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Spatial Patterns and Driving Factors of Low-Altitude Tourism Bases in China: Implications for Sustainable Regional Planning

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Abstract

The rapid development of the low-altitude economy is reshaping tourism activities, infrastructure provision, and landscape resource use, yet national-scale research on low-altitude tourism bases remains limited. Using data on 1247 bases in China, this study applies average nearest-neighbor analysis, kernel density estimation, and spatial inequality measures to characterize multi-scale patterns. The study further employs an optimal parameters-based geographical detector within a geographical nature framework to identify influencing factors and interactions. The results reveal significant clustering and regional inequality, with a pronounced east–west divide along the Heihe–Tengchong Line. A diamond-shaped core bounded by Beijing, Hangzhou, Chengdu, and Sanya, together with its 200 km buffer zone, contains 89.17% of all bases. Domestic tourism revenue, the number of low-altitude industry enterprises, general aviation airports, national tourist resorts, and domestic tourist arrivals constitute the leading factors, although the dominant factor combinations vary across base types. Factor interactions are dominated by two-factor and nonlinear enhancement. The three natures form a coupled pathway: first nature provides environmental suitability, second nature transforms resource potential into marketable tourism products, and third nature regulates implementation. General aviation infrastructure acts as an operational interface linking environmental conditions, tourism demand, industrial support, and policy arrangements. The findings provide a basis for differentiated regional zoning and type-specific facility planning, thereby informing the sustainable development of low-altitude tourism.

Keywords: low-altitude tourism bases; spatial distribution; territorial spatial planning; optimal parameters-based geographical detector; driving factors

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Academic Editor: Brian Deal

Received: 2 July 2026
Revised: 4 August 2026
Accepted: 14 August 2026
Published: 21 August 2026

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1. Introduction

The low-altitude economy is an emerging and integrated economic form driven by low-altitude flight activities and the coordinated development of related industries [1]. Advances in artificial intelligence, digital communications, unmanned aircraft systems, and electric vertical take-off and landing aircraft are transforming low-altitude airspace from a domain primarily serving conventional general aviation into a new economic space encompassing urban air mobility, drone logistics, aviation sports, aerial sightseeing, and low-altitude cultural tourism [2,3]. In parallel with the expansion of the low-altitude economy and the upgrading of tourism demand, low-altitude flight activities have become

increasingly integrated with tourism, giving rise to new products and experiences such as aerial tours, aviation sports, recreational flights, and aviation science education [4]. Unlike conventional tourism, which is largely organized around ground transportation networks and scenic-area nodes, low-altitude tourism extends tourism activities into a ground–air composite space. Paragliding, skydiving, helicopter sightseeing, hot-air ballooning, and fixed-wing flight experiences not only diversify tourism products but also reshape tourist mobility, landscape perception, and the spatial organization of destinations [5].

Low-altitude tourism bases are the principal spatial carriers of these activities and serve as important interfaces between the low-altitude economy and the tourism industry [6,7]. Different types of bases provide operational support for low-altitude transportation, aerial sightseeing, flight experiences, aviation sports, and science education. By introducing an aerial perspective and expanding the range of tourism activities, they can enhance destination attractiveness and stimulate linkages among aviation equipment manufacturing, operational services, tourism consumption, and local industries. However, their development and spatial location depend on the combined influence of natural conditions, tourism resources, market demand, aviation infrastructure, the low-altitude industrial base, and policy-institutional arrangements [8]. These conditions shape not only the feasibility and operational efficiency of individual bases but also the broader spatial development of low-altitude tourism [9]. Identifying the spatial patterns and driving factors of low-altitude tourism bases in China is therefore important for optimizing their regional layout, coordinating aviation infrastructure provision, fostering emerging tourism activities, and promoting the sustainable development of the low-altitude economy.

Existing research provides an important foundation for understanding the spatial development of low-altitude tourism. A substantial body of literature has examined the low-altitude economy, urban air mobility, and emerging aviation technologies, with particular attention to technological feasibility, market potential, public acceptance, business models, airspace governance, and safety regulation [10,11]. By framing low-altitude airspace as an emerging domain of transportation and economic activity, these studies have clarified the technological, industrial, and institutional conditions underpinning its development. However, they have largely approached low-altitude activities as technological, industrial, or governance issues, with limited consideration of the location, spatial organization, and regional embeddedness of the facilities that support their operation.

A related body of research examines the integration of aviation and tourism across three interconnected dimensions. In the domain of product and experience, research has been conducted on a range of topics including, but not limited to, aerial sightseeing, flight experiences, aviation sports, and innovation in tourism products [12–14]. At the resource and regional development dimension, research has examined resource suitability, industrial integration, and regional development [15–17], highlighting the coordination of tourism resources, aviation services, infrastructure, and related industries. At the governance dimension, scholars have focused on policy arrangements, institutional support, and operational safety [18–20]. Collectively, these studies indicate that low-altitude tourism is not merely an extension of conventional tourism products but an integrated activity system involving tourism experiences, resource utilization, industrial coordination, and institutional support. Nevertheless, most studies focus on individual products, specific destinations, or regional cases, leaving the national-scale spatial organization of low-altitude tourism bases unexplored.

Complementing these studies, tourism geography research has extensively investigated the spatial organization of tourism resources and facilities. Existing findings indicate that landscape resources, transport accessibility, market demand, regional economic development, and public service provision play important roles in shaping the locations of

tourist attractions, resorts, accommodation facilities, and destination networks [21,22]. GIS-based spatial analysis, kernel density estimation, spatial autocorrelation, and geographical detector models have therefore been widely used to identify spatial clustering, regional disparities, and the explanatory power of different locational factors [23]. This body of literature provides an important methodological and conceptual foundation for examining the spatial patterns of low-altitude tourism bases.

However, explanatory frameworks developed for conventional tourism facilities are not fully applicable to low-altitude tourism bases. Unlike traditional attractions or accommodation facilities, these bases simultaneously serve as tourism service nodes, aviation operation sites, and infrastructure-dependent activity spaces. Their spatial development is influenced not only by landscape attractiveness, tourism demand, and transport accessibility, but also by general aviation infrastructure, the low-altitude industrial base, flight safety requirements, airspace governance, and policy-institutional support. Accordingly, their spatial organization reflects the combined effects of resource endowments, market conditions, infrastructure provision, industrial capacity, and institutional arrangements.

Taken together, the existing literature reveals three interrelated research gaps. First, national-scale identification and spatial analysis of low-altitude tourism bases remain insufficient. Previous studies have largely focused on the macro-level development of the low-altitude economy, emerging aviation technologies, or specific tourism products, with limited attention to low-altitude tourism bases as geographically embedded spatial carriers. Second, tourism spatial research has yet to develop an integrated framework that links natural endowments and tourism markets with aviation infrastructure, low-altitude industrial capacity, and policy-institutional conditions. Third, existing studies have mainly examined the independent effects of individual factors, while the interaction effects through which multiple conditions jointly shape spatial patterns remain under-explored.

To address these gaps, an analytical framework is needed that integrates natural foundations, socioeconomic and infrastructural conditions, and the policy-institutional environment. The theory of geographical nature explains regional spatial patterns as the outcome of the combined effects of natural foundations, human activities, and institutional arrangements [24,25]. First nature, embodied in terrain, climate, landscape resources, and ecological conditions, provides the environmental basis and resource attractiveness for low-altitude tourism. Second nature, reflected in market demand, transport accessibility, general aviation infrastructure, and the low-altitude industrial base, shapes the conversion of natural resources into operational tourism products. Third nature captures the enabling and constraining roles of policy support, airspace governance, and safety regulation in project development and operation. These three natures are interdependent: natural resources provide potential attractions, markets and aviation infrastructure determine their development and operational capacity, and policy-institutional conditions regulate project access, resource use, and operational safety. Their combined effects and regionally differentiated configurations therefore shape the spatial clustering and regional disparities of low-altitude tourism bases.

Against this theoretical and empirical background, this study examines 1247 low-altitude tourism bases in China. Following the analytical logic of "spatial patterns–driving factors–factor interactions", it combines average nearest-neighbor analysis, kernel density estimation, the Gini coefficient, the Lorenz curve, and spatial agglomeration measurement to identify spatial clustering and regional disparities at the national, provincial, and municipal scales. An optimal-parameters geographical detector model is subsequently employed to assess the explanatory power of the selected factors and their interaction effects. Specifically, this study addresses the following research questions: (1) What spatial patterns and regional disparities characterize low-altitude tourism bases in China?

(2) Which factors explain their spatial differentiation? (3) How do these factors interact in shaping the observed spatial patterns?

This study makes three main contributions. First, it provides a systematic national-scale analysis of low-altitude tourism bases as emerging nodes that integrate tourism services and aviation operations, thereby extending tourism spatial research beyond conventional attractions and facilities. Second, it operationalizes the theory of geographical nature by incorporating natural endowments, socioeconomic conditions, aviation infrastructure, industrial capacity, and policy-institutional arrangements into a unified explanatory framework. This framework shows that the spatial organization of low-altitude tourism bases cannot be explained by tourism resources or market demand alone. Third, the study evaluates both the individual explanatory power and the interaction effects of the driving factors and translates the resulting spatial evidence into implications for differentiated regional planning, coordinated aviation infrastructure provision, and the sustainable development of low-altitude tourism.

2. Research Methods and Data Sources

This study examines 1247 low-altitude tourism bases in China. Following the analytical logic of "spatial patterns–driving factors–factor interactions", it develops a systematic research framework for spatial distribution analysis. First, average nearest-neighbor analysis is used to identify the spatial distribution structure of these bases. Kernel density estimation is then applied to reveal their spatial agglomeration characteristics. The Gini coefficient and Lorenz curve analysis are further used to quantitatively describe the balance and regional differences in their provincial distribution. Next, drawing on the theory of geographical nature, this study constructs an influencing-factor indicator system from three dimensions: the natural environment, socioeconomic conditions, and policy-institutional conditions. Finally, an optimal parameters-based geographical detector (OPGD) is used to analyze the single-factor explanatory power of each factor and to examine two-factor interaction and risk differences across different stratified intervals. In this way, the study systematically reveals the formation mechanisms underlying the spatial patterns of low-altitude tourism bases in China. The technical roadmap of this study is shown in Figure 1.

