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# Accessibility and influencing factors of leisure agriculture demonstration sites in Guangdong Province based on GWR model

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**As a key project of deepening rural reform, agricultural transformation and upgrading and beautiful rural construction, leisure agriculture plays an important role in promoting the coordinated development of urban and rural areas, rural revitalization and all-round well-off society. In this study, 386 leisure agriculture demonstration sites in Guangdong Province were selected as samples, and the spatial and temporal distribution characteristics of leisure agriculture demonstration sites were deeply analyzed with the help of GIS technology. At the same time, through the accessibility calculation formula, OLS linear regression and GWR model, the accessibility, influencing factors and spatial alienation effect of leisure agriculture demonstration sites are systematically explored. The research draws the following core conclusions: (1) The average spatial accessibility of leisure agriculture demonstration sites in Guangdong Province is 240.01 min, which is relatively low and has significant differences among cities; (2) Elevation, slope, river and road network density are identified as the main factors affecting spatial accessibility; (3)GWR model analysis shows that the regression coefficients of road network density, river density and elevation are high and fluctuate significantly, indicating that these three factors have a significant impact on the spatial distribution of leisure agriculture demonstration sites. Under the guidance of the rural revitalization strategy, through the in-depth analysis of the spatial distribution characteristics of leisure agriculture demonstration sites in Guangdong Province, specific countermeasures and suggestions were put forward to promote the further improvement and development of regional leisure agriculture.**

**Keywords** Leisure agriculture demonstration site, Spatial accessibility, Guangdong Province, Influencing factors, GWR model

With the take-off of urban economy and the advancement of urban and rural integration, a new modern agricultural production system - leisure agriculture - has gradually emerged in cities and their surrounding areas (including metropolitan centers, suburbs and economic circles)[1,2]. This system is closely based on urban economic and social development, and is committed to meeting the needs of urban residents. In the 1970s, western countries began to pay attention to leisure agriculture. Bull and Wibberley first discussed its definition, pointing out that agronomists regarded tourism as one of the multiple functions of farms, while tourism scholars classified it as rural tourism[3]. However, due to the lack of a unified theoretical system in the West, the definition of leisure agriculture has not been clear, and it is often confused with rural tourism[4]. As a product of modern economy, leisure agriculture is crucial to the development of modern agriculture[5]. By integrating agriculture, tourism and culture, leisure agriculture achieves synchronous improvement of production, life and ecology, as well as deep integration of rural industries, forming new industries, formats and models. In recent years, China's leisure agriculture has made rapid progress and become a new economic and social growth point, contributing significantly to agricultural economic growth, rural development and farmers' income. Since rural tourism was discussed in the special issue of Sustainable Tourism in 1994[6], Chinese and foreign scholars have made rich research achievements in various fields of leisure agriculture, including sustainable development[7], stakeholder analysis[8], influencing factors[9], geospatial structure[10] and driving mechanism[11]. Studies on the spatial distribution of leisure agriculture have attracted extensive attention from scholars at home and abroad. Foreign studies focus on the evolution of spatial distribution[12], the spatial correlation with scenic spots[13], and the

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spatial distribution of development potential[14], etc. At the same time, they pay attention to the spatial structure characteristics, formation mechanism and perception of experientials of leisure agriculture. Subsequently, the research was expanded to development model[15], dynamic mechanism[16] and community management[17,18], and remarkable progress was made. Nilsson pointed out that rural environment is a key factor affecting the spatial layout of leisure agriculture, and regards agricultural garden Tours as a subset[19]. Sanjay's study found that village groups in western Nepal present a core-edge structure[20]. Taking South Korea as a case, Duk-Byeong et al. discussed the driving mechanism and regional differences of rural tourism from the perspective of tourism driving force[21]. In addition, as an entity of leisure agriculture, the development of leisure agriculture enterprises has also attracted attention, and the research covers its life cycle[22], decision-making model construction and development influencing factors[23,24]. Since Wu and other scholars took the lead in exploring the spatial structure of leisure agriculture in China in 2004[25], relevant studies have been increasingly in-depth. The research covers spatial correlation[26], layout optimization[27], distribution characteristics and influencing factors[28,29], among which distribution characteristics and influencing mechanisms are particularly concerned. The research scale is divided into four levels: national[30], provincial[31], municipal[32] and regional[33], mainly provincial and municipal. Data use includes area-based data and agent-based point data[34], and point data can more clearly reveal distribution characteristics[35,36]. Research methods have shifted from descriptive statistics and map description to geo-statistics and spatial analysis, and more scientific quantitative analysis has been realized, such as nearest neighbor index[37], nuclear density analysis[38], spatial proximity analysis and spatial autocorrelation[39,40]. It has been widely used in the fields of leisure tourism[41], characteristic villages[42] and new economic phenomena[43,44], and has become a popular method for the study of spatial distribution of leisure agriculture.

While substantial empirical research has been conducted on the spatial distribution and influencing factors of leisure agriculture, especially in China, there is still a lack of integration between empirical findings and broader theoretical frameworks such as spatial accessibility theory, rural regional development models, or spatial equity in public resource allocation. Most existing studies emphasize descriptive patterns and local planning implications without engaging with conceptual debates on spatial justice, location theory, or tourism geography. In this study, we aim to contribute to the theoretical discussion by adopting a spatial accessibility perspective to examine how geographical, infrastructural, and environmental variables influence the spatial pattern of leisure agriculture. Additionally, although many international studies (e.g., in Europe, Japan, and Korea) have addressed agritourism distribution and accessibility, few have employed spatial econometric approaches such as GWR to capture regional heterogeneity. Our study responds to this gap by providing a spatially differentiated understanding of accessibility in a rapidly urbanizing context, offering insights that complement international experiences and extend the analytical scope of leisure agriculture research.

In terms of methodological approach, considering the significant spatial heterogeneity of leisure agriculture influenced by complex terrain, transportation conditions, and regional development policies, this study compared several spatial econometric models, including the Spatial Lag Model (SLM), Spatial Error Model (SEM), and Geographically Weighted Regression (GWR). SLM emphasizes spatial dependence among dependent variables, and SEM addresses spatial autocorrelation due to omitted variables. However, both are global models and may not effectively capture local variations in explanatory relationships. GWR, by contrast, estimates local parameters across space and is well suited to reveal spatial non-stationarity. Based on empirical comparison using model fit metrics such as $R^2$, AIC, and residual analysis, GWR was found to be the most suitable model for capturing the regional diversity of accessibility influences. This process strengthens both the methodological rigor and theoretical contribution of the study.

Therefore, on the basis of previous studies[45,46], this study made an in-depth analysis of the development status of 386 provincial leisure agriculture demonstration sites in Guangdong Province. ArcGIS spatial analysis tool was used to discuss their spatial distribution types, evolution and characteristics, and GWR model was further used to quantitatively analyze the influence of different factors on spatial distribution, aiming at identifying leading and secondary influencing factors. It provides reference for related research and the upgrading and development of leisure agriculture in Guangdong Province.

## Methods

### Study area

Located in southern China, Guangdong Province has a subtropical monsoon climate with geographical coordinates between 20°13 'and 25°31' north latitude and 109°39 'and 117°19' east longitude. It covers an area of 179,700 square kilometers and has 21 prefecture-level cities under its jurisdiction. The province has abundant water resources and abundant heat, with an average annual temperature of 22.3℃ and an average annual precipitation of 1777 mm, with more precipitation in the south and less in the north. In general, Guangdong has abundant agricultural resources and superior natural conditions, and its agricultural industry occupies a prominent position in the country. Although Guangdong leisure agriculture started early and has a certain basis for development, regional development imbalance and unreasonable spatial distribution have become the bottleneck restricting its further development. It is an important topic to study the characteristics and influencing factors of the spatial distribution of leisure agriculture and how to optimize the spatial distribution to promote its better development.

### Data sources

The research samples of this paper are 386 provincial leisure agriculture demonstration sites in Guangdong Province. A total of 386 provincial leisure agriculture demonstration sites will be built in seven batches from 2013 to 2020, announced by the Guangdong Provincial Department of Agriculture and Rural Affairs and the Guangdong Provincial Department of Culture and Tourism (http://dara.gd.gov.cn/). The data of social economy, agricultural base and highway mileage of counties and districts in Guangdong Province were obtained from

Guangdong Statistical Yearbook (2020). In this study, coordinates picking system of Baidu map API was used to determine the latitude and longitude of leisure agriculture demonstration sites. The spatial distribution data of China's altitude (DEM) is from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (website: http://www.resdc.cn), the slope data is extracted based on DEM data. For river and road network data, the latest vector data provided by the National Center for Basic Geographic Information (http://www.ngcc.cn/ngcc/) were used. In terms of data processing, ArcGIS 10.7 software (https://www.arcgis.com/) is mainly used for spatial processing operations such as connection and overlap.

### Research methods

**Geographically Weighted Regression (GWR)**, as an advanced spatial analysis tool, is developed on the basis of the ordinary least squares (OLS) model for accurate parameter estimation[47]. The aim of this technique is to deeply explore the spatial variation of the object at a specific scale and the potential driving factors behind it. In the face of spatial autocorrelation between independent variables, the traditional OLS model is ineffective due to its assumption of residual independence. The GWR model can flexibly address this issue, directly simulating non-stationary data and replacing global parameter estimation with local parameter estimation[48]. This ability enables GWR models to capture the non-stationarity of parameters in different spatial regions, allowing the relationship between variables to be dynamically adjusted with changes in spatial position. Additionally, because GWR incorporates the local effects of spatial objects, its analysis results are not only more accurate but also closer to the objective reality. Due to these advantages, GWR has been widely used and recognized in geography and many interdisciplinary studies involving spatial analysis.

