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Doctoral Dissertation

Influencing Patterns and Differentiated Protection of the Spatial Distribution of Traditional Villages in the Liaoxi Corridor and Liaodong Peninsula

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Abstract

Traditional villages carry rich historical and cultural heritage and play a vital role in rural revitalization and cultural transmission. However, rapid urbanization has accelerated their decline and disappearance. To explore their spatial distribution and internal patterns, this study focuses on Liaoning Province and conducts a systematic comparative analysis of two representative regions, the Liaoxi Corridor and the Liaodong Peninsula.

This study aims to compare the spatial distribution characteristics and influencing patterns of traditional villages in the Liaoxi Corridor and the Liaodong Peninsula, and to provide an evidence base for differentiated conservation. Methodologically, it integrates GIS spatial analysis, GeoDetector, geographically weighted regression (GWR), and XGBoost combined with SHAP interpretation, thereby enabling a unified comparison of spatial pattern, dominant factors, spatial heterogeneity, and nonlinear interaction effects.

The results reveal clear interregional differences. Traditional villages in the Liaoxi Corridor tend to exhibit a corridor-oriented distribution associated with topography, water systems, and accessibility conditions, whereas those in the Liaodong Peninsula show a more clustered pattern shaped more strongly by ecological and climatic constraints. The results indicate clear regional differentiation in the spatial distribution of traditional villages. The Liaoxi Corridor shows a corridor-oriented agglomeration pattern, with a nearest neighbor index of 0.871, indicating a clustered spatial structure along valleys, transportation corridors, and historical settlement belts. In contrast, the Liaodong Peninsula presents a more dispersed and heterogeneous spatial pattern, with a nearest neighbor index of 1.243, reflecting the influence of complex terrain, coastal conditions, and ecological constraints. The XGBoost-SHAP results further reveal that the dominant influencing factors differ between the two regions. In the Liaoxi Corridor, temperature, distance to city center, humidity, precipitation, and GDP show relatively high contributions, whereas in the Liaodong Peninsula, precipitation, distance to city center, temperature, GDP, and humidity play more important roles. These quantitative results provide evidence for developing differentiated protection strategies rather than applying a uniform protection model.

Based on these findings, this study proposes differentiated protection strategies for the Liaoxi Corridor and the Liaodong Peninsula, with emphasis on regionally adaptive planning, ecological–cultural integration, and infrastructure optimization, so as to promote the coordinated development of traditional village differentiated protection and rural revitalization.

Keywords: Traditional Villages; Spatial Distribution; Liaoxi Corridor; Liaodong Peninsula; GIS Spatial Analysis; Geographic Detector; XGBoost; Differentiated protection

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Chapter 1
Introduction

1.1 Research Background

Traditional villages are living fossils and open-air museums of rural history, culture and natural heritage[1]. They carry unique settlement patterns, architectural forms, production methods and living traditions, and have irreplaceable value in maintaining regional identity, ethnic memory and cultural diversity[2]. Their protection and continuation are not only related to the inheritance of Chinese agricultural civilization and the in-depth implementation of the rural revitalization strategy[3], but also in line with the United Nations Sustainable Development Goals' initiative on creating an inclusive, safe, resilient and sustainable human settlement environment[4,5,6]. Since the Ministry of Housing and Urban-Rural Development and other ministries launched the publication of the"List of Traditional Chinese Villages" in 2012, as of 2024, 8,155 villages have been included in the national list of traditional villages, forming a relatively prominent agricultural civilization settlement protection system on a global scale[1,3,7-19].

However, under the multiple pressures of rapid urbanization, industrialization and infrastructure expansion, a large number of traditional villages are facing problems such as population outflow, "hollowing out", destruction of architectural style, fragmentation of landscape and decline of cultural function. Many villages are on the verge of being abandoned or disappearing [2,13,20-23]. Some studies have pointed out that traditional villages in some parts of China have a high annual disappearance rate, indicating that the time window for the protection of traditional settlements is rapidly narrowing [9]. Internationally, traditional settlements in regions such as the Italian Alps and rural India are also facing similar predicaments such as population loss and environmental degradation [10,24], indicating that the decline of traditional villages has become a global issue. This reality highlights that simply identifying and protecting these villages in a list is far from enough. It is urgent to systematically identify the distribution pattern and driving pattern of traditional villages on a larger spatial scale, so as to provide a basis for scientific site selection, hierarchical classification and differentiated protection [2,9,25,26,27,28,29].

Studies have shown that clarifying the spatial distribution characteristics and driving patterns of traditional villages is a prerequisite for achieving the organic coupling of cultural heritage protection and sustainable rural development [2,9,12]. Under this logic, the analytical framework of "spatial pattern - influencing factors - protection path" has become an important direction for related research at home and abroad. Its core is not only to describe "where traditional villages are", but also to explain "why they are here" and "how to protect them in different contexts" [30].

1.2 Research Objectives

This study focuses on the spatial distribution characteristics of traditional villages in the Liaoxi Corridor and Liaodong Peninsula, setting a main objective and two sub-objectives, and proposing research questions accordingly [31,32][33].

The main objective is to construct an evidence base for differentiated protection—comparing the spatial distribution types of traditional villages in the Liaoxi Corridor and Liaodong Peninsula, identifying and explaining the associated inter-regional factors and interaction patterns, and transforming the results into regionally customized protection types and strategies, providing a basis for planning and governance in Liaoning Province and similar northern transitional/coastal zones. Under this main objective analysis process, two sub-objectives are further refined:

(1) SRO1: Liaoxi Corridor: Analyzing the spatial distribution characteristics of traditional villages in the Liaoxi Corridor and exploring its influencing factors, laying the foundation for subsequent comparative analysis.

(2) SRO2: Liaodong Peninsula: Analyzing the spatial distribution characteristics of traditional villages in the Liaodong Peninsula and exploring its influencing factors, contrasting with Sub-objective 1, providing support for subsequent comprehensive analysis. Based on the above objectives, this study aims to answer the following research questions:

(1) What are the spatial distribution characteristics of traditional villages in the Liaoxi Corridor and the Liaodong Peninsula? In their respective regions, is the distribution of traditional villages generally clustered or dispersed? Where are the main cluster centers and high-density "hot spots"? What are the differences in spatial types such as cluster cores and directionality between the two regions' traditional villages? What protection types do these differences correspond to?

(2) What are the similarities and differences in the distribution of traditional villages between the Liaoxi Corridor and the Liaodong Peninsula? What are the characteristics of the spatial distribution patterns (such as core density distribution and hot spots) of the traditional villages in each region? What are the differences in distribution patterns, topography, and altitude?

What are the main factors affecting the spatial distribution of traditional villages in the two regions? Among these influencing factors, what roles do natural environmental factors (such as topography) and human and social factors (such as population and transportation) play?[24] For example, compared to traditional villages in the southern region which are mostly located in low-altitude water areas[25], do traditional villages in the Liaoxi Corridor and Liaodong Peninsula show different site selection preferences?

1.3 Study Areas and Reasons for Selection

This study selects the Liaoxi Corridor and the Liaodong Peninsula as typical research areas. These two regions are located in the western inland and southeastern coastal areas of Liaoning Province, China, respectively, each with its unique geographical environment and cultural background. The Liaoxi Corridor is situated at the intersection of the agricultural and pastoral areas of northern China and the forest and hunting areas of northeastern China. Since ancient times, it has been a frontier passage for exchanges between the agricultural civilization of the Central Plains and the nomadic civilization of the north. The Ming Great Wall stretches along the Liaoxi Corridor, where multiple ethnic cultures collided and merged, leaving behind a rich historical and cultural legacy.

The Liaodong Peninsula is surrounded by the sea on three sides, bordering the Bohai Sea and the Yellow Sea. It is a strategic point where the land and sea meet in Northeast Asia, nurturing a unique maritime culture and fishing and hunting traditions. Since the Ming and Qing dynasties, it has echoed the Shandong Peninsula on the opposite shore, jointly forming a coastal defense barrier protecting the capital, with numerous coastal defense relics remaining along its coast. The Liaoxi Corridor and the Liaodong Peninsula, one inland and one coastal, one "corridor" and one "peninsula", respectively represent the typical topographic and geomorphological patterns of the transitional zone between the northern inland and the southeastern coastal areas of my country (such as mountains, hills, plains, valleys, and coastlines). The spatial distribution of their traditional villages is representative of the geographical pattern of traditional Chinese settlements. Therefore, focusing on these two regions to carry out research has the significance of nationwide promotion in China. On the one hand, these two regions have the dual elements of inland frontier and coastal defense, and the forms and functions of traditional villages present diverse characteristics. On the other hand, the intertwining of the transition between agricultural and nomadic culture and the development of coastal defense trade has shaped a unique pattern of village site selection and settlement form. In short, the traditional villages of the Liaoxi Corridor and the Liaodong Peninsula carry rich historical and cultural information and are a vivid microcosm of the distribution of traditional villages in northern China. They have outstanding representativeness and research value in the study of traditional villages nationwide [34]. In particular, the Liaoxi Corridor and the Liaodong Peninsula respectively cover the typical topographic and geomorphological patterns of the northern inland and southeastern coastal areas of my country, and are representative of the geographical distribution of traditional Chinese villages. Therefore, conducting research on these two regions has significant national implications, providing theoretical basis and practical suggestions for the classification, protection, and spatial governance of traditional villages in China.

Although the Liaoxi Corridor and the Liaodong Peninsula are both located within Liaoning Province, they represent two distinct geographical types. The Liaoxi Corridor is characterized by inland corridor-like terrain, valley systems, and historical transportation routes, whereas the Liaodong Peninsula is shaped by coastal and peninsula-type terrain, more complex topography, and different ecological conditions. Therefore, comparing these two regions within the same provincial context makes it possible to identify how different geographical settings influence the spatial distribution and preservation conditions of traditional villages. This comparison is necessary for avoiding a one-size-fits-all protection approach and for establishing differentiated protection strategies based on regional heterogeneity.

1.4 Study Structure

The study is divided into seven chapters, arranged as follows, reflecting the logical thread of moving from regional analysis to comprehensive integration:

Chapter 1 Introduction: This chapter introduces the research background, objectives, and questions, the rationale for selecting the research area, and the study structure. A background review identifies the problems, clarifies the representativeness of the selected research areas (Liaoxi Corridor and Liaodong Peninsula), and defines the core issues, overall approach, and methodological framework to be addressed.

Chapter 2 Literature Review: This chapter systematically reviews domestic and international research on the spatial distribution characteristics and influencing factors of traditional villages, summarizes the current research status and development trends, highlights shortcomings, and lays a theoretical foundation for subsequent research.

Chapter 3 Data Sources and Research Methods: This chapter explains the data sources and research methods used in this study, providing a specific technical approach combining spatial analysis and statistical analysis.

Chapter 4 Spatial Distribution Characteristics and Influencing Factors of Traditional Villages in the Liaoxi Corridor (SRO1): Taking the Liaoxi Corridor as the research object, this chapter analyzes the spatial distribution characteristics of traditional villages in the region and explores the main influencing factors that form these characteristics.

Chapter 5: Spatial Distribution Characteristics and Influencing Factors of Traditional Villages in the Liaodong Peninsula (SRO2): Taking the Liaodong Peninsula as the research object, this chapter analyzes the spatial distribution characteristics and internal differences of traditional villages in the region, explores the main influencing factors forming these characteristics, and analyzes the spatial pattern characteristics of traditional villages in coastal hilly and plain areas.

Chapter 6: Comprehensive Analysis of the Influencing Patterns of Traditional Village Distribution: Based on the aforementioned regional studies of the Liaoxi Corridor and the Liaodong Peninsula, this chapter compares and integrates the research findings of the two regions, comprehensively analyzing the influencing patterns of traditional village distribution at a more macro-level provincial scale.

Chapter 7: Discussion and Conclusion: This chapter summarizes the research results of the entire paper, proposes countermeasures and suggestions for the classification, protection, and development of traditional villages, and looks forward to future research directions.

The arrangement of the above chapters follows the logic of "first review, then research; first methodology, then empirical evidence; first regional analysis, then comprehensive analysis; and from simple to complex": First, there is an introduction, literature review, and research methodology; then, regional case studies are conducted for the Liaoxi Corridor and the Liaodong Peninsula respectively; based on this, the influencing patterns at the provincial scale are comprehensively analyzed; finally, the discussion and conclusion summarize the overall ideas and results of the paper. This structural arrangement not only identifies the spatial distribution characteristics and regional differentiation of traditional villages but also delves into the explores both the commonalities and regional heterogeneity of the two study areas, achieving a research upgrade from local to overall and from descriptive spatial analysis to explanatory and integrative analysis;from regional case evidence to province-wide comparative synthesis;from pattern identification to strategy-oriented interpretation.

Research Gaps and Their Address: (1) There is a lack of inter-regional comparative evidence of corridors(Liaoxi Corridor) and peninsulas(Liaodong Peninsula) as two representative sub-regions; (2) Existing studies rarely transform the interaction effects of natural and human factors into operational, region-specific protection typologies and strategies; (3) There is a lack of a reproducible process from spatial evidence to strategy classification. This study fills these gaps by setting up MRO, SRO1 and SRO2 and using the evidence-strategy mapping in Chapters 4–6.

Beyond identifying research gaps, this study provides new comparative findings on the spatial differentiation of traditional villages in Liaoning Province. Previous studies have mainly examined traditional villages within a single region or focused on overall spatial agglomeration. In contrast, this study reveals that traditional villages in the Liaoxi Corridor and the Liaodong Peninsula follow different spatial logics: the former shows a corridor-oriented clustering pattern, while the latter presents a more dispersed and heterogeneous pattern. More importantly, the study demonstrates that similar influencing factors operate differently across the two regions, indicating that traditional village protection should be based on region-specific spatial mechanisms rather than general conservation principles alone.

Finally, to visually present the above research logic and chapter arrangement, the overall technical route of this study is shown in Figure 1. This route fully corresponds to the seven-chapter structure of the paper, realizing a closed-loop research process from regional case analysis to provincial comprehensive integration, and from pattern identification to strategy proposal.

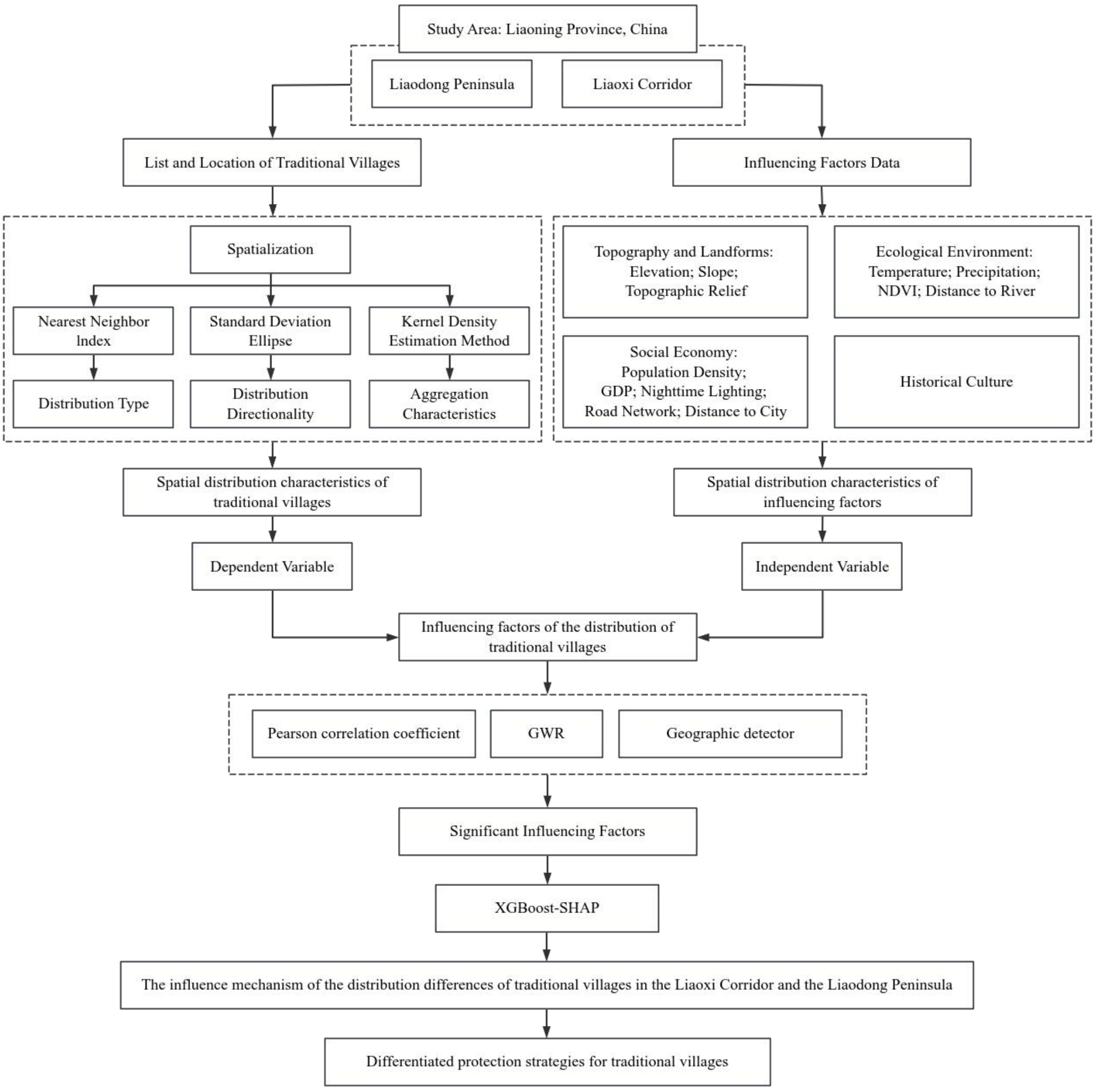

Figure 1. The Research Methodology and the Logical Framework of the Dissertation Chapters

Chapter 2
Literature Review

2.1 Current Status of Traditional Villages in China

In recent years, many international scholars have conducted systematic research on the protection and spatial distribution of traditional Chinese villages. Overall, traditional Chinese villages exhibit significant clustering and uneven distribution at the national scale. Su et al. (2022) used GIS technology to show that the distribution of traditional villages across different watershed units is highly uneven, with high-density villages concentrated in several watershed confluences and environmentally suitable areas, presenting an overall spatial clustering pattern of "core dense area–ring-core diffusion group–zonal area" [10]. Studies in Yunnan and other regions have also found that traditional villages often form a structure of "three high-density areas+multiple medium-density zones," exhibiting significant spatial autocorrelation characteristics [36]. Comparative results across multiple provinces show that traditional villages tend to cluster along relatively flat terrain, with good transportation conditions or accessible waterways, while they are relatively sparse in high-altitude, steep, or inaccessible areas [37,38,39,40].

Regarding the driving pattern, existing research generally emphasizes the coupling effect of natural environment and human social factors. On the one hand, natural geographical conditions (topography, altitude, climate and hydrology, etc.) provide basic constraints for the site selection, survival and evolution of traditional villages. Su et al. (2022) pointed out that factors such as precipitation, temperature and river density have a significant impact on the distribution of traditional villages, and the number of traditional villages and temperature and river density show an inverted U-shaped relationship within a certain range [7]. Chen and Li (2024)'s study on Zhejiang Province showed that traditional villages are mainly concentrated in low mountain and hilly areas below 200 m above sea level, and are significantly clustered in gentle slope areas within 500 m of rivers [11]. On the other hand, human and social factors (such as population density, economic development level, transportation accessibility, distribution of tourism resources and cultural heritage, etc.) play an important regulatory and amplifying role in shaping the spatial pattern of villages. Studies by Liu et al. (2023) show that population density, slope, and rainfall are negatively correlated with the number of traditional villages, while they are positively correlated with river distance, urbanization rate, and tourism resources. Among these, historical and cultural intensity and population density contribute significantly to spatial differentiation [41]. Some studies further indicate that ethnic distribution patterns and cultural factors such as intangible cultural heritage and cultural relics protection units are key drivers influencing the spatial distribution of traditional villages in multi-ethnic regions such as Southwest China [31,36][42,43,44][45,46,47][48,49,50][51,52,53,54].

However, existing literature still has two significant shortcomings: First, the research areas are mostly concentrated in the southern regions where traditional villages are highly concentrated, such as the hilly areas of Jiangnan, the southeastern coast, and the

Yunnan-Guizhou Plateau, while relatively little attention is paid to traditional villages located in the northern marginal areas, geomorphic transition zones, or coastal corridors. Second, most studies focus on single-region or macro-scale pattern analysis, lacking systematic comparison of regions with different geomorphic-ecological-social contexts within a unified framework, thus failing to reveal the differentiated driving patterns under the coupling of multiple regions and patterns. Especially within the Liaoning Province scale, systematic research on the spatial distribution characteristics and influencing factors of traditional villages in typical areas such as the Liaoxi Corridor and the Liaodong Peninsula is still scarce, with only a few recent results providing preliminary revelations of the overall trend [38,45]. Against this background, using the Liaoxi Corridor and the Liaodong Peninsula as comparative research areas has important theoretical and practical value.

The Liaoxi Corridor is located in western of Liaoning Province. It is connected to the Liaodong Bay coastal plain in the southeast and the hilly mountains in the northwest. It is an important passage and historical transportation corridor connecting Northeast China and the middle and lower reaches of the Yellow River. The land area of the region is about 54,686 km², accounting for about 37% of the total area of Liaoning Province[15]. The region has relatively good water resources, mainly belonging to the Bohai Bay, Liaohe River, Dalinghe River and Xiaolinghe River basins. The northwestern mountains include the Nuer Mountain on the Liaoning-Inner Mongolia border and the famous Yiwulü Mountain in Northeast China. The Liaoxi Corridor has been a strategic location for military strategists since ancient times. It is also an important area for the exchange and integration of multiple ethnic groups such as Han, Manchu and Mongolian. It carries the historical tradition of border defense military culture, commercial culture and agricultural culture. This diverse cultural background and the topographic gradient from plateau to plain have jointly nurtured a traditional village system with diverse forms, unique patterns and distinct local characteristics. Since 2012, 52 villages in five batches from the Liaoxi Corridor region have been included in the list of traditional Chinese villages, of which 33 are national-level and 19 are provincial-level, reflecting high historical and cultural value, landscape and settlement morphology value, as well as regional socio-economic and academic research value[15].

The Liaodong Peninsula is located at the southernmost tip of Northeast China, bordering the Yellow Sea to the east and the Bohai Sea to the west. Its southern tip faces the Shandong Peninsula across the sea. With the Dalian area as its spatial core, it lies approximately within the range of 120°53′E–123°31′E and 38°43′–40°10′N[38]. Its topography is mainly low mountains and hills and coastal capes and bays, with a winding coastline, numerous capes and islands, forming a typical transitional zone between land and sea. The southern section of the peninsula is characterized by strike-slip faults and Mesozoic tectonic remains. The deep tectonic pattern is closely related to the metallogenic system. This "basement-tectonic-geomorphic" coupled system has shaped the regional topographic framework of "low mountains-platforms-coastal plains" [38]. The climate type is temperate monsoon climate, which is significantly moderated by the ocean. The annual precipitation is about 500–1000 mm. In summer, it is often affected by the Northeast Cold Vortex process, resulting in a period of heavy precipitation and cooling. It presents a relatively warm and humid pattern with distinct seasons under the combined action of land-sea and atmospheric circulation [39]. Coastal dynamic processes and extreme weather events continue to reshape the local coastal landforms (such as sandbars, lagoons and shoreline advance and retreat), which has a long-term constraint on the safety of settlement site selection and the layout of transportation corridors [39]. In terms of human-land relations, the Liaodong Peninsula is a port city, coastal industry and manufacturing cluster. The population-industry concentration and water resources and ecological carrying capacity have long been in a tense balance. The process of watershed development and urban expansion has a profound impact on the regional ecological pattern and spatial structure [55]. Against this backdrop, traditional villages in Liaoning Province are generally clustered, and natural endowment factors (topographic relief, climate comfort, vegetation cover, etc.) generally have a stronger explanatory power for their spatial pattern than purely human factors, showing that the hill-coastal gradient and environmental suitability are fundamental constraints on the preservation and evolution of traditional villages [56].