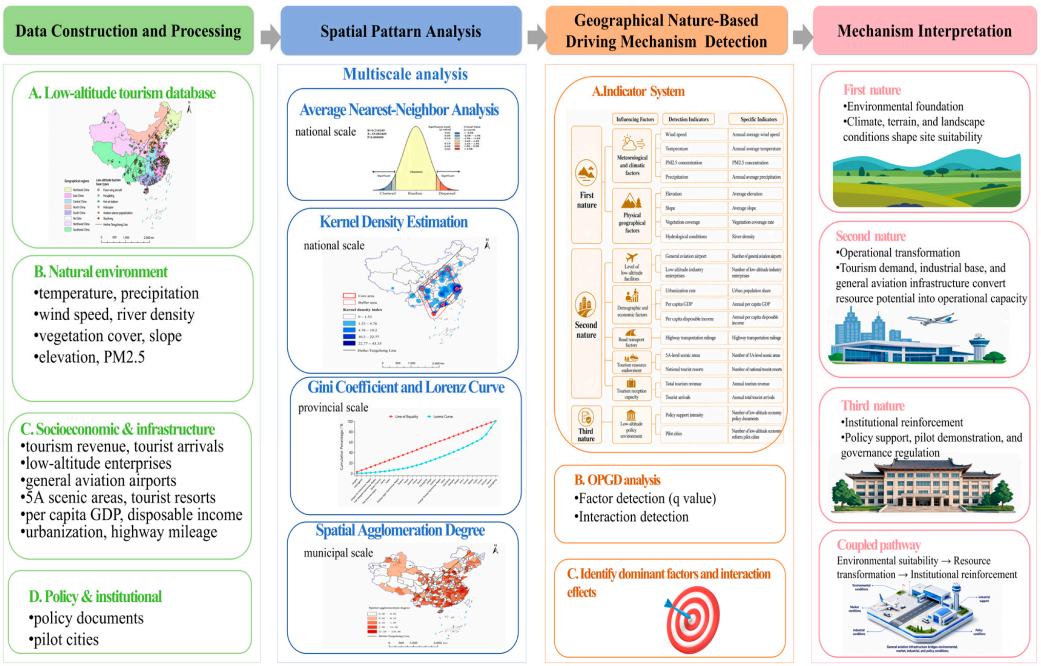


Figure 1. Technical Roadmap.

2.1. Research Methods

2.1.1. Average Nearest-Neighbor Analysis

Average Nearest-Neighbor (ANN) analysis measures the spatial proximity of point features by comparing the observed mean nearest-neighbor distance with the expected mean nearest-neighbor distance [26]. In this study, ANN analysis was used to determine the spatial distribution pattern of low-altitude tourism bases in China. The calculation formula is as follows:

$$\begin{aligned} R &= r_1/r_E \\ r_E &= 1/2\sqrt{n/A} \end{aligned} \quad (1)$$

where R denotes the nearest-neighbor index; r_1 and r_e represent the observed and expected mean nearest-neighbor distances, respectively; n is the number of low-altitude tourism bases; and A is the area of the study region. Mainland China excluding Hong Kong, Macao, and Taiwan was selected as the study area, with an area of 9,552,570 km^2. The index was calculated using the Average Nearest Neighbor tool in ArcGIS 10.8.1, and Z-score tests were applied to assess statistical significance. R < 1, R = 1, and R > 1 indicate clustered, random, and dispersed spatial patterns, respectively.

2.1.2. Kernel Density Estimation

Although average nearest-neighbor analysis can characterize the overall spatial structure of low-altitude tourism bases in China, it cannot reveal their specific spatial distribution patterns and local concentration characteristics. Therefore, kernel density estimation (KDE) was further employed to visualize the spatial density distribution and identify areas with high concentrations of low-altitude tourism bases. Kernel density estimation (KDE) is a non-parametric spatial analysis method that represents the density distribution of geographical features and identifies their spatial agglomeration characteristics. In this study, the Kernel Density tool in ArcGIS 10.8.1 was employed to examine the spatial density and clustering patterns of low-altitude tourism bases in China. The kernel density function is expressed as follows [27]:

$$\hat{f}(x) = \frac{1}{nh^d}\sum_{i=1}^{n} K\left[\frac{1}{h}(x - x_i)\right] \quad (2)$$

where $\hat{f}(x)$ denotes the estimated density at location x; $K\left[\frac{1}{h}(x - x_i)\right]$ represents the kernel function used in the kernel density estimation, with the quartic kernel function adopted by ArcGIS; x_i denotes the coordinates of sample point i (i = 1, 2, . . ., n); $(x - x_i)$ represents the distance between the estimated location x and sample point i; n is the number of sample points; h is the bandwidth or search radius; and d is the spatial dimension, with d = 2 in this study. The bandwidth was not manually specified but automatically determined by ArcGIS 10.8.1 using a spatial variant of Silverman's rule of thumb, resulting in a bandwidth of approximately 195 km.

2.1.3. Gini Coefficient and Lorenz Curve

The Gini coefficient and Lorenz curve were used to measure the degree of inequality in the provincial distribution of low-altitude tourism bases. The Gini coefficient provides a quantitative assessment of spatial imbalance, with values ranging from 0 to 1. A higher value indicates a more unequal distribution among regions, whereas a lower value represents a more balanced distribution. The Lorenz curve further illustrates the cumulative

distribution of low-altitude tourism bases across provincial administrative units. The formula for calculating the Gini coefficient is as follows [28]:

$$Gini = 1 - \frac{1}{n}(2\sum_{i=1}^{n-1} W_i + 1)C = 1 - Gini \quad (3)$$

where Gini denotes the Gini coefficient, W_i represents the proportion of low-altitude tourism bases in province i relative to the national total; n is the number of provincial-level administrative units included in the analysis; and C represents the cumulative proportion of low-altitude tourism bases. In this study, 31 provincial-level administrative units in mainland China (excluding Hong Kong, Macao, and Taiwan) were included. A larger Gini coefficient indicates stronger provincial inequality in the distribution of low-altitude tourism bases rather than local spatial clustering. Specifically, a higher value indicates that a greater proportion of bases are concentrated in a smaller number of provinces, whereas a lower value suggests a more balanced provincial distribution.

2.1.4. Spatial Agglomeration Degree

To characterize the relative concentration of low-altitude tourism bases at the municipal scale, this study adopted a spatial agglomeration degree indicator based on the resource agglomeration degree approach [29]. This indicator accounts for differences in administrative area size among cities and measures the relative concentration of low-altitude tourism bases compared with the national average. The formula is as follows:

$$D_i = \frac{A_i/S_i}{A_j/S_j} \quad (4)$$

where D_i denotes the spatial agglomeration degree of low-altitude tourism bases in city i. A_i and A_j represent the number of low-altitude tourism bases in city i and in China, respectively. S_i and S_j represent the administrative area of city i and mainland China, respectively. A value of ($D_i > 1$) indicates that the density of low-altitude tourism bases in city (i) is higher than the national average, suggesting a relatively strong agglomeration level, whereas ($D_i < 1$) indicates a lower-than-average concentration.

2.1.5. Optimal Parameters-Based Geographical Detector

The optimal parameters-based geographical detector (OPGD) extends the traditional geographical detector model by incorporating parameter optimization to reduce uncertainty associated with manually specified discretization schemes [30]. By automatically selecting the optimal combination of discretization methods and parameter settings, OPGD improves the robustness of factor detection and interaction analysis. In this study, OPGD was employed to quantify the explanatory power of potential driving factors and their interaction effects on the spatial differentiation of low-altitude tourism bases. The q-statistic is calculated as follows:

$$q = 1 - \sum_{h=1}^{L} N_h \sigma_h^2 / N\sigma^2 \quad (5)$$

where q denotes the detection value of the driving factor; N is the total number of spatial units; and L represents the number of strata generated after the discretization of explanatory factor X. N_h is the number of spatial units in stratum h. σ^2 is the variance of Y across all spatial units, and σ_h^2 is the variance of Y within stratum h. The q-value ranges from 0 to 1, with higher values indicating greater explanatory power. All OPGD analyses, including the risk-detector plots, were conducted in R version 4.5.3 using the GD package version 10.9.

2.2. Data Sources

As official data on low-altitude tourism bases is not available, this study has constructed a basic information database of low-altitude tourism bases. Due to the unavailability of data, Hong Kong, Macao, and Taiwan were excluded from the analysis, which consequently encompasses 31 provincial-level administrative regions in mainland China. A review of the relevant literature indicates that low-altitude tourism bases include several types, such as skydiving bases, paragliding bases, helicopter bases, hot-air balloon bases, fixed-wing aircraft bases, and the Aviation Science and Education Experience Center. This article utilizes the Amap Open Platform to identify low-altitude tourism bases using keywords such as "low-altitude tourism", "paragliding", "skydiving", "fixed-wing aircraft", "helicopter", "aviation science centers", and "hot-air balloon". Based on the collected data, each base was contacted by phone to verify whether it offers low-altitude tourism services and is currently in operation. In addition, a supplementary telephone-checking procedure was implemented for records with incomplete information, ambiguous business scope, duplicate names, or inconsistent location descriptions. During this process, the research team verified the operational status, main activity type, service content, and location information of each uncertain record. Records that could not be confirmed as low-altitude tourism bases were excluded from the final database. As of March 2026, after screening and organizing the data, the following figures were obtained: 195 fixed-wing bases, 79 aviation science education bases, 599 paragliding bases, 32 hot-air balloon bases, 209 skydiving bases, and 133 helicopter bases, for a total of 1247 low-altitude tourism bases (Table 1).

Table 1. Types and Number of Low-Altitude Tourism Bases in China.

Low-Altitude Tourism Base Type	Number
Paragliding base	599
Skydiving base	209
Fixed-wing aircraft base	195
Helicopter base	133
Aviation science education base	79
Hot-air balloon base	32
Total	1247

Influencing Factor Data

The specific sources and methods for obtaining each type of influencing factor data are as follows: Spatial vector data were obtained from the map database of the National Geomatics Center of China. Elevation, temperature, wind speed, and precipitation data were obtained from the Resource and Environmental Science Data Center of the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (https://www.resdc.cn (accessed on 23 April 2026)). Per capita GDP and per capita disposable income were compiled from the Statistical Communiqués on National Economic and Social Development released by each province. Data on 5A-level scenic areas and national tourist resorts were obtained from the official website of the Ministry of Culture and Tourism. Data on general aviation airports were obtained from the official website of the Civil Aviation Administration of China (http://www.caac.gov.cn/index.html (accessed on 30 April 2026)). Data on low-altitude industry enterprises was obtained from Qichacha (https://www.qcc.com/). Policy documents and the number of pilot cities were compiled from information published on the official websites of local governments.