However, before selecting GWR, this study also compared it with other spatial econometric models to evaluate its suitability. The Ordinary Least Squares (OLS) model was first used as a baseline analysis. While OLS offers a global estimation of parameters, it assumes spatial homogeneity and does not account for spatial non-stationarity, making it inadequate for capturing the local variations in accessibility. Spatial Error Model (SEM) and Spatial Lag Model (SLM) were also considered, as both models address spatial autocorrelation issues—SEM accounts for spatial dependence caused by omitted variables, while SLM models the spatial dependence of the dependent variable. Although both SEM and SLM are suitable for capturing global spatial effects, they do not effectively deal with local spatial heterogeneity, which is crucial for the analysis of leisure agriculture accessibility.

Therefore, GWR was chosen as the most suitable model for this study. Through empirical comparison using model performance indicators such as model fit ($R^2$), AIC (Akaike Information Criterion), and residual analysis, GWR demonstrated superior performance in capturing the local variations in the spatial accessibility of leisure agriculture sites in Guangdong Province. Specifically, the local estimates from GWR provided a much finer understanding of the spatial dynamics, which neither OLS nor SLM/SEM could reveal. This is particularly important in the context of leisure agriculture, where accessibility factors such as road network density, river density, and elevation may have highly localized impacts that vary significantly across different regions.

To analyze the spatial distribution characteristics of leisure agriculture demonstration sites in Guangdong Province, this study employed several spatial analysis methods, including kernel density estimation, nearest distance method, and geographical concentration index method. The current accessibility level of each leisure agriculture demonstration site was measured using real-time monitoring via Baidu Map and an accessibility measurement model. In analyzing the influencing factors of spatial accessibility, linear density was introduced to explore the relationship between accessibility and river/road network density, while grid valuation was used to assess the relationship between accessibility and factors such as mountain elevation and slope. Finally, the **GWR model** was applied to identify the key factors influencing spatial accessibility levels and their varying degrees of impact across different regions.

## Spatial distribution characteristics

### Quantitative distribution characteristics

This study uses BaiduMap to accurately pick space coordinates of 386 leisure agriculture demonstration sites in Guangdong Province. Then, Excel is used to catalogue, classify and sort out the obtained warp and weft coordinate data. On this basis, with the help of ArcGIS 10.7 software (https://www.arcgis.com/), these demonstration sites were visually analyzed on the map of Guangdong Province (https://guangdong.tianditu.gov.cn/), and the results were shown in Fig. 1. The demonstration sites of leisure agriculture were distributed in 21 cities in Guangdong Province, but showed uneven distribution characteristics. At present, Guangdong Province has announced a total of seven batches of provincial leisure agriculture demonstration sites, with different colors representing different batches. The largest number of cities are Shaoguan and Heyuan, there are 30, Shenzhen is the least, only 3, each city has an average of 18.4 leisure agriculture demonstration sites.

In this study, the nearest proximity method was used to determine the spatial distribution model of leisure agriculture demonstration sites in Guangdong Province. The closest proximity distance, as a measure of the degree of proximity between point elements in geographic space, reveals the distribution characteristics of these demonstration sites. By calculation, the theoretical nearest neighbor distance is 11.70 km, but the actual value is 10.50 km, with the nearest neighbor point index R reaching 0.90, which indicates that the spatial distribution of the demonstration points presents a cohesive feature. Further, Ripley K(r) function analysis based on distance was carried out by Crimestat software, and the agglomeration state of demonstration sites was deeply discussed. The analysis results (see Fig. 2) show that the agglomeration degree of demonstration sites generally exceeds the maximum expected value of random distribution, indicating that within the research scale, leisure agriculture demonstration sites show significant agglomeration distribution characteristics, and with the change of distance, their agglomeration degree presents an overall trend of "first increase and then decrease".

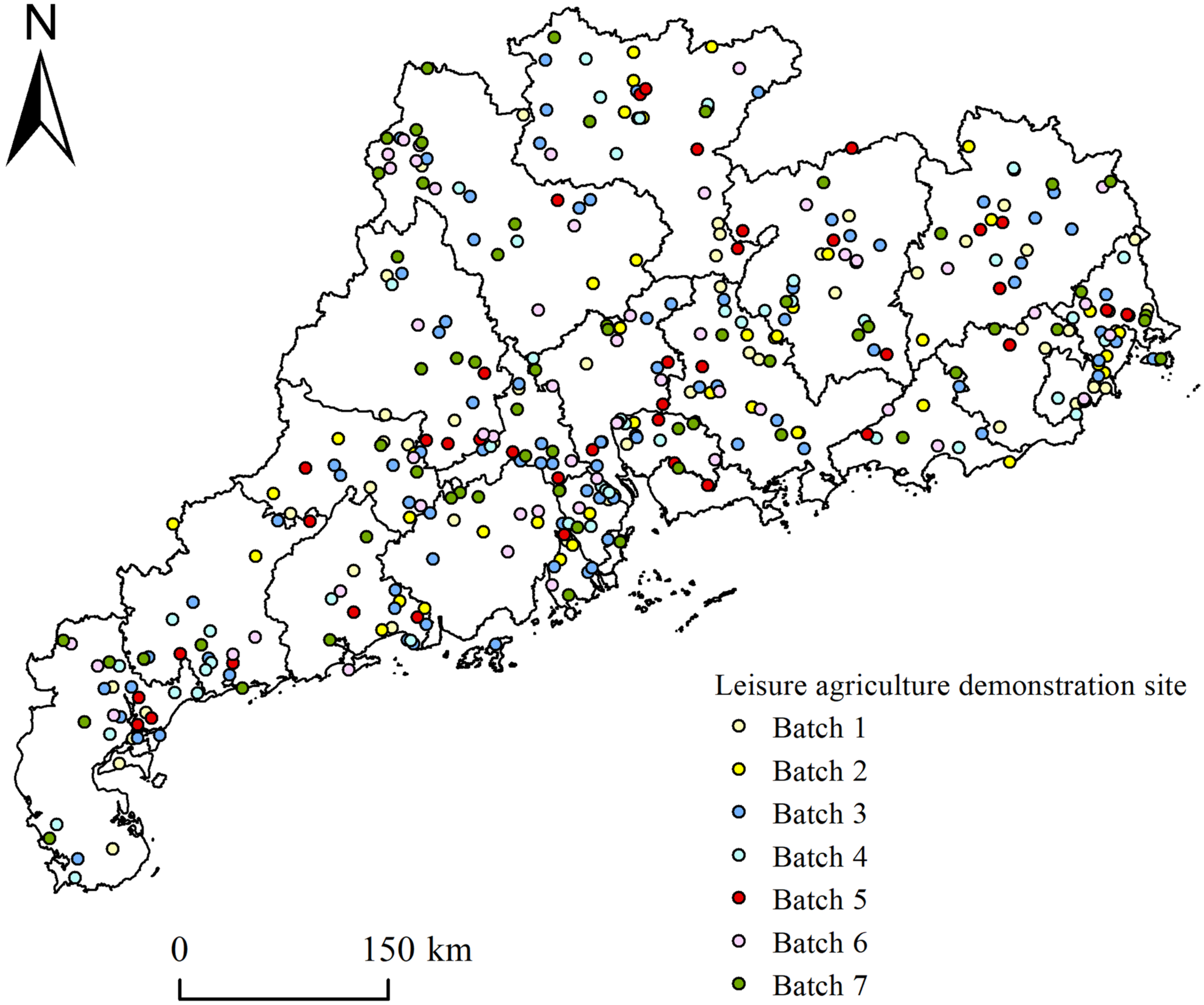


**Fig. 1**. Distribution of leisure agriculture demonstration sites in Guangdong Province. ArcGIS 10.7 software (https://www.arcgis.com/).

## Spatial distribution balance

Table 1 shows the calculation results of geographical concentration index, Gini coefficient and imbalance index of each batch of leisure agriculture demonstration sites in Guangdong Province. By analyzing the data in Table 1, it can be seen that the geographical concentration index of these seven batches of demonstration sites exceeds the standard value of complete average distribution (18.38), which indicates that since the establishment of leisure agriculture demonstration sites in Guangdong Province in 2013, the spatial distribution of these demonstration sites at the municipal level mainly presents the characteristics of imbalance and concentration. However, it is worth noting that the extent of this imbalance is gradually showing a weakening trend.

This study calculated the imbalance index B of each batch of leisure agriculture demonstration sites in Guangdong Province (see Table 1) to assess the distribution completeness of demonstration sites at different scale levels. Analysis of the data in Table 1 reveals that the imbalance index of these seven batches of demonstration sites ranges from 0.225 to 0.313, indicating that since 2013, the spatial distribution of leisure agriculture demonstration sites in Guangdong Province at the municipal level of all scales and levels is generally incomplete and shows a tendency of centralized distribution.

