜ Long et al., 2018; QIAN Lili et al., 2015; HU Zui et al., 2015). As a result, the holistic nature of village-space research has become increasingly prominent. However, in-depth analysis and interpretation of particular spatial characteristics remain insufficient. Regarding research methodology, there is a growing trend to integrate qualitative and quantitative approaches to analyze and interpret complex spatial phenomena and underlying mechanisms. Among these, space syntax and ArcGIS surface statistical analysis have been widely applied in studies of traditional villages (TAO Wei et al., 2013; LI Bohua et al., 2015). Yet they are insufficient to fully explain the multidimensional human-environment spatial coupling. The geographically weighted regression (GWR) model, a key tool in spatial statistics, is a key tool for the quantitative analysis of spatially varying relationships (SONG Weixuan et al., 2017; ZHANG Yaojun et al., 2012) and offers strong explanatory power for spatial patterns. Building on this research context and trend, this study adopts accessibility as a focal spatial attribute, and employs ArcGIS, web-crawling techniques, and other modern geographical analytical tools to conduct an in-depth analysis of the spatio-temporal evolution, processes, and determinants of spatial accessibility for 263 traditional villages in Guangdong Province. Moreover, it uses the GWR model to examine the local effects and spatial spillovers of the determinants. On one hand, this approach offers a new analytical perspective on traditional villages in Guangdong Province and deepens research on their spatial

characteristics. On the other hand, as accessibility is crucial to the formation of traditional villages, the preservation of their traditional features, and the formulation of future protection strategies, accessibility research can thus provide a critical foundation for classifying, protecting, and revitalizing traditional villages.

1 Data sources and research methods

1.1 Data sources

The list of 263 traditional villages in Guangdong Province, covering the first to fifth batches, was obtained from the website of the Ministry of Housing and Urban-Rural Development (MOHURD) of the People's Republic of China. The latitude and longitude coordinates of these villages were obtained by geocoding village names in Baidu Map, followed by coordinate correction. Historical road data were sourced from the *Historical Atlas of Guangdong* [16]. River-network and road-network spatial data were obtained from the latest vector datasets provided by the National Geomatics Center of China (NGCC). Current accessibility was measured using the shortest real-time driving time obtained from Baidu Map. The primary data were processed, quantified, and analyzed using spatial tools in ArcGIS 10.2, including raster mosaicking, table joining, and data extraction.

1.2 Research methods

A quantitative analysis of traditional Chinese villages in Guangdong Province was conducted, employing kernel density estimation, nearest neighbor analysis, and the geographic concentration index to characterize their spatial distribution patterns. The spatio-temporal evolution of historical accessibility was analyzed using cost-distance modeling and raster overlay techniques. Current accessibility levels of individual traditional villages were assessed using real-time travel time data from Baidu Map and an accessibility assessment model. To analyze the determinants of spatial accessibility, line density was employed to represent river and road network densities, and their associations with accessibility were examined; raster-based reclassification was used to examine how terrain elevation and slope relate to accessibility; finally, the geographically weighted regression (GWR) model was adopted to identify

the key determinants of spatial accessibility in traditional villages and quantify their spatially varying effects.

2 Spatial distribution characteristics of the traditional villages in Guangdong Province

2.1 Spatial distribution density of the traditional villages

The 263 traditional villages in Guangdong Province were abstracted as point features and visualized using kernel density estimation (KDE), a method that estimates the spatial intensity of geographic phenomena across a region. After iterative adjustment, a bandwidth of 180 km was se-

lected to generate the kernel density map of the traditional villages (Figure 1). The analysis indicates that the spatial distribution is uneven, with two primary clusters—north-eastern Meizhou and the Guangzhou-Foshan border region—and two secondary clusters—the Chaozhou-Shantou border region and northwestern Qingyuan. In contrast, areas such as Maoming, Yangjiang, and Yunfu contain only a few sparsely scattered villages. Overall, the traditional villages display a dumbbell-shaped pattern, with major concentrations in the central Pearl River Delta and northeastern Guangdong.