3. Distribution Characteristics of Low-Altitude Tourism Bases in China

3.1. Significant Spatial Differences and an Overall East-High–West-Low Pattern

At the national scale, low-altitude tourism bases in China show a clear east-high–west-low spatial distribution pattern (Figure 2). Approximately 90% of these bases are located

east of the Heihe–Tengchong Line, whereas only 122 bases are located west of the line. This pattern broadly corresponds to China's east–west differences in population, economic activity, infrastructure, and environmental conditions, which are examined further in the factor-detection analysis. At the geographical regional scale, East China has the largest number of low-altitude tourism bases, with 393 bases, accounting for 31.52% of the national total. Northeast China has the fewest bases, with only 36, accounting for 2.89% of the total. South China has 297 bases, while Southwest China, North China, and Central China have 187, 142, and 133 bases, respectively. Northwest China has only 59 bases. Overall, 70.33% of low-altitude tourism bases in China are located in East China, South China, and Southwest China, indicating that natural, social, and economic conditions significantly influence their spatial distribution. At the provincial scale, Zhejiang, Guangdong, and Hainan have relatively large numbers of low-altitude tourism bases, and these bases are also more concentrated in these provinces. By contrast, Gansu, Ningxia, Qinghai, Inner Mongolia, Heilongjiang, and Jilin have fewer bases and a more scattered distribution. Overall, the spatial distribution of low-altitude tourism bases in China is uneven, presenting an east-high, west-low pattern divided by the Heihe–Tengchong Line.

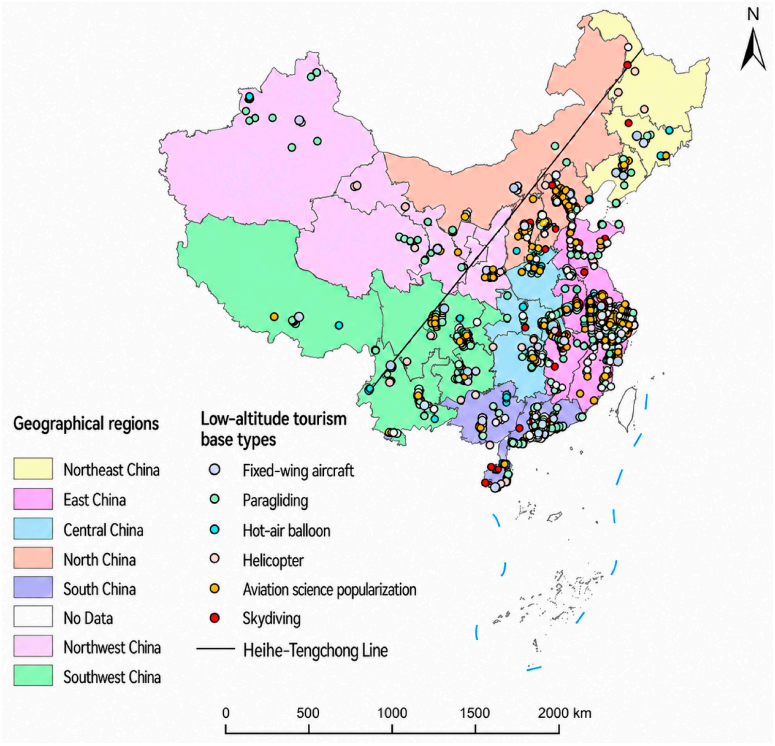


Figure 2. Spatial distribution of low-altitude tourism bases in China.

The average nearest-neighbor analysis indicates that low-altitude tourism bases in China exhibit a significant clustered spatial pattern. The observed mean nearest-neighbor distance (r_1) was 11.78 km, which was substantially lower than the expected mean nearest-neighbor distance (r_e) of 54.97 km under a random spatial distribution. The nearest-neighbor index (R) was 0.214, with a Z-score of −53.08 and a *p*-value below 0.001, indicating that the observed clustering pattern is statistically significant. These results suggest that low-altitude tourism bases are not randomly distributed across China but tend to concentrate in specific regions.

3.2. Pronounced Core-Area Agglomeration and an Outward-Declining Diamond-Shaped Distribution Pattern

While ANN analysis confirms the overall clustered distribution of low-altitude tourism bases, it does not reveal the location and intensity of local concentrations. Therefore, kernel

density estimation was further applied to identify spatial hotspots and characterize the detailed distribution pattern. The spatial distribution of low-altitude tourism bases in China is markedly uneven, characterized by dense concentrations in the east and sparse distribution in the west. Coastal areas and central and eastern China show relatively high levels of agglomeration, whereas western China exhibits a comparatively sparse distribution. Multiple high-density cores have emerged (Figure 3). According to the kernel density analysis, the Yangtze River Delta shows the most prominent agglomeration. Distinct high-value areas have also formed in the Pearl River Delta, coastal Hainan, the Beijing–Tianjin–Hebei region, and the Chengdu–Chongqing region. Based on the locations of these high-density cores, Beijing, Hangzhou, Chengdu, and Sanya were selected as four peripheral core cities and the vertices of a diamond-shaped structure. Guangzhou lies within this diamond-shaped area, and together these cities form an interconnected five-node core region. Red circles identify the four peripheral core cities; the red polygon outlines the diamond-shaped core area, and the outer red boundary denotes the 200 km buffer zone.Beijing is a significant political, economic, and integrated transportation hub within China. Hangzhou is located within the confines of the Yangtze River Delta urban agglomeration, a region characterised by the relative dynamism of its tourism economy and low-altitude industry. Chengdu is a significant central city in the southwestern region of China. Sanya is distinguished by its unique coastal tourism resources, while Guangzhou occupies a pivotal role as a major gateway city and a pivotal transportation nexus within South China.

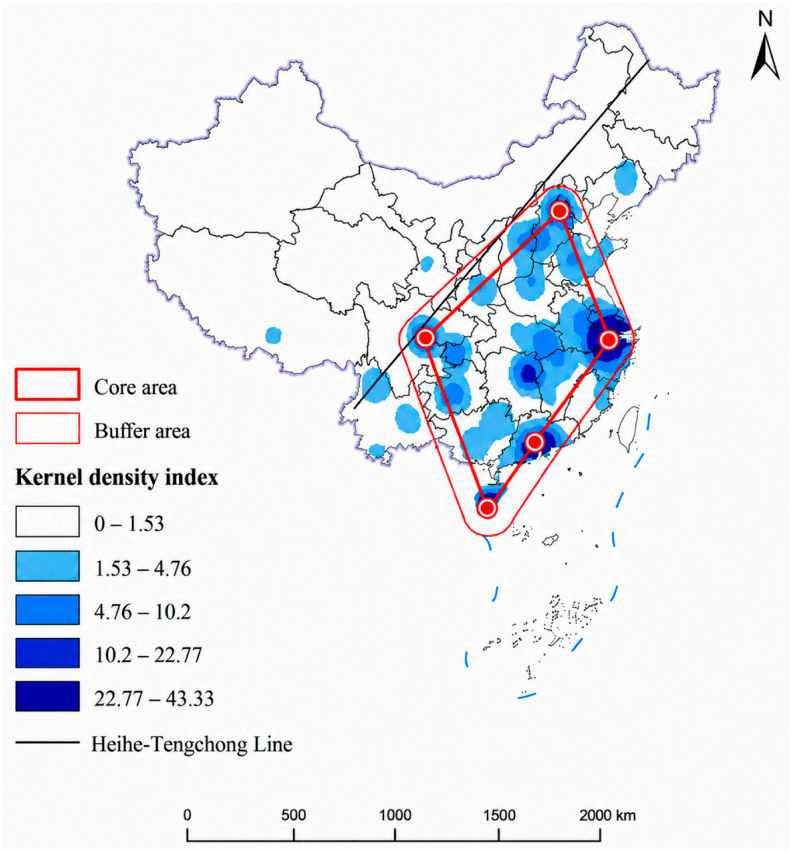


Figure 3. Kernel density distribution of low-altitude tourism bases in China.

The diamond-shaped boundary formed by linking Beijing, Hangzhou, Chengdu, and Sanya was defined as the core area. Low-altitude tourism bases were then spatially screened based on their geographical coordinates. The core area contains 614 low-altitude tourism bases, accounting for 49.24% of the national total. Following related studies [31], a 200 km

buffer zone was constructed around the core area. The core area and buffer zone together contain 1112 low-altitude tourism bases, accounting for 89.17% of the national total. Only 135 bases, or 10.83%, are located outside the buffer zone, where their spatial distribution is relatively dispersed. These findings indicate that low-altitude tourism bases in China have formed a spatial agglomeration pattern primarily supported by urban agglomerations in central, eastern, and southern China, with agglomeration intensity gradually declining from the core area toward the periphery.

3.3. Marked Interprovincial Differences and Highly Uneven Provincial Distribution

As shown by the Lorenz curve (Figure 4), the interprovincial distribution of low-altitude tourism bases in China is clearly imbalanced. The curve lies below the line of perfect equality and displays a pronounced curvature, indicating that these bases are unevenly distributed across provinces and provincial inequality/interprovincial concentration. Specifically, provinces with fewer bases show a slow cumulative increase. The lower-ranked half of provinces accounts for only about one-quarter of the national total, suggesting that the development of low-altitude tourism bases remains relatively underdeveloped in Qinghai, Heilongjiang, Ningxia, Inner Mongolia, Tibet, and Gansu. As the cumulative ranking shifts toward provinces with a greater number of bases, the slope of the Lorenz curve gradually increases, and the cumulative share rises rapidly in provinces such as Guangdong, Henan, Sichuan, Hunan, and Hubei. This pattern indicates that low-altitude tourism bases are clearly concentrated in a small number of advantaged provinces. According to Equation (3), the Gini coefficient is 0.40, indicating that the interprovincial distribution of low-altitude tourism bases in China has reached a relatively pronounced level of differentiation. Overall, the distribution shows an uneven pattern in which most provinces account for a relatively small share, whereas a few provinces account for a substantially larger share. This suggests that the spatial layout of low-altitude tourism bases is shaped by multiple factors, including resource endowments, market demand, transport location, the tourism industrial foundation, and development conditions of the low-altitude economy. Consequently, interregional development disparities persist.

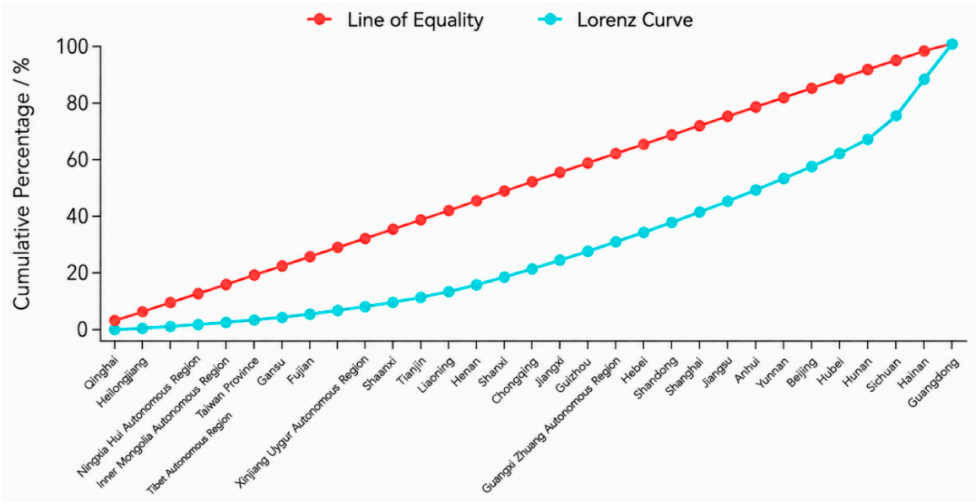


Figure 4. Lorenz curve of the provincial distribution of low-altitude tourism bases in China.