In summary, the Liaoxi Corridor and the Liaodong Peninsula represent two typical geomorphological-social situations: the inland corridor type and the coastal peninsula type, respectively. The former is characterized by land routes, multi-ethnic exchanges, and mountain valley patterns, while the latter is more strongly associated with a transitional marine environment, port-industrial agglomeration, and coastal hilly landforms. The two regions differ significantly in their natural geographical foundation, resource endowment, development path, and cultural accumulation, yet both belong to the northern traditional village clusters characterized by "belt-shaped corridors" and "marginal transition zones," but have long been relatively neglected by mainstream research. A systematic comparative study on the spatial distribution characteristics and driving patterns of traditional villages in the Liaoxi Corridor and Liaodong Peninsula can not only fill the gap in existing research on regional types and scales [55,56], but also provide a solid empirical foundation for proposing a “differentiated protection” path that fits the differences in geomorphology, ecology and culture [30,41,57,58,59,60,61,62,63,64,65,66].

2.2.Research Methods for Spatial Distribution Characteristics Analysis of Traditional Villages

Various GIS spatial statistical methods were used to quantitatively describe and visualize the distribution patterns of traditional villages. For example, the nearest neighbor index (NNI) was calculated to determine whether the spatial distribution of village points was clustered, uniform, or random [2,67]; density heat maps were generated using kernel density estimation (KDE) to reveal high-density clustering areas in the distribution of traditional villages [68-71]; standard deviation ellipse analysis was used to measure the directionality and dispersion of village distribution [40,70,71]; the global Moran's index (Moran's I) was used to test the overall spatial autocorrelation ($I > 0$ indicates clustering), and combined with local LISA analysis to identify significant "high-high" clustering areas or "low-low" cold spots [2,68,71,72]. The comprehensive application of multiple methods can reveal the spatial pattern characteristics of traditional villages from both global and local perspectives, such as clustering intensity, distribution pattern, and their relationship with topographic orientation [2].

2.2.1 Nearest Neighbor Index

To reveal the clustering and dispersion characteristics of the spatial distribution of traditional villages, this study employs the Nearest Neighbor Index (NNI) for quantitative measurement. The NNI is a classical indicator used to evaluate the spatial arrangement of point features by comparing the observed mean nearest neighbor index distance with the expected mean distance under complete spatial randomness. Its basic form is expressed as follows:

$$R = \frac{Do}{De}$$

In the formula, where R denotes the nearest neighbor index ratio, Do is the observed mean nearest neighbor index distance, and De is the expected mean distance under a random distribution. In general, $R < 1$ indicates a tendency toward clustering, $R \approx 1$ indicates a near-random pattern, and $R > 1$ indicates a tendency toward dispersion. The theoretical basis of this method can be traced to the classical nearest neighbor index approach proposed by Clark and Evans (1954)[73], and ArcGIS likewise interprets Average Nearest Neighbor Index results using the combined information of the nearest neighbor index ratio, z-score, and p-value.

To avoid relying solely on the R value, this study further adopts a combined interpretation criterion based on the nearest neighbor index ratio (R), z-score, and p-value reported by the ArcGIS Spatial Statistics tool. Specifically, when $R < 1$ and the z-score is negative, the point pattern tends toward clustering; when $R > 1$ and the z-score is positive, the pattern tends toward dispersion; and when $R \approx 1$ with a z-score close to zero, the pattern is considered close to random. Statistical significance is assessed using conventional confidence thresholds: $|z| > 1.65$, $|z| > 1.96$, and $|z| > 2.58$, corresponding approximately to the 90%, 95%, and 99% confidence levels, respectively. When the z-score falls near zero and the p-value is not statistically significant, the null hypothesis of complete spatial randomness cannot be rejected[74].

Pattern status	z-score range	p-value range	Nearest neighbor ratio R	Interpretation
Significant clustering	$z < -2.58$	$p < 0.01$	$R < 1$	Significantly clustered at the 99% confidence level
Significant clustering	$-2.58 < z < -1.96$	$0.01 < p < 0.05$	$R < 1$	Significantly clustered at the 95% confidence level
Marginal clustering	$-1.96 < z < -1.65$	$0.05 < p < 0.10$	$R < 1$	Marginally clustered at the 90% confidence level
Random distribution	$-1.65 \leq z \leq 1.65$	$p \geq 0.10$	$R \approx 1$	No sufficient evidence to reject complete spatial randomness
Marginal dispersion	$1.65 < z < 1.96$	$0.05 < p < 0.10$	$R > 1$	Marginally dispersed at the 90% confidence level
Significant dispersion	$1.96 < z < 2.58$	$0.01 < p < 0.05$	$R > 1$	Significantly dispersed at the 95% confidence level
Significant dispersion	$z > 2.58$	$p < 0.01$	$R > 1$	Significantly dispersed at the 99% confidence level

Table 1. Interpretation criteria for Nearest Neighbor Index (NNI) based on R, z-score, and p-value.

Accordingly, this study summarizes the interpretation criteria used for NNI results in Table 1. It should be noted that this table is compiled by the author based on the output logic of the ArcGIS Average Nearest Neighbor Index tool and standard statistical significance thresholds, rather than reproduced directly from a single published source[74].

This study uses the "Average Nearest Neighbor Index tool in Spatial Statistics Tools module in the ArcGIS 10.1 platform to calculate the nearest neighbor index of 14 traditional villages in the Liaodong Peninsula to determine their spatial distribution characteristics. By statistically analyzing the observed nearest neighbor index distances and theoretical values of the villages, R values for traditional villages at different levels (overall, national, and provincial) are obtained, providing a basis for subsequent comparisons of distribution balance and interpretation of structural characteristics.

2.2.2 Standard Deviation Ellipse

The standard deviation ellipse is a spatial statistical tool widely used to characterize the distribution patterns of point features such as traditional villages. The fields listed in Table 2 provide quantitative measures of the spatial dispersion and directional trend of the point dataset, explained as follows:

1. CenterX and CenterY represent the geographic centroid coordinates (longitude and latitude or projected coordinates) of the distribution.
2. XStdDist and YStdDist measure the spatial dispersion along the major (long) and minor (short) axes of the ellipse, respectively, where larger values indicate greater spread.
3. Rotation specifies the orientation angle of the ellipse's major axis relative to the north, indicating the predominant directional trend.
4. Shape_Length and Shape_Area quantify the ellipse's perimeter and coverage area, reflecting the spatial extent and complexity of the distribution.

Collectively, these metrics enable a comprehensive understanding of the spatial morphology and orientation of traditional village clusters (See Table 2).

Field Name	Chinese Name	Meaning Explanation
CenterX	Ellipse Center X Coordinates	The coordinates of the center of gravity (center) of an ellipse in the east–west direction, usually in longitude or projected coordinates X values. It reflects the "geographic mean center" of the spatial distribution of villages in this category.
CenterY	Ellipse Center Y Coordinate	The coordinate of the center of gravity of the ellipse in the north–south direction, usually the latitude or projected coordinate Y value.
XStdDist	The standard deviation of the X-axis	Indicates the degree of spatial dispersion of village points in the major axis direction (long axis direction). Larger values indicate a more "elongated" spatial distribution. The unit is usually meters.
YStdDist	Y-axis standard deviation	Indicates the degree of dispersion of village points in the sub-axis direction (short-axis direction). The smaller the value, the more concentrated the distribution is on the major axis.
Rotation	Angle of	The angle (in degrees °) of the long axis of an ellipse relative

	rotation	to due north, usually counterclockwise. Reflects the directional trend of the overall distribution of villages.
Shape_Length	Perimeter of an ellipse	The length of the boundary line of an ellipse in meters, reflecting the "closeness" or "peripheral complexity" of the entire spatial extent.
Shape_Area	Area of the ellipse	The area of the standard deviation ellipse (in square meters) reflects the total amount of spatial extent "covered" by the distribution of villages in this category. The larger the value, the wider the distribution.

Table 2. Spatial distribution metrics of standard deviational ellipses and their definitions.

2.2.3 Kernel Density Analysis

Kernel density estimation (KDE) is a nonparametric density estimation method used to estimate the density function of a spatial distribution. This method primarily assesses the spatial characteristics of the clustering of traditional villages within a specific region by calculating the density of point elements within that region. Its main calculation formula is as follows:

$$f(s) = \sum_{i=1}^{n} \frac{1}{h^2} k(\frac{s - ci}{h}) \quad (1)$$

Where ***f(s)*** represents the kernel density function, $\boldsymbol{n}$ represents the number of points whose linear distance to point $\boldsymbol{s}$ is less than or equal to the bandwidth $\boldsymbol{h}$, $\boldsymbol{h}$ represents the bandwidth, and $\boldsymbol{k}$ represents the distance relationship between each element point $\boldsymbol{s}$ and the core point $\boldsymbol{ci}$. When applying this formula for detailed analysis, the following conclusion can be drawn: if a geographic event occurs anywhere within a village, its probability will vary depending on the location. Conversely, the probability of a geographic event is higher in village areas with dense point elements and lower in village areas with sparse point elements. This method calculates the point element density around each grid cell, displays the location of spatial point concentrations, and generates relevant data.

2.3 Quantitative Analysis of influencing factors

This section aims to answer three related questions: which factors are more important for the spatial distribution of traditional villages, whether their effects vary across space, and whether multiple factors may operate together in a nonlinear manner. To address these questions, this study combines Geographic Detector, GWR, and XGBoost-SHAP. Specifically, Geographic Detector is used to identify the explanatory power of individual factors and to test whether factor interactions are enhanced when combined; GWR is used to examine whether the influence of a factor varies across locations; and XGBoost-SHAP is introduced to capture more complex nonlinear effects, threshold responses, and interaction patterns that are difficult to detect using conventional statistical models. In this way, the influencing patterns of traditional villages can be examined from complementary perspectives rather than from a single model alone.

Driving factor analysis employs a combination of quantitative models, including geospatial detectors, spatial regression, and machine learning. Geospatial detectors are a statistical method based on spatial heterogeneity theory, which measures the magnitude of driving effects by calculating the explanatory power (q-value) of independent variables on the spatial differentiation of subsidiary variables [37,56]. This method does not rely on linear assumptions, is naturally robust to multicollinearity, and is suitable for identifying the individual and interactive effects of each factor. Regarding spatial regression, an ordinary least squares (OLS) regression model is first established as a foundation to test spatial autocorrelation; then, a spatial lag model or spatial error model is selected based on the Lagrange multiplier test to handle spatial dependence; furthermore, geographically weighted regression (GWR) or multi-scale GWR models are introduced to make the regression coefficients vary with spatial location, thereby analyzing the spatial non-stationarity of driving relationships [2,37,70,71]. For example, Liu et al. (2023) implemented decision trees and spatial lag models using Python and combined them with geospatial detectors to reveal the influence of 15 factors on village distribution and their interaction effects [41].

In this study, we divided the influencing factors into two categories: natural factors (environment (climate, topography, etc.)[63]), and human factors(population, economy and cultural resources[64], transportation on location[65]). After screening the correlation of each type of factor, we used GWR and Geographic Detector to conduct analysis. In plain language, GWR is used to test whether the same factor plays the same role everywhere, or whether its influence becomes stronger or weaker in different places, and the interactive detection module of Geographic Detector assessed the synergistic effect between factors, so as to comprehensively explore the driving pattern of multi-factor coupling[37,56].More specifically, GWR allows regression coefficients to vary spatially, thereby identifying local differences in the relationships between driving factors and village distribution.

2.3.1 Geographic Detector

Geographic Detector is used here to answer two related questions: which factors are more strongly associated with the spatial distribution of traditional villages, and whether the interaction between two factors enhances that explanatory relationship. In this study, the GeoDetector framework is mainly used to evaluate factor significance and interaction effects, while the correlation coefficient (R^2) is introduced as a supplementary indicator to reflect the relative strength of association between individual factors and village distribution.

Figures 2 and 3 present scatterplots for the Liaoxi Corridor and Liaodong Peninsula, respectively. In these figures, the horizontal axis represents the p-value produced by GeoDetector, indicating the statistical significance of each factor, while the vertical axis represents the correlation coefficient (R^2), indicating the relative strength of association between each factor and the spatial distribution of traditional villages. Each point corresponds to one influencing factor and is labeled accordingly, such as slope, NDVI, GDP, and road network density. In general, smaller p-values indicate higher statistical significance, whereas larger R^2 values indicate stronger associations with village distribution.

By combining these two dimensions, the figures provide an intuitive basis for comparing the relative importance of different factors in the two regions. Factors located in the upper-left part of the plot may be understood as having both relatively stronger associations and higher statistical significance, whereas factors with relatively high R^2 values but larger p-values should be interpreted more cautiously. On this basis, the subsequent interaction detector analysis can further reveal whether paired factors exhibit enhanced explanatory effects, thereby helping to clarify the coupled driving mechanisms behind the spatial distribution of traditional villages.

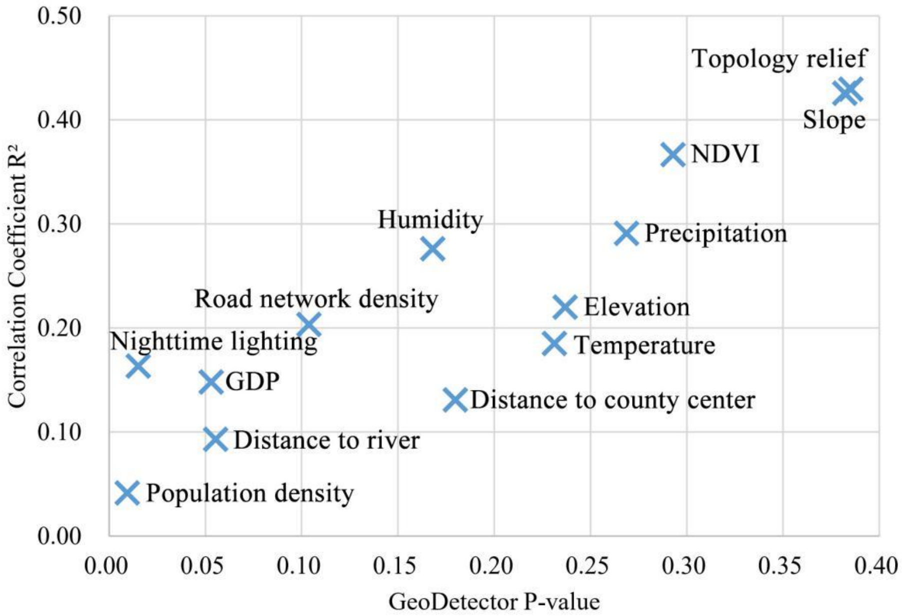

Figure 2. Scatterplot of factor significance and correlation strength in the Liaoxi Corridor.

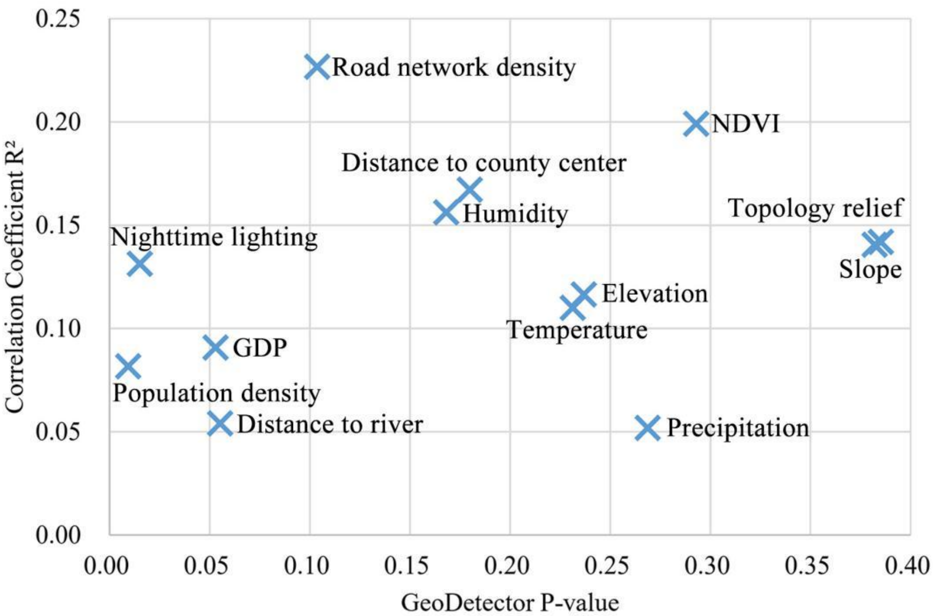

Figure 3. Scatterplot of factor significance and correlation strength in the Liaodong Peninsula.

2.3.2 XGBoost-SHAP Model

In plain language, the XGBoost-SHAP framework is introduced to answer how multiple factors jointly influence village distribution when their effects are nonlinear, conditional, or interactive, rather than simply linear and independent.

(1) Overview of Model Method: XGBoost (Extreme Gradient Boosting) is a gradient boosting algorithm based on decision tree ensemble, which has efficient parallel computing and regularization capabilities [73]. Compared with traditional GBDT, XGBoost performs second-order derivative approximation optimization on the loss function and introduces strategies such as shrinkage, thereby improving the model's ability to fit complex relationships and suppressing overfitting [73]. However, machine learning models are often criticized as "black boxes" and it is difficult to explain their internal patterns [74,75]. In order to improve the transparency of the model, the game theory-based interpretation method SHAP (Shapley Additive Explanations) has emerged in recent years. SHAP calculates the marginal contribution value of each feature to the model's prediction, thereby quantifying the interpretability of the model's decision-making process.

XGBoost+SHAP Interpretation Framework: Combining the XGBoost model with SHAP can extract the direction of influence, nonlinear response characteristics and interaction effects of each influencing factor on the distribution of traditional villages while obtaining high-precision fitting [68]. Specifically, XGBoost is first used to fit and predict the spatial distribution of traditional villages (such as village density or existence). Then, the SHAP value of each feature under each sample is calculated. These SHAP values reflect the degree of positive or negative influence and contribution of the features to the prediction results [74]. By averaging or summing the SHAP values of the entire sample, the global influence ranking of each feature (i.e., variable importance) can be obtained. In addition, the interaction decomposition of SHAP can quantify the interaction strength between two factors and draw an interaction influence "heat map" to reveal the synergistic or inhibitory effects on the distribution of traditional villages when two factors work together [74]. Compared with the traditional linear model, the XGBoost+SHAP method can identify implicit nonlinear relationships and interaction effects, such as finding the threshold inflection point of a certain environmental factor or the "double-edged sword" effect of transportation accessibility on village distribution, which is crucial for a deeper understanding of complex human-land relationships [74]. In summary, the unified machine learning framework of XGBoost+SHAP can fairly compare the influence patterns of traditional villages in the Liaoxi Corridor and Liaodong Peninsula on the same data basis. This method has both strong nonlinear fitting ability and clear interpretability, and has obvious advantages in comprehensively revealing the differences in the spatial pattern of traditional villages driven by multiple factors[74].

Reason for Method Selection:

This study does not rely solely on linear or semi-parametric models because the distribution of traditional villages is influenced by multiple natural and human factors whose effects are often nonlinear, conditional, and interdependent. In practice, factors such as elevation, slope, river proximity, precipitation, and accessibility may not exert monotonic effects; instead, they may exhibit threshold ranges, diminishing returns, or context-dependent interactions. Under such circumstances, conventional linear models may not adequately represent the complexity of the observed spatial associations.

Meanwhile, GeoDetector and GWR, although already employed in this study, serve different analytical purposes and cannot fully substitute for a machine-learning-based interpretive framework. GeoDetector is advantageous for measuring the explanatory power of factors and detecting interaction enhancement, whereas GWR is useful for examining spatial non-stationarity. However, these approaches are less capable of capturing complex nonlinear response surfaces and do not directly yield a unified contribution-based metric for cross-regional comparison.

Accordingly, XGBoost was selected because it can flexibly model nonlinear relationships and automatically learn interaction structures among predictors without imposing strict parametric assumptions. To address the interpretability problem typically associated with ensemble learning models, SHAP was further introduced to quantify the marginal contribution of each feature to model predictions. This combination enables the study to move beyond predictive accuracy alone and to interpret influencing patterns in terms of feature importance, directionality, nonlinear response, and pairwise interaction. In addition, because SHAP values are expressed within a unified additive framework, they provide an effective basis for comparing the influencing patterns of traditional villages between the Liaoxi Corridor and the Liaodong Peninsula. Thus, the XGBoost-SHAP framework constitutes a necessary methodological complement to the preceding GeoDetector and GWR analyses.

2.4 Differentiated Protection of Traditional Villages: Concept, Logic, and Types

"Differentiated protection" is not a homogenized approach under a unified standard, but rather a diagnosis based on the heterogeneity of the village's natural-ecological foundation, historical and cultural lineage, and contemporary development pressures. It precisely connects spatial evidence with policy tools, ensuring that the protected objects, boundaries, and methods are comparable, verifiable, and executable in different contexts. Its concept aligns with the international frameworks of "Historic Urban Landscape (HUL)" and "Authenticity/Integrity," namely, coordinating material heritage and natural factors, human factors, and community participation within the overall landscape and dynamic processes, thereby avoiding a "one-size-fits-all" approach and a tendency towards "static landscape" [1–3]. In the dual-zone comparison context of "inland corridor-coastal peninsula" in Liaoning Province, China, heterogeneity mainly stems from three mutually coupled main lines:

(a) Geographical morphology template: corridor (linear valleys and mountain passes) vs. peninsula (coastal protrusions and bay systems);

(b)Ecological and environmental constraints:topography-hydrology (slope/undulation, valley/alluvial fan) vs. climate-coastal interaction (sea breeze and salt spray, tides/storm surges, coastal ecological corridors);

(c) Socio-cultural patterns: land defense and post station network (border defense, passes, valley settlement chains) vs. maritime trade and port network (fishing and salt, commercial ports, sea worship culture). These differences are also evidenced in domestic regional-scale studies of traditional villages, manifested as significant clustering and spatial imbalance [9].

Accordingly, this study constructs a "factor-associated—interactive pattern—protection menu" mapping using multi-source spatial evidence (KDE, SDE, GeoDetector, GWR, XGBoost+SHAP) in Chapters 4–6, and proposes three types of operable protection (the following strategy points can be directly linked to the corresponding methodological evidence) [4–7,60]:

I. Corridor-Topography-Associated Type (Liaoxi)

Core Insight: The combination of topographic relief/slope, altitude, and distance from major rivers dominates village clustering, with valley axes forming the geometric framework of settlement zones (KDE/SDE shows a "ribbon-bead" pattern; GeoDetector and SHAP indicate the dominance of topographic indicators and their enhanced interaction with road networks/hydrology) [4,6,7,60]. Key Strategy Points: 1) Topographic Buffering: Implement tiered construction restrictions in the transition zone between the slope foot and alluvial fan to prevent the disruption of small-scale drainage patterns; 2) Valley Axis Maintenance: Maintain open visual corridors along the main valley axis and tributaries to preserve the continuous readability of the "path-village entrance-water system"; 3) Visual Control: Establish "key visual anchor points" at mountain promontory nodes, and include tall structures and their material colors in the visual corridor control list.