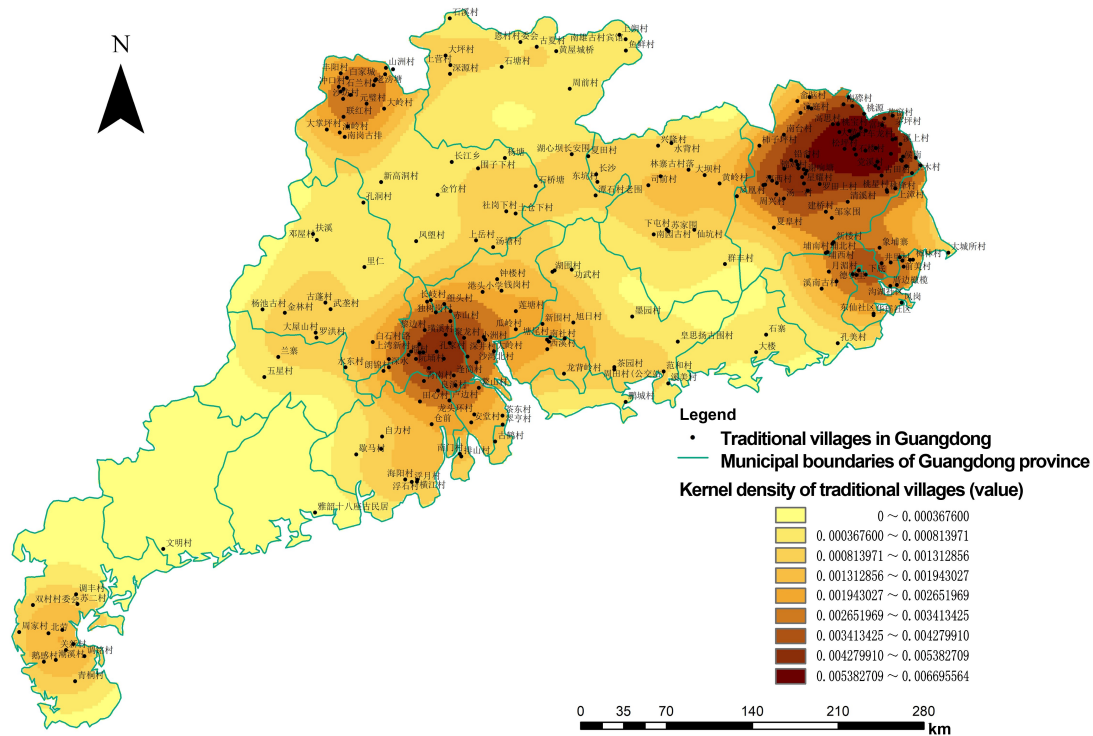


Figure 1 Kernel density analysis of traditional villages in Guangdong Province

2.2 Types and degrees of spatial distribution of the traditional villages

The spatial distribution type of the traditional villages was determined using nearest-neighbor analysis, a geographic measure reflecting the proximity of point features in space. Calculations show that the theoretical nearest-neighbor distance (i.e., expected under random distribution) is 18.66 km, while the observed distance is 16.97 km, yielding a nearest-neighbor index of ($R= 0.90$). Since ($R < 1$), this indicates a clustered spatial distribution.

A municipal-level statistical analysis was conducted for the traditional villages (Figure 2). With 263 traditional

villages ($T= 263$) across 21 prefecture-level cities ($n= 21$), the calculated geographic concentration index is ($G= 35.94$), whereas the expected index under even distribution is ($G_0= 10.45$). As ($G > G_0$), this confirms that, at the municipal scale, the villages are significantly concentrated, mainly in Meizhou, Qingyuan, and Foshan.

3 Spatio-temporal evolution of spatial accessibility in the traditional villages

Accessibility research in traditional villages assesses the ease of access to villages. On one hand, historical spatial analysis helps reveal the relationship between accessibility and village siting. On the other hand, accessibility

influences the socio-economic development of villages and the preservation of traditional culture: Villages with high accessibility are more susceptible to urbanization and industrialization, whereas villages with limited transport connectivity experience fewer external influences, facilitat-

ing cultural preservation and continuity. By conducting a spatial analysis of current spatial accessibility, the study provides an overall understanding of present conditions and ranks all 263 villages according to accessibility, thereby supporting tailored strategies for their protection and revitalization.

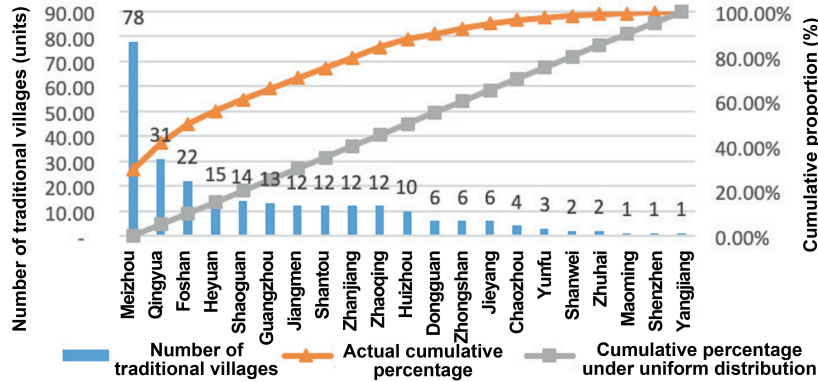


Figure 2 Municipal-level statistics of traditional villages in Guangdong Province

3.1 Analysis of the evolution of historical spatial accessibility

Based on the founding years of each traditional village, the study examines the spatio-temporal evolution of historical accessibility. In assessing spatial accessibility, some scholars argue that roads, riverbanks, water bodies, and land-use types are key factors influencing travel costs [17]. Considering the characteristics of the study area, this study adopts the principle that accessibility increases with proximity to historical land and water routes and with lower elevation and gentler slopes. Accordingly, three evaluation factors—historical land and water routes, terrain elevation, and terrain slope—were selected to analyze historical accessibility. Accessibility associated with historical routes was determined based on the distance from the raster cell representing each village to historical routes. In ArcGIS 10.2, multiple buffer zones of 5 km, 10 km, 20 km, 40 km, and 100 km were created and raster values were reclassified, with scores assigned from 5 (lowest accessibility) to 1 (highest accessibility). Elevation and slope were evaluated using a similar scoring method (Table 1). For comparison, accessibility values were normalized and classified into five levels, from Level 1 (highest) to Level 5 (lowest).

The analysis demonstrates that from the Song to the Qing dynasties, historical accessibility and historical routes exhibited a clear point-axis progressive develop-

ment pattern, with accessibility having gradually expanded outward from Guangzhou along six primary axes (Figure 3): Guangzhou-Dongguan-Huizhou-Chaozhou; Guangzhou-Huizhou-Heyuan-Meizhou; Guangzhou-Shaoguan; Guangzhou-Qingyuan; Guangzhou-Foshan-Zhaoqing-Yunfu; and Guangzhou-Foshan-Jiangmen-Zhanjiang. Accessibility had expanded along these axes across successive dynasties, accompanied by the continuous enlargement of core high-accessibility zones. From the Song to the Qing dynasties, Level 1 (highest) accessibility areas expanded significantly, evolving from linear belts into planar regions. By the Ming dynasty, Level 1 (highest) areas had already covered most of Guangzhou, Foshan, Dongguan, and Zhongshan, while low-accessibility regions continued to recede. Historically, Guangzhou and Foshan featured dense road networks and have long served as major commercial corridors; consequently, they exhibited comparatively high village accessibility. In the Song dynasty, low-accessibility zones were primarily located in the mountainous regions of Qingyuan, Heyuan, and Huizhou. By the Qing dynasty, most of these areas had been incorporated into Level 1 (highest) to Level 3 accessibility zones. However, due to rugged terrain, the areas around Qingyun and Jiulian Mountains in Heyuan, Qiwei and Luohe Mountains in Qingyuan, and Yunwu Mountain in Yunfu remained persistent low-accessibility zones, where traditional villages are sparsely distributed.