3.4. Clear Differentiation in Municipal Agglomeration Levels, with High-Value Cities Concentrated Along the Southeastern Coast and in Core Urban Agglomerations

The spatial agglomeration degree indicator was used to further characterize the municipal-scale agglomeration pattern of low-altitude tourism bases in China (Figure 5). Overall, agglomeration levels show clear differentiation, characterized by a spatial structure

in which low-value cities dominate, high-value cities are limited in number, and medium- to high-value cities are locally clustered.

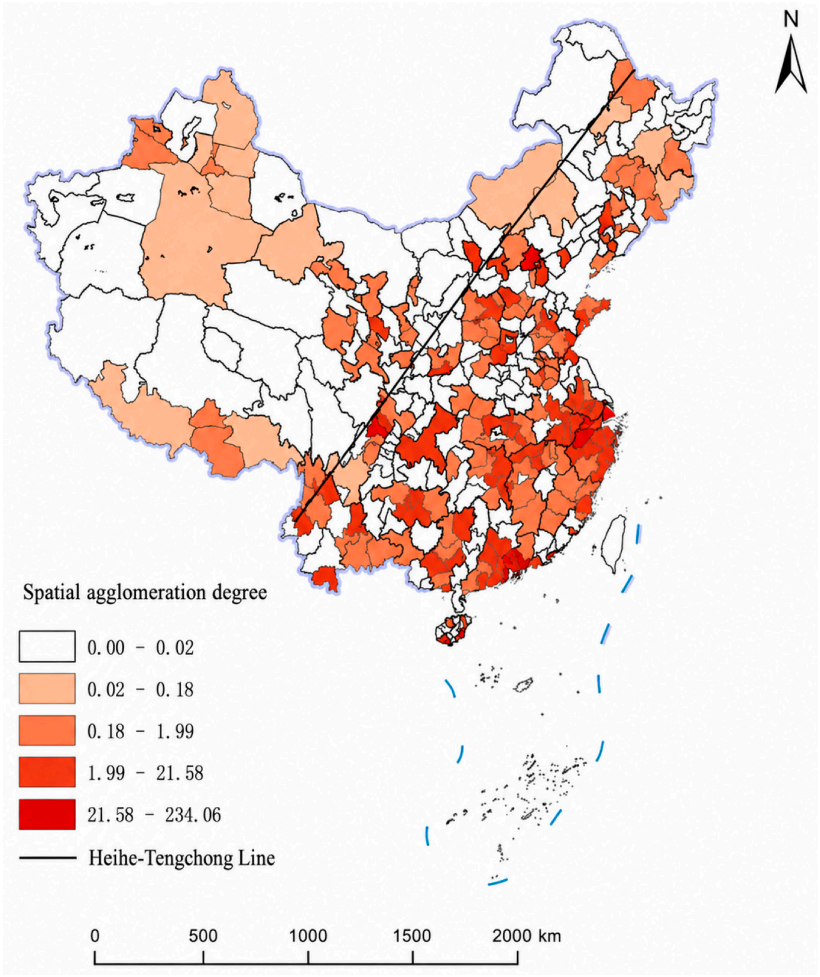


Figure 5. Spatial agglomeration pattern of low-altitude tourism bases in China.

In terms of the number of cities at each level, 180 cities have a spatial agglomeration degree of zero, accounting for 48.00% of all cities. This finding suggests that a significant number of cities have yet to establish effective agglomerations of low-altitude tourism bases. These cities are mainly distributed contiguously across Northwest China, Southwest China, and areas west of the Heihe–Tengchong Line, exhibiting a pronounced contiguous low-value pattern. The number of cities at the relatively low, medium, and relatively high agglomeration levels is 13, 89, and 77, respectively, corresponding to 3.47%, 23.73%, and 20.53% of all cities. Only 16 cities reach the highest agglomeration level, accounting for 4.27% of the total. This small number indicates that the spatial layout of low-altitude tourism bases in China remains highly uneven and that substantial room remains for improving the overall level of agglomeration.

In terms of spatial distribution, cities at the relatively high level and above are mainly located east of the Heihe–Tengchong Line, especially in the southeastern coastal region and major urban agglomerations. The Pearl River Delta, the Yangtze River Delta, and coastal Hainan form prominent high-value agglomeration areas, showing clear coastal orientation and strong reliance on urban agglomerations. At the same time, inland and northern core cities, such as Chengdu and Beijing, also show strong agglomeration advantages. This indicates that regions with a stronger economic foundation, active tourism consumption markets, favorable transport locations, and stronger comprehensive service capacity are more likely to support the large-scale development of low-altitude tourism bases.

Specifically, Sanya has the largest number of low-altitude tourism bases, with 58 bases. Its spatial agglomeration degree reaches 234.055, ranking first in China and making it the most prominent city for low-altitude tourism base agglomeration nationwide. Zhuhai, Lingshui Li Autonomous County, Shenzhen, Wanning, and Huzhou also have relatively high spatial agglomeration degrees, with values of 102.091, 99.212, 82.829, 61.403, and 56.643, respectively. In addition, Shanghai, Zhongshan, Dongguan, Chengdu, Zhoushan, Beijing, Hangzhou, Qionghai, Huizhou, and Guangzhou are also classified within the highest agglomeration level. This indicates that high-value agglomeration of low-altitude tourism bases depends not only on coastal tourism resources but also on urban economic development, tourism market size, and regional transportation networks.

Overall, the spatial agglomeration pattern of low-altitude tourism bases in China shows clear eastern advantages, coastal concentration, and urban-agglomeration orientation. The southeastern coastal region, core tourism cities, and major urban agglomerations have become key spatial carriers for high-value agglomeration of low-altitude tourism bases. By contrast, areas west of the Heihe–Tengchong Line and some inland regions are still dominated by low-value or zero agglomeration. In the future, considerable room remains for optimization in low-altitude tourism resource development, infrastructure improvement, and regional spatial coordination.

4. Influencing Mechanisms of the Spatial Distribution of Low-Altitude Tourism Bases in China

4.1. Construction of the Indicator System

Geographical nature refers to the relatively stable and immobile internal attributes of a region. It reflects the basic conditions and evolutionary logic underlying regional spatial differences [22]. In the 1990s, Krugman introduced the distinction between first nature and second nature to explain regional resource agglomeration and spatial structural evolution, arguing that regional development is fundamentally shaped by natural environmental endowments. Meteorological and climatic conditions, together with the physical geographical foundation, constitute the inherent constraints and underlying foundation for regional development. These conditions are defined as first nature. Specific indicators include wind speed, temperature, visibility, precipitation, elevation, slope, vegetation coverage, and hydrological conditions, all of which affect the suitability of regional resource development and the regional spatial carrying capacity. The complete indicator system is presented in Table 2.

With the advancement of industrialization, urbanization, and marketization, human activities have played an increasingly important role in shaping regional spatial patterns. Socioeconomic factors have therefore become major driving forces, including infrastructure construction, industrial development level, demographic and economic conditions, transport connections, tourism resource endowments, and tourism reception capacity. Together, these factors constitute second nature. Second nature highlights the influence of the overall regional development foundation and market support capacity on spatial agglomeration [31].

Under contemporary economic conditions, institutional supply and policy innovation have become important drivers of regional development. These factors form third nature, represented by the innovation environment and institutional conditions. Third nature includes policy support intensity, reform pilot programs, and institutional innovation capacity. It affects the spatial layout and evolution of low-altitude tourism bases by optimizing the development environment, strengthening resource allocation, and improving regional competitiveness.

Table 2. Indicator System and Description of Influencing Factors for the Distribution of Low-Altitude Tourism Bases in China.

Dimension	Influencing Factors	Detection Indicators	Code	Specific Indicators
First nature	Meteorological and climatic factors	Wind speed	X1	Annual average wind speed
		Temperature	X2	Annual average temperature
		Visibility	X3	PM2.5 concentration
		Precipitation	X4	Annual average precipitation
	Physical geographical factors	Elevation	X5	Average elevation
		Slope	X6	Average slope
		Vegetation coverage	X7	Vegetation coverage rate
		Hydrological conditions	X8	River density
Second nature	Level of low-altitude facilities	General aviation airport	X9	Number of general aviation airports
		Low-altitude industry enterprises	X10	Number of low-altitude industry enterprises
	Demographic and economic factors	Urbanization rate	X11	Urban population share
		Per capita GDP	X12	Annual per capita GDP
		Per capita disposable income	X13	Annual per capita disposable income
	Road transport factors	Highway transportation mileage	X14	Highway transportation mileage
	Tourism resource endowment	5A-level scenic areas	X15	Number of 5A-level scenic areas
		National tourist resorts	X16	Number of national tourist resorts
	Tourism reception capacity	Total tourism revenue	X17	Annual tourism revenue
		Tourist arrivals	X18	Annual total tourist arrivals
Third Nature	Low-altitude policy environment	Policy support intensity	X19	Number of low-altitude economy policy documents
		Pilot cities	X20	Number of low-altitude economy reform pilot cities

The spatial distribution of low-altitude tourism bases in China results from the combined effects of the three types of geographical nature. First nature affects the landscape quality, site selection, and environmental carrying capacity of bases through natural resource endowments [32]. Second nature influences their layout through socioeconomic conditions, including low-altitude facilities, demographic and economic conditions, road transport, tourism resource endowments, and tourism reception capacity. Third nature facilitates development through the policy environment and institutional innovation.

Accordingly, this study adopts the following indicator system. First nature includes wind speed, temperature, visibility, precipitation, elevation, slope, vegetation coverage rate, and hydrological conditions [33]. Second nature includes general aviation airports, low-altitude industry enterprises, urbanization rate, per capita GDP, per capita disposable income, highway mileage, 5A-level scenic areas, national tourist resorts, total tourism revenue, and tourist arrivals [1,34–38]. Third nature includes policy support intensity and the number of pilot cities. The number of low-altitude tourism bases is used as the dependent variable, and the geographical detector (Geodetector) model is applied to conduct single-factor detection and interaction detection analyses. On this basis, an analytical framework is developed to examine the mechanisms influencing spatial distribution.

4.2. Single-Factor Detection

To identify the differentiated effects of the three natures on the spatial differentiation of various types of low-altitude tourism bases, factor detection was conducted using the number of fixed-wing aircraft, aviation science education, paragliding, hot-air balloon, skydiving, and helicopter bases as dependent variables (Table 3). Overall, second nature

exhibited the most stable and extensive explanatory power, whereas the effects of the first and third natures varied substantially across base types.