II.Peninsula-Ecological-Climate Dominant Type (Liaodong) Core Insights: Precipitation/temperature gradients and the integrity of the coastal ecosystem, along with NDVI, coastline morphology, and wind salt exposure, collectively shape village distribution (SHAP shows a high global contribution from ecological and climatic variables; the interaction with cultural resource density and road network density exhibits a "double-edged effect") [7,60]. Key Strategy Points: 1) Coastal Landscape Integrity: Establish a negative list based on the longitudinal continuity of "sea-beach-slope-village-field"; 2) Wind and Salt Exposure Mitigation: Deploy salt-tolerant and windproof multi-layered forest belts along the prevailing wind direction, and optimize facade materials and window opening ratios on the windward side; 3) Ecological-Cultural Belt Continuity: Couple the sea-worship sites, fishing and salt relics, and wetland corridors to form a joint protection unit of "cultural nodes-ecological corridors".

III. Urbanization-Squeezed Interface Type (Commonality of Two Zones) Core Insight: Urban expansion and proximity to transportation corridors create tension between "accessibility improvement - spatial compression - cultural dilution" (GWR shows the negative gradient effect of distance from the city center/main road; SHAP interactively indicates the nonlinear effect of "transportation × topography/ecology") [5,60]. Key Strategy Points: 1) Heritage Core Zoning: Establish a zoning and grading "value-intensity" matrix centered on the street network, courtyard layout, and key nodes (temples/archways/ancient wells); 2) Adaptive Reuse: Introduce low-disturbance, reversible functions (community museums, intangible cultural heritage workshops, cultural tourism); 3) Traffic Pressure Management: Establish "pedestrian priority zones + restricted traffic hours" on the periphery, protecting the street scale and living interface through detours and off-peak traffic.

2.4.1Methodological Integration and Process Implementation

This study constructs a closed loop of spatial statistics, causal induction, and strategy mapping to establish an operational process for differentiated protection:

1) Identification: KDE/SDE characterizes“where clustering/diffusion”and anisotropic patterns [4];

2) Attribution: GeoDetector quantifies“who dominates/who interacts”, and GWR captures “where it is stronger/weaker”[5–6];

3) Explanation: XGBoost+SHAP provides globally consistent interpretable evidence (clear paths of main effects and interaction effects) [7,60];

4) Mapping: Translates “dominant factors-interaction combinations” into “control items-spatial units-implementation tools”,and couples it with the multi-agent participation and monitoring and evaluation pattern under the HUL framework[1–3].

Through the above process, differentiated protection moves from a concept to an executable “menu-based, zoned, and threshold-based”policy toolkit, and achieves cross-regional comparability and verifiability under dual-zone comparison [1–3,60].

2.5 Overview of Regional Studies

There are very few systematic studies on the overall pattern of traditional villages in Liaoning Province. Tao et al. (2024) analyzed the distribution of traditional villages in Liaoning Province and found that they are generally clustered and highly uneven within the province: traditional villages are mainly concentrated in western Liaoning[35]. At the city and county level, Chaoyang, Jinzhou, Huludao, Panjin, Anshan, Dalian and other municipal districts have a large number of traditional villages[35]. It is worth noting that the study found that the standard deviation ellipse of traditional villages in Liaoning is oriented in the southwest-northeast direction, which is roughly consistent with the direction of the main mountain ranges in Liaoning; in terms of spatial density, the western part is a continuous belt along the southwest-northeast axis, while the central and eastern parts are scattered or clustered along the edge[36]. Analysis of influencing factors shows that natural factors of human settlement environment (such as topography, water source and climate) play a dominant role in the distribution of villages, while human factors show a complex influence with both positive and negative effects. Overall, this study fills the research gap at the regional level in Liaoning and also shows that this field still needs more detailed and in-depth analysis[35].

2.5.1 Study of Traditional Villages in the Liaoxi Corridor

The Liaoxi Corridor is located in western of Liaoning Province, with terrain more strongly associated with mountains and hills. Research by Cao and Kim (2025) indicates that the distribution of traditional villages in this region exhibits significant clustering and uneven distribution. Specifically, Cao et al. used the nearest neighbor index to find that the overall distribution of villages in the Liaoxi Corridor shows obvious spatial clustering (nearest neighbor index ratio R = 0.871, significantly less than 1), with traditional villages exhibiting a "point-like clustering" distribution characteristic, mostly concentrated in relatively flat and easily accessible areas, while the village density is very low in relatively remote peripheral areas. Standard deviation elliptic analysis further reveals that the traditional villages in the Liaoxi Corridor generally exhibit a distinct southwest-northeast zonal distribution, with a principal axis azimuth of approximately 63°[34,35]. This orientation is consistent with the valley topography and river orientation of the region, indicating that villages mostly extend linearly along valleys and basins. Studies suggest that natural topography (altitude, slope, etc.) constitutes the basic conditions for the selection of traditional villages, while the historical evolution of the "cultural corridor" and policy factors have macroscopically reinforced this southwest-northeast zonal distribution pattern [30].

2.5.2 Research on Traditional Villages in Liaodong Peninsula

The topography of Liaodong Peninsula is mainly low mountains, hills and plains, bordering the Bohai Sea and the Yellow Sea. Compared with the Liaoxi Corridor, research literature on traditional villages in Liaodong Peninsula is extremely scarce. Geographically, the distribution characteristics of traditional villages in this region may be different: due to the influence of coastal plains and urbanization, some villages may be concentrated in coastal plains or suburbs of cities (some studies have pointed out that there are many traditional villages in the Dalian and Anshan areas) [36]; at the same time, the peninsula has a low and small topography, and the direction of large valleys has a weaker restriction on the distribution of villages. Overall, traditional villages in Liaodong Peninsula may be more distributed in patches, and are greatly affected by the maritime climate, transportation network and economic development, rather than forming a significant zonal cluster along the mountains like in the Liaoxi Corridor. Due to the current lack of detailed research on the Liaodong Peninsula, the spatial distribution characteristics and driving patterns of traditional villages in this region require further investigation in this study.

2.6 Literature Review and Research Innovation

The review of existing literature reveals that research on the geography of traditional villages has achieved certain results: most studies use a combination of GIS spatial analysis and econometric models to reveal the distribution patterns and influencing patterns of villages [7,69]. The conclusions emphasize the complex coupling effect of natural and social factors, such as the fundamental influence of natural conditions like water systems, topography, and climate on the spatial pattern of traditional villages, and the mediating role of human factors such as population, transportation, and cultural heritage [7,26]. However, regional-level research still has limitations: systematic comparative studies of Liaoning Province and its various regions (Liaoxi and Liaodong) are very scarce, with most limited to small-scale sampling or single-scale analysis. This study aims for innovation based on previous work. Firstly, it provides the first systematic comparative analysis of the spatial patterns of traditional villages in two typical regions: the Liaoxi Corridor and the Liaodong Peninsula, filling a gap in our understanding of the differences in the distribution of traditional villages in the northern "belt-shaped" transitional zone and coastal edge areas. Secondly, it comprehensively applies various spatial statistical methods, such as kernel density analysis, hotspot analysis, and standard deviation ellipse, combined with tools like geographic detectors, to quantitatively assess the influence of natural environmental factors (e.g., topography, altitude) and human factors (e.g., population density, accessibility, and cultural heritage distribution). This study will also explore the similarities and differences in the site selection preferences (e.g., proximity to water sources, low-altitude areas) of traditional villages in the study area. In conclusion, this study expands upon research methods and regional perspectives, providing a scientific basis for the classification, protection, and spatial planning of traditional villages.

Overall, this study contributes to the literature in three aspects. First, it develops a comparative framework for analyzing traditional villages in the Liaoxi Corridor and the Liaodong Peninsula. Second, it integrates GIS spatial analysis, GeoDetector, GWR, and XGBoost-SHAP into a unified analytical framework to examine spatial patterns, factor effects, spatial heterogeneity, and nonlinear relationships in a complementary way. Third, it links comparative empirical evidence with differentiated protection and planning strategies. Therefore, the study contributes to both the regional comparison and the methodological advancement of traditional village research in Liaoning Province.

Chapter 3
Data Sources and Research Methods

3.1 Data Acquisition and Preprocessing

This study first constructed a multi-source spatial database. The geographic coordinates of the research objects (traditional villages and related settlements) were obtained from the national list of traditional villages, provincial list, statistical yearbooks and online map platforms, and were uniformly projected and verified in GIS [2,68,69]. The driving factor data covers multi-dimensional indicators such as natural environment, human factors and cultural resources, including: topographic factors (such as elevation, slope and aspect) calculated using digital elevation model (DEM) [34]; climate factors (annual precipitation, annual average temperature, etc.) from meteorological yearbooks and interpolated by GIS [36]; traffic accessibility factors (Euclidean distances from villages to major highways and towns calculated based on OpenStreetMap road data, etc.) [36]; human factors (population density, GDP, etc.) and cultural heritage factors (distribution of intangible cultural heritage, density of cultural relics and historical sites, etc.) [78]. All spatial data were unified in coordinate system under the ArcGIS platform and underwent cleaning and standardization processes, such as removing duplicate coordinate points, filling missing values, and making data of different dimensions comparable through z-score standardization or range normalization [2,36]. In addition, multicollinearity diagnosis of driving factor data was performed using tools such as Python and SPSS to remove highly correlated redundant indicators, thereby improving the robustness of subsequent modeling and analysis [79,80,81].

3.1.1 Data Sources and Research Objects

This study selected 33 national-level traditional villages and 19 provincial-level traditional villages in the Liaoxi Corridor identified between 2012 and 2024 as research objects (see Table 3) and 7 national-level traditional villages and 7 provincial-level traditional villages in the Liaodong Peninsula as research objects (see Table 4). The geographical coordinates of the villages were determined as follows: a 1:500,000 vector map of Liaoning Province with map approval number GS(2019)3266 was used as the base map, combined with Baidu Maps place name search and Google Geographic Information System (Google GIS). This study uses ArcGIS 10.1 as the technical platform to construct a spatial attribute database of traditional villages in the Liaoxi Corridor. Traditional villages are treated as point elements, and a series of geographic information technology analyses and processing are carried out using GIS spatial analysis technology.

Name	City	County/District	Town/Street	Level
Longgangzi Village	Jinzhou	Beizhen City	Futun Subdistrict	National
Xinbaozi Village	Huludao	Suizhong County	Lijiapu Township	National
Xiaojiadian Village	Chaoyang	Chaoyang County	Yangshan Town	National
Tangzhangzi Village Bapangou	Chaoyang	Chaoyang County	Beisijiazi Township	National
iansuo Village	Huludao	Suizhong County	Qiansuo Town	National
Shangkouzi Village	Panjin	Dawa County	Xi’an Town	Provincial
Desheng Village	Panjin	Panshan County	Desheng Town	Provincial
Gaoqibao Village	Jinzhou	Beizhen City	Baojia Township	Provincial
Sujiayingzi Village	Chaoyang	Chaoyang County	Qidaoling Town	Provincial
Zhangjiyingzi Village	Chaoyang	Chaoyang County	Heiniuyingzi Township	Provincial
Baiyin’aili Village	Chaoyang	Kalaqin Left Wing Mongol Autonomous County	Nanshao Subdistrict	National
Kangguan Village	Chaoyang	Lingyuan City	Songzhangzi Town	Provincial
Guozhangzi Village	Chaoyang	Lingyuan City	Liuzhangzi Township	Provincial
Shaoguodi Village	Chaoyang	Lingyuan City	Daoerdeng Town	Provincial
Laoxigou Village	Chaoyang	Jianping County	Heishui Town	Provincial
Dongguan Branch	Chaoyang	Kalaqin Left Wing Mongol Autonomous County	Guandahai Management Area	Provincial
Shuangta Village	Jinzhou	Beizhen City	Beizhen Subdistrict	Provincial
Dayi Village	Jinzhou	Beizhen City	Dashi Town	Provincial
Fosi Village	Fuxin	Fuxin Mongol Autonomous County	Fosi Town	National
Yamen Village	Fuxin	Fuxin Mongol Autonomous County	Daban Town	Provincial
Wangfu Village	Fuxin	Fuxin Mongol Autonomous County	Wangfu Town	Provincial
Bajiazi Village	Chaoyang	Chaoyang County	Wangyingzi Township	Provincial

Er’angou Village	Chaoyang	Lingyuan City	Goumenzi Town	National
Lieshanliang Village	Chaoyang	Lingyuan City	Sanshijiazi Town	National
Xidazhangzi Village	Chaoyang	Chaoyang County	Liucheng Town	National
Sandaogou Village	Chaoyang	Chaoyang County	Xiwujiazi Township	National
Fengzhangzi Village Baicaogou	Chaoyang	Chaoyang County	Shangzhi Township	Provincial
Xindi Village	Chaoyang	Chaoyang County	Xiwujiazi Township	National
Sanjuxing Village	Chaoyang	Beipiao City	Shangyuan Town	National
Botaigou Village	Chaoyang	Beipiao City	Daban Town	National
Pandaogou Village	Huludao	Lianshan District	Tashan Township	National
Wangjiadian Village	Huludao	Suizhong County	Jiabeiyan Township	National
Sanjia Village	Chaoyang	Chaoyang County	Shengli Town	National
Wujiazi Village	Chaoyang	Kalaqin Left Wing Mongol Autonomous County	Gongyingzi Town	Provincial
Sunjiadian Village	Chaoyang	Chaoyang County	Shengli Town	National
Nanwa Village	Chaoyang	Chaoyang County	Bolochi Town	Provincial
Sanfu Village	Chaoyang	Beipiao City	Xiafu Development Zone	National
Xigou Village	Huludao	Suizhong County	Yong’an Township	National
Shifo Village	Jinzhou	Beizhen City	Futun Subdistrict	National
Huashan Village	Jinzhou	Beizhen City	Dashi Town	National
Tianshenghao Village	Chaoyang	Lingyuan City	Sanjiazi Township	Provincial
Huzhangzi Village	Chaoyang	Lingyuan City	Sandaohazi Township	Provincial
Shimengou Village	Chaoyang	Lingyuan City	Qianjin Township	Provincial
Xiaowopu Village	Chaoyang	Lingyuan City	Siguanyingzi Town	National
Shierguanyingzi Village	Chaoyang	Lingyuan City	Wulanbai Town	National
Jinlingsi Village	Chaoyang	Beipiao City	Daban Town	National
Banjita Village	Jinzhou	inghai City	Banjita Town	National
Mangniutun Village	Jinzhou	inghai City	Cuiyan Town	National
Huangmuzhangzi Village	Huludao	Suizhong County	Jiabeiyan Township	National
Xitai Village	Huludao	Xingcheng City	Sandaogou Township	National
Danian Village	Jinzhou	inghai City	Shenjiatai Town	National
Miliying Village	Chaoyang	Beipiao City	Baoguolao Town	National

Table 3. Roster of research subjects(Liaoxi Corridor)

Name	City	County/District	Town/Street	Level
Dong Shequ	Dalian	Zhuanghe City	Qingdui Town	Provincial
Xi Shequ	Dalian	Zhuanghe City	Qingdui Town	Provincial
Xinchengzi Village	Benxi	Benxi Manchu Autonomous County	Dongyingfang Township	Provincial
Tongjiang Village	Dandong	Kuandian Manchu Autonomous County	Xialuhe Township	National
Xialin Village	Anshan	Haicheng City	Ximu Town	Provincial
Beici Village	Anshan	Xiyuan Manchu Autonomous County	Chaoyang Town	Provincial
Ronghua Village	Dalian	Zhuanghe City	Ronghuashan Town	Provincial
Gushao Stone Village	Anshan	Haicheng City	Ximu Town	Provincial
Dingziyu Village	Anshan	Xiuyan Manchu Autonomous County	Shimiaozi Town	National

Hekou Village	Dandong	Kuandian Manchu Autonomous County	Changdian Town	National
Xutun Village	Dalian	Wafangdian City	Xutun Town	National
Dongmatun Village	Dalian	Wafangdian City	Xutun Town	National
Lianshanguan Village	Benxi	Benxi Manchu Autonomous County	Lianshanguan Town	National
Dongdayu Village	Dandong	Donggang City	Gushan Town	National

Table 4. Roster of research subjects（Liaodong Peninsula）.

To explore the factors influencing the spatial distribution of traditional villages in the Liaoxi Corridor and Liaodong Peninsula, this study selected 13 natural and human factors (see Table 5). Among them, 8 natural factors were selected from the dimensions of topography, climate, and environment; and 5 human factors were selected from the dimensions of population, economy, and transportation location. All data in this study were processed using the Arc Toolbox / Spatial Analyst Tools / Zonal / Zonal Statistics tools in ArcGIS 10.3. Subsequently, the processed Excel data was imported into the vector data of the study area through the Join function to construct an impact factor index database, thereby realizing the quantification and spatialization of natural and human factors [77,107,115,133,134].

Class I	Class II	Indicators	Data Source
Natural Factors	Terrain Factors	Elevation	
		Slope	http://www.gscloud.cn
		Surface relief	
	Climate Factors	Temperature	
		Precipitation	http://www.resdc.cn
		Humidity	
	Environmental Factors	Distance to water system	http://ngcc.sbsm.gov.cn/
		NDVI	http://www.resdc.cn
Human Factors	Population and Economy	Population density	
		Night lighting	http://www.resdc.cn
		GDP	
	Transportation Location	Road network density	http://ngcc.sbsm.gov.cn/
		Distance to city center	

Table 5. Data sources and descriptions.

3.2 Analysis of Influencing Factors

Further analysis shows that natural geographical conditions are the key driving factor for the spatial distribution of traditional villages [45,67]. The topographic relief (such as slope and surface undulation) of the Lingxi Corridor has the highest correlation with village distribution, indicating that hilly terrain and topographic barriers provide villages with a relatively independent living environment [36]. At the same time, vegetation cover (NDVI) is positively correlated with village density, and dense forest and grassland resources are conducive to the sustainable development of villages [7,8]. In contrast, climate factors have a weak correlation with village distribution, while the correlation coefficient of modern human factors (population density, GDP, etc.) is low or even negative (|R|<0.2), indicating that contemporary economic development has a limited impact on the spatial pattern of traditional villages. Historical and cultural factors are also indispensable: the Liaoxi Corridor has been an important route for the integration of northern ethnic groups and military operations since ancient times. Historical processes such as immigration and settlement, border reclamation, and ethnic integration have profoundly influenced the site selection and evolution of villages. In summary, multiple factors, including topography, ecological environment, human factors, and historical culture, have collectively shaped the spatial distribution pattern of traditional villages in the Liaoxi Corridor:

Topographic factors: The degree of topographic relief is highly correlated with village distribution [36]. The Liaoxi Corridor is mostly composed of low mountains and hills, with traditional villages mainly located at the foot of mountains and in gentle river valleys at low to medium altitudes. These areas avoid the risk of flooding in low-lying areas and have relatively warm and humid climates, suitable for agricultural production and habitation. In addition, the complex topography also isolates high-altitude villages, protecting some historical relics; while in the plains, transportation is convenient and economic development is rapid, leading to the gradual replacement of traditional villages by modern towns and infrastructure.

Climate and ecological factors: Studies have shown that vegetation cover (NDVI) is significantly positively correlated with village distribution. The southern part of the Liaoxi Corridor is influenced by the ocean monsoon, resulting in a higher average annual temperature; the northern plateau area is cooler and has abundant rainfall [7,8]. This north-south difference in climate and ecological conditions, as well as the ecological gradient at different altitudes within the region, provides a diverse natural environmental basis for village distribution.

Socioeconomic factors: Contemporary population and economic indicators have little impact on the distribution of traditional villages[15]. Geographic detector analysis results show that the correlation coefficients between economic variables such as population density and GDP and the spatial distribution of villages are extremely low (almost no statistical impact). This indicates that current urbanization and industrial development have a greater impact on emerging settlements and a smaller impact on the existing pattern of traditional villages.

Historical and cultural factors: As an ancient transportation route and ethnic convergence area, the Liaoxi Corridor has seen many villages initially located due to historical migrations, border defense settlements, and ethnic integration. This profound cultural heritage not only affects the spatial distribution of villages but is also reflected in traditional architectural styles and village layouts[35]. In conclusion, the interaction between natural geography and human history drives the spatial layout of traditional villages in the region[82,83,84].

Chapter 4 Spatial Distribution Characteristics and Influencing Factors of Traditional Villages in the Liaoxi Corridor

4.1 Spatial Distribution Characteristics of Traditional Villages in the Liaoxi Corridor

4.1.1 Spatial Distribution Types

Figure 4 shows the spatial distribution pattern of traditional villages in the Liaoxi Corridor, covering the distribution of national and provincial-level traditional villages in various prefecture-level cities (Chaoyang, Jinzhou, Huludao, Fuxin, and Panjin). The study found that the distribution of villages in different cities in the Liaoxi Corridor is significantly uneven. Chaoyang City has 31 traditional villages, accounting for 59.6% of the total; Jinzhou City has 9 (17.3%); Huludao City has 7 (13.5%); Fuxin City has 3 (5.8%); and Panjin City has only 2 (3.8%). Overall, traditional villages exhibit significant spatial clustering characteristics, with hierarchical differentiation and regional unevenness in their distribution. National-level traditional villages (red dots) are more densely distributed within the study area, especially forming relatively obvious clusters in Chaoyang City and Jinzhou City, while provincial-level traditional villages (blue dots) are relatively scattered, mostly distributed in areas on the edge of the region, with complex terrain and relatively inconvenient transportation.

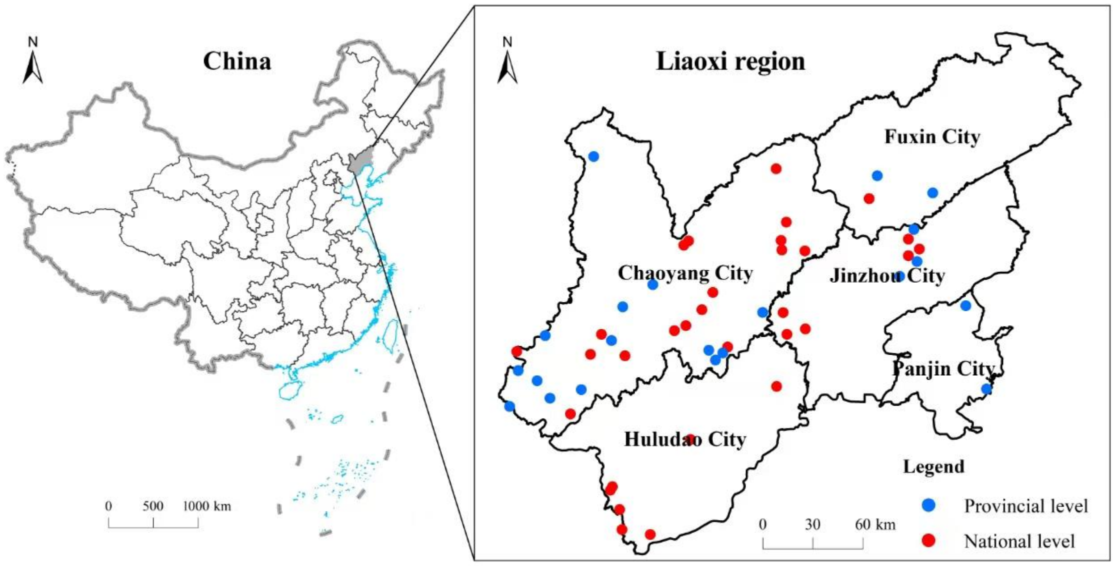

Figure 4. Distribution of traditional villages in the Liaoxi region.