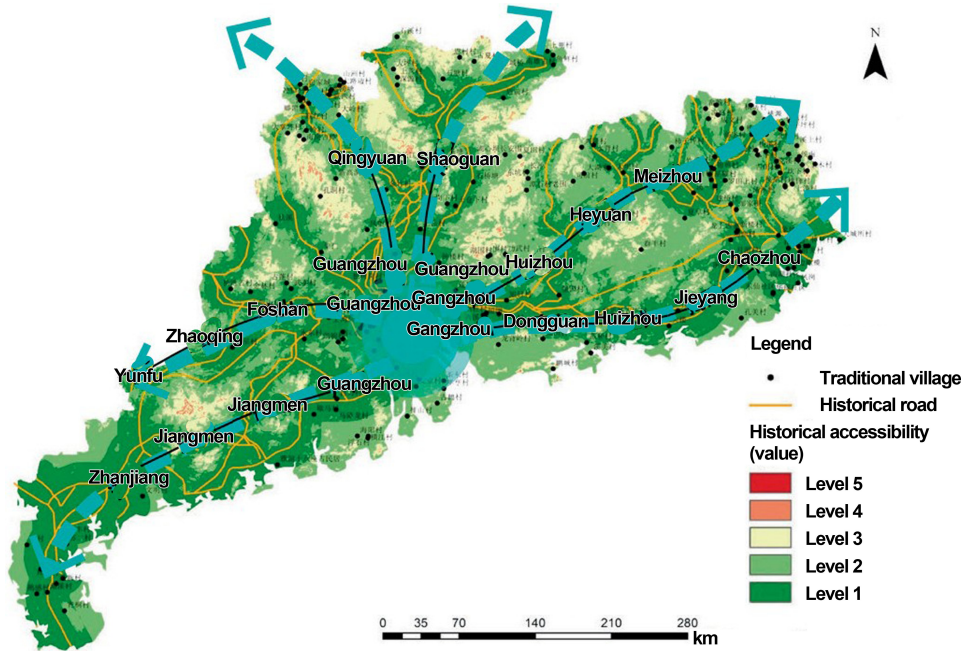


Figure 3 Six-axis expansion and evolution of spatial accessibility in traditional villages in Guangdong Province

Table 1 Evaluation factors, classification, and scoring for historical spatial accessibility of traditional villages in Guangdong Province

Evaluation Factor	Classification	Score
Historical land/water routes	Distance at 0-2 km	5
	Distance at 2-5 km	4
	Distance at 5-10 km	3
	Distance at 10-20 km	2
	Distance at 20-50 km	1
Terrain elevation	Elevation below 100 m	5
	Elevation at 100-200 m	4
	Elevation at 200-400 m	3
	Elevation at 400-800 m	2
	Elevation above 800 m	1
Terrain slope	Slope at 0°-7°	5
	Slope at 7°-15°	4
	Slope at 15°-30°	3
	Slope at 30°-40°	2
	Slope above 40°	1

The study further reveals that historical accessibility exerted a leading effect on the establishment of traditional villages. From the Song to the Qing dynasties, accessibility continuously improved, and a significant construction boom of traditional villages in Guangdong occurred during the Ming dynasty. As a result, the enhancement of regional accessibility served as a strong attractor for village

siting and establishment. This leading effect is particularly evident in Hakka traditional villages in parts of Meizhou, Heyuan, and Qingyuan (Figure 4).

3.2 Analysis of current spatial accessibility

Current spatial accessibility of Guangdong’s traditional villages was assessed using real-time shortest travel times from each village to all prefecture-level cities, extracted via the web-crawling tool “Octoparse” from Baidu Maps. Given real-world constraints—including real-time traffic conditions, road infrastructure quality, traffic signal delays, and congestion—this real-time approach yields a more accurate and realistic estimate of village accessibility [18].

Accessibility values for all 263 traditional villages were computed using Formulas (1) and (2) [19] and subsequently standardized to a 0-1 scale (Table 2). The results show that the mean travel time is 256.18 minutes, indicating overall low accessibility with substantial inter-city disparities. The accessibility ranking reveals that the top ten villages are all located in Guangzhou and Foshan—for instance, Langjin Village (Foshan), Zhonglou Village (Guangzhou), and Daqitou Village (Foshan)—demonstrating that the Guangzhou-Foshan metropolitan region exhibits the highest accessibility. In contrast, villages in Zhanjiang generally show the poorest accessibility, followed by those in Meizhou; notably, the six lowest-ranked

villages are all situated in Zhanjiang, including Zhoujia, Tiaoming, and Qingtong Villages.