Table 3. Detection Results of Influencing Factors for the Distribution of Low-Altitude Tourism Bases in China.

Dimension	Influencing Factors	Specific Indicators	q-Value						
			Overall	Fixed-Wing Aircraft Bases	Aviation Science Bases	Para-Gliding Bases	Hot-Air Balloon Bases	Sky-Diving Bases	Heli-Copter Bases
First nature	Meteorological & climatic factors	X1	0.0923	0.0852	0.0265	0.0352	0.0431	0.0964	0.1491
		X2	0.1716	0.0536	0.0631	0.0981	0.0425	0.3163	0.4755
		X3	0.0480	0.0391	0.0762	0.0255	0.0790	0.0390	0.0613
		X4	0.0628	0.0328	0.0441	0.0839	0.0383	0.0502	0.0798
	Physical geographical factors	X5	0.0325	0.0202	0.0519	0.0313	0.0659	0.0313	0.0517
		X6	0.0466	0.0563	0.0453	0.0404	0.0375	0.0556	0.0881
		X7	0.0749	0.0893	0.1140	0.0658	0.0376	0.0633	0.0444
		X8	0.1549	0.0878	0.1140	0.1223	0.0125	0.1108	0.0784
Second nature	Level of low-altitude facilities	X9	0.3405	0.2221	0.1602	0.2405	0.0533	0.2482	0.1710
		X10	0.3464	0.2631	0.3982	0.2792	0.0180	0.2387	0.1148
	Demographic & economic factors	X11	0.2223	0.1444	0.2494	0.1527	0.0413	0.1260	0.0568
		X12	0.1722	0.1454	0.1573	0.1205	0.0173	0.1088	0.1488
		X13	0.2106	0.2413	0.1519	0.1972	0.0209	0.0930	0.2885
	Road Transport factors	X14	0.1046	0.0278	0.1766	0.1356	0.0232	0.1237	0.0130
	Tourism resource endowment	X15	0.2023	0.1205	0.2207	0.1661	0.0303	0.1517	0.1494
		X16	0.3065	0.0706	0.1358	0.2435	0.1216	0.1880	0.1587
	Tourism reception capacity	X17	0.3862	0.2854	0.4790	0.3891	0.1481	0.2241	0.2864
		X18	0.3018	0.3103	0.4150	0.1326	0.0820	0.1560	0.1351
Third nature	Low-altitude policy environment	X19	0.2227	0.0826	0.1705	0.2324	0.1512	0.1575	0.2026
		X20	0.1924	0.0008	0.1530	0.2737	0.0018	0.1884	0.0349

4.2.1. Effects of First Nature

First nature had the most pronounced effects on helicopter and skydiving bases, with q-values of 0.1285 and 0.0954, respectively. Temperature was the most important natural factor for both base types, with q-values reaching 0.4755 and 0.3163, respectively. These results indicate their strong dependence on suitable flight periods, operational stability, and favorable climatic conditions. Paragliding bases were primarily influenced by river density, temperature, precipitation, and vegetation conditions. River density had the greatest explanatory power (q = 0.1223), highlighting the importance of ecological landscapes and environments suitable for outdoor activities. By contrast, first nature played mainly a foundational or supplementary role in the development of fixed-wing aircraft and aviation science education bases. Its independent explanatory power for hot-air balloon bases was also relatively weak. Overall, the effects of natural conditions on each base type depend on the technical requirements of the flight activity and its landscape-based experiential attributes.

4.2.2. Effects of Second Nature

Second nature constituted the principal driving force behind the development of all six types of bases, although the dominant factors differed among them. Aviation science education bases showed the strongest dependence on the tourism market and urban service capacity. The q-values of total domestic tourism revenue, the total number of domestic tourists, and the number of low-altitude industry enterprises were 0.4790, 0.4150, and 0.3982, respectively. Fixed-wing aircraft bases exhibited a distinct "market–industry–infrastructure" driving pattern. The total number of domestic tourists, tourism revenue, the number of low-altitude industry enterprises, and the number of general aviation airports all demonstrated strong explanatory power. Paragliding bases primarily depend on tourism revenue, low-altitude industry enterprises, national tourist resorts, and

general aviation airports. This finding suggests that paragliding has gradually evolved from a single outdoor sport into a compound tourism product embedded within mature destinations and aviation service systems.

Skydiving bases showed the strongest dependence on general aviation airports and low-altitude industry enterprises, reflecting their substantial requirements for specialized infrastructure and technical support. Helicopter bases were primarily influenced by per capita disposable income and tourism revenue, demonstrating a pronounced orientation toward the high-end market. Second nature had relatively weak explanatory power for hot-air balloon bases, whose spatial layout depended more heavily on specific tourism scenarios.

Therefore, fixed-wing aircraft and skydiving bases can be classified as infrastructure- and industry-dependent. Aviation science education bases are driven by the tourism market and urban service capacity. Paragliding bases develop through the combined support of destinations, markets, and aviation services, whereas helicopter bases exhibit a distinct orientation toward high-income consumers.

4.2.3. Effects of Third Nature

The effects of third nature also varied across base types. Paragliding bases were the most strongly influenced by policy and institutional conditions. The q-values of the number of policy documents and pilot cities were 0.2324 and 0.2737, respectively. These findings indicate that local pilot programs and policies promoting cultural tourism integration and outdoor sports can substantially facilitate project implementation. The policy environment also had strong explanatory power for skydiving and aviation science education bases. It can promote their agglomeration through infrastructure construction, the introduction of operating entities, and the expansion of demonstration projects. For hot-air balloon bases, the number of policy documents was the single factor with the greatest explanatory power ($q = 0.1512$). This result suggests that local festivals, demonstration activities, and policy-led organization may be important conditions for their formation. Helicopter bases depended primarily on targeted policy support rather than the general designation of a city as a pilot city. Policy factors for fixed-wing aircraft bases did not pass the significance test. This finding indicates that policy cannot substitute for airports, market demand, or an established industrial foundation. Instead, it can promote development only when these essential conditions are already in place.

4.3. Interaction Detection

The effects of factor interactions on the spatial differentiation of low-altitude tourism bases demonstrate greater complexity and stronger coupling in comparison to single-factor effects (see Table 4). It is evident that the overall interactions are predominantly characterised by two-factor enhancement and nonlinear enhancement. This observation signifies that the effects of various influencing factors do not merely additively accumulate. Instead, they generate higher-level comprehensive explanatory power through interaction (Figure 6). The interaction-type matrix further demonstrates that enhancement relationships predominate (Figure 7), indicating that the spatial configuration of low-altitude tourism bases is influenced by robust multi-factor synergistic driving forces.

In terms of specific factor interactions, several natural-environment variables, including precipitation, PM2.5 concentration, slope, and elevation, did not pass the significance test in single-factor detection. The single-factor explanatory power of vegetation coverage rate was also relatively weak. However, their explanatory power increased markedly after interaction with key variables, especially general aviation airports and low-altitude industry enterprises. These interactions mainly appeared as two-factor enhancement or nonlinear enhancement. This suggests that natural-environment factors are not irrelevant

to the layout of low-altitude tourism bases; rather, their effects often need to be activated through infrastructure, industrial support, or market conditions.

Among these interactions, the interaction between vegetation coverage rate and general aviation airports was the strongest, with a q-value of 0.5680. The interaction q-values of PM2.5 concentration × general aviation airports, slope × general aviation airports, and precipitation × low-altitude industry enterprises were 0.5333, 0.5097, and 0.4824, respectively. These values were all much higher than the single-factor explanatory power of the corresponding variables, reflecting clear conditional dependence and nonlinear amplification effects in the spatial differentiation of low-altitude tourism bases.

Among all variables, general aviation airports showed the strongest interaction effects. Their average interaction q-value reached 0.4678, and their maximum interaction q-value was 0.5680. This indicates that general aviation airports are a pivotal factor affecting the spatial differentiation of low-altitude tourism bases. They exhibited strong interactions with several types of variables, including ecological landscapes, tourism resources, climatic conditions, market size, policy support, and industrial foundation. This reflects the core supporting function of aviation infrastructure in resource transformation, market connection, and industrial carrying capacity.

Table 4. Interaction of influencing factors of spatial distribution of low-altitude tourism bases in China.

Type	C	A + B	Criterion	Interaction Type
Fixed-wing aircraft bases	X8 ∩ X17 = 0.5131	X8 (0.0878) + X17 (0.2854)	C > A + B	Nonlinear enhancement
	X9 ∩ X18 = 0.5563	X9 (0.2221) + X18 (0.3103)	C > A + B	Nonlinear enhancement
	X11 ∩ X18 = 0.5515	X11 (0.1444) + X18 (0.3103)	C > A + B	Nonlinear enhancement
	X12 ∩ X18 = 0.5402	X12 (0.1454) + X18 (0.3103)	C > A + B	Nonlinear enhancement
	X18 ∩ X20 = 0.5311	X18 (0.3103) + X20 (0.0008)	C > A + B	Nonlinear enhancement
Aviation science education bases	X3 ∩ X18 = 0.6120	X3 (0.0762) + X18 (0.4150)	C > A + B	Nonlinear enhancement
	X15 ∩ X17 = 0.6114	X15 (0.2207) + X17 (0.4790)	max (A, B) < C ≤ A + B	Two-factor enhancement
Paragliding bases	X6 ∩ X9 = 0.5497	X6 (0.0404) + X9 (0.2405)	C > A + B	Nonlinear enhancement
	X9 ∩ X13 = 0.5285	X9 (0.2405) + X13 (0.1972)	C > A + B	Nonlinear enhancement
	X17 ∩ X20 = 0.5414	X17 (0.3891) + X20 (0.2737)	max (A, B) < C ≤ A + B	Two-factor enhancement
Hot-air balloon bases	X6 ∩ X18 = 0.4977	X6 (0.0375) + X18 (0.0820)	C > A + B	Nonlinear enhancement
Skydiving bases	X2 ∩ X9 = 0.4990	X2 (0.3163) + X9 (0.2482)	max (A, B) < C ≤ A + B	Two-factor enhancement
Helicopter bases	X2 ∩ X17 = 0.5690	X2 (0.4755) + X17 (0.2864)	max (A, B) < C ≤ A + B	Two-factor enhancement

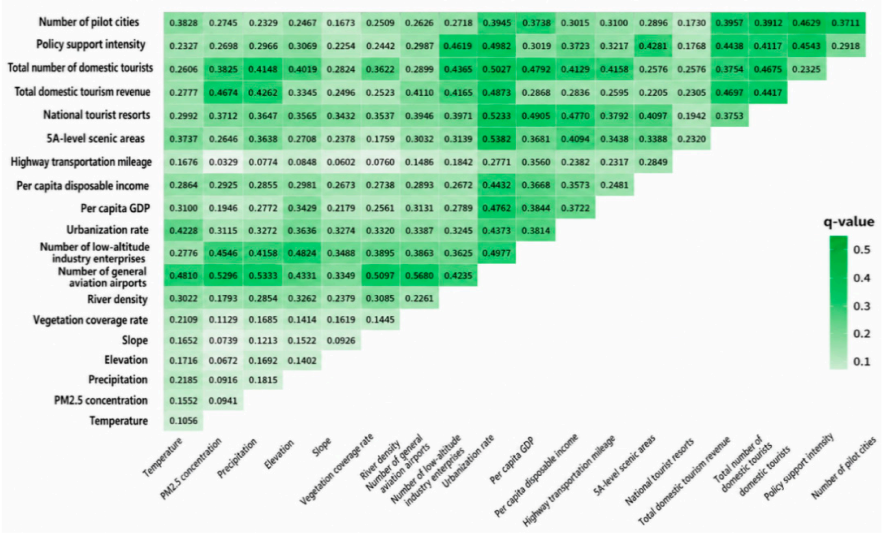


Figure 6. Interaction Detection Results of Influencing Factors for the Distribution of Low-Altitude Tourism Bases in China.