Further observations reveal that the spatial distribution of villages is closely related to the natural geographical environment and the historical and cultural development of the region. For example, in Chaoyang City, due to its relatively flat terrain and long agricultural history, the area not only has a large number of traditional villages, but also a significantly higher proportion of national-level villages compared to other urban areas. In contrast, the distribution of traditional villages in Fuxin City and Panjin City exhibits a point-like, isolated pattern with weak spatial connectivity due to different natural conditions or recent development intensities. Overall, the spatial distribution of national and provincial-level villages shows a "core-periphery" pattern at the geographical scale, reflecting the complexity of the coupling between natural and human elements in the region [63,82,83,84].

4.1.2 Balanced Spatial Distribution

Based on the results of the nearest neighbor index analysis (Table 6), the spatial distribution of traditional villages in the Liaoxi Corridor shows clustering characteristics. Specifically, the average observed distance of all traditional villages is 15.136 km, the theoretical average distance is 17.374 km, and the nearest neighbor index R = 0.871 (<1), significantly lower than the critical value for random distribution, indicating that these villages have obvious spatial clustering and are in a non-equilibrium distribution state.

Village Type	Mean Observed Distance (km)	Expected Mean Distance (km)	Nearest-Neighbor Index R	Z-score	P-value:
Total	15.136	17.374	0.871	-1.776	0.075
National level	16.097	16.273	0.989	-0.115	0.908
Provincial level	24.139	22.437	1.076	0.665	0.505

Table 6. Average nearest-neighbor distance and index.

Further comparison revealed differences in the spatial organization characteristics of traditional villages at different levels (see Table 6): the R-value of national-level villages was 0.989, approaching a random distribution, indicating that their site selection prioritized cultural representativeness and balanced distribution, with insignificant spatial clustering; the R-value of provincial-level villages was 1.076, greater than 1, exhibiting a certain degree of dispersion, suggesting a more dispersed geographical distribution, possibly influenced by geographical barriers or historical migration routes.

Overall, influenced by natural topography, cultural corridors, historical development, and policy selection patterns, the spatial distribution of traditional villages in the Liaoxi Corridor is not uniform, but rather exhibits a spatial pattern of "clustered but uneven" and "point-like clustering." Villages are more densely distributed in areas with suitable terrain and convenient transportation, while they are sparsely distributed in peripheral areas. This spatial unevenness provides a basis for subsequent regional classification protection and spatial optimization planning [80,86,87,88].

4.1.3 Spatial Distribution Directionality

Standard deviation ellipse analysis results show that the overall distribution center of traditional villages in the Liaoxi Corridor is located at 120.39°E, 41.23°N, with a principal axis azimuth of approximately 63°, trending northeast to southwest. Specifically, the major axis of the ellipse for national-level villages is 109.91 km with an azimuth of 47°; the major axis of the ellipse for provincial-level villages is 140.79 km with an azimuth of 76°. This indicates that provincial-level villages have a wider spatial distribution range and stronger extension (Table 7). While provincial-level villages have a wider spatial distribution range and stronger extension, national-level villages are more concentrated. The standard deviation ellipse of the overall distribution (Figure 5) clearly depicts the central location and principal axis direction of the village spatial layout: the ellipse has a narrow, elongated shape trending southwest to northeast, indicating that the villages extend in a strip along this direction. The center of the ellipse (centroid) is located slightly south of the study area, close to the main village cluster. This area has relatively flat terrain and favorable resource conditions, making it the geographical center of the village layout in the entire region. The fact that the major axis is much longer than the minor axis means that, compared to the vertical direction, the villages are more dispersed and have a larger span along the main axis, exhibiting significant anisotropic characteristics in their spatial pattern.

Village Type	CenterX	CenterY	XStdDist	YStdDist	Rotation	Shape_Length	Shape_Area
Total	120.3907	41.2349	120,229.0213	59,399.8127	63.03°	580,597.3786	22,433,800,775
National Level	120.3873	41.1922	109,907.4401	51,136.0609	47.20°	522,901.6645	17,654,634,966
Provincial	120.3957	41.2979	140,794.9502	53,305.5949	76.11°	641,129.2285	23,574,656,648

Table 7. Standard deviation ellipse data table(Liaoxi).

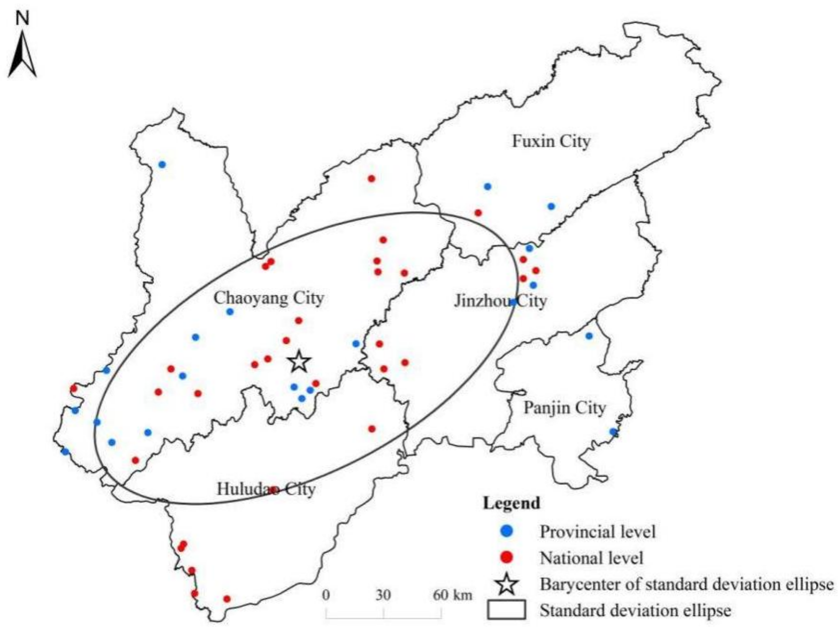

Figure 5. Standard deviation ellipse of overall village distribution(Liaoxi).

The aforementioned spatial characteristics are not accidental, but rather the result of the combined effects of multiple factors. For example, some studies have pointed out that in some mountainous villages, settlements are often distributed linearly along major transportation routes and concentrated in flat areas at lower altitudes, which is similar to the situation in the study area. In the Liaoxi Corridor, the river valley corridors and basins between mountains and hills provide villages with resources such as land and water. Villages are mostly distributed in valleys with gentler slopes and more usable land. At the same time, natural environmental factors such as topography (altitude, slope) determine the basic pattern of village distribution[38], while humanistic and social factors such as traditional ethnic settlement customs, modern rural construction, and policy intervention further strengthen the spatial form of villages clustering along major corridors. In other words, the natural environment is the "foundation" of the village spatial structure, humanistic culture is the internal driving force, and planning policies are the external driving force. The three together shape the northeast-southwest strip distribution pattern of traditional villages in the Liaoxi Corridor.

This linear spatial pattern provides important insights for rural planning and governance. On the one hand, in terms of infrastructure and resource allocation, we should follow the direction of the linear distribution of villages: the main roads, water supply and power supply and other infrastructure should be laid out along the northeast-southwest axis, while strengthening the construction of horizontal roads and public transportation in the vertical direction to improve the accessibility and connectivity of villages at both ends of the linear area. On the other hand, in terms of the equalization of public services, we need to pay attention to the service imbalance caused by linear distribution. Some studies have pointed out that we should coordinate the regional development, set up high-level public service facilities in the main settlement areas, and set up basic services in remote villages to balance efficiency and fairness[83]. Finally, in terms of cultural heritage protection, linear distribution brings both opportunities for centralized protection and challenges for decentralized protection. If there are traditional village cultural resources clustered along the axis in the study area, we can consider building a cultural tourism corridor along the northeast-southwest direction to implement contiguous protection or overall development of villages clustered along the line; at the same time, we should also pay attention to villages scattered outside the axis and prevent them from declining due to being isolated from hot spots through individual measures. As Wu et al. stated, a comprehensive understanding of the spatiotemporal patterns of traditional villages across multiple scales is of great significance for protecting traditional culture, revitalizing traditional villages, and achieving sustainable urban and rural development [89].

The standard deviation ellipse of the distribution of national-level traditional villages (Figure 6, Table 7) shows a more concentrated distribution pattern. Although the ellipse of national-level villages is aligned with the ellipse of the overall villages (both are southwest-northeast), its area is smaller, its dispersion is lower, and the center of the ellipse is significantly biased towards the Jinzhou area. This indicates that the spatial center of gravity of national-level traditional villages does not completely coincide with the spatial center of gravity of all villages. One study pointed out that traditional villages in China generally exhibit a distribution pattern of "more in the east and less in the west" [78]. This pattern is caused by multiple factors: (1) Topographic factors: National-level traditional villages are mostly distributed in alluvial plains and low hilly areas, which are prone to forming contiguous settlements (compared to the western high mountain areas); (2) Transportation factors: Areas with convenient transportation are more likely to form settlement belts; (3) Economic and cultural factors: Areas with more developed economies and rich cultural heritage are more likely to produce national-level villages [88]. Furthermore, due to the stringent selection criteria and limited number of villages included in the national-level traditional village list, local governments often prioritize the promotion and protection of a few representative villages (such as those surrounding Jinzhou), further exacerbating the spatial clustering of national-level villages. Overall, the distribution of national-level traditional villages exhibits directional characteristics similar to that of villages as a whole, but is also more concentrated and smaller in scale. This clustering pattern offers important insights for village planning: more infrastructure and public service resources should be invested in core cluster areas; while traditional villages in surrounding remote areas should not be neglected and need to be supported through differentiated policies to avoid creating "protection islands."

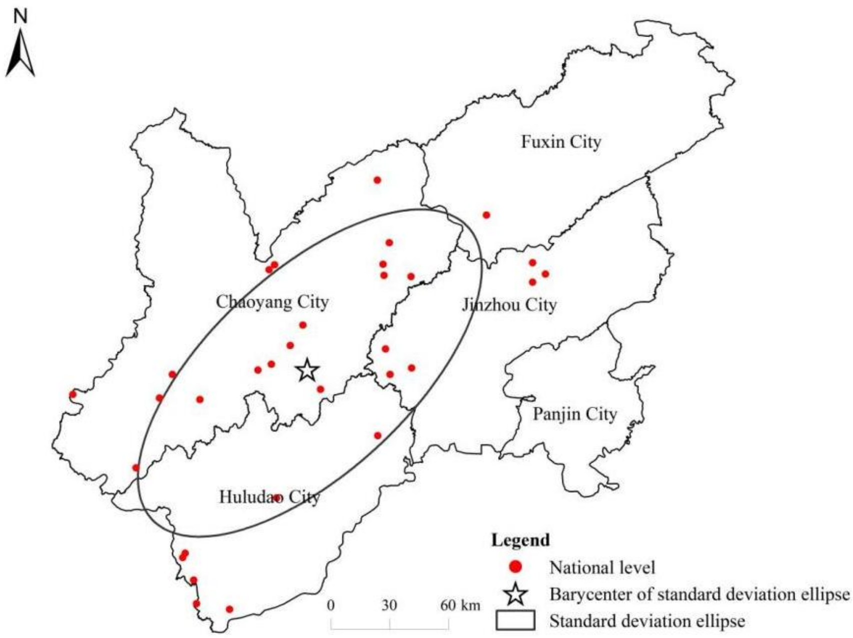

Figure 6. Standard deviation ellipse of national-level village distribution(Liaoxi).

The standard deviation ellipse of the distribution of provincial villages (Figure 7, Table 7) shows a wider coverage and similar directional trends. The standard deviation ellipse of provincial villages has a larger coverage area and a longer major axis, and it runs in a southwest-northeast direction. Its center of gravity is basically consistent with the center of the overall distribution of villages, indicating that provincial villages generally cover the main agglomeration areas. Compared with national villages, provincial villages are more numerous and more dispersed, usually located in economic centers, plains and hills. This distribution feature is influenced by natural, economic and social conditions. For example, a large number of villages are often concentrated in major river valleys and plains, and all cities and counties have the intention to apply for provincial villages, ultimately forming a spatial pattern that roughly matches the population distribution and transportation network [14,91]. It can be seen that the distribution of provincial villages not only shows directional agglomeration characteristics, but also has a wider geographical coverage. In rural planning, this feature means that infrastructure and public services need to be allocated in a more balanced way over a wider area: it is necessary to strengthen the service supply to the main agglomeration areas, and also to extend the service scope to the dispersed areas to avoid regional development imbalances. At the level of cultural heritage protection, given the large number and wide distribution of provincial villages, a strategy of “combining concentration and decentralization” should be adopted: regional protection and joint development can be implemented in densely populated village areas, while differentiated protection plans should be formulated for scattered villages to ensure the fairness and comprehensiveness of cultural heritage protection [92].

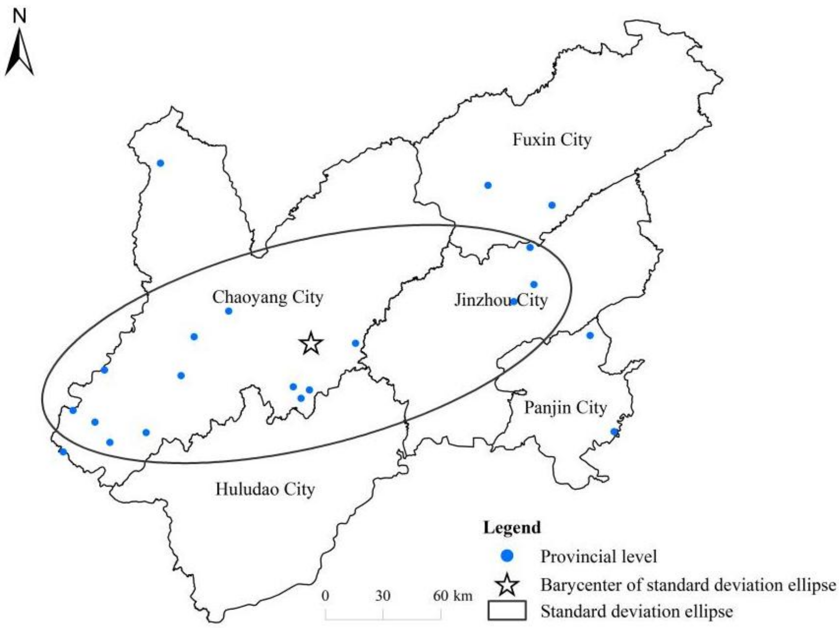

Figure 7. Standard deviation ellipse of provincial village distribution(Liaoxi).

4.1.4 Spatial Distribution and Clustering Characteristics

Using the kernel density analysis tool in ArcGIS 10.1, kernel density estimation was performed on 52 traditional villages in the Liaoxi Corridor, and a kernel density distribution map of traditional villages in the Liaoxi Corridor was drawn (Figure 8, Table 8). The results show that the traditional villages in this region are mainly concentrated in two high-density "hotspot" areas, located in Chaoyang County and Beizhen City respectively. The Daqingshan Mountains in northern Chaoyang County have an elevation of over 1000 meters, with the main peak at approximately 1153 meters; Yiwulü Mountain, where Beizhen City is located, is one of China's five major sacred mountains. Overall, these high-density clusters are mostly located in the foothills and hilly areas. Due to the relatively lagging transportation development and limited economic development in these areas, external interference with traditional villages has been reduced to some extent, which helps to protect the integrity and continuity of the villages.

	Classification	Quantity	Average	Min	Max	List
1	0-10	7	7.0470	6.3425	9.9030	Shangkouzi Village, Desheng Village, Laoxigou Village, Yamen Village, Pandaogou Village, Xitai Village, and Miliying Village
2	10-20	19	16.3410	11.2558	19.8958	Xinbaozi Village, Qiansuo Village, Sujiayingzi Village, Kangguan Village, Fosi Village, Wangfu Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Xindi Village, Sanjuxing Village, Wangjiadian Village, Wujiazi Village, Nanwa Village, Sanfu Village, Tianshenghao Village, Huzhangzi Village, Mangniutun Village
3	20 and above	26	25.8243	20.1914	32.9528	Longgangzi Village, Xiaojiadian Village, Tangzhangzi Village, Bapangou, Gaoqibao Village, Zhangjiyingzi Village, Baiyinaili Village, Guozhangzi Village, Shaoguodi Village, Dongguanfenchang, Shuangta Village, Dayi Village, Bajiazi Village, Fengzhangzi Village, Baicaogou, Botaigou Village, Sanjia Village, Sunjiadian Village, Xigou Village, Shifo Village, Huashan Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Banjita Village, Huangmuzhangzi Village, Danian Village

Table 8. The overall village kernel density.(Liaoxi)

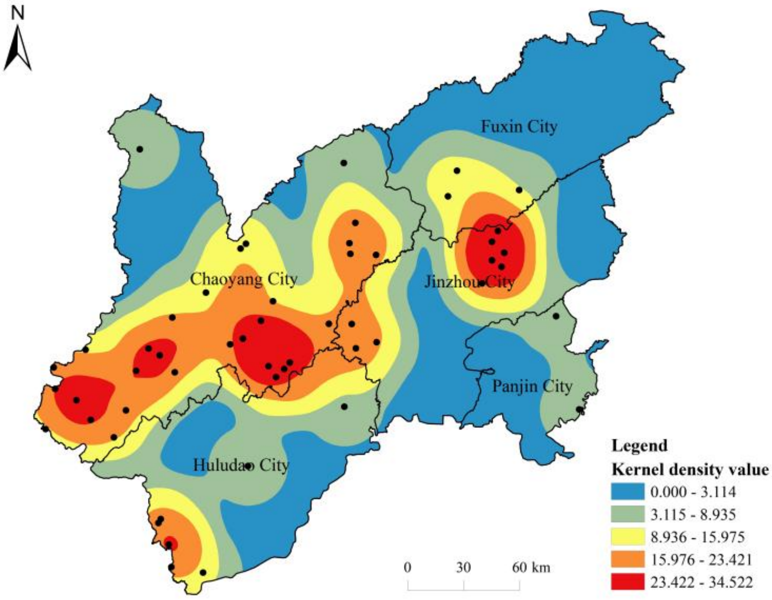

Figure 8. The overall village kernel density map(Liaoxi).

Furthermore, Beipiao City and Kazuo County (Kazuo County) together constitute a secondary high-density area. Beipiao City is known as the "Hometown of Chinese Folk Art," and its rich folk legends are listed as national intangible cultural heritage. Kazuo County is known as the "Hometown of Golden Tripods," and as a typical Mongolian autonomous county, the Mongolian population accounts for about one-fifth of the county's total population. This profound historical and cultural heritage has laid a solid foundation for the protection of local traditional villages. The results of kernel density analysis present the concentration of village distribution in a smooth manner, highlighting the high-density hotspots of traditional villages in the region (Figure 8 shows high kernel density values in warm colors). A clear high-density cluster zone has formed in the Jinzhou radiation zone and some hilly areas in the southwest; conversely, the kernel density values in the northwestern part of the Liaoxi Corridor and its eastern edge are close to zero (shown in cool colors), meaning that there are almost no traditional villages in these areas. This density distribution pattern quantitatively confirms the highly concentrated characteristics of village distribution: only a few areas have formed significant cluster centers, while the village density in most areas is extremely low, showing a strong "hotspot-colds" differentiation in space. This spatial clustering phenomenon stems from both the influence of natural geographical conditions (e.g., mountainous terrain hinders external transportation, reducing the penetration of modernization) and the settlement pattern shaped by historical transportation corridors and multi-ethnic cultural exchanges [93]. Traditional villages in highly concentrated areas often retain relatively complete spatial textures and cultural traditions, which helps to form stable clan networks, handicraft inheritance systems, and folk belief systems, which are important carriers of regional cultural heritage protection [94].

However, the coexistence of high concentration and high dispersion also brings prominent issues regarding spatial equity: although high-density areas have great potential for protection and development, resource investment and tourism development may be overly concentrated there, while low-density areas are often neglected due to a lack of economies of scale, facing the dual dilemma of insufficient protection funds and backward infrastructure [94]. This "hot spot-cold spot" spatial pattern reflects the imbalance in rural planning and public resource allocation. It is necessary to formulate a tiered infrastructure construction plan and protection strategy in future planning to ensure that different types of traditional villages can receive appropriate development support and promote coordinated urban and rural development [95].

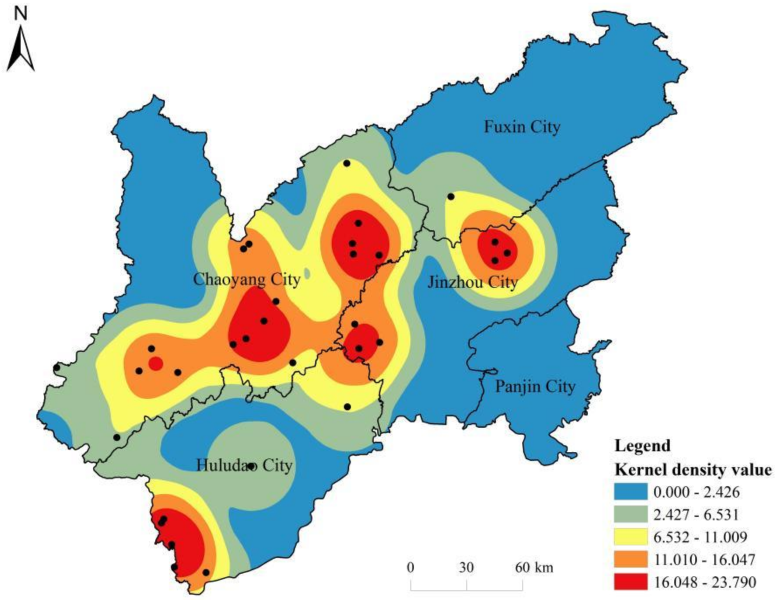

Figure 9. Kernel density distribution map of national-level villages(Liaoxi).

Further comparison of the spatial clustering of villages at different levels using kernel density analysis reveals a more concentrated trend in the kernel density distribution of national-level traditional villages (Figure 9). Due to the relatively small number of national-level villages, their kernel density maps only show a few prominent hotspots: the highest density values are concentrated in a very few core areas (such as the area around Jinzhou, near Chaoyang, and the southwestern end of the corridor), which have become the main clustering centers of national-level villages; while in most areas of the study region, the kernel density of national-level villages is almost zero. This means that, apart from the hotspot areas, most areas of the Liaoxi Corridor have almost no national-level traditional villages. Compared to the overall village kernel density distribution, national-level villages exhibit higher spatial concentration and fewer hotspots, reflecting a certain degree of bias in the protection resources or policy investment in this region—villages on the national protection list are often concentrated in specific advantageous areas. This highly concentrated "center-periphery" pattern reflects the priority and selectivity of the allocation of national-level protection resources[89]: On the one hand, centralized protection is conducive to forming economies of scale, facilitating unified planning and concentrated investment, and driving the development of cultural heritage tourism; on the other hand, it may also exacerbate the weakness of cultural heritage protection in peripheral areas, causing a large number of villages not included in the national list to fall into the dilemma of "protection islands"[96]. From the perspective of cultural heritage management, this spatial imbalance is both the result of intensive use of resources and exposes the problem of the limited scope of protection of the national list[75]. When high-level protection resources and policies only benefit a limited area, traditional villages and their cultural spaces in non-hotspot areas may be continuously marginalized. To alleviate this problem, we should encourage the establishment of a multi-level, multi-subject collaborative protection pattern, and provide protection support for villages not included in the national list through local policy support and cultural corridor construction, so as to avoid the cultural memory break caused by differences in administrative levels[97,98].