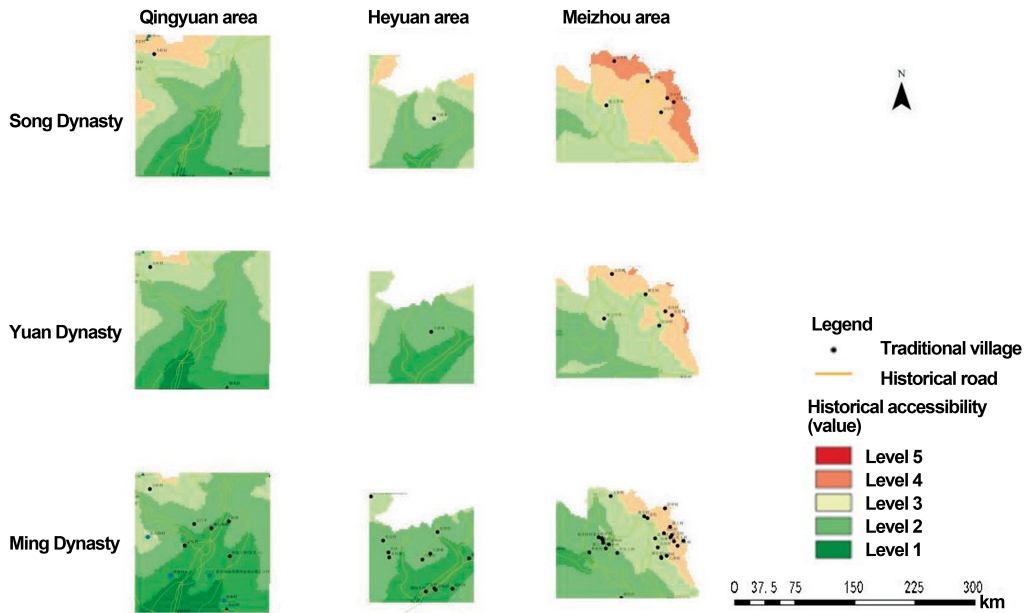


Figure 4 Historical accessibility and the development of traditional villages

Table 2 Current spatial accessibility ranking of traditional villages in Guangdong Province

Ranking	Name	Spatial Accessibility	Ranking	Name	Spatial Accessibility
1	Langjin Village, Foshan	1.0000	254	Shangmu Village, Meizhou	0.1612
2	Zhonglou Village, Guangzhou	0.9922	255	Shangzhang Village, Meizhou	0.1608
3	Daqitou Village, Foshan	0.9883	256	Guanxin Village, Zhanjiang	0.1419
4	Xinwei Village, Guangzhou	0.9875	257	Gongxia Village, Meizhou	0.1170
5	Julong Village, Guangzhou	0.9845	258	Chaoxi Village, Zhanjiang	0.1080
6	Huangpu Village, Guangzhou	0.9845	259	Egan Village, Zhanjiang	0.0769
7	Gualing Village, Guangzhou	0.9804	260	Donglin Village, Zhanjiang	0.0698
8	Tangnan Village, Foshan	0.9720	261	Qingtong Village, Zhanjiang	0.0550
9	Langtou Village, Guangzhou	0.9687	262	Tiaoming Village, Zhanjiang	0.0207
10	Gangtou Village, Guangzhou	0.9648	263	Zhoujia Village, Zhanjiang	0.0000

Kriging interpolation was further applied to examine the overall spatial pattern of current accessibility across Guangdong’s traditional villages (Figure 5). The results reveal a concentric, stepwise decrease in accessibility radiating outward from the Pearl River Delta. High-accessibility zones are concentrated in central regions, including Guangzhou, Foshan, Dongguan, Zhongshan, and Huizhou; whereas peripheral and border areas such as Zhanjiang, Meizhou, Qingyuan, and Shaoguan exhibit markedly lower accessibility. Notably, the current spatial accessibility pattern closely resembles that of historical accessibility.

$$K_j = \frac{1}{n} \sum_{i=1}^n E_{ij} \tag{1}$$

$$K = \frac{(\max K_j - K_j)}{(\max K_j - \min K_j)} \tag{2}$$

Where K_j denotes the raw accessibility of traditional village j , n is the number of prefecture-level cities, and E_{ij} represents the shortest travel time from village j to city i . The standardized accessibility value is also denoted as K_j . m represents the “number of traditional villages” in the study area.

4 Analysis of factors influencing spatial accessibility of the traditional villages

4.1 Village site selection and spatial accessibility

4.1.1 Landscape pattern

For traditional villages, the residential environment and local landscape patterns are critical factors in site se-

lection. They influence geomantic principles and play decisive roles in production, daily life, defense, and mitigating natural hazards. The dominant ethnic groups in Guangdong—Guangfu, Hakka, and Chaoshan—are descendants of Han migrants from the Central Plains. Fleeing prolonged warfare, they undertook arduous southward migrations into remote frontier regions, carving out settlements through immense hardship. Their primary goal was

to secure stable livelihoods by adapting to and leveraging local natural conditions. The micro-geographic ideal of “living with mountains and waters” has become a shared guiding principle for traditional village siting in Guangdong. Consequently, landscape pattern is regarded as the primary factor influencing spatial accessibility. To preliminarily explore its spatial mechanisms, three proxy variables—elevation, slope, and river density—were selected.