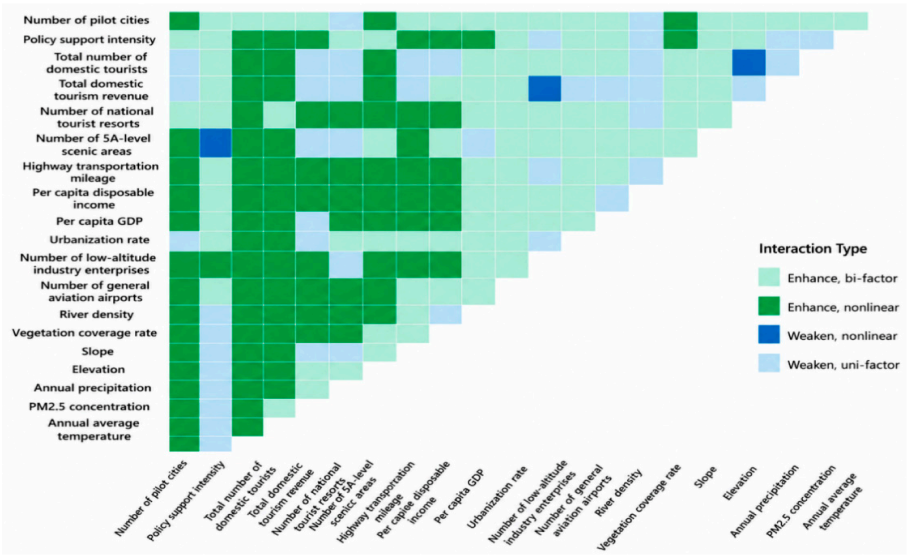


Figure 7. Interaction-type matrix of factors influencing the spatial distribution of low-altitude tourism bases in China.

In addition to general aviation airports, several other variables also showed active interactions with other factors, including national tourist resorts, low-altitude industry enterprises, domestic tourist arrivals, and urbanization rate. Their average interaction q-values were 0.3917, 0.3897, 0.3742, and 0.3574, respectively. This indicates that tourism carrying capacity, industrial foundations, tourist-market size, and urban development level are also important synergistic variables jointly influencing the spatial formation of low-altitude tourism bases.

In terms of high-value interaction combinations, several interactions showed strong enhancement effects. In addition to vegetation coverage rate × general aviation airports, the interaction q-value between general aviation airports and 5A-level scenic areas was 0.5382. The interaction q-value between temperature and general aviation airports was 0.5296, while that between general aviation airports and national tourist resorts was 0.5233. The interaction q-value between general aviation airports and domestic tourist arrivals was 0.5027. In addition, several interaction q-values approached or exceeded 0.49, including general aviation airports × Policy support intensity, general aviation airports × low-altitude industry enterprises, low-altitude industry enterprises × national tourist resorts, and general aviation airports × domestic tourism revenue.

These results show that the spatial layout of low-altitude tourism bases is not determined by any single factor, nor is it shaped solely by aviation infrastructure, tourism resources, or industrial conditions. Rather, it depends on the synergistic coupling among infrastructure support, tourism resource endowments, industrial organization capacity, market demand, and the policy environment.

From the perspective of interactions among the three types of geographical nature, second nature had the highest average interaction q-value with other factors, reaching 0.3494. Third nature ranked second, with a value of 0.3262, whereas first nature had the lowest value, at 0.2622. The interaction between second and third nature factors was the strongest, appearing as a two-factor enhancement with an average q-value of 0.3614. By contrast, interactions among first nature factors were the weakest, with an average q-value of only 0.1716.

These results further confirm the basic constraining role of first nature, the dominant role of second nature, and the empowering role of third nature in shaping the distribution of low-altitude tourism bases in China.

4.4. Risk Detection

The risk detection results further reveal the differentiated effects of influencing factors across different stratified intervals, as reflected by the mean number of low-altitude tourism bases within each interval (Figure 8). Y indicates a statistically significant difference between strata, whereas N indicates no significant difference. Significant differences are observed across the stratified levels of variables related to economic development, industrial foundations, tourism resources, and policy support. These findings indicate that low-altitude tourism bases are not evenly distributed under all conditions but tend to agglomerate in regions with higher levels of comprehensive development.

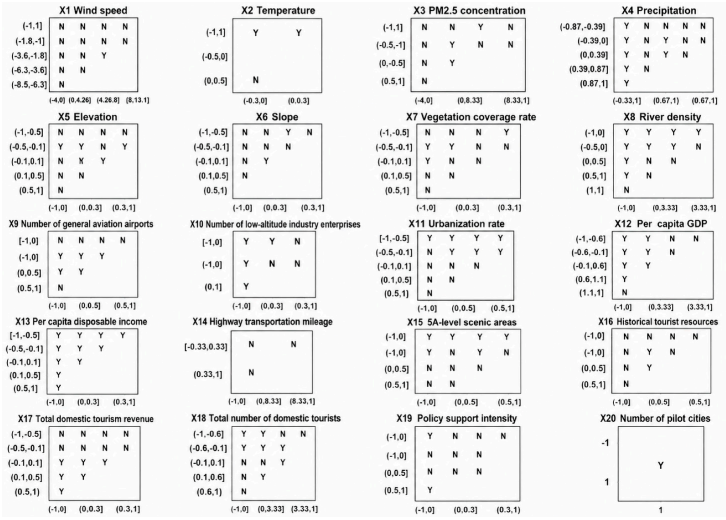


Figure 8. Risk-detection significance matrix of factors influencing the spatial distribution of low-altitude tourism bases in China.

The risk mean results further support this pattern (Figure 9). Blue indicates the minimum stratum mean, red indicates the maximum, and gray indicates intermediate values. When variables such as general aviation airports, low-altitude industry enterprises, national tourist resorts, 5A-level scenic areas, domestic tourism revenue, domestic tourist arrivals, and pilot cities fall within higher-level groups, the corresponding mean number of low-altitude tourism bases is generally higher. This reflects a clear tendency for low-altitude tourism bases to concentrate in regions with more favorable development conditions.

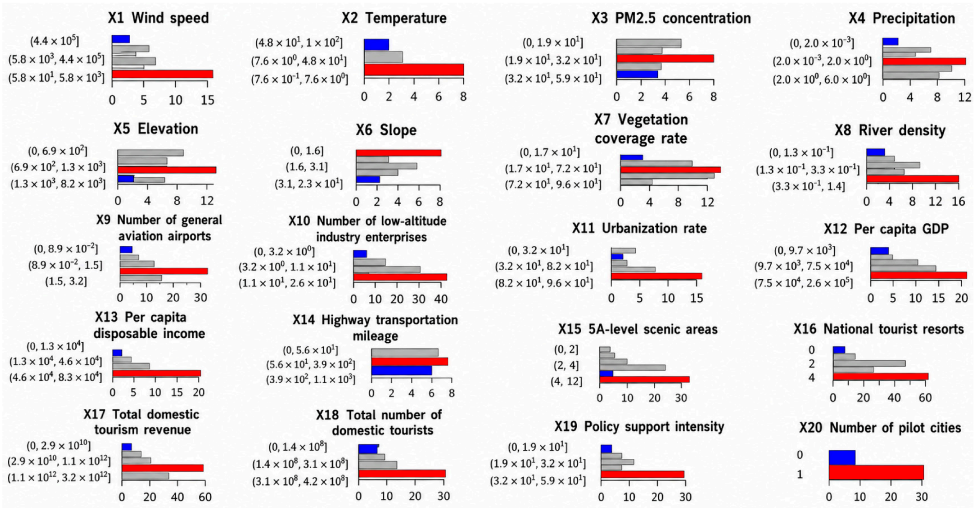


Figure 9. Risk-detection mean values of factors affecting the spatial distribution of low-altitude tourism bases.

Specifically, regions with larger numbers of general aviation airports tend to contain more low-altitude tourism bases, highlighting the importance of aviation infrastructure as a practical prerequisite for their development. It is evident that general aviation airports play a pivotal role in facilitating the take-off and landing of aircraft. They are instrumental in the effective management of operational schedules and the assurance of safety measures. Consequently, these airports enhance the accessibility and efficiency of low-altitude tourism activities.

Similarly, regions with more low-altitude industry enterprises exhibit higher average numbers of tourism bases. This suggests that the development of low-altitude tourism bases relies heavily on the presence of related market entities and industrial chains. Industrial agglomeration can enhance project development, equipment supply, operational services, and technical support, thereby increasing the likelihood of base formation.

In terms of tourism resources and market foundations, higher-level groups of national tourist resorts, 5A-level scenic areas, domestic tourism revenue, and domestic tourist arrivals are all associated with larger numbers of low-altitude tourism bases. This indicates that low-altitude tourism bases are more likely to be located in regions with stronger tourism attractiveness, larger tourist flows, and more mature consumer markets. High-grade scenic areas and tourist resorts provide stable tourist sources, high-quality scenic environments, and mature reception services, while stronger tourism revenue and tourist arrivals indicate greater consumption capacity and market potential. Therefore, the development of low-altitude tourism bases depends not only on aviation conditions but also on the broader tourism-economic foundation of a region.

In addition, higher-level groups of pilot cities correspond to larger mean numbers of bases, indicating that policy pilots and institutional support have a clear promoting effect on the layout of low-altitude tourism bases. Pilot cities often have first-mover advantages in low-altitude economy development, industrial cultivation, infrastructure construction, and institutional innovation, making them more likely to attract related projects and resources. This shows that the policy environment can further promote the spatial concentration of low-altitude tourism bases by lowering institutional barriers, strengthening development expectations, and improving resource allocation efficiency.