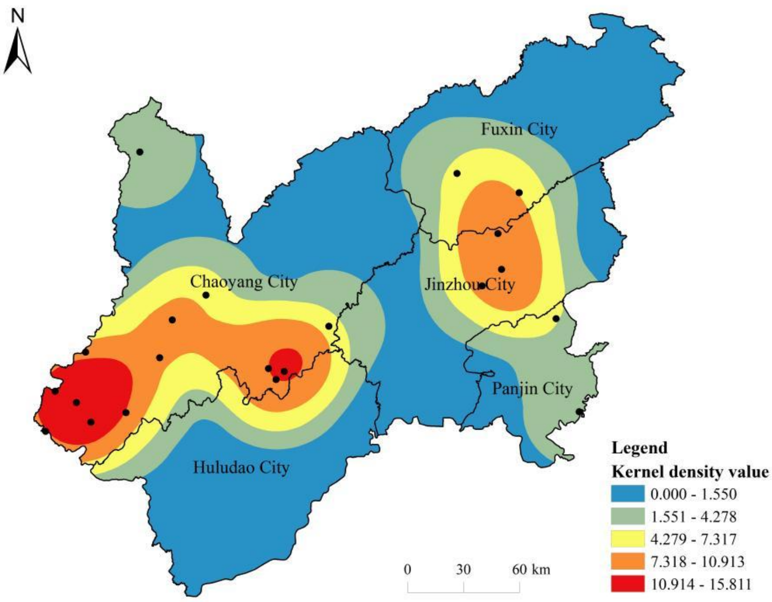

Figure 10. Kernel density distribution map of provincial villages(Liaoxi).

In comparison, the core density distribution of provincial traditional villages (Figure 10) is wider but still highly uneven. Due to the large number of provincial villages, the core density map shows a large high-density area in the southwest (where the core density is highest in the region), and a secondary high-density cluster has formed in the Jinzhou-Chaoyang area; however, despite the expanded coverage, there are still large areas with low density (blue area in Figure 10), indicating that provincial villages are still sparsely distributed in many parts of the Liaoxi Corridor. Overall, provincial villages have formed multiple clusters in a wider space, but the problem of uneven distribution remains prominent. The establishment of the provincial list has brought more villages with local value into the protection system, making up for the lack of coverage of the national list, and forming some new secondary hotspots in the region [95,97]; this reflects the positive role of the provincial level in the protection of traditional villages, and helps to build a multi-center, multi-node cultural heritage network on a larger scale, and enhance the resilience of the overall cultural heritage system [5].

However, it should be noted that there is also an imbalance in distribution at the provincial level: due to differences in economic foundation, enthusiasm for application, and policy emphasis in various regions, the proportion of villages in some areas included in the provincial list is significantly lower. This indicates that in future planning, it is necessary to promote spatial fairness in the protection of traditional villages by strengthening grassroots cultural protection forces, improving the list application pattern, and formulating differentiated support policies [99]. At the same time, provincial traditional villages can be used as nodes in the regional cultural heritage network. Through networked layout, contiguous protection, and regional coordinated development, complementary sharing and holistic protection of traditional culture can be achieved, avoiding the risks of over-tourism and homogenization of cultural landscapes caused by the development of single hotspots [100].

4.2 Analysis of Factors Affecting the Distribution of Traditional Villages in the Liaoxi Corridor

The results of the geographic detector analysis show that natural geographic factors are the dominant factors affecting the spatial distribution of traditional villages in the Liaoxi Corridor. Among them, slope and surface relief have the highest correlation with village distribution (correlation coefficient $R \approx 0.43$), and their geographic detector q value also reaches about 0.38, showing a strong influence; vegetation cover (measured by NDVI) is positively correlated with village distribution ($R \approx 0.367$, $q \approx 0.29$), indicating that areas with good vegetation conditions are more conducive to the preservation of traditional villages; while climatic factors (such as precipitation and temperature) have a relatively weak influence on village distribution or are even negatively correlated. On the contrary, the correlation coefficients between human factors (such as population density and regional GDP) and the distribution of traditional villages are generally low, and some are even negative ($|R| < 0.2$, $q < 0.1$), which means that the contemporary level of economic development has a limited direct impact on the distribution of traditional villages, and to some extent, higher development intensity may have a "diluting" effect on the pattern of traditional villages [34].

4.2.1 Topographical Factors

Topography is one of the key geological environmental factors influencing the distribution of traditional villages. Elevation affects various environmental elements such as surface water distribution patterns, temperature and humidity, biogeographical boundaries, and land type classification. It also influences the regional environment, village architectural forms, and the cultural customs shaped by the local villagers' production and lifestyle.

This study uses 30-meter resolution digital elevation model (DEM) data provided by the National Geospatial Data Cloud (www.gscloud.cn), combined with a 1:500,000 scale map of Liaoning Province. Based on field surveys and corrections, spatial overlay elevation analysis of traditional villages in the Liaoxi corridor was conducted using ArcGIS 10.1 software. The DEM data was reclassified using the Natural Breaks method.

The analysis results are shown in Figure 11 and Table 9.

The low mountains and hills of the Liaoxi Corridor provide a relatively closed and independent living environment for traditional villages. These topographical conditions are not only conducive to the formation of distinctive natural environments and folk cultures, but also provide necessary natural geographical and ecological support for the protection and sustainable development of traditional villages.

	Classification	Quantity	Average	Min	Max	List
1	0-100	5	34.4134	1.7142	80.5238	Qian Suo Village, Shang Kou Zi Village, De Sheng Village, Shuang Ta Village, Ban Ji Ta Village
2	100-200	11	153.2881	108.15	198.0952	Longgangzi Village, Xinbaozi Village, Gaoqibao Village, Sujiayingzi Village, Fosi Village, Wangfu Village, Shifo Village, Jinlingsi Village, Mangniutun Village, Xitai Village, Danian Village
3	200 and above	36	451.3098	201.25	818.0833	Xiaojiadian Village, Tangzhangzi Village, Bapangou, Zhangjiyingzi Village, Baiyinaili Village, Kangguan Village, Guozhangzi Village, Shaoguodi Village, Laoxigou Village, Dongguanfenchang, Dayi Village, Yamen Village, Bajiazi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Fengzhangzi Village, Baicaogou, Xindi Village, Sanjuxing Village, Botaigou Village, Pandaogou Village, Wangjiadian Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Sanfu Village, Xigou Village, Huashan Village, Tianshenghao Village, Huzhangzi Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Huangmuzhangzi Village, Miliying Village

Table 9 . Elevation(Liaoxi).

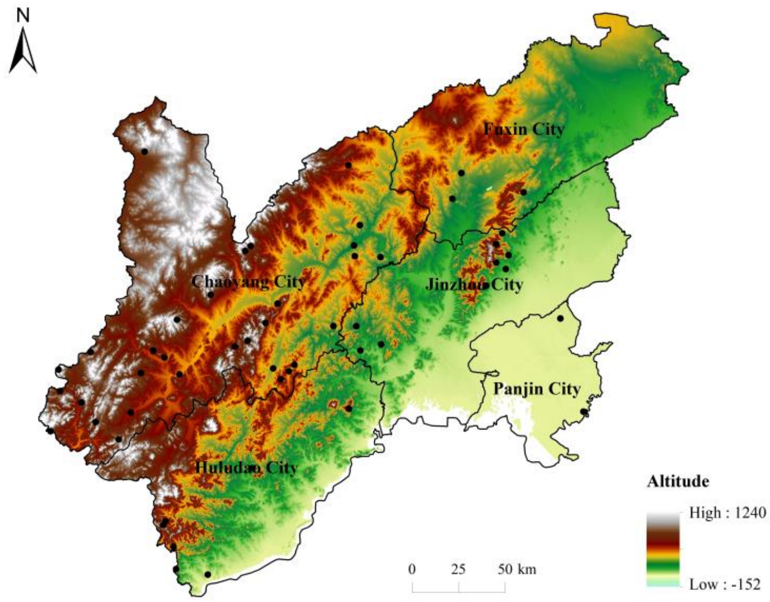

Figure 11. Elevation diagram(Liaoxi).

Figure 11 shows the elevation distribution characteristics of the Liaoxi Corridor region. The landform of this region generally presents a gradient pattern of "low in the southeast and high in the northwest". The elevation gradually rises from less than 50 meters in the coastal low plains to about 1,000 meters in the western mountainous areas, reflecting the coexistence of plains, hills and mountains. The elevation difference has a profound impact on climate conditions, land use patterns and the selection of traditional village sites. High-altitude areas have cold climates, short growth cycles and poor soil conditions, which are more suitable for forestry or animal husbandry. Low-altitude areas have mild climates and fertile soils, which are more suitable for agricultural development. This vertical differentiation has led to different livelihood patterns and spatial layouts of villages at different elevations [101,102]. In the Liaoxi Corridor, traditional villages are mostly distributed in the foothills and gentle river valleys at low and medium altitudes, which can avoid the risk of flooding in low-lying areas and maintain warm and suitable climate conditions, which is conducive to agricultural development and human settlement [35]. Complex topography makes high-altitude areas relatively isolated, mitigating the impact of external factors on villages and preserving more historical villages. In contrast, low-altitude plains have convenient transportation and rapid economic development, leading to the gradual replacement of traditional villages by modern towns. Therefore, elevation plays a fundamental regulatory role in village distribution [97,102]. From a rural planning perspective, villages in high-altitude areas face challenges such as difficult infrastructure construction, lagging economic development, and difficulties in ensuring equitable access to services. However, their environmental isolation also provides potential opportunities for the protection of traditional culture and the development of distinctive economies.

As shown in Figure 12 and Table 10, slope distribution is closely related to topography. Mountainous areas have steeper slopes, while plains have gentler slopes, exhibiting significant spatial heterogeneity. High slope values are mainly distributed in the western mountainous and hilly areas, where transportation is inconvenient and development is limited. In contrast, low-altitude areas such as the Liaohe Plain have slopes close to 0°, with flat terrain conducive to agriculture and urban layout. Overall, slope gradually decreases from the central mountains to the surrounding plains and is negatively correlated with population and transportation distribution, reflecting a preference for human activities in flatter areas.

	Classification	Quantity	Average	Min	Max	List
1	0-5	17	2.9967	0.3078	4.6758	Qian Suo Village, Shang Kou Zi Village, De Sheng Village, Zhang Ji Ying Zi Village, Lao Xi Gou Village, Shuang Ta Village, Fo Si Village, Ya Men Village, Wang Fu Village, San Fu Village, Tian Sheng Hao Village, Jin Ling Si Village, Ban Ji Ta Village, Mang Niu Tun Village, Xi Tai Village, Danian Village, Mi Li Ying Village
2	5-10	15	7.3259	5.2483	9.6455	Xiaojiadian Village, Gaoqibao Village, Sujiayingzi Village, Baiyin'aili Village, Kangguan Village, Guozhangzi Village, Dongguanfenchang, Dayi Village, Bajiazi Village, Fengzhangzi Village, Baicaogou, Sanjuxing Village, Botaigou Village, Shifo Village, Huzhangzi Village, Xiaowopu Village
3	10and above	20	12.7238	10.0333	20.5572	Longgangzi Village, Xinbaozi Village, Tangzhangzi Village, Bapangou, Shaoguodi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Xindi Village, Pandaogou Village, Wangjiadian Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Xigou Village, Huashan Village, Shimengou Village, Shierguanyingzi Village, Huangmuzhangzi Village

Table 10 . Slope(Liaoxi).

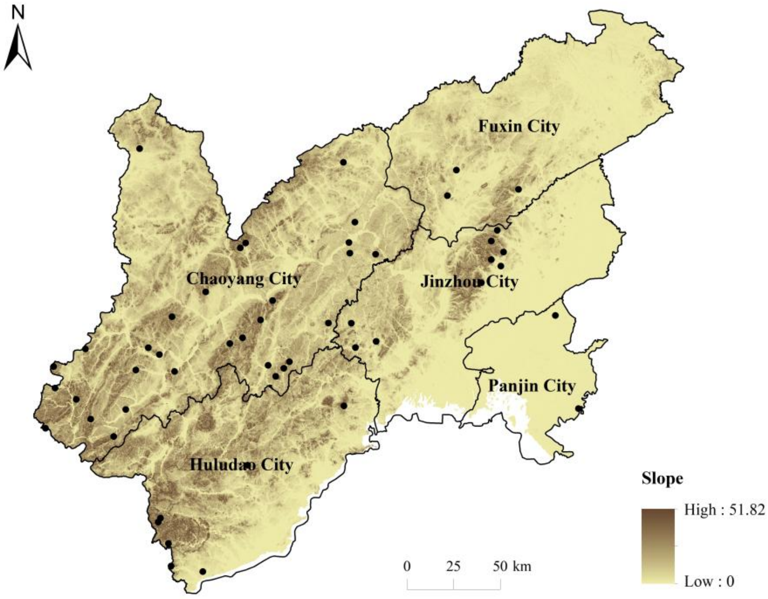

Figure 12. Slope diagram(Liaoxi).

The Liaoxi Corridor exhibits significant spatial heterogeneity in slope, with steeper slopes in the western mountainous and hilly areas and gentler slopes in the eastern plains. Steep slopes limit the distribution and expansion of traditional villages, restrict agricultural activities, and hinder infrastructure development, resulting in a scattered and small-scale village pattern. Conversely, the nearly flat Liaohe Plain facilitates dense village distribution and large-scale layout, providing favorable conditions for agricultural production and urbanization. Slope distribution is negatively correlated with population density and accessibility, reflecting a preference for settlement and development in flat areas. These findings suggest that differentiated strategies should be developed based on local topography and ecological conditions during village protection and development.

	Classification	Quantity	Average	Min	Max	List
1	0-10	5	4.0478	2.0	6.2105	Qian Suo Village, Shang Kou Zi Village, De Sheng Village, Shuang Ta Village, Wang Fu Village
2	10-20	10	17.2928	13.9523	19.8571	Laoxigou Village, Fosi Village, Yamen Village, Sanfu Village, Tianshenghao Village, Jinlingsi Village, Banjita Village, Mangniutun Village, Danian Village, Miliying Village
3	20 and above	37	46.4328	20.1111	97.6666	Longgangzi Village, Xinbaozi Village, Xiaojiadian Village, Tangzhangzi Village, Bapangou, Gaoqibao Village, Sujiayingzi Village, Zhangjiyingzi Village, Baiyinaili Village, Kangguan Village, Guozhangzi Village,

	Shaoguodi Village, Dongguanfenchang, Dayi Village, Bajiazi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Fengzhangzi Village, Baicaogou, Xindi Village, Sanjuxing Village, Botaigou Village, Pandaogou Village, Wangjiadian Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Xigou Village, Shifo Village, Huashan Village, Huzhangzi Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Huangmuzhangzi

Table 11 . Topographic relief(Liaoxi).

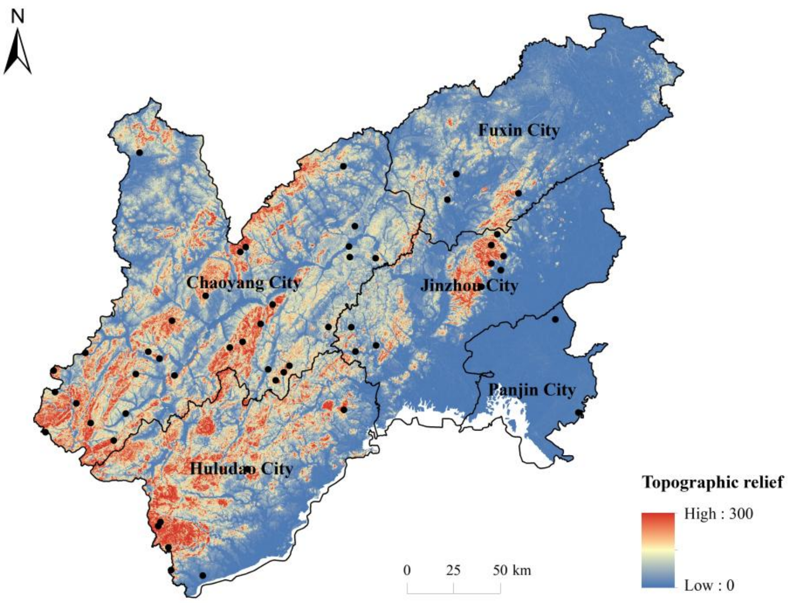

Figure 13. Diagram of topographic relief(Liaoxi).

As shown in Figure 13 and Table 11, topographic relief significantly affects the accessibility of traditional villages, infrastructure construction, and ecological risk management. In the Liaoxi Corridor, areas with high topographic relief are often characterized by fragmented terrain and steep mountains, making it difficult to construct transportation infrastructure. The village layout is mainly composed of scattered small settlements, making it difficult to form an economic agglomeration effect [101]. In contrast, areas with low topographic relief have gentle terrain, which is suitable for large-scale agricultural production and road construction. Villages tend to have a large-scale concentrated distribution, and the level of economic development is relatively high. There is a significant negative correlation between topographic relief and population density and economic density. The economic development of areas with high topographic relief is significantly constrained [102]. In addition, mountainous terrain also increases ecological risks. Natural disasters such as landslides and soil erosion occur frequently, posing additional challenges to village development. However, these areas have the potential to develop ecotourism and specialty agriculture. Through reasonable planning, the disadvantages of the natural environment can be transformed into distinctive advantages for economic development. Therefore, a deeper understanding of the impact of topographic relief on the spatial distribution of traditional villages is helpful in coordinating the relationship between environmental protection and economic development.

4.2.2 Climate and Ecological Factors

As shown in Figure 14 and Table 12, the average annual temperature exhibits a spatial distribution trend of gradually decreasing from the coast to the inland and from south to north. The southern coastal areas, due to their lower latitude and the moderating effect of the ocean, have relatively higher temperatures, with an average annual temperature of 9-10℃. The northern inland highlands, influenced by altitude and latitude, have relatively lower temperatures, with an average annual temperature of approximately 5℃. The temperature difference between the north and south ends can reach 4-5℃. This temperature gradient reflects significant regional differences, indicating a clear spatial heterogeneity in thermal conditions between the north and south, and between the coastal and inland areas within the study region.

	Classification	Quantity	Average	Min	Max	List
1	0-10	34	9.3308	7.8538	9.9916	Tangzhangzi Village, Bapangou, Baiyin'aili Village, Kangguan Village, Guozhangzi Village, Shaoguodi Village, Laoxigou Village, Dongguanfenchang, Dayi Village, Fosi Village, Yamen Village, Wangfu Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Xindi Village, Sanjuxing Village, Botaigou Village, Wangjiadian Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Sanfu Village, Shifo Village, Huashan Village, Tianshenghao Village, Huzhangzi Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Huangmuzhangzi
2	10 and above	18	10.3689	10.047	11.3867	Longgangzi Village, Xinbaozi Village, Xiaojiadian Village, Qiansuo

2	Village, Shangkouzi Village, Desheng Village, Gaoqibao Village, Sujiayingzi Village, Zhangjiyingzi Village, Shuangta Village, Bajiazi Village, Fengzhangzi Village, Baicaogou, Pandaogou Village, Xigou Village, Banjita Village, Mangniutun Village, Xitai Village, Danian Village

Table 12 . Temperature(Liaoxi).

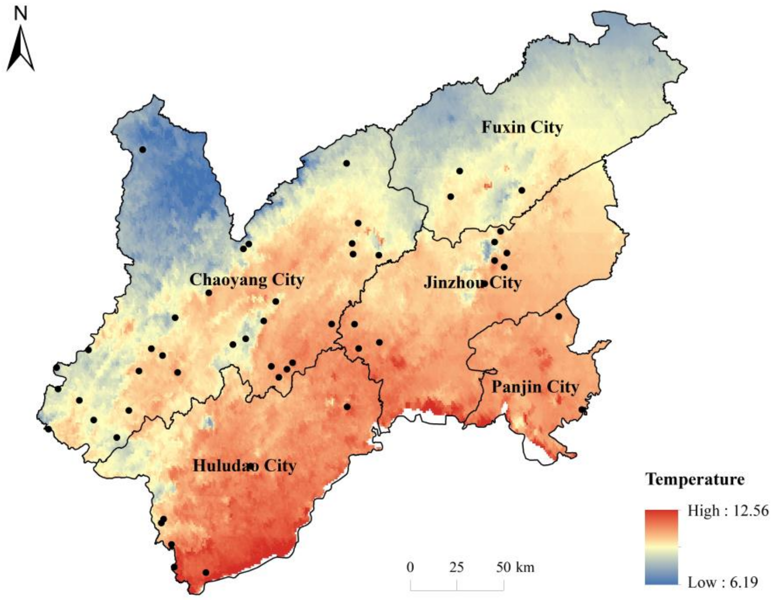

Figure 14. Temperature diagram(Liaoxi).

As shown in Figure 15 and Table 13, there is a significant gradient difference in precipitation distribution, gradually increasing from the arid northwest to the humid southeast. The average annual precipitation in the inland areas of the northwest (such as the areas around Chaoyang and Fuxin) is relatively low, about 400-500 mm, reflecting semi-arid characteristics, while the average annual precipitation in the coastal areas of the southeast (such as the areas around Huludao and Panjin) is higher due to the influence of monsoons and the ocean, reaching 600-700 mm. The spatial heterogeneity of precipitation is obvious, and the difference in precipitation between the north and south directly affects vegetation cover and agricultural production, reflecting the uneven distribution of water resources among regions.

	Classification	Quantity	Average	Min	Max	List
1	0-500	23	445.0233	408.8155	490.4953	Tangzhangzi Village, Bapangou, Sujiayingzi Village, Baiyinaili Village, Kangguan Village, Laoxigou Village, Dongguanfenchang, Fosi Village,

						Xidazhangzi Village, Sandaogou Village, Xindi Village, Sanjuxing Village, Botaigou Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Sanfu Village, Tianshenghao Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Danian Village, Miliying Village
2	500 and above	29	547.9830	510.3723	694.4869	Longgangzi Village, Xinbaozi Village, Xiaojiadian Village, Qiansuo Village, Shangkouzi Village, Desheng Village, Gaoqibao Village, Zhangjiyingzi Village, Guozhangzi Village, Shaoguodi Village, Shuangta Village, Dayi Village, Yamen Village, Wangfu Village, Bajiazi Village, Er'angou Village, Lieshanliang Village, Fengzhangzi Village, Baicaogou, Pandaogou Village, Wangjiadian Village, Xigou Village, Shifo Village, Huashan Village, Huzhangzi Village, Shimengou Village, Banjita Village, Mangniutun Village, Huangmuzhangzi Village, Xitai Village

Table 13 . Precipitation(Liaoxi).