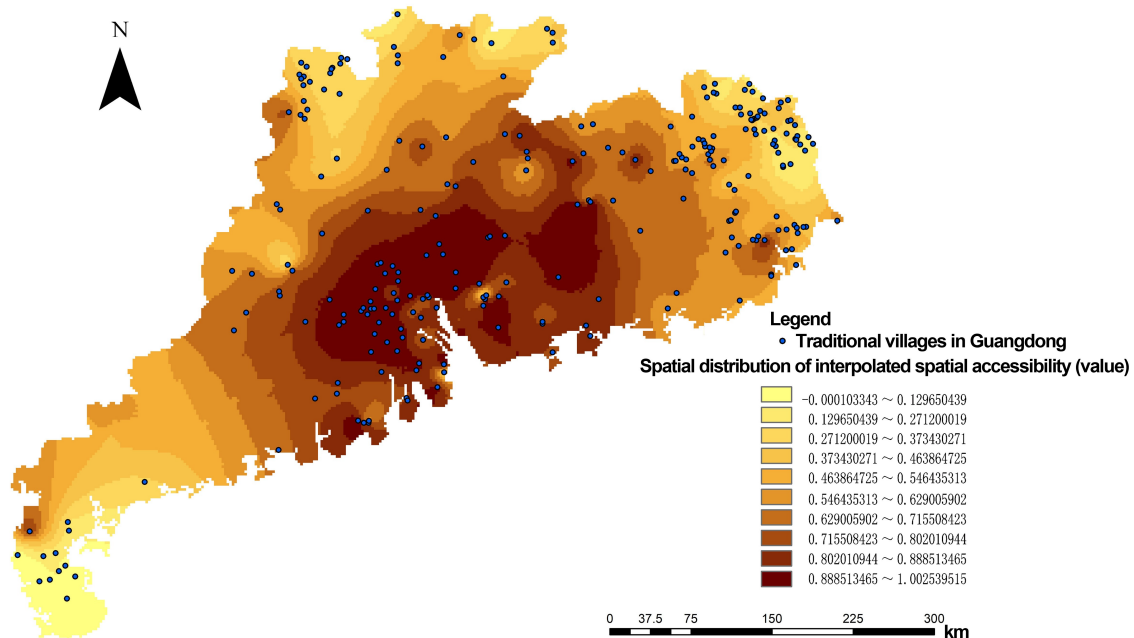


Figure 5 Kriging interpolation map of current spatial accessibility for traditional villages in Guangdong Province

Elevation (Figure 6) was first used to assess topographic influence. The analysis indicates that northern and eastern Guangdong feature higher terrain, where villages are nestled within mountainous areas and relatively isolated from external interference, resulting in lower spatial accessibility. In contrast, traditional villages in the Pearl River Delta occupy low-lying terrain and generally exhibit higher accessibility. Using raster extraction techniques, elevation values were obtained for all villages: The highest (753.98 m) occurs at Dazhang Village, Daping Town, Lian-nan Yao Autonomous County, Qingyuan; the lowest (-12.22 m) is recorded at Donglin Village, Nanxing Town, Leizhou City, Zhanjiang—a substantial elevational range. Subsequently, slope values were extracted, ranging from 0° to 21° (mean = 2.30°). Dazhang Village again registers the steepest slope, while Huayao Community, Longtian Town, Chaonan District of Shantou, exhibits the gentlest. Cross-

referencing these metrics with accessibility rankings reveals that villages with higher elevation and steeper slopes tend to have lower accessibility, indicating that topography partially constrains access [20].

Traditional village siting in Guangdong exhibits a pronounced dependence on river systems. Line-density analysis of major rivers (Figure 7) shows that areas with high village density often coincide with regions of high river density—particularly in Foshan, Zhongshan, Meizhou, Qingyuan, and Shantou. Notably, traditional villages in the Tanjiang Basin (in Zhongshan), Meijiang Basin (in Meizhou), Rongjiang Basin (in Shantou), and Lianjiang Basin (in Qingyuan) demonstrate strong spatial coupling with their respective river networks. Integrating this finding with the Kriging-based accessibility map (Figure 5), both the density and proximity of nearby rivers are associated with higher village accessibility.