## Density of spatially distributed nuclei

In order to explore the distribution characteristics of point elements, this study adopts the kernel density estimation method, and generates a smooth and hierarchical kernel density analysis chart, which intuitively shows the distribution of leisure agriculture demonstration sites in the region and highlights the local characteristics of leisure agriculture demonstration sites. Kernel density estimation method is based on the occurrence probability of geographical events in the region. It is believed that geographical events may occur at any location in the target region, but the occurrence probability is different in different locations. Generally, the more concentrated

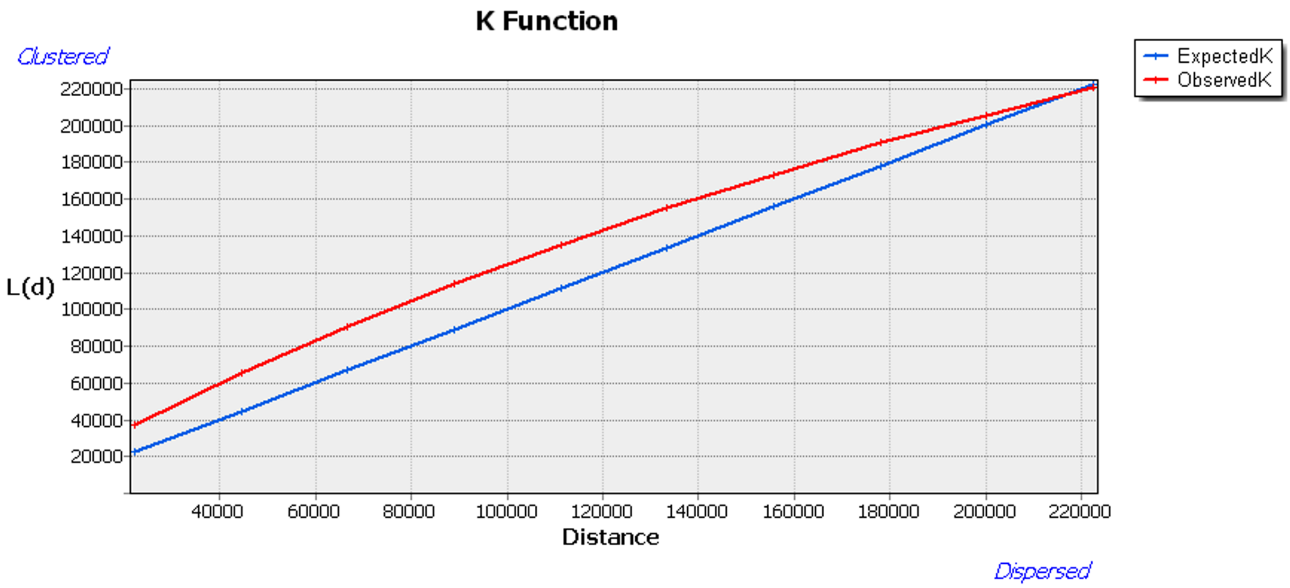


**Fig. 2**. Ripley K (r) function analysis results of leisure agriculture demonstration site in Guangdong Province.

| Batch | Year | E | B |
|---|---|---|---|
| 1 | 2013 | 25.380 | 0.225 |
| 2 | 2014 | 28.020 | 0.255 |
| 3 | 2016 | 23.727 | 0.245 |
| 4 | 2017 | 28.344 | 0.147 |
| 5 | 2018 | 26.220 | 0.313 |
| 6 | 2019 | 25.768 | 0.285 |
| 7 | 2020 | 24.381 | 0.303 |

**Table 1**. Geographical concentration index and unbalance index of the distribution of leisure agriculture demonstration sites in Guangdong Province.

the point elements are, the greater the probability of geographical events. Conversely, the more dispersed the point elements are, the less likely the geographical events are to occur. In this study, 386 leisure agriculture demonstration sites in Guangdong Province were abstracted as point elements, and kernel density estimation method was used for visual display (see Eq. 1).

$$f_n(x) = \frac{1}{nh^d} \sum_{i=1}^{n} k\left(\frac{x - X_i}{h}\right) \tag{1}$$

where $K(x\text{-}x_i/h)$ is the kernel density equation, $x_i$ is the kernel density of each point, $x$ is the kernel density at the center of the grid, $h$ is the threshold, $n$ is the number of points within the threshold range, and D is the dimension of the data. Its geometric function requires that the density at the center of each $x_i$ point is the highest and that this decreases as the points move away from the center. When the distance from the center reaches a certain threshold value (the edge of the window), the density is zero, and the core density at the grid center $x$ is the sum of the densities within the threshold range.

The kernel density estimation (KDE) method in the spatial analysis tool density of ArcGIS 10.7 software (https://www.arcgis.com/) was used to analyze the spatial distribution density of leisure agriculture demonstration sites in Guangdong Province (https://guangdong.tianditu.gov.cn/). After repeated adjustments and optimizations, the best visualization effect was achieved, and the kernel density analysis map of leisure agriculture demonstration sites in Guangdong Province was finally generated, as shown in Fig. 3. The results show that the spatial distribution of leisure agriculture demonstration sites in Guangdong Province presents an unbalanced state, forming two highly clustered areas, the northeastern part of Meizhou and the border area of Guangzhou and Foshan, and two secondary clustered areas, the border area of Chaozhou and Shantou and the northwestern part of Qingyuan. In Shenzhen, Dongguan, Shanwei and other places, the distribution of leisure agriculture demonstration sites is sparse; In general, the demonstration sites of leisure agriculture in Guangdong Province show a dumbbell-shaped distribution pattern in the central region of the Pearl River Delta and the northeast region of Guangdong Province.

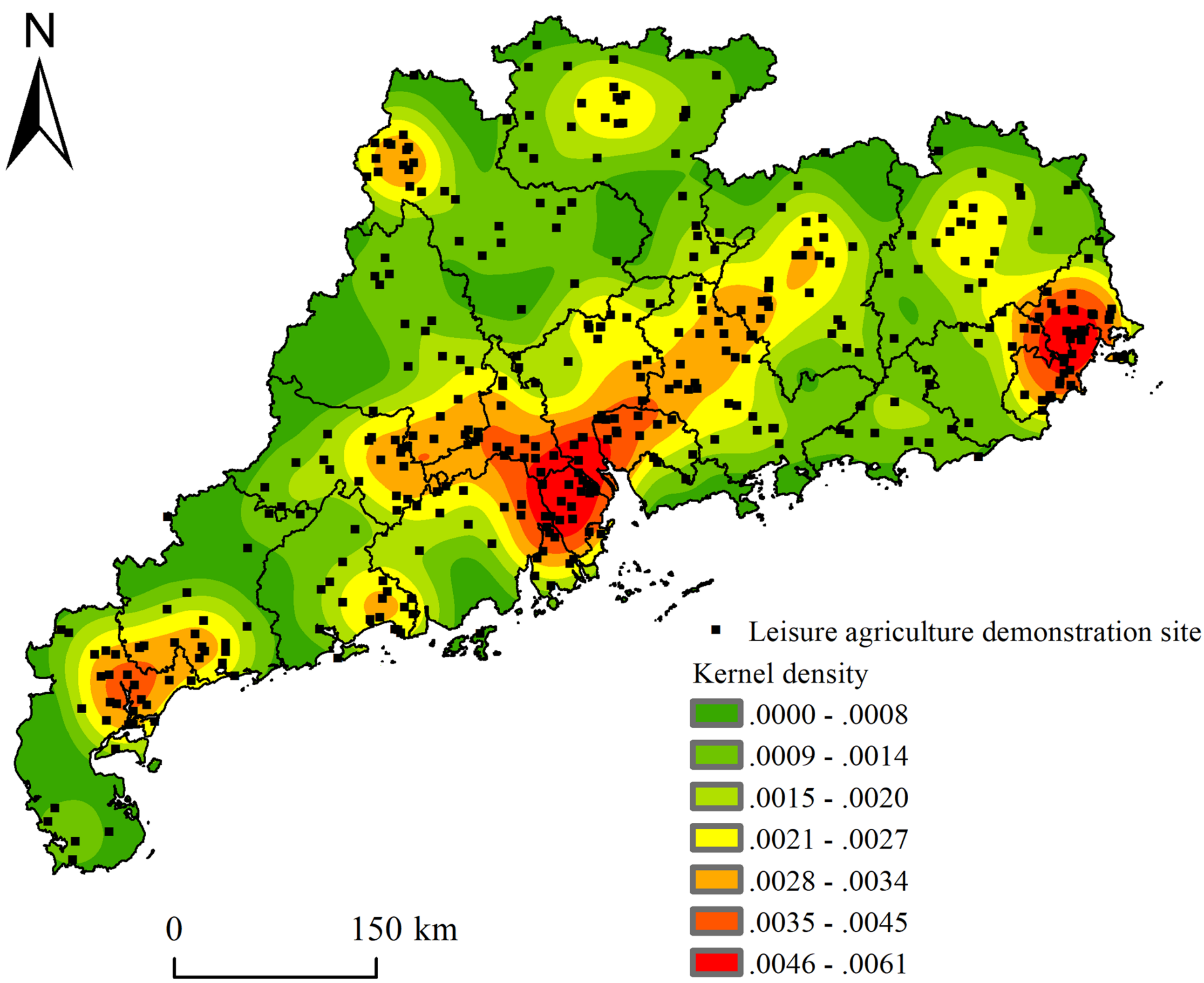


**Fig. 3**. Schematic diagram of nuclear density of leisure agriculture demonstration sites in Guangdong Province. ArcGIS 10.7 software (https://www.arcgis.com/).