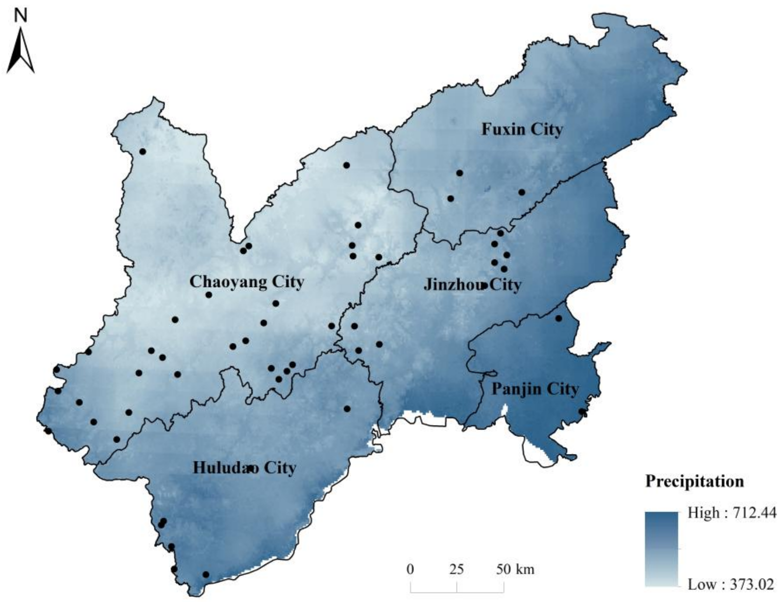

Figure 15. Precipitation diagram(Liaoxi).

Precipitation in the Liaoxi Corridor region exhibits a significant spatial gradient, gradually increasing from the northwest inland to the southeast coast. This distribution pattern is primarily influenced by the East Asian monsoon system and topographical conditions. The northwest (such as Chaoyang and Fuxin) suffers from low average annual precipitation due to inland climate and topographic barriers, classifying it as a typical semi-arid region. In contrast, the southeast (such as Huludao and Panjin), bordering the Bohai Sea, experiences a significant increase in average annual precipitation due to the moderating influence of maritime climate. This spatial heterogeneity of precipitation not only affects regional vegetation distribution and ecological patterns but also directly constrains the spatial layout of agricultural production and the distribution characteristics of traditional villages. Generally speaking, areas with abundant precipitation are conducive to village clustering and agricultural development, while arid areas have sparse villages and limited production activities. Furthermore, the uncertainty of the spatiotemporal distribution of precipitation under the background of climate change poses higher adaptive management requirements for regional water resource security and the sustainable development of traditional villages.

As shown in Figure 16 and Table 14, the spatial distribution of relative humidity is roughly consistent with the precipitation pattern. The coastal and water-rich areas have higher humidity, while the arid inland areas have lower humidity. The southeastern coastal areas maintain high atmospheric humidity throughout the year due to their proximity to the Bohai Bay and wetlands (such as Panjin Wetland), while the northwest is far from the ocean, with sparse precipitation and dry air, resulting in lower relative humidity. The spatial differences in humidity reflect the unevenness of regional water vapor conditions, which affects vegetation growth and soil moisture, and is closely related to precipitation gradient and land cover type.

	Classification	Quantity	Average	Min	Max	List
1	0-55	31	52.9622	50.4550	54.8727	Xiaojiadian Village, Tangzhangzi Village, Bapangou, Sujiayingzi Village, Zhangjiyingzi Village, Baiyin'aili Village, Kangguan Village, Guozhangzi Village, Shaoguodi Village, Laoxigou Village, Dongguanfenchang, Bajiazi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Fengzhangzi Village, Xindi Village, Sanjuxing Village, Botaigou Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Sanfu Village, Tianshenghao Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Danian Village, Miliying Village
2	55-60	16	57.0131	55.6910	58.8996	Longgangzi Village, Gaoqibao Village, Shuangta Village, Dayi Village, Fosi Village, Yamen Village, Wangfu Village, Pandaogou Village, Wangjiadian Village, Shifo Village, Huashan Village, Huzhangzi Village, Banjita Village, Mangniutun Village, Huangmuzhangzi Village, Xitai Village
3	60 and above	5	61.2867	60.3244	62.7101	Xinbaozi Village, Qiansuo Village, Shangkouzi Village, Desheng Village, Xigou Village

Table 14 . Humidity(Liaoxi).

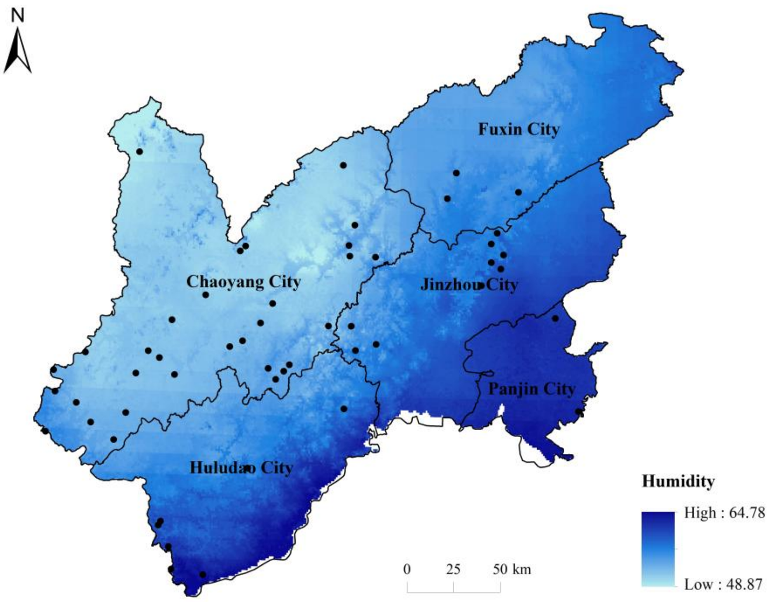

Figure 16. Humidity diagram(Liaoxi).

The spatial distribution of relative humidity exhibits a significant gradient, gradually decreasing from the humid southeastern coastal zone to the arid northwest inland zone. This pattern is primarily influenced by regional climatic conditions, distance from oceanic moisture sources, and topographic barriers. Coastal and wetland areas (such as Panjin) have higher air humidity, which is conducive to lush vegetation growth and fertile soil, while arid inland areas (such as Fuxin and Chaoyang) are more prone to ecological fragility and land degradation. The spatial heterogeneity of humidity is closely related to precipitation patterns and land cover types, ultimately affecting the suitability of traditional village settlements.

4.2.3 Environmental Factors

The Normalized Difference Vegetation Index (NDVI) ranges from 0 to 0.69, with significant spatial differences in vegetation cover (Figure 16 and Table 15). High NDVI values (around 0.6-0.7) are mainly distributed in areas with dense vegetation and favorable hydrothermal conditions, such as the humid southern regions or some mountainous forest areas. Low NDVI values (below 0.2) are mostly concentrated in urban built-up areas, bare land, or arid agricultural and pastoral areas (such as the sparsely populated northwest regions). Overall, NDVI is positively correlated with precipitation and topography: areas with abundant precipitation and favorable topography have better vegetation cover, while areas with high human activity intensity or limited natural conditions have sparse vegetation and significant spatial heterogeneity.

The NDVI values in the Liaoxi Corridor exhibit significant spatial heterogeneity, with an overall distribution pattern showing an increasing trend from northwest to southeast (Figure 17). High NDVI values (around 0.6-0.7) are mainly concentrated in the southern humid zone, hilly areas, and densely forested regions, reflecting a favorable ecological foundation and suitable hydrothermal conditions. Conversely, in the arid northwest, urban built-up areas, bare land, and some agricultural and pastoral areas, NDVI values are generally below 0.2, indicating poor vegetation cover. The formation of the NDVI spatial pattern is closely related to natural factors such as precipitation, topography, and soil, as well as human activities. Areas with abundant precipitation, flat terrain, and fertile soil tend to have higher vegetation cover, while human activities such as urban expansion, industrial and mining development, and overgrazing lead to a significant decrease in NDVI in some areas, reflecting the fragility of the ecosystem and the need for restoration. In addition, traditional villages are mostly distributed in areas with high NDVI values, and favorable vegetation conditions not only enhance ecological livability but also provide a basic guarantee for the sustainable development of villages.

	Classification	Quantity	Average	Min	Max	List
1	-1-0	0	0	0	0	None
2	0-0.5	45	0.4220	0.3003	0.4925	Longgangzi Village, Xinbaozi Village, Xiaojiadian Village, Tangzhangzi Village, Bapangou, Qiansuo Village, Shangkouzi Village, Desheng Village, Gaoqibao Village, Sujiayingzi Village, Zhangjiyingzi Village, Baiyinaili Village, Kangguan Village, Guozhangzi Village, Shaoguodi Village, Laoxigou Village, Dongguanfenchang, Shuangta Village, Dayi Village, Fosi Village, Yamen Village, Wangfu Village, Bajiazi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Fengzhangzi Village, Baicaogou, Xindi Village, Sanjuxing Village, Botaigou Village, Pandaogou Village, Sanjia Village, Sunjiadian Village, Nanwa Village, Sanfu Village, Shifo Village, Tianshenghao Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Banjita Village, Mangniutun Village, Xitai Village, Danian Village, Miliying Village
3	0.5 and above	7	0.5318	0.5010	0.5630	Wangjiadian Village, Wujiazi Village, Xigou Village, Huashan Village, Huzhangzi Village, Shimengou Village, Huangmuzhangzi Village

Table 15 . NDVI (Normalized Difference Vegetation Index)(Liaoxi).

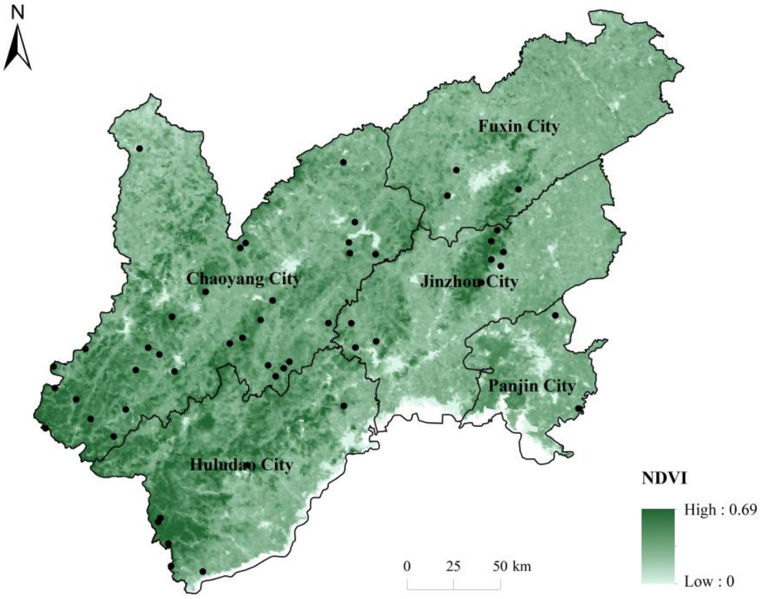

Figure 17. NDVI (Normalized Difference Vegetation Index) diagram(Liaoxi).

The distance from the river index reflects the proximity of each region to the nearest river, with a value ranging from 0 to approximately 0.39 (the maximum value corresponds to an actual distance of approximately 40 kilometers) (Figure 18 and Table 16). Spatially, this index exhibits a characteristic of "low values in areas near the river and high values in areas far from the river": areas along major rivers and water systems (distance from the river is close to 0) form a low-value zone, while inland highlands or basins far from the river network have high distance from the river (close to 0.3-0.4). This indicates that the distribution of water systems within the study area is uneven, with some areas far from permanent water sources. Overall, the distance from the river is negatively correlated with the degree of human settlement: areas near rivers are often more conducive to agricultural development and settlement formation, while areas far from water sources have sparse population distribution, demonstrating significant spatial differences.

	Classification	Quantity	Average	Min	Max	List
1	0-0.05	30	0.0178	0.006	0.0493	Longgangzi Village, Xinbaozi Village, Xiaojiadian Village, Tangzhangzi Village, Bapangou, Qiansuo Village, Shangkouzi Village, Desheng Village, Gaoqibao Village, Zhangjiyingzi Village, Baiyinaili Village, Dongguanfenchang, Shuangta Village, Fosi Village, Bajiazi Village, Er'angou Village, Xidazhangzi Village, Fengzhangzi Village, Baicaogou, Sanjuxing

						Village, Pandaogou Village, Sanjia Village, Sunjiadian Village, Sanfu Village, Xigou Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Banjita Village, Mangniutun Village, Xitai Village
2	0.05 and above	22	0.1110	0.050	0.2625	Sujiayingzi Village, Kangguan Village, Guozhangzi Village, Shaoguodi Village, Laoxigou Village, Dayi Village, Yamen Village, Wangfu Village, Lieshanliang Village, Sandaogou Village, Xindi Village, Botaigou Village, Wangjiadian Village, Wujiazi Village, Nanwa Village, Shifo Village, Huashan Village, Tianshenghao Village, Huzhangzi Village, Huangmuzhangzi Village, Danian Village, Miliying Village

Table 16 . Distance to river(Liaoxi).

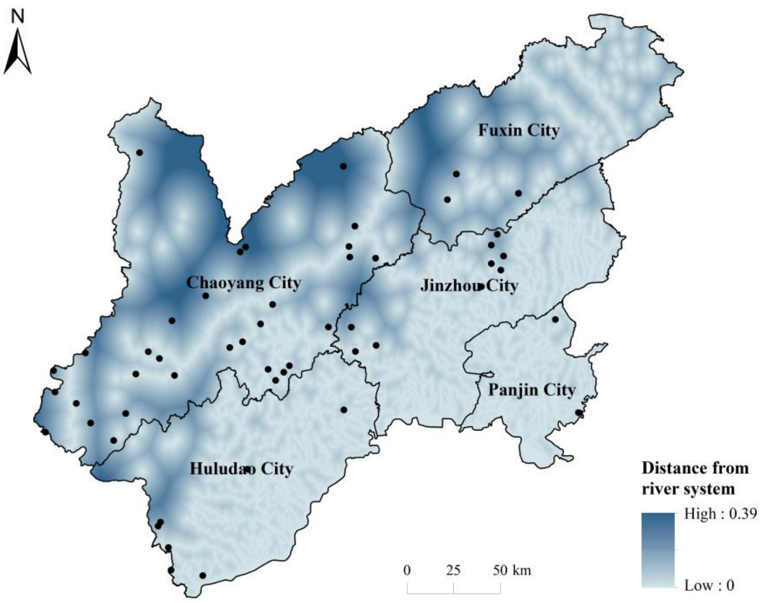

Figure 18. Distance to river diagram(Liaoxi).

Distance to waterways, as a spatial variable measuring the accessibility of surface water systems, reflects the proximity of various locations within a region to major rivers or water bodies. As shown in the figure, this indicator exhibits a significant zonal distribution pattern: low-value areas extend along major rivers and tributaries, indicating high water resource accessibility, while high-value areas are concentrated in inland highlands and basins far from rivers, reflecting the uneven distribution of water resources. This spatial heterogeneity not only reflects the structural characteristics of natural hydrological networks but also profoundly influences regional residential patterns and settlement site selection. Distance to waterways is highly negatively correlated with population density and agricultural land distribution. Low-value areas along rivers, due to abundant water resources and fertile land, have become densely populated areas of traditional villages and agricultural settlements, with high population and production activity; while high-value areas often suffer from water scarcity, fragile ecological environments, low land use intensity, and sparse settlement distribution. In addition, the distance to waterways is significantly coupled with the level of regional socio-economic development and infrastructure layout. Areas near waterways are not only suitable for settlement formation, but also facilitate transportation and material circulation, serving as key corridors for regional development. Therefore, in the protection and spatial planning of traditional villages, it is necessary to attach great importance to the ecological function of waterways and their guiding role in the spatial pattern of settlements.

4.2.4 Population and Economic Factors

As shown in Figure 19 and Table 17, the population density distribution in the Liaoxi Corridor region exhibits a clear dualistic characteristic of "urban agglomeration and rural hollowing out." In recent years, the rural population has continued to migrate to urban areas, leading to an exacerbation of the "hollowing out" phenomenon in rural areas. Many traditional villages have experienced population loss and are gradually shrinking [70,71]. The decrease in population makes it difficult to maintain public service facilities (schools, medical care, etc.) in rural areas, further reducing service accessibility and exacerbating urban-rural spatial inequality [70,71]. This spatial distribution pattern of population profoundly affects the efficiency of resource allocation and infrastructure construction, forming a negative cycle of "population-services." To address the problem of village hollowing out, the government has implemented the "Rural Revitalization" strategy, proposing to reshape the economic functions of villages and improve the level of public services through the development of cultural tourism, rural accommodation, and characteristic industries, so as to achieve village revitalization [107]. A reasonable population layout helps to promote the optimization of rural resource allocation, but planners also need to find a balance between maintaining village vitality and protecting traditional culture.

	Classification	Quantity	Average	Min	Max	List
1	0-50	19	35.0588	9.7339	49.7962	Xiaojiadian Village, Shaoguodi Village, Laoxigou Village, Bajiazi Village, Lieshanliang Village, Sandaogou Village, Fengzhangzi Village, Baicaogou, Sanjuxing Village, Botaigou Village, Pandaogou Village, Wangjiadian Village, Wujiazi Village, Nanwa Village, Sanfu Village, Xigou Village, Huashan Village, Huzhangzi Village, Xiaowopu Village, Huangmuzhangzi Village

2	50-100	18	73.7297	51.5354	94.8126	Tangzhangzi Village, Bapangou, Gaoqibao Village, Sujiayingzi Village, Zhangjiyingzi Village, Kangguan Village, Guozhangzi Village, Fosi Village, Yamen Village, Er'angou Village, Xidazhangzi Village, Xindi Village, Sanjia Village, Sunjiadian Village, Shimengou Village, Shierguanyingzi Village, Jinlingsi Village, Mangniutun Village, Miliying Village
3	100 and above	15	245.3042	106.5866	732.7411	Longgangzi Village, Xinbaozi Village, Qiansuo Village, Shangkouzi Village, Desheng Village, Baiyin'aili Village, Dongguanfenchang, Shuangta Village, Dayi Village, Wangfu Village, Shifo Village, Tianshenghao Village, Banjita Village, Xitai Village, Danian Village

Table 17 . Population density(Liaoxi).

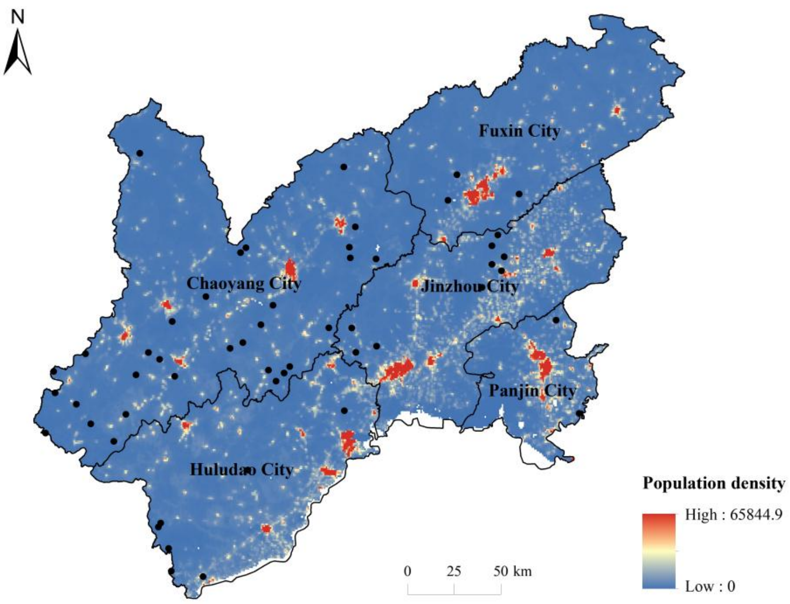

Figure 19. Population density diagram(Liaoxi).

As shown in Figure 20 and Table 18, the distribution of nighttime light intensity exhibits a significant urban agglomeration characteristic, with the luminous intensity reaching its peak in the main urban centers and rapidly decreasing in the surrounding rural areas. The brightness values range from near zero in unlit areas (remote villages or uninhabited areas) to high values in urban built-up areas, indicating an extreme spatial imbalance in the intensity of human nighttime activities. Taking central cities such as Jinzhou as an example, the nighttime light intensity in their urban areas is much higher than that in the surrounding counties, and the brightness decreases significantly with increasing distance from the city, presenting a typical "core-periphery" gradient pattern. The high heterogeneity of nighttime light distribution reflects the spatial concentration of regional economic activities and population distribution, which is highly consistent with socioeconomic factors such as regional GDP and population density.

	Classification	Quantity	Average	Min	Max	List
1	0-0.5	48	0.0321	0.0	0.4978	Longgangzi Village, Xinbaozi Village, Xiaojiadian Village, Tangzhangzi Village, Bapangou, Shangkouzi Village, Gaoqibao Village, Sujiayingzi Village, Zhangjiyingzi Village, Kangguan Village, Guozhangzi Village, Shaoguodi Village, Laoxigou Village, Dongguanfenchang, Dayi Village, Fosi Village, Yamen Village, Wangfu Village, Bajiazi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Fengzhangzi Village, Baicaogou, Xindi Village, Sanjuxing Village, Botaigou Village, Pandaogou Village, Wangjiadian Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Sanfu Village, Xigou Village, Shifo Village, Huashan Village, Tianshenghao Village, Huzhangzi Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Banjita Village, Mangniutun Village, Huangmuzhangzi Village, Xitai Village, Danian Village, Miliying Village
2	0.5 and above	4	2.2116	0.5169	5.3359	Qiansuo Village, Desheng Village, Baiyinaili Village, Shuangta Village

Table 18 . Nighttime lighting(Liaoxi).

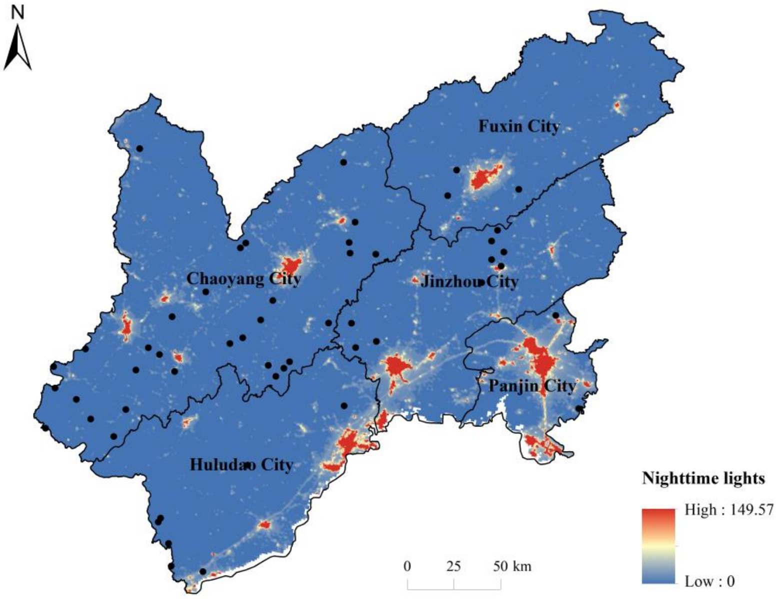

Figure 20. Nighttime lighting diagram(Liaoxi).

Furthermore, the distribution of low-value nighttime light areas highly overlaps with that of traditional villages, indicating that the level of nighttime human activity and economic development in traditional village areas is relatively low, providing data support for the evaluation of the living environment and the formulation of rural revitalization strategies.

The distribution of traditional villages in the Liaoxi Corridor is significantly correlated with the region's economic development level. According to data from the Liaoning Statistical Yearbook [109], Liaoning Province's GDP in 2015 was 2,867.45 billion yuan, with an average of 204.818 billion yuan. Among the five cities in the Liaoxi Corridor, Jinzhou and Panjin have relatively small GDP differences, at 132.733 billion yuan and 125.654 billion yuan respectively. Chaoyang, Huludao, and Fuxin, ranked from highest to lowest, are all at a relatively low level in terms of total economic output in the province, and the combined GDP of these three cities is only 2.55% higher than the provincial average.