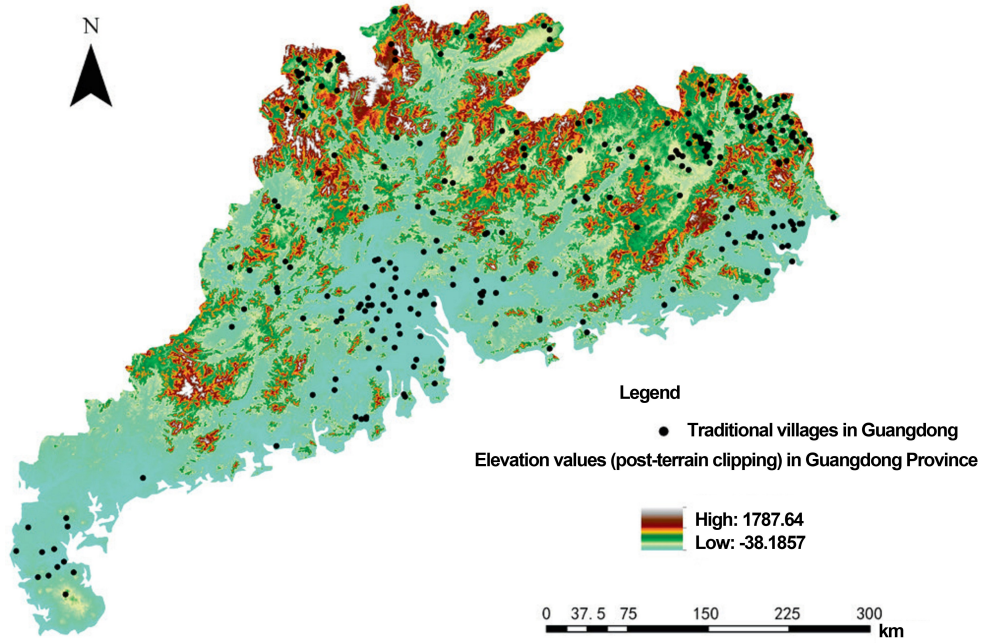


Figure 6 Overlay of traditional villages and elevation in Guangdong Province

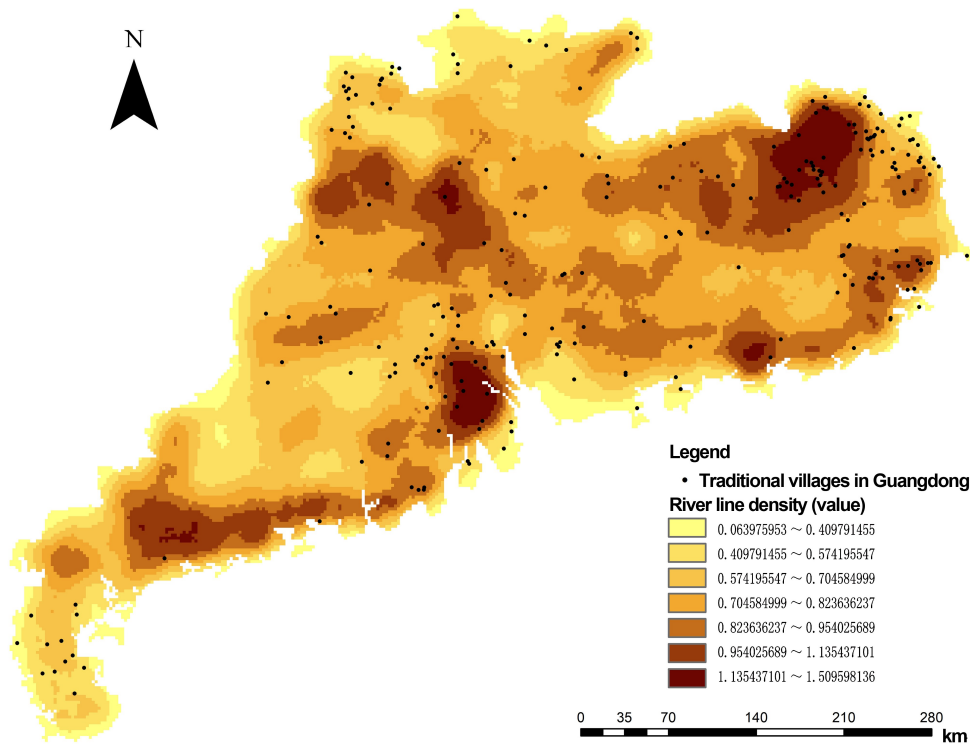


Figure 7 Overlay of traditional villages and river density in Guangdong Province

4.1.2 Transportation and commerce

Over time—particularly since the Ming and Qing dynasties—regional economies in Guangdong have steadily developed, accompanied by continuous improvements in both land and water transportation infrastructure. Settlements situated along major routes gradually flourished, giving rise to a distinct

category of transportation-and commerce-oriented villages. In the Pearl River Delta, the dense road network contributes to generally high spatial accessibility of traditional villages. By contrast, in the mountainous regions of northern and eastern Guangdong—where arable land is scarce—many villages emerged along key historical post roads and

rural thoroughfares, leveraging transport advantages to “engage in trade widely despite limited farmland.” This pattern aligns closely with the previously analyzed spatial association between traditional villages and historical road networks.

A line-density analysis of major roads was performed, and road density was classified into five levels using the Jenks natural breaks classification method, with Level 1 denoting the highest density and Level 5 the lowest. Village distribution across these levels reveals a clear gradient: 7 villages in Level-5 areas, 13 in Level-4, 38 in Level-3, 77 in Level-2, and 128 (48.67%) in Level-1 zones. Notably, nearly half of all traditional villages are located in the highest road-density areas. Overlaying this classification with the village accessibility map confirms a strong correspondence between road-network density and spatial accessibility: Villages in better-connected areas consistently exhibit higher accessibility levels.

4.2 Analysis of accessibility determinants based on the GWR model

4.2.1 Classical OLS linear regression

The accessibility score (Y) of each traditional village was specified as the dependent variable, with five explanatory variables: Elevation (X_1), river density (X_2), minimum distance to the nearest water body (X_3), road-network density (X_4), and slope (X_5). An ordinary least squares (OLS) regression model was constructed (Table 3). All variance inflation factor (VIF) values were well below the common threshold of 7.5, indicating no serious multi-

collinearity, and the Jarque-Bera test for residual normality yielded non-significant results. The regression results indicate that elevation, river density, and road-network density significantly influence village accessibility, with elevation and road-network density significant at the 1% level. To further investigate the spatially varying impacts of terrain, hydrological networks, and transportation infrastructure on accessibility, a (GWR) model is employed in the following section to capture local parameter heterogeneity and potential spatial spillover effects.

4.2.2 Parameter estimation of the GWR model

(1) Basic GWR model

The GWR model extends the conventional OLS regression framework by explicitly accounting for spatial heterogeneity in regression coefficients. Grounded in a solid theoretical foundation, GWR relaxes the global stationarity assumption of traditional linear regression and enables the estimation of location-specific relationships. It is particularly effective at capturing local spatial non-stationarity and potential spillover effects of explanatory variables [19]. The basic formulation is as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_m \beta_m(u_i, v_i)x_{im} + \epsilon_i \quad (3)$$

where (Y_i) denotes the spatial accessibility value of the traditional village at location (i); (X_{im}) represents the value of the (m)-th explanatory variable at location (i); (u_i, v_i) are the projected coordinates of location (i); ($\beta_0(u_i, v_i)$) is the location-specific intercept; ($\beta_m(u_i, v_i)$) denotes the local regression coefficient for the (m)-th explanatory variable; and (ϵ_i) is the random error term at location (i).

Table 3 OLS regression results for spatial accessibility levels of traditional villages in Guangdong Province

Model parameter	Coefficient	T-value	P-value	Standard deviation	VIF
Intercept	0.479262	8.327723	0.000000*	0.05755	—
Elevation	-0.000584	-4.460519	0.000015*	0.000131	1.873205
River density	0.135372	2.146143	0.032799*	0.063077	1.088187
Minimum distance to nearest water body	-0.00005	-1.137354	0.256459	0.000044	1.14038
Road-network density	0.77827	6.354451	0.000000*	0.012248	1.280014
Slope	0.007715	1.156613	0.248515	0.00667	1.707599
R ²	—	—	0.3099586	—	—
Adjusted R ²	—	—	0.295995	—	—
Jarque-Bera Test	—	—	4.996988	—	—
AICc	—	—	-59.816308	—	—

For spatially autocorrelated data, the GWR model typically yields smaller residuals than the classical OLS model. By assigning a unique set of coefficients to each observation, GWR captures local spatial non-stationarity, which can be visualized through coefficient maps in ArcGIS.