## Analysis of spatial accessibility

Baidu map is used to obtain the shortest time distance of 386 leisure agriculture demonstration sites in Guangdong Province to each prefecture level city in real time, taking into account the real-time road conditions during driving, the impact of road infrastructure, the waiting time of traffic lights, road congestion and other realistic factors. The accessibility level of target leisure agriculture demonstration sites can be obtained more accurately and truly by using the real-time measurement method[45].

In this study, the spatial accessibility of 386 leisure agriculture demonstration sites in Guangdong Province was measured according to formulas 2 and 3[49], and the results were standardized, so that the value range was unified to 0 ~ 1 (see Table 2). The results show that the average spatial accessibility of leisure agriculture demonstration sites in Guangdong Province is 240.01 min, and the overall level is low and there are significant differences among different cities. From the perspective of spatial accessibility, most of the top ten leisure agriculture demonstration sites are located in Guangzhou and Dongguan, indicating that these two regions have the highest spatial accessibility of leisure agriculture demonstration sites. The accessibility of leisure agriculture demonstration sites in Zhanjiang is generally low, followed by Meizhou City, and the last eight demonstration sites are located in Zhanjiang City.

The Kriging interpolation method in ArcGIS 10.7 software (https://www.arcgis.com/) was further used to analyze the overall distribution of the current spatial accessibility of leisure agriculture demonstration sites in Guangdong Province (https://guangdong.tianditu.gov.cn/), as shown in Fig. 4. The results show that the current spatial accessibility presents the distribution characteristics of descending layer by layer and step by step from the Pearl River Delta region as the center. Specifically, the central regions such as Guangzhou, Dongguan, Foshan, Zhongshan and Huizhou have a high level of accessibility, while the regions located in the inter-provincial margins such as Zhanjiang, Meizhou, Qingyuan and Shaoguan have a low level of accessibility.

| Ranking | Name | Accessibility | Ranking | Name | Accessibility |
|---|---|---|---|---|---|
| 1 | Deen Lake Leisure Ecological Park | 0.9976 | 377 | Maoming Xinyi Tianma Mountain Tourism Development Co., Ltd | 0.2051 |
| 2 | Guangzhou Nansha Dongsheng Agricultural Tourism Park | 0.9931 | 378 | Xinba Village, Sanshui Yao Township, Lianzhou City | 0.1918 |
| 3 | Guangzhou Haipenshui Farm | 0.9928 | 379 | Maode Grand View Garden | 0.1563 |
| 4 | Guangzhou Lvhang Agricultural Sightseeing Park | 0.9925 | 380 | Haifeng Village, Nansan Island, Zhanjiang | 0.1502 |
| 5 | Dongguan Jingu Modern Ecological Agriculture Sightseeing Park | 0.9891 | 381 | Lianjiang Zhutouwei Planting Cooperative | 0.1501 |
| 6 | Guangzhou Guansheng International Seed Science Park Co., Ltd | 0.9858 | 382 | Lianjiang Minghuang Jinhua Tea Ecological Park | 0.1433 |
| 7 | Guangdong Huisiji Orchard | 0.9840 | 383 | Zhanjiang Xuwen Shenzhou Mulan Garden | 0.1140 |
| 8 | Shunde Xindi Farm of Guangdong Shunde Dadi Garden Environment Engineering Co., Ltd | 0.9827 | 384 | Leizhou City or Zuishanzhuang Agricultural Development Co., Ltd | 0.0769 |
| 9 | Dongguan Olympic Vegetable Demonstration Base | 0.9826 | 385 | Zhengmao Huafengling Modern Agricultural Base | 0.0493 |
| 10 | Cool Lucky Fruit Forest Leisure Agriculture Park | 0.9976 | 386 | Pineapple Sea Tourist Area, Longmen Village, Xuwen County | 0.0000 |

**Table 2**. Accessibility ranking of leisure agriculture demonstration sites in Guangdong Province.

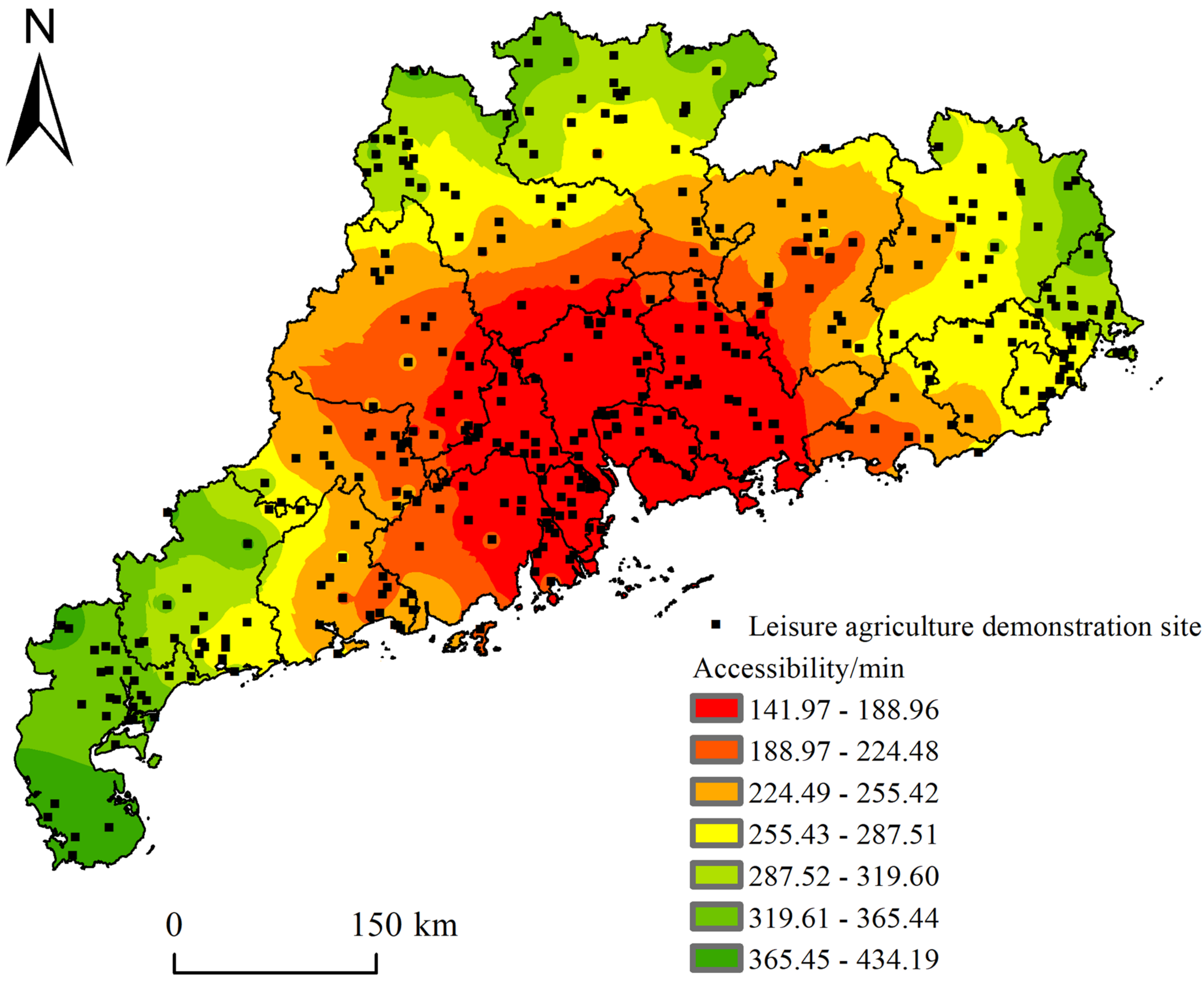


**Fig. 4**. Kriging interpolation spatial distribution map of spatial accessibility of leisure agriculture demonstration sites in Guangdong Province. ArcGIS 10.7 software (https://www.arcgis.com/).

$$K_j = \frac{1}{n}\sum_{i=1}^{n} E_{ij} \quad (2)$$

$$K = (\max K_j - K_j)/(\max_{1\le j\le m} K_j - \min_{1\le j\le m} K_j) \quad (3)$$

where $K_j$ represents the accessibility of the leisure agriculture demonstration site *j*, *n* refers to the number of prefecture-level cities, $E_{ij}$ is the shortest distance from the leisure agriculture demonstration site *j* to city *i*, and *K* represents the standardized value of accessibility of the leisure agriculture demonstration site.