The relatively underdeveloped yet stable human-land relationship and relatively weak socio-economic development in this region have provided favorable conditions for the preservation of traditional villages. Chaoyang City has the largest distribution of traditional villages, accounting for 46.15% of the province's total and 62.22% of the total in the Liaoxi Corridor. Apart from Jinzhou and Panjin, Chaoyang City has a relatively high GDP level, which is closely related to the region's socio-economic strength in residential renovation and its awareness of strengthening the preservation and protection of traditional villages.

As shown in Figure 21 and Table 19, the spatial distribution of GDP is extremely uneven, with economic output highly concentrated in a few core cities and industrial areas, while the GDP values of peripheral areas are significantly lower. As can be seen from the figure, the total GDP of municipal districts such as Jinzhou and Panjin is much higher than that of surrounding counties, forming a clear economic "highland," while the vast rural areas and mountainous areas are "lowlands," highlighting the "core-periphery" structure of the regional economy. The GDP distribution is basically consistent with indicators such as nighttime light and population density, indicating that economic activities have a high degree of spatial agglomeration. In terms of numerical range, the GDP density in the city center reaches the regional peak, while the remote areas are close to the lowest value, reflecting significant differences in regional development levels and prominent spatial heterogeneity.

	Classification	Quantity	Average	Min	Max	List
1	0-1000	49	391.2239	203.9047	899.5	Longgangzi Village, Xinbaozi Village, Xiaojiadian Village, Tangzhangzi Village, Bapangou, Qiansuo Village, Gaoqibao Village, Sujiayingzi Village, Zhangjiyingzi Village, Baiyinaili Village, Kangguan Village, Guozhangzi Village, Shaoguodi Village, Laoxigou Village, Dongguanfenchang, Shuangta Village, Dayi Village, Fosi Village, Yamen Village, Wangfu Village, Bajiazi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou Village, Fengzhangzi Village, Baicaogou, Xindi Village, Sanjuxing Village, Botaigou Village, Wangjiadian Village, Sanjia Village, Wujiazi Village, Sunjiadian Village, Nanwa Village, Sanfu Village, Xigou Village, Shifo Village, Huashan Village, Tianshenghao Village, Huzhangzi Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Banjita Village, Mangniutun Village, Huangmuzhangzi Village, Xitai Village, Danian Village, Miliying Village
2	1000-1500	2	1412.4962	1377.4210	1447.5714	Desheng Village and Pandaogou Village
3	1500 and above	1	2106.3571	2106.3571	2106.3571	Shangkouzi Village

Table 19 . GDP distribution(Liaoxi).

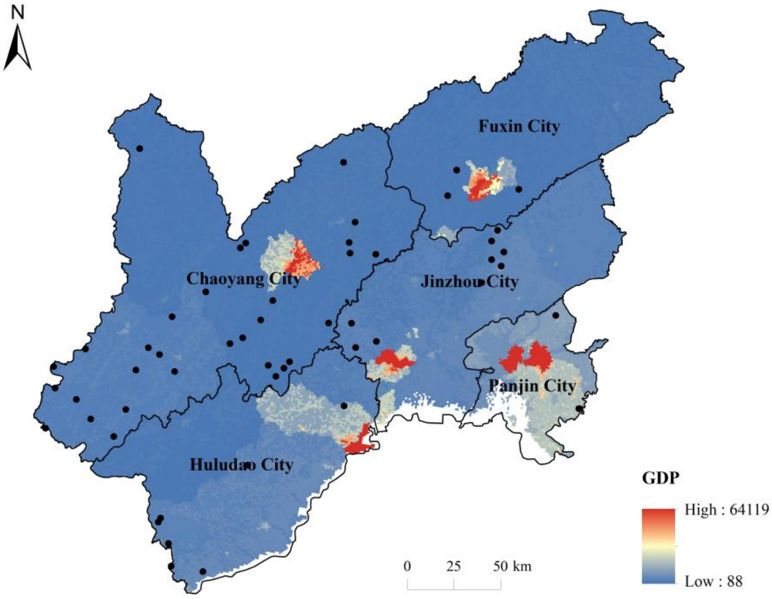

Figure 21. GDP distribution diagram(Liaoxi).

4.2.5 Transportation and Location Factors

Road network density distribution exhibits a gradient from the center to the periphery, with the highest density of transportation infrastructure near cities and main roads, while transportation infrastructure is relatively sparse in remote areas (Figure 22 and Table 20). High road density exists between major cities and in coastal economic zones (such as Jinzhou-Panjin), forming regional transportation corridors, while road density is sparse in the western hilly areas, and many remote towns have low road density. Overall, the spatial distribution of the road network is highly correlated with population and economic activity: high-density transportation network "cores" form in plains and urban agglomerations, while transportation "gaps" appear in areas with complex terrain or sparse populations. Road network density is closely related to topographical conditions and economic development levels, reflecting a significant spatial imbalance in infrastructure supply.

	Classification	Quantity	Average	Min	Max	List
1	0-50	7	44.4995	40.2448	47.9110	Tangzhangzi Village, Bapangou Village, Kangguan Village, Shaoguodi Village, Sanjuxing Village, Sanjia Village, Sunjiadian Village, Huashan Village
2	50-100	32	75.5857	50.1708	98.5125	Xiaojiadian Village, Zhangjiyingzi Village, Laoxigou Village, Dongguanfenchang, Dayi Village, Fosi Village, Yamen Village, Wangfu Village, Bajiazi Village, Er'angou Village, Lieshanliang Village, Xidazhangzi Village, Sandaogou

						Village, Fengzhangzi Village, Baicaogou, Xindi Village, Botaigou Village, Pandaogou Village, Wangjiadian Village, Wujiazi Village, Nanwa Village, Xigou Village, Tianshenghao Village, Huzhangzi Village, Shimengou Village, Xiaowopu Village, Shierguanyingzi Village, Jinlingsi Village, Mangniutun Village, Huangmuzhangzi Village, Xitai Village, Danian Village, Miliying Village
3	100 and above	13	131.6672	100.5105	197.5712	Longgangzi Village, Xinbaozi Village, Qiansuo Village, Shangkouzi Village, Desheng Village, Gaoqibao Village, Sujiayingzi Village, Baiyinaili Village, Guozhangzi Village, Shuangta Village, Sanfu Village, Shifo Village, Banjita Village

Table 20 . Road network density(Liaoxi).

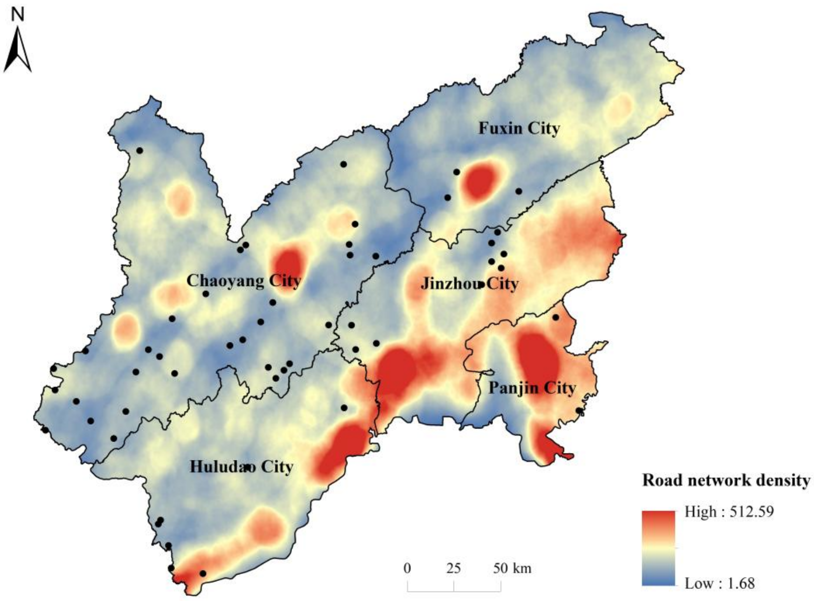

Figure 22. Road network density diagram(Liaoxi).

The road network density in the Liaoxi Corridor exhibits spatial differentiation from the center to the periphery. High-density areas are mainly concentrated in cities such as Jinzhou and Panjin and their adjacent coastal economic zones, forming regional transportation corridors. In contrast, the hilly areas and remote towns in the western rural region are "blank zones" with sparse transportation networks and insufficient service coverage. This spatial heterogeneity reflects not only the constraints of topographical conditions and economic development levels but also its close relationship with population distribution and urbanization.

Road network density has a dual impact on the spatial pattern of traditional villages: on the one hand, a high-density road network facilitates the flow of regional resources and access to development opportunities, but may also exacerbate the urbanization pressure and spatial homogenization risks of traditional villages; on the other hand, while low-density areas help protect the originality of settlement patterns, they also face challenges in terms of accessibility and infrastructure supply. It is recommended to formulate comprehensive policies for zoned transportation development and the protection of traditional villages, taking into account topographical, economic, and historical factors.

This variable reveals the spatial pattern of urban spheres of influence, exhibiting a multi-center, circular gradient structure. As shown in Figure 23 and Table 21, the lowest distance values appear in the areas surrounding major cities (prefecture-level cities), forming multiple overlapping low-value circles. The distance gradually increases with distance from any city center, reaching its maximum at the regional edge (maximum 1.78, approximately 200 km). This distribution reflects the existence of multiple city centers within the study area, whose spheres of influence are adjacent to each other but do not cover the entire region. Areas far from all cities (such as the northwest edge) exhibit significant spatial isolation. Overall, the distance distribution from city centers confirms the multi-core structure of the regional urban system and suggests lower accessibility to urban services and resources in peripheral areas.

	Classification	Quantity	Average	Min	Max	List
1	0-0.5	27	0.3400	0.1735	0.4998	Longgangzi Village, Xiaojiadian Village, Tangzhangzi Village, Bapangou, Shangkouzi Village, Desheng Village, Gaoqibao Village, Sujiayingzi Village, Zhangjiyingzi Village, Shuangta Village, Dayi Village, Fosi Village, Yamen Village, Wangfu Village, Bajiazi Village, Xidazhangzi Village, Sandaogou Village, Xindi Village, Botaigou Village, Pandaogou Village, Sunjiadian Village, Sanfu Village, Shifo Village, Huashan Village, Jinlingsi Village, Banjita Village, Mangniutun Village, Danian Village
2	0.5-1	10	0.7015	0.5318	0.9868	Baiyin'aili Village, Dongguan Branch Farm, Fengzhangzi Village, Baicaogou, Sanjuxing Village, Sanjia Village, Wujiazi Village, Nanwa Village, Shierguanyingzi Village, Xitai Village, Miliying Village
3	1 and above	15	1.3399	1.0811	1.7221	Xinbaozi Village, Qiansuo Village, Kangguan Village, Guozhangzi

	Village, Shaoguodi Village, Laoxigou Village, Er'angou Village, Lieshanliang Village, Wangjiadian Village, Xigou Village, Tianshenghao Village, Huzhangzi Village, Shimengou Village, Xiaowopu Village, Huangmuzhangzi Village

Table 21 . Distance to city center(Liaoxi).

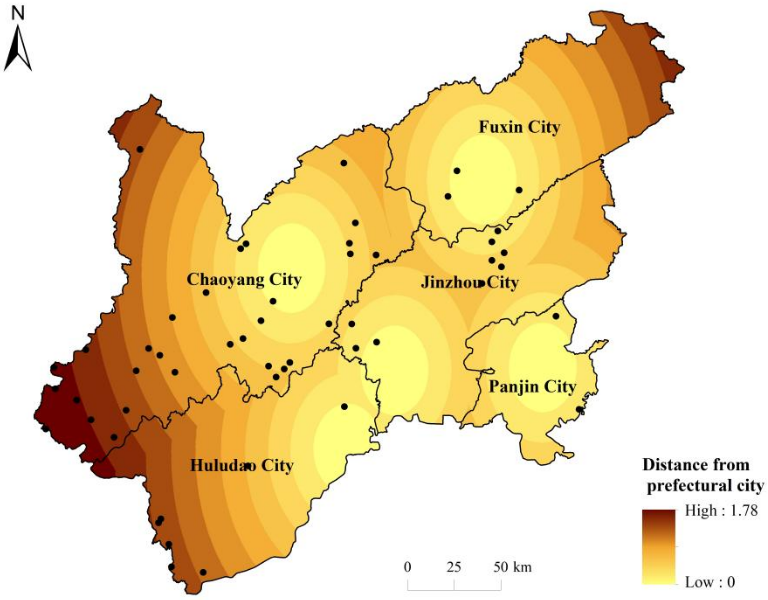

Figure 23. Distance to city center(Liaoxi).

This variable depicts the spatial differentiation pattern of urban influence, exhibiting a typical "multi-center, ring-decreasing" characteristic. The map shows that prefecture-level cities (such as Jinzhou, Chaoyang, Fuxin, Huludao, and Panjin) constitute multiple influence centers in the region, forming low-value zones centered on these cities. These low-value zones expand outwards in a ring shape, overlapping between different cities to form multiple service radiation circles. The distance value gradually increases with distance from the city center, reaching a peak at the periphery (maximum value of 1.78, corresponding to a physical distance of approximately 200 km), indicating that these areas are relatively less influenced by the city center, exhibiting a spatial island effect.

This spatial structure reflects the typical characteristics of the multi-core urban system in the Liaoxi Corridor region, confirming the complementarity and spatial differentiation of urban service functions in the region. However, the accessibility of infrastructure, public services, and economic resources to surrounding areas far from the city center is significantly reduced, which has a significant impact on the spatial distribution of traditional villages, population flow, and development opportunities.

Furthermore, the overlapping urban radiation zones caused by the multi-center structure help mitigate the negative impact of the "siphoning effect" of single-center cities on balanced regional development, contributing to enhanced resilience and inclusiveness of the entire urban system. However, high-distance areas at regional boundaries still face problems such as insufficient urban service coverage and uneven resource distribution, which need to be considered in spatial planning and policy formulation.

In summary, the spatial distribution of distances from urban centers is not only a physical representation of the area of urban influence, but also a comprehensive reflection of the regional socio-economic structure and resource accessibility, which is of great significance for understanding the development status of traditional villages and regional balanced development strategies.

4.2.6 Historical and cultural factors

Since ancient times, the Liaoxi Corridor has been the core passage of strategic geography in northern China, connecting the Central Plains in the south and the hinterland of Northeast Asia in the north. It plays a key role in the communication between the North China Plain and the Northeast region. It was the front line for dynasties to consolidate the border and resist the invasion of northern nomadic peoples [108]. The Liaoxi Corridor region has witnessed a series of major historical events and changes. For example, at the end of the Eastern Han Dynasty, Cao Cao led his army north to conquer the Wuhuan. After defeating the enemy in the Bailang Mountain area of Liaoxi, he climbed Jieshi Mountain to view the sea, leaving behind a famous historical chapter. During the Wei, Jin, and Northern and Southern Dynasties, the Xianbei Murong clan established the Former and Later Yan regimes in the Chaoyang area of Liaoxi, forming the "Three Yan Ancient Capitals" [74].During the Sui and Tang Dynasties, this area was an important passage for the Tang army's eastward expedition against Goguryeo, leaving behind famous historical events such as Xue Rengui's great victory. The Battle of Ningyuan at the end of the Ming Dynasty directly affected the strategic direction of the Later Jin (Qing Dynasty), and Wu Sangui's introduction of the Qing army into the pass further highlighted the geopolitical influence of the Liaoxi Corridor [74,75]. One of the important battlefields of the Liaoshen Campaign was located in this area, further establishing its important strategic position [74].

The Liaoxi Corridor was not only a strategic location but also a vital space for the migration, settlement, and cultural exchange of various ethnic groups in northern China. Historically, the Wuhuan, Xianbei, Khitan, Jurchen, Mongol, and Manchu peoples used this region as a link to engage in frequent military confrontations and cultural exchanges with the Han Chinese of the Central Plains, gradually forming a unique socio-cultural landscape characterized by ethnic fusion and coexistence [107,108]. Especially during the Ming and Qing dynasties, the implementation of the military-agricultural colony system and the garrison system in the Liaoxi region attracted a large number of Han, Mongol, and Manchu soldiers and civilians to settle there. Guangningwei (present-day Beizhen area) was the most representative region. Beizhen was not only a crucial military stronghold in the nine border regions of Liaodong during the Ming dynasty but also a convergence point of Central Plains agricultural civilization, northern nomadic civilization, and mountain hunting culture, forming a unique landscape that combined military defense with cultural integration [107,108].

In addition, the Liaoxi Corridor region has preserved a rich variety of cultural heritage and traditional village resources. For example, Yiwulü Mountain in Beizhen is one of the "Five Great Mountains" in Chinese history. Its mountain god worship culture covers local beliefs and folk rituals with distinctive Manchu characteristics. The important royal mausoleum site - the Liao Dynasty Xianling Mausoleum - provides valuable materials for the study of the Liao Dynasty imperial mausoleum system and the funeral culture of northern ethnic regimes [75]. Other heritage resources in the Liaoxi Corridor, such as the Niuheliang Hongshan Culture Site in Chaoyang City, the Liao Dynasty architectural complex of Fengguo Temple in Yixian County, the Ming and Qing Dynasty garrison city sites in the coastal areas of Jinzhou and Huludao, and the traditional ancient villages in Jianchang County, not only reflect the interweaving of diverse cultures in the Liaoxi region and the inheritance of these heritage resources, but also provide important material evidence and research basis for understanding the historical development, village settlement pattern and cultural evolution of the region [76]. It is evident that the Liaoxi Corridor not only occupies a key position in the military strategic landscape, but also profoundly carries the historical context of the integration of northern ethnic groups and the imprint of the interweaving of diverse Chinese cultures, and has extremely high research value and protection significance [107,108,109].

4.3 Discussion

4.3.1 Comparison and Implications of Research Results

This study found that traditional villages in the Liaoxi Corridor are mainly clustered in a strip along suitable terrain such as foothills and river valleys, exhibiting a clear "core-periphery" spatial structure. This is consistent with the limiting effect of topography and water resources on village distribution that has been generally emphasized in existing studies: nationwide, traditional villages are mostly distributed in low-altitude areas with abundant water resources and relatively underdeveloped economies [9,76], and the situation in the Liaoxi Corridor also conforms to this general rule. At the same time, our study further highlights the special characteristics of the Liaoxi Corridor: unlike the multi-area clustering of traditional villages in some regions, the Liaoxi Corridor has villages distributed linearly and continuously along the corridor due to its long and narrow geographical corridor [77]. This linear clustering pattern is rare in the hilly areas of the south, reflecting the uniqueness of the "corridor-type" settlement pattern in the north. In addition, the kernel density and elliptic analysis results of this study show that the distribution of villages in the Liaoxi Corridor has significant directionality and concentration, which is basically consistent with the southwest-northeast orientation mentioned in the overall pattern study of Liaoning Province [77]. Therefore, our results not only verify the dominant role of the natural environment (topography, climate, water system) in the distribution of traditional villages, but also show that the Liaoxi Corridor has some unique characteristics in terms of spatial organization that are different from those of the southeast inland areas, namely, a linear corridor-like clustering pattern.

4.3.2 Relative importance and pattern of influence factors

Quantitative analysis by geographic detectors shows that among the influencing factors of the distribution of traditional villages in the Liaoxi Corridor, the overall effect of natural environmental factors is dominant, followed by factors such as accessibility. In particular, annual precipitation, topographic relief, slope and vegetation cover have the highest explanatory power for the distribution of villages. Among them, the importance of annual precipitation is particularly prominent, which is consistent with the results of studies across the country: Su et al. found that annual precipitation (26.06%) and annual average temperature (19.50%) are the most important influencing factors in the distribution of traditional villages across the country [10]. In the Liaoxi Corridor, abundant precipitation and suitable heat conditions are conducive to the maintenance of agricultural activities and small-scale water conservancy systems. Therefore, traditional villages are concentrated in the river valleys and plain transition zones with abundant precipitation. However, excessively high or low precipitation and temperature conditions are not conducive to the preservation of villages [10]. Vegetation cover (NDVI), as a representation of ecological carrying capacity, also shows a positive effect—areas with high NDVI values (forests or farmland) often provide a better natural environment, which helps the formation and preservation of settlements. Topographic factors (such as altitude and slope) have relatively low q values in the model, possibly because although the altitude difference in the Liaoxi Corridor is large, settlements are mostly concentrated in the low and medium altitude zones, and the overall topographic screening effect has been completed historically. Therefore, the differences in climate gradient and ecological conditions have a more significant impact on the distribution pattern of villages.

In contrast, human and social factors are generally negatively correlated with the number of traditional villages: areas close to urban centers, with higher GDP and higher population density tend to have fewer traditional villages. This indicates that urbanization and modern economic development have, to some extent, "diluted" the distribution pattern of traditional villages, which is consistent with the research conclusions of multiple regions. For example, studies in the upper reaches of the Yellow River have found that high density of traditional villages often corresponds to low population density and low urbanization rate[78]; Chen et al.'s analysis of the whole country also shows that traditional villages are mostly distributed in areas with relatively backward population and economy[76]. In the Liaoxi Corridor, the impact of transportation accessibility is twofold: on the one hand, moderate transportation convenience helps villages maintain and develop industries such as rural tourism; but on the other hand, excessively high road network density often corresponds to plains with high urbanization, where traditional villages have been renovated or disappeared. Therefore, climate-ecological suitability and moderate accessibility together shape the pattern of traditional villages in the Liaoxi Corridor, and the phenomenon that traditional villages are more difficult to preserve in more economically developed areas deserves attention[9,78].

4.3.3 Suggestions for the Protection of Traditional Villages

and Regional Development in the Liaoxi Corridor

Given the unique natural and cultural background of the Liaoxi Corridor, the protection of traditional villages should be closely integrated with the coordinated development of urban and rural areas. First, traditional villages rich in cultural heritage should be included in the key protection scope of national land spatial planning, and the protection boundaries of the layout and historical and cultural features of traditional villages should be clearly defined. Rational utilization should be promoted through the development of rural tourism, achieving revitalization through protection [79,10]. Second, it is necessary to innovate cross-regional collaborative protection patterns, strengthen cultural cooperation between adjacent areas, and avoid protection gaps caused by administrative divisions. It is recommended that local characteristics be reflected in infrastructure construction, avoiding "one-size-fits-all" urbanization development, and preventing damage to the overall environment and features of traditional villages. In the Liaoxi Corridor region, relevant cities and counties should break down administrative boundaries and collaboratively create cultural heritage corridors or protection networks. For example, the traditional village clusters along the Daqingshan-Yiwulüshan line in northern Chaoyang and northern Jinzhou should be planned and protected as a whole corridor, and experience exchange between regions should be strengthened to form a situation of "regional linkage and contiguous protection."

4.4 Conclusion

This study employed GIS spatial analysis and other methods to conduct an in-depth investigation into the spatial distribution characteristics and influencing factors of traditional villages in the Liaoxi Corridor. The main conclusions and insights are as follows:

(1)Spatial Pattern: Traditional villages in the Liaoxi Corridor exhibit a significant clustered distribution pattern with marked regional differences. Villages are mainly distributed in areas with relatively favorable natural conditions, including hilly foothills and river valley plains. The central section of the Jinzhou-Linghai Corridor and the southern part of the Suizhong-Xingcheng Corridor form prominent core clusters, while the village density is lower in the northern part of the corridor and the surrounding mountainous areas, showing an overall decreasing distribution trend from south to north.