(2) Parameter regression analysis of the GWR model

The results show that the GWR model yields an AICc value of 318.552 (Table 4), which is substantially lower than that of the OLS model (-59.816). The overall goodness-of-fit (R) increases markedly from 0.295995 under the OLS model to 0.759459 under the GWR model—an improvement of nearly 46%. These results demonstrate the superiority and necessity of the GWR model in the present spatial accessibility analysis.

Local regression results for factors influencing the spatial accessibility of traditional villages in Guangdong (Table 5) show that the median and mean coefficients for elevation, river

Table 5 Quintile summary of GWR coefficients for spatial accessibility levels

Determinant	Minimum	Upper quartile	Median	Lower quartile	Maximum	Mean	Test
Elevation	-0.00285	-0.00136	-0.00063	-0.00020	0.00033	-0.00080	0.00
River density	-0.35982	-0.00476	0.02870	0.14940	0.43465	0.06582	0.01
Road-network density	-0.34248	0.02153	0.12167	0.21037	0.94143	0.12743	0.00

① Influence of elevation on spatial accessibility

The influence of elevation on the spatial accessibility of traditional villages in Guangdong generally exhibits a concentric weakening pattern radiating outward from the Pearl River Delta, showing an inverse coupling with the regional topography that rises progressively toward eastern, western, and northern Guangdong. Except in peripheral areas of northern and eastern Guangdong, elevation is predominantly negatively associated with accessibility—indicating that mountainous terrain generally impedes village accessibility across most of the province. However, the magnitude of this effect is relatively weak. The negative impact of elevation on accessibility is weaker in Guangzhou, Foshan, Dongguan, and Zhongshan (regression coefficients close to zero), whereas in northwestern Qingyuan, northern Shaoguan, and northeastern Meizhou, the coefficients are close to zero or marginally positive. When considered alongside the spatial clustering of traditional villages, elevation shows directional differences in its impact between the densely populated Pearl River Delta

density, and road-network density share consistent signs and comparable magnitudes, suggesting broadly uniform effects on spatial accessibility. The mean coefficients reflect average marginal contributions, ranked as: Road-network density> river density> elevation. However, the marginal effects of the explanatory variables exhibit directional differences under different spatial conditions. These local variations are illustrated through the visualization of regression results (Figure 8).

Table 4 GWR model parameter estimates for spatial accessibility levels of traditional villages in Guangdong Province

Model parameter	Parameter value
Bandwidth	80110.30368
AICc	-318.552267
Sigma	0.124056
R	0.795724
Adjusted R	0.759459

and Meizhou regions, with strong internal homogeneity and spatial autocorrelation within each. A similar spatial pattern is observed in the analysis of road-network density. Overall, the influence of elevation on accessibility is spatially non-uniform.

② Influence of river density on spatial accessibility

River density influences the spatial accessibility of traditional villages in Guangdong through a clear inter-municipal division of positive and negative effects. Positive associations are observed in Qingyuan and Shaoguan (northern Guangdong) and in Meizhou, Jieyang, and Shantou (eastern Guangdong), whereas negative associations occur in western Guangdong, the southern coastal cities of the Pearl River Delta, Foshan, and Heyuan. The highest regression coefficients are concentrated along the provincial border areas of eastern, western, and northern Guangdong.

③ Influence of road-network density on spatial accessibility

The influence of road-network density on the spatial accessibility of traditional villages varies markedly across

municipalities, with regression coefficients generally increasing from central Guangdong toward the periphery. Negative coefficients are primarily observed in Heyuan and Zhaoqing. High positive impacts are concentrated along the western and northern border regions. Notably, in the northern border area, elevation, river density, and road-network density exhibit concurrent high positive coefficients—reflecting a spatial coupling of their positive influences. In the western bor-

der region, road-network density is the primary determinant among the three: A one-unit increase in road-network density raises the normalized accessibility score by approximately 0.94143, indicating a substantial improvement in accessibility. By contrast, Guangzhou, Foshan, and Jiangmen exhibit low absolute regression coefficients, suggesting that accessibility in these well-connected areas is relatively insensitive to further increases in road-network density.