## Analysis of influencing factors on Spatial accessibility

### Accessibility influencing factor hypothesis

The difference in spatial accessibility of leisure agriculture demonstration sites in Guangdong Province stems from long-term human-land interaction, that is, the result of mutual adaptation between people and the mountain environment based on production and living needs, which is deeply affected by regional natural conditions and human activities. According to the principle of quantification of variables, this study starts with natural factors such as terrain, terrain and river, and deeply discusses the factors that affect the spatial accessibility differentiation of these demonstration sites. Generally speaking, landscape conditions and road facilities are the key factors affecting the accessibility of leisure agriculture demonstration sites. Through comparative analysis of the accessibility value of the leisure agriculture demonstration site and the elevation, slope, river density and road network density data of the location, the following findings are obtained: The time from the demonstration site to the central city is correlated with its elevation value, and the time cost of the demonstration site with higher elevation value is greater than that of the leisure agriculture demonstration sites with lower elevation value. There are few demonstration sites in the areas with large slope, and their accessibility is relatively low due to the zigzag mountain road. Most of the demonstration sites are close to rivers, and river density has a positive effect on their accessibility. Most of the demonstration sites are located in areas with low road network density, while those with high road network density are more accessible. Based on this, it is assumed that the accessibility level of leisure agriculture demonstration sites is negatively correlated with elevation and slope, and positively correlated with river density and road network density[31,50]. Use ArcGIS 10.7 software (https://www.arcgis.com/).

to draw a overlay map (https://guangdong.tianditu.gov.cn/) of mountain elevation, slope, and leisure agriculture demonstration points (see Figs. 5 and 6). The analysis results show that the spatial accessibility of North and east Guangdong is low because of the high terrain. The demonstration sites in the Pearl River Delta region generally have high spatial accessibility due to their low topography. Use ArcGIS 10.7 software (https://www.arcgis.com/) to draw overlay maps (https://guangdong.tianditu.gov.cn/) of river density, road network density, and leisure agriculture demonstration sites (see Figs. 7 and 8). The analysis results show that there is a significant correlation between the location of demonstration sites and river systems. Through the analysis of the line density of the main water systems, it is found that areas with dense demonstration sites are often also areas with high river density. Most leisure agriculture demonstration sites are located in areas with low road network density, while leisure agriculture demonstration sites with higher road network density have higher accessibility levels.

### Analysis of spatial accessibility factors based on the GWR model

*OLS classical linear regression*

This study takes the accessibility of leisure agriculture demonstration sites in Guangdong Province as the dependent variable and draws reference from previous studies[31,46]. The explanatory variables selected are elevation, slope, road network density, and river density. The rationale behind choosing these variables is as follows: elevation is associated with terrain difficulty, influencing transportation access; slope affects land suitability for agriculture and infrastructure; river density impacts both accessibility and tourism potential; and road network density is directly correlated with ease of travel to the sites. The analysis results (see Table 3) show that the variance inflation factor (VIF) of each parameter is much lower than 7.5, indicating that the selected explanatory variables are reasonable and there is no multicollinearity issue. Additionally, the results of the Jarque-Bera Test confirm that the regression equation satisfies the assumption of normality, ensuring unbiased and effective parameter estimation. Further observation of the T-value and P-value of the test results shows that elevation and river density significantly affect accessibility, while slope and road network density do not have significant effects.

*Model selection*

In this study, various spatial econometric models, including OLS regression, Spatial Error Model (SEM), Spatial Lag Model (SLM), and Geographically Weighted Regression (GWR), were compared to determine the most suitable model for analyzing spatial accessibility. OLS regression served as the baseline model, providing global regression coefficients. However, it failed to account for spatial heterogeneity and could not capture the local variations within the data. SEM and SLM models were considered next, as they address spatial autocorrelation and spatial dependence. While these models do offer advantages in handling spatial relationships, they remain global models and were unable to effectively capture the local differences that are critical in this study.

After conducting a comparative analysis using statistical indicators such as AIC, $R^2$, and log-likelihood, the GWR model was selected as the optimal model. Unlike the other models, GWR estimates coefficients at each spatial location, which allows for precise capturing of spatial variability and local coefficient differences. The results from the comparison clearly show that the GWR model outperformed OLS, SEM, and SLM in terms

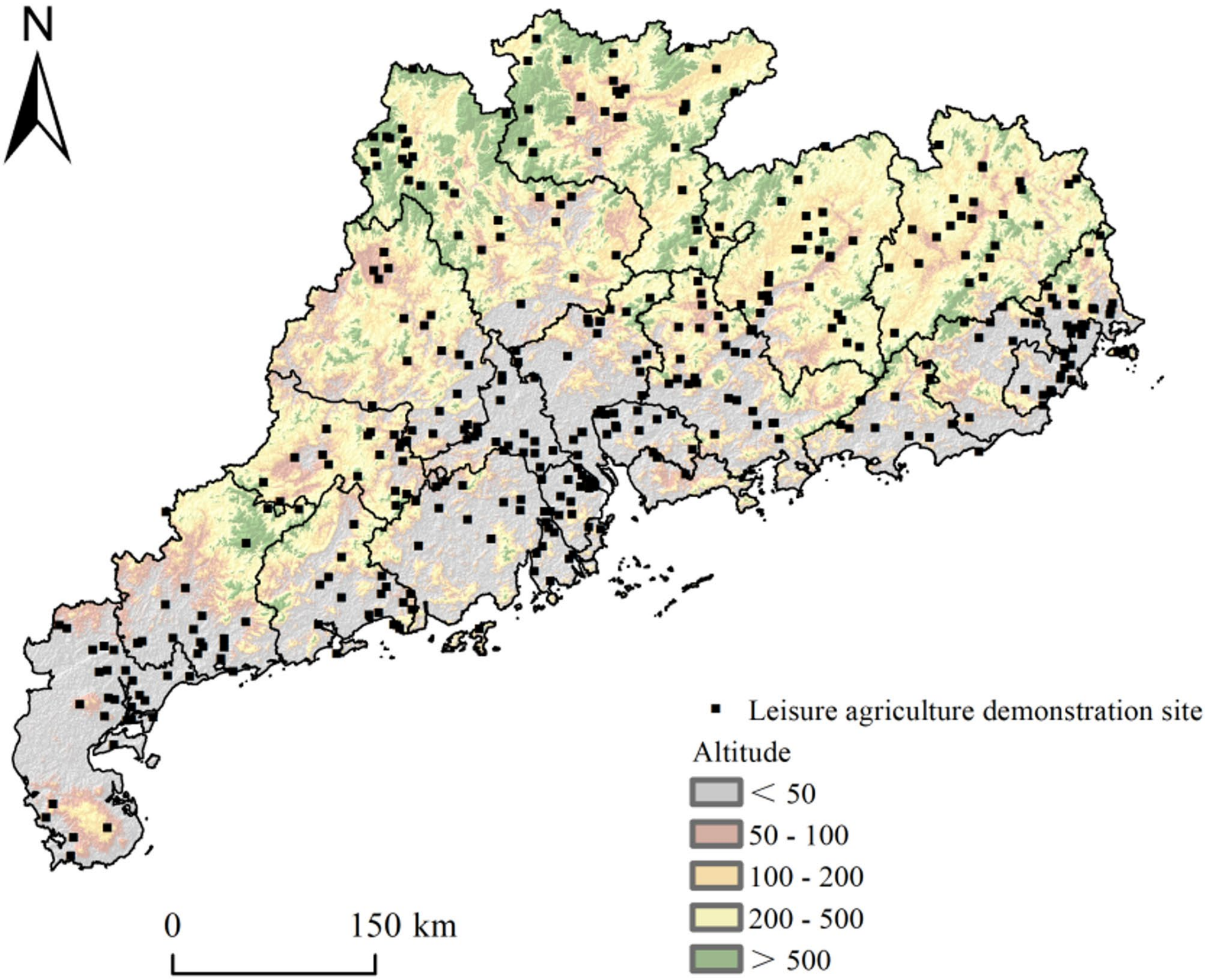


**Fig. 5**. Overlay map of leisure agriculture demonstration site and mountain elevation in Guangdong Province. ArcGIS 10.7 software (https://www.arcgis.com/).

of fit, making it the most effective tool for analyzing spatial accessibility in this study. Table 4 presents the comparison results, where the superior AIC and $R^2$ values of GWR validate its necessity and effectiveness in spatial accessibility analysis.

*GWR model parameter regression*

The geographical weighted regression model (GWR) is an optimization and upgrading of the traditional OLS linear regression model, and its core feature is that it deeply considers the differences and dynamic changes of regression coefficients in geographical space. Relying on a solid theoretical foundation and a sound supporting system, this model transcends the global thinking of general linear regression and focuses mainly on the hysteresis and spillover effects of evaluation factors in local space[49]. The basic model expression is as follows:

$$\mathrm{Y_i} = \beta_0 \mathrm{U_i V_i} + \sum_{m} \beta_{\mathrm{m}} \mathrm{U_i V_i X_{im}} + \varepsilon_{\mathrm{i}} \tag{4}$$

where $Y_i$ is the spatial accessibility value of the leisure agriculture demonstration site at location $i$; $X_{im}$ is the value of the m-th explanatory variable at site location $i$;($U_i$,$V_i$)are the projection coordinates of location $i$; $\beta_0$ ($U_i$,$V_i$) represents the intercept of the regression equation; $\beta_m$ ($U_i$, $V_i$) represents the regression value of the m$^{th}$ explanatory variable at the spatial location $i$; $m$ represents the number of independent variables of the model; $\varepsilon_i$ is the random error at $i$.