Overall, the three forms of geographical nature play different roles in the spatial differentiation of low-altitude tourism bases. First nature mainly provides underlying conditions and suitability constraints. Temperature, hydrological conditions, wind speed, and vegetation coverage exhibit moderate explanatory power, indicating that climatic conditions, hydrological landscape resources, flight environments, and ecological backgrounds influence the spatial layout of bases. Although precipitation, PM2.5 concentration, slope, and elevation exhibit relatively weak explanatory power as single factors, their explanatory power increases markedly when they interact with variables such as general aviation airports and low-altitude industry enterprises. This suggests that natural conditions exert their influence mainly through coupling with socioeconomic factors. Second nature is the dominant factor shaping the spatial distribution of low-altitude tourism bases. Domestic tourism revenue, low-altitude industry enterprises, general aviation airports, national tourist resorts, and tourist arrivals all show strong explanatory power. The interaction detector and risk detector results further indicate that aviation infrastructure, industrial support, tourism resource endowments, and market demand jointly constitute the core driving mechanism of base agglomeration. Third nature plays an empowering and reinforcing role. Policy support intensity and pilot cities both reach the significance level, and their high-value groups correspond to larger mean numbers of bases. This indicates that policy supply, pilot demonstration, and institutional innovation can effectively strengthen regional development conditions and facilitate the preferential siting of

low-altitude tourism bases in regions with comparative advantages. Collectively, the three forms of geographical nature shape the spatial distribution of low-altitude tourism bases in China through differentiated pathways.

5. Influencing Mechanisms

In the context of accelerated low-altitude economic growth, expanding policy support, and heightened tourism demand, low-altitude tourism bases in China have evolved into integrated spatial nodes that combine tourism services, flight operations, industrial support, and institutional governance. The present study interprets the spatial differentiation of the factor and interaction detection results in accordance with the theory of geographical nature (see Figure 10). The findings suggest that the three natures do not function independently or in a uniform sequence. Instead, first nature defines resource potential and environmental suitability, second nature determines the capacity to transform this potential into operational tourism products, and third nature regulates and reinforces project implementation through policy and institutional arrangements.

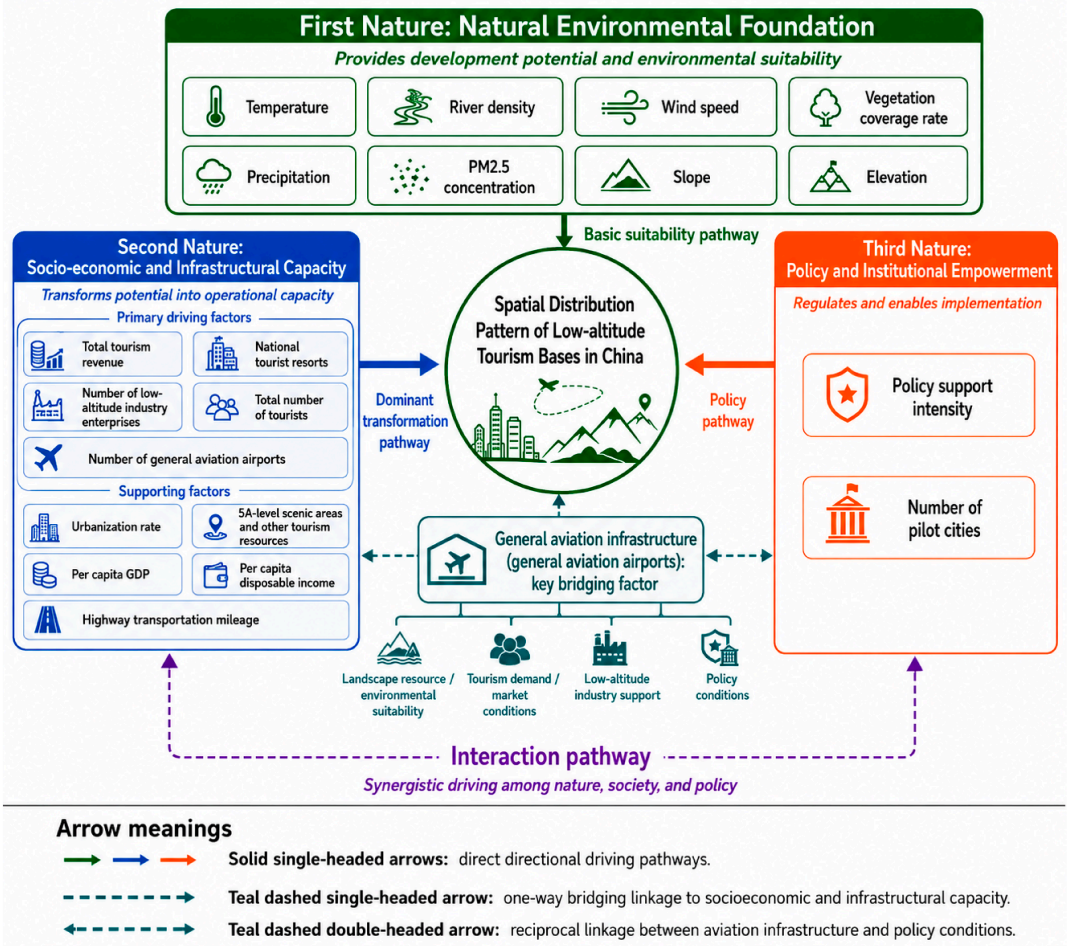


Figure 10. Influencing mechanism of the spatial distribution of low-altitude tourism bases in China based on geographical nature theory.

First nature provides the environmental foundation and technical suitability for the spatial distribution of low-altitude tourism bases. Among the natural factors, temperature exhibits the strongest explanatory power, followed by river density and wind speed, whereas elevation shows the weakest independent explanatory power. Temperature affects seasonal operating windows, tourist comfort, and flight stability, whereas wind speed directly constrains flight safety and operational feasibility. Hydrological and vegetation

conditions, in turn, contribute to landscape attractiveness and the quality of outdoor recreation. However, the influence of natural factors varies substantially across different types of bases. Temperature is particularly influential for skydiving and helicopter bases, whereas river density and vegetation coverage are more closely associated with paragliding bases. Precipitation, PM2.5 concentration, and slope, together with elevation, generally show limited independent explanatory power, but their explanatory power increases markedly when they interact with tourism demand, general aviation airports, and other socioeconomic factors. This suggests that natural suitability constitutes a necessary but not sufficient condition for the formation of bases, defining development potential rather than determining actual siting outcomes.

Second nature plays the dominant role in converting resource potential into actual development and operational capacity. Domestic tourism revenue exhibits the highest explanatory power, followed by the number of low-altitude industry enterprises, general aviation airports, and national tourist resorts, as well as domestic tourist arrivals. Tourism revenue and tourist arrivals reflect market size, consumption intensity, and destination reception capacity, whereas low-altitude industry enterprises supply equipment, operational services, technical expertise, and professional support. General aviation airports, in turn, offer take-off and landing facilities, maintenance services, flight support, and safety assurance. National tourist resorts and high-grade scenic areas provide well-established tourism environments and relatively stable visitor flows, whereas the urbanization rate, household income, the level of economic development, and road network density further condition market reachability and service provision capacity. The influence of second nature is also type-specific: fixed-wing and skydiving bases depend more strongly on aviation facilities and industrial support; aviation science education bases are closely associated with tourism markets and urban services; paragliding bases rely on the combined support of mature destinations, markets, and aviation facilities; and helicopter bases display a pronounced orientation toward high-income tourism markets. Taken together, these results indicate that socioeconomic endowments, rather than natural conditions alone, determine whether latent resource advantages are translated into operational low-altitude tourism bases.

Third nature operates mainly through institutional empowerment, conditional reinforcement, and regulatory guidance of implementation. Policy support intensity exhibits greater explanatory power than pilot-city status, although its influence differs across base types. Policy factors are particularly influential for paragliding, aviation science education, skydiving, and hot-air balloon bases; these base types are more closely linked to demonstration programmes, outdoor recreation policies, event-based promotion, and tourism–aviation integration initiatives. By contrast, policy factors exhibit weak independent explanatory power for fixed-wing bases, suggesting that policy support alone is unlikely to compensate for deficiencies in airport facilities, market demand, and industrial capacity. The results of the interaction detector further indicate that the influence of policy is conditional. For example, the interaction between tourist arrivals and pilot-city status substantially enhances the explanatory power for the spatial distribution of fixed-wing bases, whereas the interaction between tourism revenue and pilot-city status improves the explanation of the spatial differentiation of paragliding bases. Policy and institutional conditions therefore function primarily by mobilizing resources, raising development expectations, and facilitating project approval, thereby reinforcing regions in which market and operational foundations are already in place. This indicates that third nature amplifies rather than generates locational advantages.

The results of the interaction detector reveal that most factor combinations exhibit either two-factor enhancement or nonlinear enhancement. This indicates that the spatial differentiation of low-altitude tourism bases results from the coupling of environmental

suitability, market demand, industrial capacity, aviation infrastructure, and policy support, rather than from any single factor acting in isolation. General aviation airports play a particularly prominent role in this coupling process. Although their independent explanatory power is not the highest for all base types, they are frequently involved in enhanced interactions with temperature, slope, tourism demand, household income, and industry-related variables. General aviation infrastructure can therefore be interpreted as an operational interface linking natural resource potential, tourism markets, industrial services, and policy implementation. Through this bridging role, suitable landscapes and market demand can be converted into accessible, safe, and commercially viable low-altitude tourism activities. These findings underscore that the formation of low-altitude tourism bases is governed by multi-factor coupling, in which aviation infrastructure functions as a critical mediating condition.

Overall, the spatial formation of low-altitude tourism bases can be understood as a differentiated transformation process. First nature provides environmental potential and technical suitability; second nature converts this potential into operational capacity through market demand, facility provision, and industrial services; and third nature regulates and reinforces this conversion process through institutional support. The relative salience and configuration of these dimensions vary with the technical requirements, consumption characteristics, and operational modes of different base types. This transformation mechanism helps to explain why regions endowed with favorable natural conditions do not necessarily develop low-altitude tourism at a significant scale in the absence of mature tourism markets, general aviation infrastructure, industrial services, and supportive institutional conditions. The three forms of geographical nature thus operate in a hierarchical and mutually dependent manner, in which each successive dimension conditions the realization of the preceding one.

6. Discussion

6.1. Spatial Agglomeration, Regional Differentiation, and Type-Specific Heterogeneity

Low-altitude tourism bases in China exhibit significant spatial clustering and regional inequality, with dense concentrations in eastern coastal regions, major urban agglomerations, and mature tourism destinations, and relatively sparse distributions in western and northeastern China. This pattern is broadly consistent with Li et al. [8], who identified an east–west imbalance and a coastal "three-pole and multiple-node" structure centered on the Yangtze River Delta, Pearl River Delta, and Hainan Island. The consistency between the two studies suggests that eastern and coastal concentration represents a relatively stable spatial regularity rather than an outcome specific to a particular dataset or method.