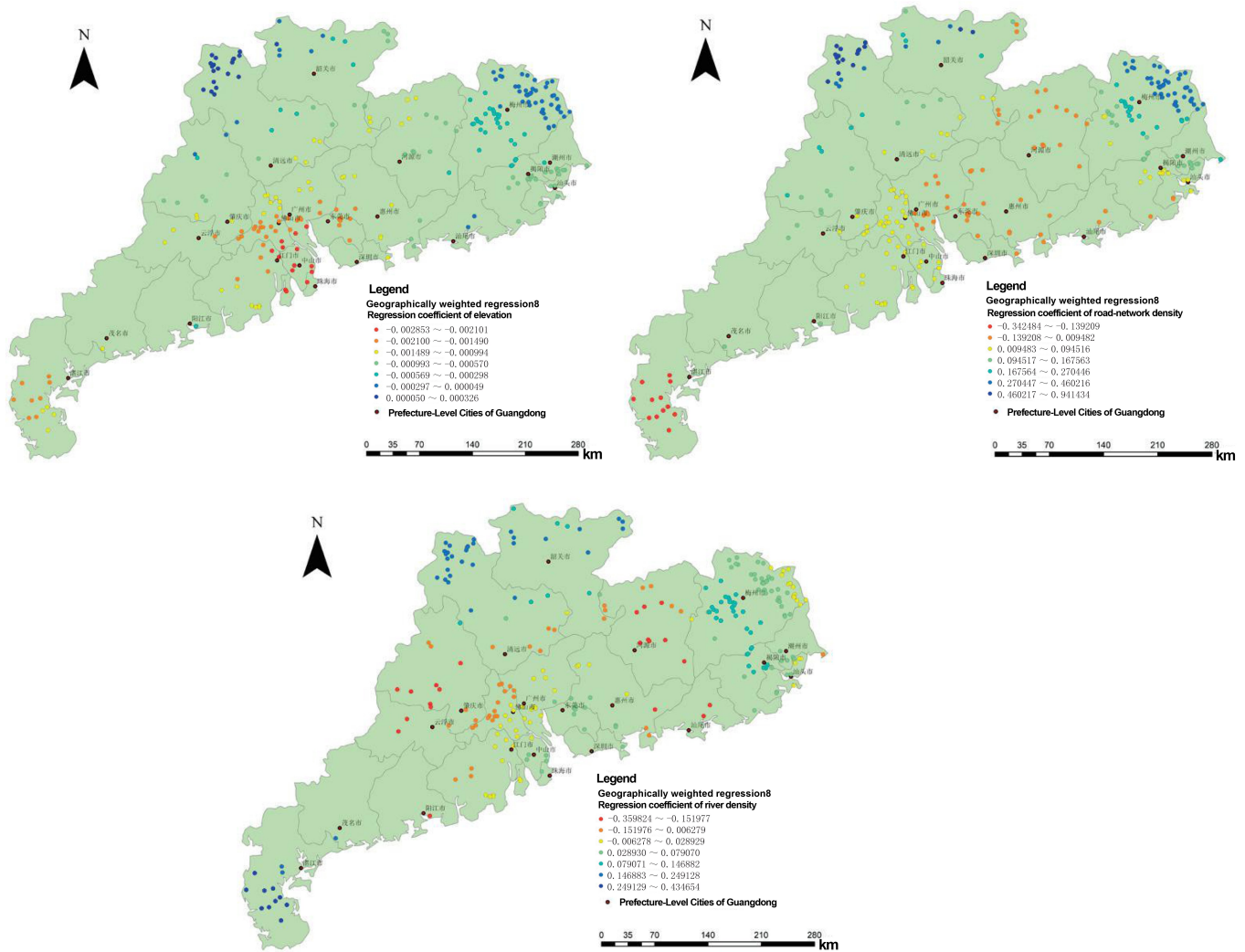


Figure 8 Spatial distribution of GWR regression coefficients for elevation, river density, and road-network density

5 Conclusions and discussion

5.1 Conclusions

As of June 2019, 263 traditional villages in Guangdong Province were listed in the officially published national register. At the provincial scale, their spatial distribution is uneven, forming a dumbbell-shaped concentration pattern between central Pearl River Delta and north-

eastern Guangdong. At the municipal scale, the villages are primarily concentrated in Meizhou, Qingyuan, and Foshan. This study employs modern geographic analytical tools and methods to conduct an in-depth analysis of the spatio-temporal evolution, processes, and determinants of spatial accessibility for these 263 traditional villages, and applies the GWR model to investigate local effects and spatial spillovers of accessibility-related factors. The anal-

ysis reveals that:

(1) From the Song to the Qing dynasties, historical accessibility and historical road networks exhibited a clear point-axis progressive development pattern, radiating outward from Guangzhou along six major axes. By the Ming dynasty, Level-1 accessibility areas already covered most of Guangzhou, Foshan, Dongguan, and Zhongshan.

(2) The average shortest travel time from each traditional village to all prefecture-level cities is 256.18 minutes, indicating generally low spatial accessibility with significant inter-municipal variation. Villages in the Guangzhou-Foshan area exhibit the highest spatial accessibility, whereas those in Zhanjiang and Meizhou rank lowest. Current spatial accessibility displays a concentric, stepwise decline from the Pearl River Delta toward surrounding regions, closely resembling the historical spatial accessibility pattern.

(3) In analyzing the determinants of spatial accessibility, the dominant Guangfu, Hakka, and Chaoshan populations—descendants of Han migrants from the Central Plains—share settlement ideals such as “living with mountains and waters” and practical demands for “transportation and commerce,” both of which significantly influence spatial accessibility. Coupling these factors with village spatial distribution using ArcGIS 10.2 further confirms the associations between spatial accessibility and elevation, slope, river density, and road-network density.

(4) Finally, local regression analysis using the GWR model reveals that elevation, river density, and road-network density exert broadly consistent effects on spatial accessibility, with their relative contributions ranked as: Road-network density > river density > elevation. However, the marginal effects of each factor exhibit directional heterogeneity across space. Specifically, the influence of elevation on spatial accessibility weakens concentrically from the Pearl River Delta toward surrounding regions; river density displays distinct inter-municipal zones of positive and negative effects; and road-network density shows marked inter-municipal variation, with regression coefficients increasing from central Guangdong toward peripheral areas.

5.2 Discussion

Under China’s national rural revitalization strategy,

traditional villages face unprecedented opportunities and challenges. Villages with high spatial accessibility, such as those in the Guangzhou-Foshan area, benefit from convenient living conditions and strong social vitality, enabling them to leverage cultural tourism for socio-economic revitalization. However, their traditional cultures are more vulnerable to modern production and lifestyle pressures, intensifying the tension between preservation and development. In contrast, villages with low spatial accessibility, such as those in Zhanjiang and Meizhou, experience less impact from urbanization and industrialization, which helps preserve agrarian culture and traditional rural life. Yet, poor transportation access and inadequate infrastructure contribute to severe depopulation, aging, and low vitality. Revitalization in these areas should prioritize improving residents’ living conditions while safeguarding traditional living landscapes. Differences in spatial accessibility thus shape divergent pathways for preservation and revitalization.

This study assesses current spatial accessibility using real-time driving data and does not consider newer transport modes such as high-speed rail. As China’s transport network continues to evolve, the spatial accessibility of traditional villages will change dynamically—a key direction for future research.

Sources of Figures and Tables

All figures and tables in this paper are prepared by the authors.

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