For data with spatial autocorrelation effect, GWR model performs better than traditional OLS linear regression model in terms of residual reduction, parameter estimation accuracy and hypothesis testing significance. The model assigns independent coefficients to each sample space, so as to capture and display local features of spatial variation more effectively in ArcGIS map display. The analysis shows that the AICC value of the GWR model is -1208.357 (Table 5), which is better than the AICC value of -246.214 generated by the general OLS regression;

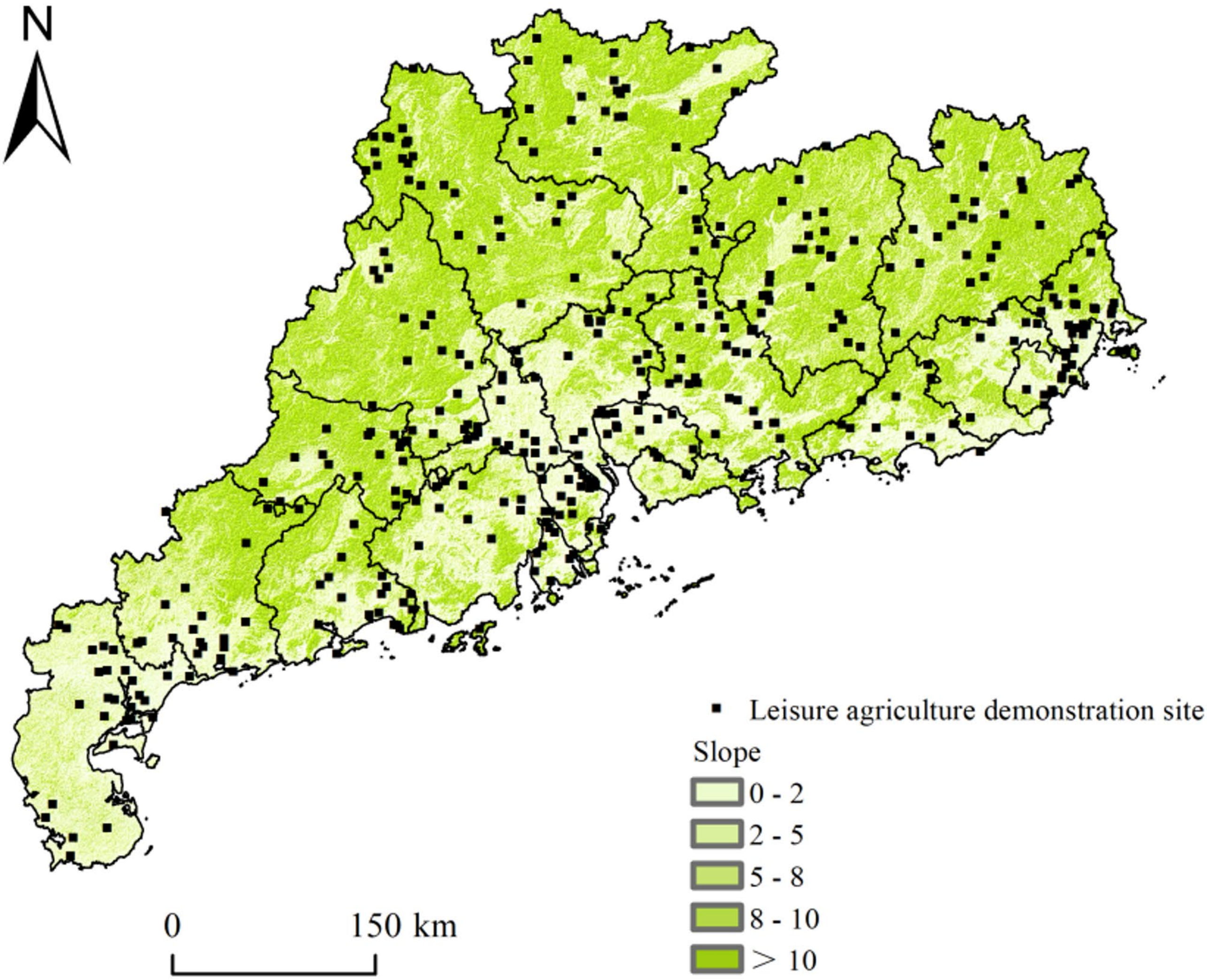


**Fig. 6**. Overlay map of leisure agriculture demonstration sites and slopes in Guangdong Province. ArcGIS 10.7 software (https://www.arcgis.com/).

the overall goodness of fit (R) of the GWR model is superior compared to the OLS model (0.056 vs. 0.958); thus showing the effectiveness and necessity of the GWR model in spatial accessibility analysis.

In order to further analyze the specific impact of various variables on the accessibility of leisure agriculture demonstration sites in Guangdong Province, this study systematically sorted out the analysis results of the GWR model and selected six statistical indicators, including minimum value, upper quartile, median value, lower quartile value, maximum value and average value, to draw Table 6. The average regression coefficient of each variable in the GWR model effectively reveals the average contribution level of these factors to accessibility. It is worth noting that the regression coefficient of the variable presents positive and negative differences, wherein the positive coefficient indicates that the variable has a positive effect on the accessibility of leisure agriculture demonstration sites, while the negative coefficient indicates that it has an inhibitory effect[51].

GWR regression analysis shows that the regression coefficients of road network density, river density and elevation are not only large, but also fluctuate significantly, which indicates that these three variables have a significant impact on the spatial distribution of leisure agriculture demonstration sites. However, the marginal effects of these factors differ in direction under different spatial conditions, so we visualized the regression results. Using ArcGIS 10.7 software (https://www.arcgis.com/), an in-depth visualization analysis was conducted on the regression coefficients of various variables output by the GWR model, and a spatial distribution map (https://guangdong.tianditu.gov.cn/) of each variable coefficient was drawn (see Fig. 9), thus systematically exploring the spatial differences in the impact effects of each variable. Further observation shows that the regression coefficients of road network density, river density and elevation coexist with positive and negative ones, indicating that these variables promote the accessibility of leisure agriculture demonstration sites in some areas, while restrict them in other areas.

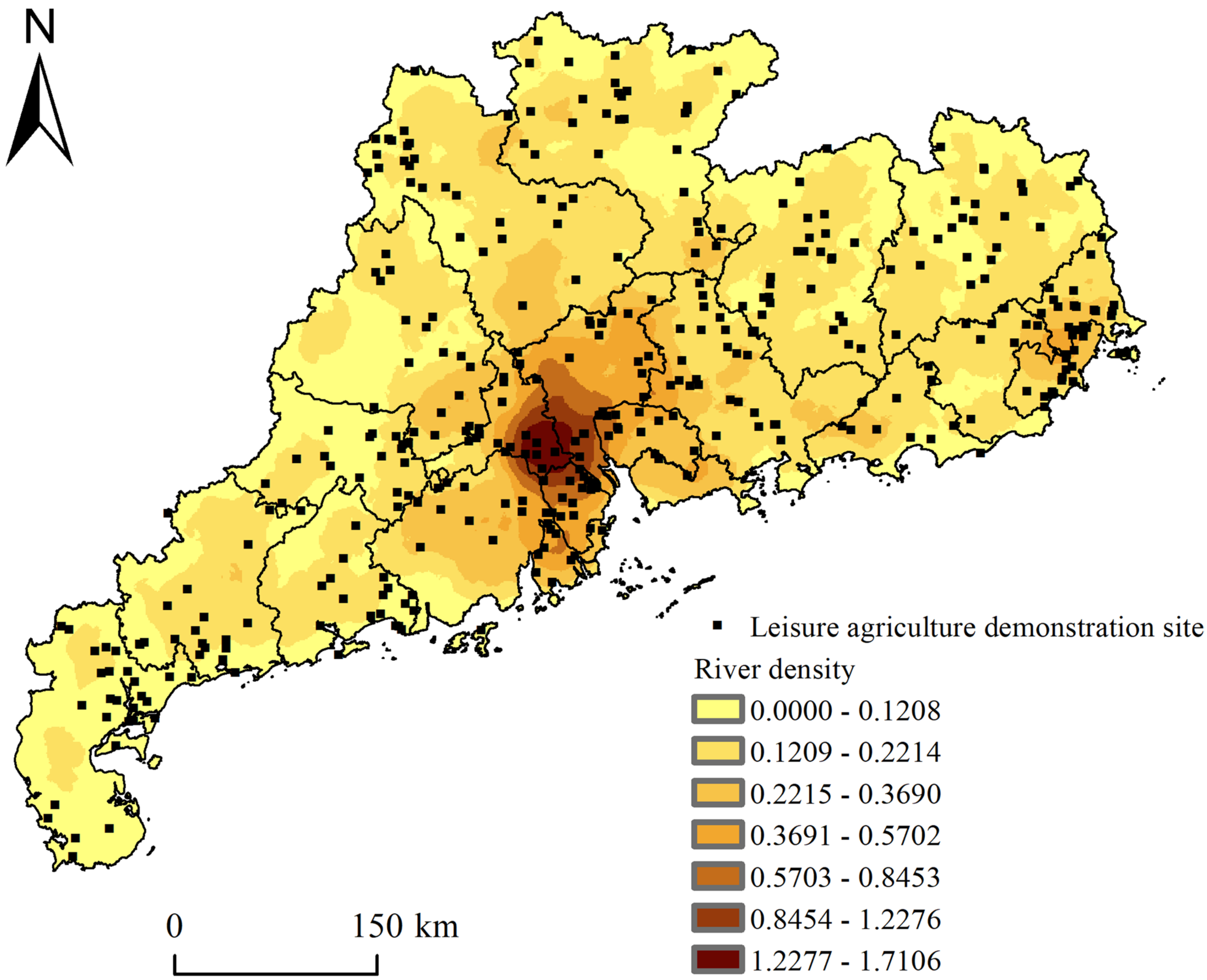


**Fig. 7**. Overlay map of leisure agriculture demonstration site and water system density in Guangdong Province.

## Conclusion and discussion

### Conclusion

As of March 2020, Guangdong Province has announced seven batches of 386 provincial leisure agriculture demonstration sites. The distribution of these leisure agriculture demonstration sites is uneven on the city-scale, forming a dumbbell-shaped distribution pattern mainly in the middle of the Pearl River Delta and northeast Guangdong, especially in Shaoguan, Heyuan and Qingyuan cities. By means of modern geographical analysis tools and methods, the spatial accessibility of these 386 demonstration sites and its influencing factors are deeply studied. The GWR model was used to explore the local effects and spatial spillovers of spatial accessibility factors of leisure agriculture demonstration sites in Guangdong Province, and the following conclusions were drawn:

1. The distribution of leisure agriculture demonstration sites in Guangdong Province is uneven at the city scale, showing a centralized trend, but the imbalance is gradually weakening.
2. The shortest time from leisure agriculture demonstration sites to prefecture-level cities in Guangdong Province was 240.01 min on average, the overall level was low, and the inter-city difference was significant; The accessibility is highest in Guangzhou and Dongguan, and lowest in Zhanjiang and Meizhou. The spatial accessibility of leisure agriculture demonstration sites in Guangdong Province decreased from the Pearl River Delta region to the periphery in a circular and stepped pattern.
3. Coupling analysis using **ArcGIS 10.7** confirmed the correlation between spatial accessibility of leisure agriculture demonstration sites in Guangdong Province and elevation, slope, river density, and road network density.
4. The local regression analysis of the **GWR model** showed that the regression coefficients of road network density, river density, and elevation were large and fluctuated significantly, indicating that these variables had a great influence on the spatial distribution of leisure agriculture demonstration sites in Guangdong Province.

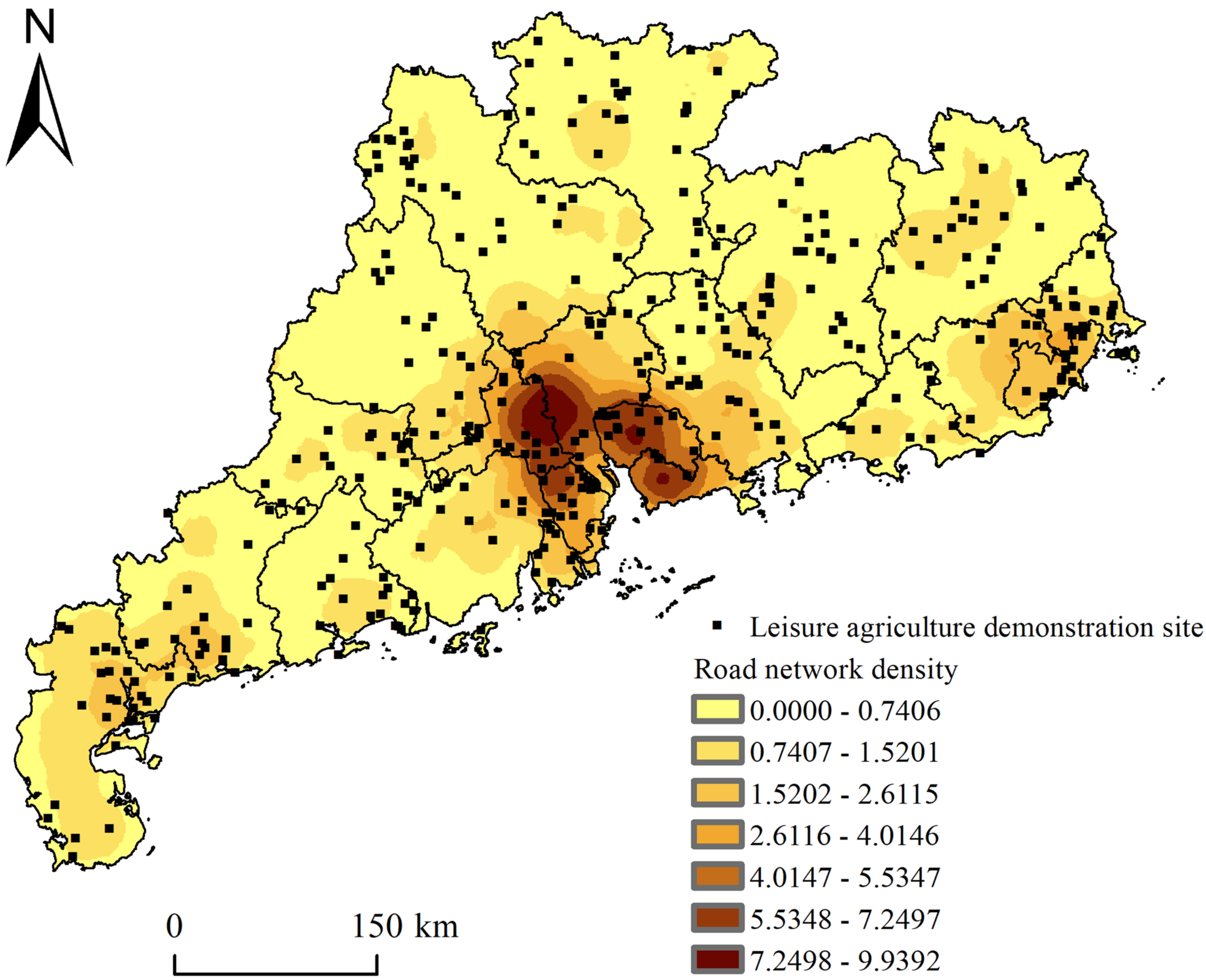


**Fig. 8**. Overlay map of leisure agriculture demonstration sites and road network density in Guangdong Province. ArcGIS 10.7 software (https://www.arcgis.com/).

| Model parameter | Coefficient | T value | *P* value | Standard deviation | VIF |
|---|---|---|---|---|---|
| Intercept | 0.587 | 33.934 | 0.000* | 0.017 | – |
| Altitude value | − 0.292 | − 4.699 | 0.000* | 0.062 | 1.412 |
| Value of slope | − 0.042 | − 0.669 | 0.504 | 0.062 | 1.369 |
| River density | 0.629 | 6.236 | 0.000* | 0.101015 | 2.890587 |
| Road network density | 0.1 | 1.564 | 0.119 | 0.074739 | 3.071 |
| $R^2$ | – | – | 0.388 | – | – |
| Adjusted $R^2$ | – | – | 0.056 | – | – |
| Jarque Bera Test | – | – | 27.409 | – | – |
| AICC | – | – | − 246.214 | – | – |

**Table 3**. OLS regression results of accessibility level of leisure agriculture demonstration sites in Guangdong Province. ***Means significant at 1% level, ** means significant at 5% level, * means significant at 10% level.

| | Variable | Coefficient | Std.Error | z-value | Probability |
|---|---|---|---|---|---|
| SEM | CONSTANT | 235.714 | 24.080 | 9.789 | 0 |
| | DEM | 0.051 | 0.007 | 7.806 | 0 |
| | Slope | 0.365 | 0.206 | 1.772 | 0.076 |
| | Road | 0.175 | 0.052 | 3.390 | 0.001 |
| | Water | − 0.114 | 0.033 | − 3.418 | 0.001 |
| | LAMBDA | 0.967 | 0.011 | 85.102 | 0 |
| | $R^2$ | 0.947 | | AIC | 3311.82 |
| | Log likelihood | − 1650.912 | | Schwarz criterion | 3331.6 |
| SLM | W_data | 0.937 | 0.013 | 69.895 | 0 |
| | CONSTANT | 20.541 | 7.057 | 2.911 | 0.004 |
| | DEM | 0.032 | 0.006 | 5.245 | 0 |
| | Slope | 0.421 | 0.229 | 1.837 | 0.066 |
| | Road | 0.146 | 0.046 | 3.151 | 0.002 |
| | Water | − 0.095 | 0.030 | − 3.194 | 0.001 |
| | $R^2$ | 0.942 | | AIC | 3337.450 |
| | Log likelihood | − 1662.720 | | Schwarz criterion | 3361.180 |
| GWR | $R^2$ | 0.969 | | AIC | 2208.357 |
| | Log likelihood | − 1631.720 | | Schwarz criterion | 3302.430 |

**Table 4**. Comparison of Spatial econometric models for accessibility Analysis.

| Model parameter | Parameter value |
|---|---|
| Bandwidth | 58144.650 |
| AICC | − 1208.357 |
| Sigma | 0.046 |
| $R^2$ | 0.969 |
| Adjusted $R^2$ | 0.958 |

**Table 5**. Regression results of GWR model parameter values for accessibility level of leisure agriculture demonstration sites in Guangdong Province.

| Influence factor | Minimum | Maximum | Mean | Above quartile | Lower quartile | Median | Test |
|---|---|---|---|---|---|---|---|
| Altitude value | − 1.814 | 0.361 | − 0.307 | − 0.429 | − 0.135 | − 0.295 | 0.273 |
| Value of slope | − 0.509 | 0.177 | − 0.078 | − 0.116 | − 0.041 | − 0.065 | 0.083 |
| River density | − 1.881 | 2.057 | 0.127 | − 0.102 | 0.599 | 0.068 | 0.747 |
| Road network density | − 0.935 | 3.702 | 0.523 | 0.119 | 0.899 | 0.369 | 0.546 |

**Table 6**. Quintile observation table of GWR model of accessibility level of leisure agriculture demonstration sites in Guangdong Province.