This study extends previous hotspot-based descriptions by identifying a diamond-shaped core bounded by Beijing, Hangzhou, Chengdu, and Sanya. The core contains 49.24% of all bases, while the core and its 200 km buffer zone together contain 89.17%, revealing a pronounced core–periphery structure. This pattern broadly corresponds to a recent provincial assessment that classified Guangdong, Jiangsu, Zhejiang, Beijing, and Sichuan as China's first-tier regions for low-altitude economic development [39]. These regions reinforce the major northern, eastern, western, and southern concentration areas identified in this study, suggesting that low-altitude tourism agglomeration is closely related to broader industrial, market, and infrastructural foundations. However, Hainan was classified in the third tier, whereas Sanya emerged as a major municipal hotspot, reflecting differences in spatial scale and research focus. More generally, the result is consistent with tourism research showing that tourism activities often develop through cumulative concentration rather than uniform spatial diffusion [40], while aviation systems may further reshape tourism demand and strengthen established destinations and gateway cities [41].

The six types of bases also follow distinct locational logics. Fixed-wing and skydiving bases depend strongly on aviation facilities and industrial support; aviation science education bases are more closely associated with urban markets and public services; paragliding bases rely on a combination of ecological landscapes, tourism demand, aviation services, and policy support; hot-air balloon bases depend more heavily on particular scenic settings and event-based promotion; and helicopter bases display a pronounced orientation toward favorable climatic conditions and high-income markets. International studies similarly indicate that terrain, wind conditions, land cover, and operational safety jointly determine the suitability of recreational flying sites [42,43], while aviation accessibility and tourism demand tend to reinforce one another [44,45]. Low-altitude tourism bases therefore do not follow a uniform locational model: outdoor experience-oriented projects are more sensitive to environmental and technical suitability, whereas capital- and service-intensive projects are more firmly embedded in urban markets and aviation service networks.

6.2. Interaction Effects and the Bridging Role of General Aviation Infrastructure

The OPGD results indicate that the spatial differentiation of low-altitude tourism bases is associated with combinations of factors rather than isolated determinants. Most interactions show two-factor or nonlinear enhancement, which is broadly consistent with previous findings [8]. The present study further interprets these effects through the theory of geographical nature. First nature defines resource potential, environmental suitability, and technical constraints. Second nature determines whether this potential can be transformed into operational tourism products through markets, industries, infrastructure, and urban services. Third nature regulates and reinforces implementation through policy support and institutional arrangements.

Representative interactions illustrate these relationships. The enhanced effects of slope and general aviation airports on paragliding bases, temperature and general aviation airports on skydiving bases, and tourism demand and pilot-city status demonstrate that natural suitability becomes developmentally effective only when combined with market demand, aviation facilities, industrial capacity, and institutional support. The theoretical value of geographical nature therefore lies not merely in classifying factors, but in explaining the conversion and coupling processes through which environmental potential becomes operational tourism activity.

General aviation airports play an important bridging and enabling role in this process. Although their independent explanatory power is not always the highest for every base type, they repeatedly interact with climatic conditions, landscape resources, tourism demand, household income, and industry-related variables. General aviation airports and related facilities provide operational space, flight services, maintenance support, professional personnel, emergency response, and safety assurance. They therefore connect tourism resources and market demand with practical operation and the wider aviation industry. This interpretation is consistent with research showing that airports may generate broader catalytic effects by improving accessibility and linking regional economic activities and services [46].

General aviation infrastructure should consequently be understood as an operational interface rather than simply another transport variable. Its bridging role also helps explain why some resource-rich regions remain weakly developed: attractive landscapes alone cannot support stable low-altitude tourism without sufficient market demand, aviation facilities, industrial services, and institutional arrangements. By conceptualizing low-altitude tourism bases as integrated tourism–aviation nodes, this study extends tourism spatial research and advances geographical nature theory from a static classification framework toward a relational explanation of spatial development.

6.3. Implications for Differentiated and Sustainable Regional Planning

The pronounced spatial concentration and regional disparities identified in this study require differentiated zoning strategies. In the diamond-shaped core and other high-density urban agglomerations, planning should shift from numerical expansion toward service quality, operational efficiency, network coordination, and product specialization. Secondary agglomeration regions, including inland gateway cities and emerging tourism centers, should connect distinctive tourism resources with aviation facilities, regional markets, and specialized operators to cultivate complementary growth poles. Development in western, northeastern, and ecologically sensitive regions should be more selective and based on market feasibility, environmental carrying capacity, flight conditions, and existing infrastructure rather than direct replication of eastern models.

Planning should also reflect the distinct requirements of different base types. Fixed-wing and skydiving bases should be coordinated with general aviation airports, professional operators, maintenance services, and emergency systems. Paragliding bases should prioritize terrain, meteorological stability, landscape quality, ecological sensitivity, and take-off and landing safety. Hot-air balloon projects require suitable atmospheric conditions, distinctive tourism settings, and event-management capacity. Helicopter bases should be linked with high-demand destinations, high-income markets, transport hubs, and specialized aviation services. Aviation science education bases are more suitable for metropolitan areas and regional centers with concentrated populations, educational demand, public facilities, and convenient accessibility.

A hierarchical aviation–tourism network should further coordinate national gateway nodes, regional aviation-tourism hubs, and locally specialized experience bases. At the regional level, planning should integrate general aviation airports, temporary take-off and landing sites, ground transport, tourism destinations, emergency services, and airspace management. At the project level, site selection should consider land availability, ecological constraints, noise impacts, flight safety, market coverage, infrastructure capacity, and redundant construction. Emerging low-altitude infrastructure research similarly emphasizes the need to balance safety, economic viability, land conditions, service capacity, social effects, and regional demand [47]. Sustainable planning should therefore move beyond increasing the number of bases and integrate ecological protection, flight safety, market feasibility, infrastructure provision, and institutional governance into site selection and project implementation.

6.4. Limitations and Future Research

This study is subject to several limitations. First, although the national database compiled for this study was constructed through multi-source collection, telephone verification, and manual screening, some newly established, seasonal, temporarily inactive, or informally operated bases may not have been included. Second, several potentially important variables—including airspace accessibility, regulatory efficiency, technological innovation, aviation human capital, and safety performance—could not be incorporated owing to the lack of consistent data at the national scale. In addition, differences in the reference years of certain variables may introduce a degree of temporal mismatch. Third, the findings reveal spatial associations rather than causal relationships, since tourism markets, aviation infrastructure, and base development are likely to be mutually reinforcing, which raises the possibility of endogeneity. Finally, analyses conducted at the municipal or equivalent administrative level may be sensitive to the modifiable areal unit problem (MAUP). Future research could draw on longitudinal and multiscale data and incorporate additional aviation-related and institutional variables. The application of spatial econometric or quasi-

experimental approaches would further help to trace temporal evolution and to strengthen causal inference.

7. Conclusions

Using data on 1247 low-altitude tourism bases in China, this study combined average nearest-neighbor analysis, kernel density estimation, the Gini coefficient, the Lorenz curve, and the spatial agglomeration indicator to examine their spatial patterns at multiple scales. Guided by the theory of geographical nature, an optimal parameters-based geographical detector was further applied to evaluate the explanatory power, interaction effects, and type-specific differences in the selected factors. The main conclusions are as follows.

First, low-altitude tourism bases in China exhibit significant spatial clustering and pronounced regional inequality. The average nearest-neighbor index was 0.214, confirming a statistically significant clustered distribution. At the national scale, the bases display a clear east–west divide along the Heihe–Tengchong Line. At the provincial scale, the Gini coefficient of 0.40 indicates substantial interprovincial inequality. Kernel density estimation further identifies a diamond-shaped core bounded by Beijing, Hangzhou, Chengdu, and Sanya. The core itself contains 49.24% of all bases, while the core and its 200 km buffer zone together contain 89.17%. At the municipal scale, high relative concentrations are primarily found in the Yangtze River Delta, Pearl River Delta, coastal Hainan, and several major inland gateway cities, whereas many cities in northwestern and western China exhibit low or zero concentration.

Second, the spatial differentiation of low-altitude tourism bases is jointly associated with natural environmental conditions, socioeconomic and infrastructural capacity, and policy and institutional support, with second nature exhibiting the most stable and substantial explanatory power. Among all individual factors, domestic tourism revenue exhibits the highest explanatory power, followed by the number of low-altitude industry enterprises, general aviation airports, and national tourist resorts, and by domestic tourist arrivals, whereas elevation exhibits the weakest explanatory power. Within the three natures, temperature, domestic tourism revenue, and policy support intensity constitute the strongest individual factors within the first, second, and third natures, respectively. These results indicate that natural suitability provides an initial foundation, whereas market demand, industrial capacity, and aviation infrastructure play a more decisive role in converting resource potential into marketable low-altitude tourism products.

Third, the dominant factors differ substantially across base types. Fixed-wing bases follow a market-driven, infrastructure-driven, and industry-driven pattern, whereas aviation science education bases are mainly associated with urban tourism markets and public service capacity. Paragliding bases exhibit a combined pattern shaped by policy support, market conditions, and ecological landscapes, while hot-air balloon bases depend more heavily on policy support and particular scenic settings. Skydiving bases are strongly associated with climatic suitability and aviation facilities, whereas helicopter bases display a pronounced dependence on climatic suitability, tourism revenue, and high-income markets. These differences indicate that low-altitude tourism bases do not follow a uniform locational logic; rather, their locational patterns are shaped by the technical requirements, market orientation, service functions, and operational characteristics of each activity type.

Fourth, factor interactions are predominantly characterized by two-factor enhancement and nonlinear enhancement, indicating that the observed spatial patterns cannot be attributed to single factors acting in isolation. The three natures operate through interdependent rather than parallel pathways: first nature defines resource potential and environmental suitability, second nature determines the capacity to transform that potential into accessible and operational tourism products, and third nature shapes and reinforces

project implementation through policy and institutional arrangements. General aviation airports are frequently involved in enhanced interactions with climatic conditions, landscape resources, tourism demand, household income, and industry-related variables. This finding suggests that aviation infrastructure functions as a critical operational interface linking resource potential, market demand, and industrial support with project implementation.

Author Contributions: Conceptualization, L.Z.; methodology, J.H.; data curation, J.H.; writing—review and editing, Y.J.; visualization, Y.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Natural Resources "Ministry-Province Cooperation" China Spatial Planning Online Monitoring Network (CSPON) Project, grant number 2023ZRBSHZ068, and the Scientific Research Project of the Hebei Provincial Department of Education, grant number QN2025061.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. The underlying low-altitude tourism base database is not publicly archived because it includes manually verified records compiled from multiple sources.

Conflicts of Interest: The authors declare no conflict of interest.

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