However, the marginal effects of each factor varied in different spatial contexts, showing that the influence of these factors changes according to regional differences and local conditions.

## Policy recommendations

Based on the analysis of the spatial accessibility of leisure agriculture demonstration sites in Guangdong Province, this study provides specific recommendations for improving the development of leisure agriculture, with differentiated strategies for **urban** and **rural** areas.

In **urban fringe areas**, where the population density is higher, infrastructure development should be supported through **Public-Private Partnerships (PPP)**. This model would allow for the efficient development of essential infrastructure, such as roads, parking lots, and visitor services, by leveraging both public funding and private sector expertise and investment. The PPP approach ensures that the financial burden on local governments is minimized, while encouraging private investments in infrastructure that will directly benefit the local economy.

In **rural areas**, the development of leisure agriculture sites can be supported through **collective economic models** or **government subsidies**. These models can facilitate community involvement in infrastructure development, ensuring that the local population benefits directly from tourism revenue. Government subsidies

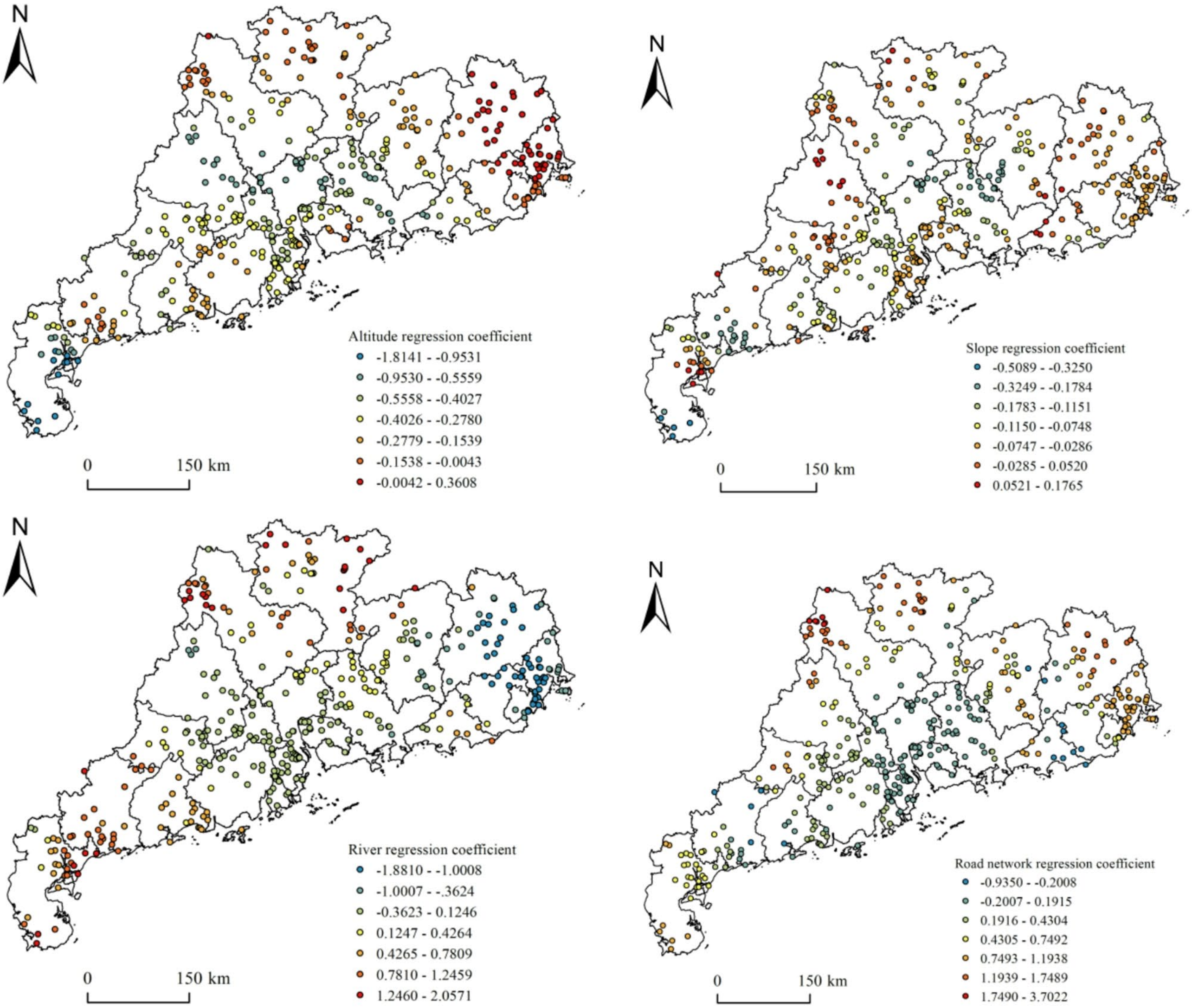


**Fig. 9**. Spatial distribution map of regression coefficient of altitude, slope, river density and road network density. ArcGIS 10.7 software (https://www.arcgis.com/).

can help reduce the initial capital costs, making rural development more financially feasible. These approaches will also promote local employment opportunities and improve the overall sustainability of leisure agriculture development.

Considering **financial feasibility**, the development of leisure agriculture requires access to various funding sources. We recommend the establishment of **tourism-specific funding programs** that can be used for infrastructure projects, environmental protection, and cultural integration. These funds could come from local governments, national programs, or even private investors who are interested in promoting rural tourism. It is crucial to ensure that these funding sources are well managed and directed toward projects that provide long-term benefits.

To ensure the successful implementation of these policies, we suggest **gradual improvements in accessibility** by prioritizing areas with the greatest potential for development. In addition, we recommend setting up **pilot projects** in specific regions to test the feasibility and effectiveness of the proposed infrastructure models and to gather data on the most efficient ways to integrate local resources, culture, and tourism activities. These pilot projects will provide valuable insights that can be used to refine policies and expand successful initiatives to other areas in Guangdong Province.

## Discussion

The spatial distribution of leisure agriculture demonstration sites in Guangdong Province reveals a dumbbell-shaped pattern. This distribution suggests a concentration of sites in both urbanized areas and peripheral regions, with fewer sites in intermediate areas. The development of leisure agriculture plays a key role in promoting the prosperity of rural industries. Industry serves as a driving force for agricultural and rural modernization, with industrial prosperity being a crucial economic support for rural revitalization. As a new field integrating agriculture and tourism, leisure agriculture accessibility research is vital for promoting local economies and rural revitalization.

This pattern can be attributed to several factors, including economic, policy, and historical influences. The concentration of leisure agriculture sites in urbanized areas can be explained by rapid urbanization and infrastructure development, which make these areas more accessible for tourists and investors. In contrast, peripheral areas, often rich in natural resources and scenic landscapes, have been prioritized for rural tourism development by the government, further encouraging the growth of leisure agriculture sites. Policies aimed at enhancing rural tourism and agricultural integration have fostered this spatial clustering. Additionally, the historical development of infrastructure, such as road networks and transportation links, has contributed to the concentration of sites in both the core urban areas and certain peripheral regions.

Further, the concept of spatial spillover effects plays a significant role in the observed patterns. Accessibility to leisure agriculture sites in one region can influence the development of neighboring regions, creating regional synergies. For instance, areas with high accessibility may draw visitors from surrounding regions, enhancing the economic vitality of these adjacent areas and contributing to a clustering effect of leisure agriculture sites. This interdependence between regions highlights the importance of considering boundary effects—such as proximity to administrative zones or transport networks—when designing policies for leisure agriculture development.

The findings also support the view that leisure agriculture should be developed in a way that balances environmental protection and cultural preservation. Strengthening infrastructure and service facilities, such as roads, parking lots, and charging stations, is crucial to meet the growing demand for self-driving tourism. However, green development principles should be prioritized, particularly around water systems and sources, to prevent environmental degradation. Integrating rural culture and agricultural brands will further enhance the attractiveness of leisure agriculture, promoting regional cultural heritage and increasing the competitiveness of agricultural products.

At present, the quantitative analysis of leisure agriculture is often limited to surface-level characteristics such as quantity and scale, with most research on its influencing factors being qualitative. This study, however, uses the GWR model and combines both qualitative and quantitative methods to explore the accessibility factors affecting leisure agriculture demonstration sites in Guangdong Province. Unlike previous studies that primarily focus on distribution characteristics, this study integrates both natural mechanisms and resource conditions to explore the formation mechanisms behind spatial patterns. It also considers the spatial spillover effects and accessibility of leisure agriculture sites, drawing new and differentiated conclusions. The innovation of this research lies in its comprehensive study of the spatial distribution and accessibility evolution of leisure agriculture sites in Guangdong, providing both theoretical and empirical extensions to previous work in this field. Future research should predict the development prospects and spatial distribution of leisure agriculture sites, taking into account the influence of out-of-province tourists and air traffic, and further investigate comprehensive accessibility methods.

## Data availability

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

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## Author contributions

Zhenjie Liao and Lijuan Zhang wrote the main manuscript text and Zhenjie Liao prepared Figs. 1, 2, 3, 4, 5, 6, 7, 8 and 9. All authors reviewed the manuscript.

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## Declarations

## Competing interests

The authors declare no competing interests.

## Additional information

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