(2)Natural Environment: Natural geographical conditions play a dominant role in the spatial layout of traditional villages in the Liaoxi Corridor. Topography is the most critical influencing factor—traditional villages are mostly located in areas with moderate slopes, flat terrain, and proximity to water sources. Abundant water resources further reinforce the clustered distribution of settlements. Climate factors such as precipitation and temperature provide basic conditions for agricultural production, but their regional variability is slightly weaker than that of topography and water resources.

(3)Human and social factors also significantly influence village distribution. Accessibility has a prominent impact on the modern development and preservation of traditional villages: traditional villages are generally distributed along historically convenient corridors, and improvements in modern transportation infrastructure further enhance their accessibility and tourism development potential. Economic development level has a dual impact on village layout; economically underdeveloped areas tend to retain the historical features of traditional settlements more easily, while traditional villages in economically developed areas are more likely to be altered or disappear. Historical and cultural background also plays an important role in village patterns; the spatial distribution of traditional villages in the Liaoxi Corridor profoundly reflects the region's historical evolution, with the long-term integration of multi-ethnic cultures and the frontier defense system shaping the layout characteristics of settlements.

(4)Spatial correlation characteristics: There are significant spatial correlations between traditional villages in the Liaoxi Corridor and the distribution of arable land resources, ecological environment, and cultural heritage. Most traditional villages are located in fertile farmland and near water, reflecting a high degree of dependence between humans and the land. Areas with good ecological environments (lush vegetation and abundant water resources) typically correspond to areas where traditional villages are well-preserved. Furthermore, many villages are surrounded by cultural landscapes such as historical sites and traditional building complexes, reflecting a high degree of coupling between cultural elements and spatial distribution. This verifies the applicability of the "production base-environmental constraint" theory in the Liaoxi Corridor, while also emphasizing the role of historical and cultural factors.

(5)Theoretical and Practical Significance: The above research results enrich our understanding of the spatial distribution patterns of traditional villages, providing new empirical evidence for the study of traditional settlements in northern frontier regions, particularly revealing the causes of the corridor-type agglomeration pattern in the Liaoxi Corridor. Theoretically, this study emphasizes the comprehensive coupling effect of natural, social, and cultural factors, expanding the perspective of traditional village spatial research. Practically, these findings can provide references for rural revitalization, cultural heritage protection, and spatial planning in the Liaoxi Corridor and similar regions. We recommend integrating the protection of traditional villages into the rural revitalization strategy. This involves optimizing infrastructure and public service provision to promote coordinated regional economic development and cultural heritage preservation. Simultaneously, efforts should be intensified to protect and restore villages with outstanding historical and cultural value, clearly defining protection boundaries and strictly controlling development intensity to achieve sustainable regional development and cultural continuity.

Looking ahead, future research can further explore the dynamic evolution patterns of traditional villages and delve into strategies for sustainable cultural development, thereby refining the theoretical framework and practical pathways for the protection and utilization of traditional villages. In the ongoing process of modernization, only by inheriting culture through development and revitalizing villages through protection can a true win-win situation be achieved for economic, social, and cultural heritage preservation.

Chapter 5
Spatial Distribution Characteristics and Influencing Factors of Traditional Villages in the Liaodong Peninsula (SRO2)

5.1 Spatial Distribution Characteristics of Traditional Villages in the Liaodong Peninsula

5.1.1 Spatial Distribution Types

National and provincial-level traditional villages in the Liaodong Peninsula are distributed in Dalian, Anshan, Dandong, and Benxi. While their overall scale is smaller than that of the Liaoxi Corridor, their spatial distribution is also uneven (Figure 24). Dalian has 5 traditional villages, accounting for 35.7% of the total; Anshan has 4 (28.6%); Dandong has 3 (21.4%); and Benxi has 2 (14.3%). This indicates that the number of traditional villages in the Liaodong Peninsula is small and their distribution is uneven. Overall, the spatial pattern of traditional villages in the Liaodong Peninsula is a combination of point-like settlements and strip-like distribution: some villages form local clusters along the foothills and valleys, while others are scattered at the peninsula tip and in the open coastal plains. National-level traditional villages (red dots) are concentrated near Dandong and Dalian, forming a cluster along the coast and border; provincial-level traditional villages (blue dots) are relatively scattered, mostly distributed in the hilly and mountainous areas of Anshan and Benxi. This pattern indicates that traditional villages on the Liaodong Peninsula exhibit a spatial characteristic of "local core - broad periphery": relatively suitable terrain such as foothills and river valleys are the core of village settlements, while highly urbanized coastal plains become the sparse periphery of villages.

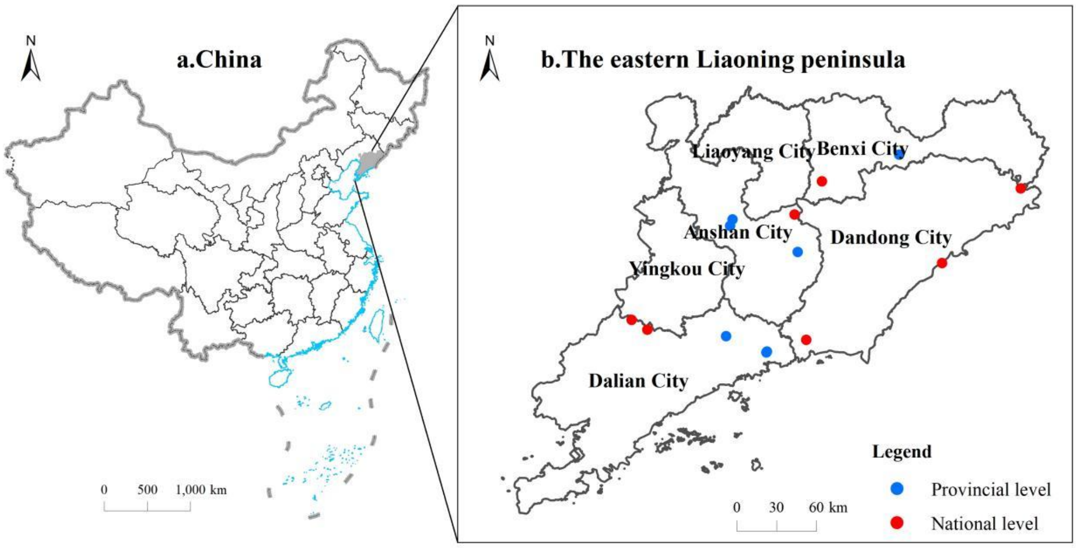

Figure 24. Distribution of traditional villages in the Liaodong region.

Further observation reveals that the spatial distribution of traditional villages on the Liaodong Peninsula is closely related to the mountain and sea topography and historical development channels. Overall, villages form an arc-shaped "core" in the low-mountain-river valley transition zone of Benxi-Liaoyang-Anshan, while appearing as scattered "peripheries" at the peninsula tip and coastal open areas. National-level villages (red dots) are relatively concentrated in the foothills and river valleys surrounding Benxi, Liaoyang, and Dandong, reflecting a site selection pattern of "close to mountains and water, relatively stable terrain, and high preservation of traditional patterns." Provincial-level villages (blue dots) are more widely distributed around the urban corridor of Anshan-Yingkou-Dalian, but due to the influence of modern port industry and urban expansion, they exhibit a strip-like-patterned pattern with weak spatial continuity. Taking Dandong as an example, the strip-like clustering based on the Yalu River valley and hilly terrain is more pronounced, with a relatively higher proportion of national-level villages. In contrast, coastal cities such as Dalian and Yingkou, affected by rapid urbanization and shoreline development, have traditional villages that are mostly preserved in an "island-like" manner. Overall, the region exhibits a distinct "core-periphery" spatial structure: the core is a habitable zone composed of foothills, river valleys, and gentle hills, while the periphery consists of highly urbanized coastal areas and open plains far from the foothills, reflecting the distribution pattern of villages under the coupling of natural constraints and human processes.

5.1.2 Spatial Distribution of Equilibrium

Based on the Nearest-Neighbor Index (NNI) analysis (Table 22), the traditional villages on the Liaodong Peninsula exhibit a discrete/uniform distribution. The average observed distance of all traditional villages is 29.704 km, higher than the theoretical average distance of 23.902 km, with a calculated R = 1.243 (>1). This indicates that the actual nearest-neighbor distance between villages is approximately 24.3% smaller than the expected value of a random distribution (a difference of 5.802 km), suggesting an overall spatial repulsion effect or homogenization trend, significantly deviating from a clustered pattern.

Village Type	Mean Observed Distance (km)	Expected Mean Distance (km)	Nearest-Neighbor Index R	Z-score	P-value
Total	29.704	23.902	1.243	1.737	0.082
National level	49.921	32.49	1.537	2.715	0.006
Provincial level	29.143	22.518	1.294	1.489	0.136

Table 22. Average nearest-neighbor distance and index.

Further comparison revealed significant differences in the spatial organization characteristics of traditional villages at different levels (see Table 22). In terms of the nearest neighbor index, the R-values were ranked as follows: national level (1.537) > provincial level (1.294) > overall (1.243), all three being greater than 1, indicating a discrete distribution rather than clustering or complete randomness on a global scale. The corresponding average observed distances were all greater than the expected distances: national level 49.921 km > 32.490 km (difference 17.431 km), provincial level 29.143 km > 22.518 km (difference 6.625 km), and overall level 29.704 km > 23.902 km (difference 5.802 km). Among them, national-level villages exhibit the highest dispersion, with significantly increased distances between locations. This reflects considerations of representativeness and inter-regional balance in the selection process, as well as the cross-county "sparse distribution" pattern constrained by mountainous terrain and transportation corridors. Provincial-level villages, while also dispersed, are relatively closer to the overall level, exhibiting a weakly dispersed—zonal—dispersion.

Overall, traditional villages on the Liaodong Peninsula present a spatial pattern of "dispersion but stratification" on a global scale: national-level villages are the most dispersed, followed by provincial-level villages, with the weakest overall. Combining this with the habitable zone along the Benxi-Liaoyang-Anshan foothills-river valley shown in the location map above, it can be inferred that pocket-like/strip-like micro-clusters still exist locally, but are masked by global-scale dispersion. Further multi-scale tests using kernel density/hotspot analysis and Ripley's K can be conducted to distinguish the spatial characteristics of parallel global dispersion and local clustering, providing a basis for formulating an optimization strategy of "national-level—provincial-level stratified protection, and equal emphasis on zonal corridors and nodes—patches."

5.1.3 Spatial Distribution Directionality

Standard deviation elliptic analysis results show that the overall distribution center of traditional villages on the Liaodong Peninsula is located at 123.49°E, 40.40°N, with a principal axis azimuth of approximately 63.87°and a major axis of approximately 235.87 km, generally trending northeast-southwest (Table 23). Among them, the ellipse center of national-level villages is at 123.65°E, 40.42°N, with a major axis of 292.89 km and an azimuth of 70.55°. These villages exhibit a narrow and elongated ellipse shape (short-to-major axis ratio≈0.34), demonstrating the strongest spatial extension.

The corresponding ellipse area and perimeter are approximately 22,621 km² and 653.19 km², respectively, indicating a more sparse cross-city distribution and a stronger corridor-like characteristic. The ellipse centered at 123.33°E and 40.38°N, with a major axis of 171.54 km, an azimuth of 32.92°, and a minor-to-major axis ratio of approximately 0.52. The ellipse area is approximately 12,030 km², and the circumference is approximately 420.0 km. It exhibits a relatively more concentrated distribution and a more pronounced localized zonal clustering characteristic. All three types of ellipses—overall, national, and provincial—show a northeast-southwest orientation, but the national-level ellipse has the largest coverage and strongest directional characteristic, while the provincial-level ellipse has a smaller area and higher cohesion. This reflects the differentiated constraints imposed by the peninsula foothills-valleys and coastal corridors on the distribution of traditional villages.

Village Type	CenterX	CenterY	XStdDist	YStdDist	Rotation	Shape_Length	Shape_Area
Total	123.491	40.399	117932.987	55345.959	63.87°	562,267	20,505,552,000
National Level	123.647	40.424	146445.680	49167.560	70.55°	653,192	22,620,651,000
Provincial	123.334	40.375	44643.806	85771.282	32.92°	419,963	12,029,650,000

Table 23. Standard deviation ellipse data table.

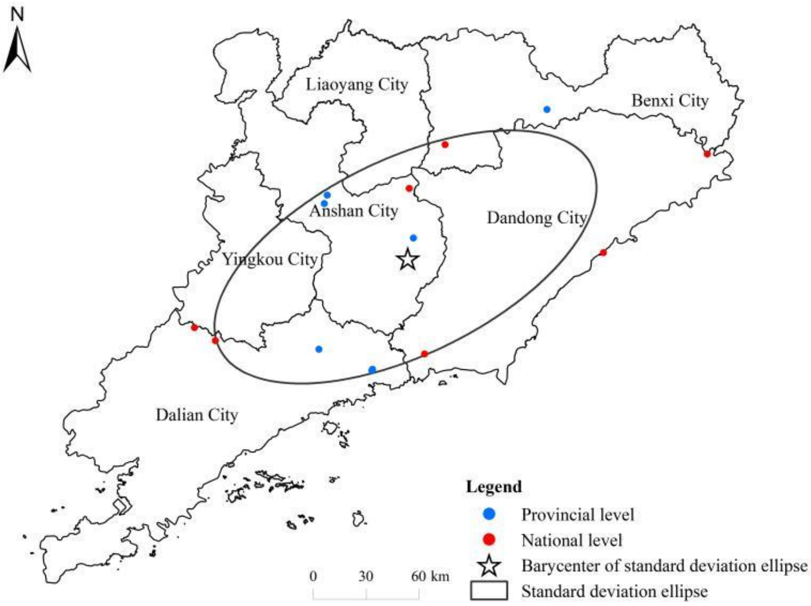

Figure 25. Standard deviation ellipse of overall village distribution.

As shown in Figure 25, the standard deviation ellipse reveals the overall distribution characteristics and directional trends of spatial elements [113,114]. Standard deviation ellipse analysis of all traditional villages on the Liaodong Peninsula shows that its major axis is much larger than its minor axis, and it generally runs southwest-northeast, consistent with the orientation of the main mountain ranges in Liaoning Province [115,116,117]. This indicates that the villages extend further in this direction. The centroid of the ellipse is located in the western part of the central peninsula, coinciding with the traditional village clusters in Jinzhou and Huludao [115,116,117]. Combined with the kernel density distribution, it can be seen that a high-density cluster has formed in the western part of the Liaodong Peninsula (centered on the Jinzhou-Huludao area), while the villages in the coastal and mountainous areas are relatively sparsely distributed, exhibiting an overall zonal extension pattern. This demonstrates that the traditional villages in Liaodong exhibit significant spatial anisotropy: extending in a zonal pattern along the major axis and relatively concentrated along the minor axis, presenting a distribution characteristic that combines zonal and cluster features.

This spatial pattern is determined by the combined effects of multiple factors. In terms of natural environment, the Liaodong Peninsula belongs to the warm temperate monsoon climate zone, with mild winters and cool summers, and a humid and habitable climate [118,122], which is conducive to agricultural production and village formation. The peninsula's topography shows significant east-west differences: the Qianshan Mountains run through it from north to south, with the eastern part mostly mountainous and hilly, while the western part and coastal areas are the Liaohe Plain and other low-lying areas. Therefore, traditional villages are mostly located along plains, river valleys, and coastlines, while they are relatively sparse in steep, densely forested mountainous areas. In addition, the lower reaches of the Liaohe River and the Daling River, among other waterways, run through the peninsula [118,120], historically facilitating irrigation and navigation, leading to the formation of many ancient settlements along the river basins [118,121]. Transportation conditions also significantly influence the distribution: north-south trunk lines such as the Shenyang-Dalian Expressway connect major cities like Shenyang and Dalian, and economic and logistical activities along these lines promote the extension of village distribution, thus strengthening the clustering trend along the major axis of the ellipse.

Humanistic and historical factors also play an important role. Liaodong has historically been an important part of the "Liaoxi Corridor," where Central Plains culture and Northeast ethnic groups blended [118,122]. The region boasts a rich historical and cultural heritage and diverse ethnic traditions, with numerous villages historically clustered around Jinzhou and Huludao. Furthermore, the recent publication of national and provincial lists of protected traditional villages has led relevant departments to require these villages to develop protection plans [120,121,122], emphasizing "development within protection, and protection within development," and integrating traditional village protection with the rural revitalization strategy to vigorously develop rural tourism and cultural industries [121,122]. These policies have promoted the regional protection and utilization of traditional villages, resulting in village clusters exhibiting either contiguous protection or linear development patterns.

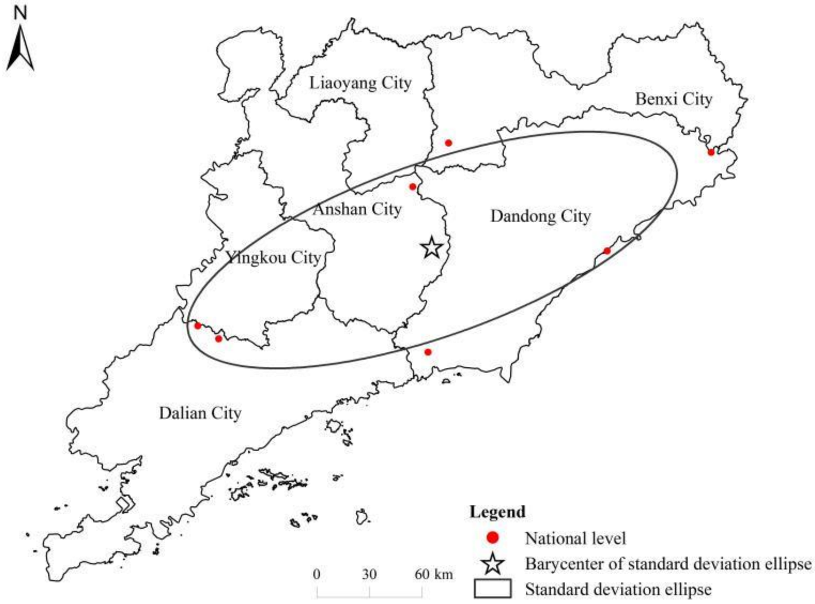

Figure 26. Standard deviation ellipse of national-level village distribution.

As shown in Figure 26, the major axis of the ellipse of the national-level traditional villages in the Liaodong Peninsula is about 146 km and the minor axis is about 49 km, with a direction of about 70°[123]. The ellipse of the national-level traditional villages has a higher flattening (a larger ratio of major to minor axis), indicating that it extends more significantly along the main direction and has a smaller lateral dispersion. In terms of the center of gravity, the center of the national-level traditional villages is slightly northeast of the overall villages, suggesting that they are more distributed in coastal hills or transportation hub areas. Both the overall villages and the national-level traditional villages are clustered [35], but the clustered areas of the national-level traditional villages are more concentrated due to the fewer locations. Natural topography dominates the distribution characteristics: villages in plains are mostly clustered along rivers and farmland edges, villages in hills are linearly distributed along mountain streams and valleys, and villages in mountainous areas are distributed in a scattered cluster [124]. The convenience of transportation and policy review guidance are secondary factors - high-quality traditional villages are mostly distributed near major transportation routes and areas rich in cultural resources [35,125,126]. Comprehensive analysis reveals that multiple factors, including topography, water systems, and historical culture, interact to influence the distribution pattern of national-level villages. In terms of planning and protection, the overall framework of "mountains, water, and fields" should be followed: priority should be given to protecting village clusters and their ecological corridors, while simultaneously improving transportation infrastructure to avoid isolated development. A coordinated protection system should be established at the watershed or block level to enhance regional coherence.

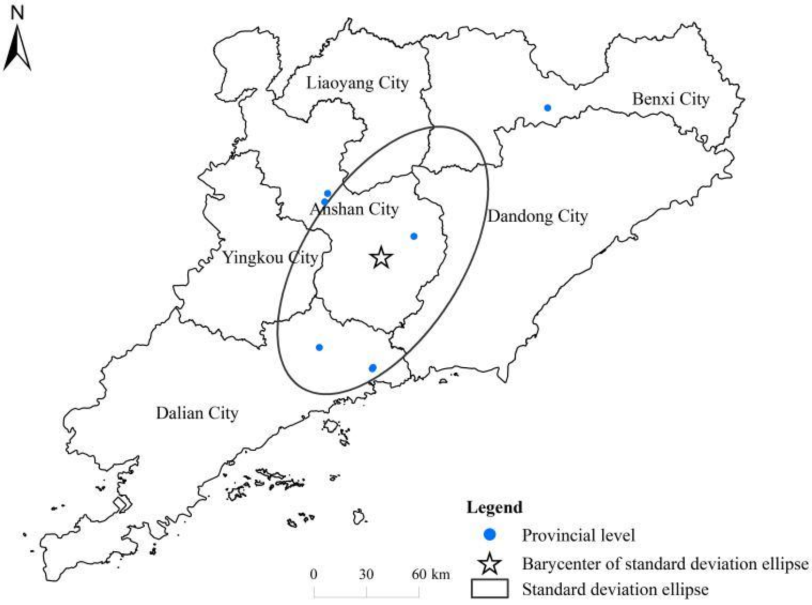

Figure 27. Standard deviation ellipse of provincial village distribution.

As shown in Figure 27, the standard deviation ellipse of the provincial traditional villages in the Liaodong Peninsula is significantly elongated, with the major axis being more than twice the length of the minor axis. The flatness is relatively large (≈0.52), and the rotation angle of the major axis is about 32.9°, indicating that the distribution of villages has obvious directionality. The major axis of the ellipse is roughly northeast-southwest, which is similar to the southwest-northeast direction of the ellipse of traditional villages in Liaoning Province [27], and generally extends along the direction of the peninsula mountain range. The centroid of the ellipse is located near longitude 123.33°E and latitude 40.38°N, which falls exactly between Zhuanghe City in Dalian and Xiuyan/Haicheng area in Anshan, and basically coincides with the main gathering areas of these two provincial traditional villages. In terms of spatial distribution, the provincial traditional villages are not evenly distributed, but rather in a belt-like clustering pattern: one part is concentrated in the coastal hilly area in the south of Dalian, and the other part is concentrated in the mountainous and hilly areas in the north of Anshan. The northeast-southwest direction indicated by the major axis of the ellipse can be regarded as the distribution direction of the villages along the valley of the water system and the transportation corridor, and the distribution density gradually weakens at both ends along this axis.

5.1.4 Spatial Distribution and Clustering Characteristics

This study used the kernel density analysis function in ArcGIS 10.1 spatial analysis tools to calculate the kernel density of 14 traditional villages (7 national-level and 7 provincial-level) in the Liaodong Peninsula, generating a kernel density distribution map of traditional villages in the Liaodong Peninsula (Figure 28 and Table 24). The results show that the traditional villages in the Liaodong Peninsula generally exhibit a distribution characteristic of "a small number concentrated and locally clustered".

High-density areas are mainly distributed in the area where the hills in the south of the peninsula meet the river valleys in the central part of the peninsula, while other areas have few villages and generally low kernel density values. Due to the peninsula's terrain being mostly mountainous and hilly, with relatively limited flat areas, and influenced by transportation corridors and historical and cultural settlements, traditional villages tend to concentrate in areas with better resource conditions and less development interference, thus forming a spatial pattern where a few high-value core areas coexist with large areas of low-value areas.

	Classification	Quantity	Average	Min	Max	List
1	0-10	10	6.966	5.172	9.324	Xinchengzi Village, Tongjiang Village, Beici Village, Ronghua Village, Dingziyu Village, Hekou Village, Xutun Village, Dongmatun Village, Lianshanguan Village, Dongdayu Village
2	10 and above	4	11.34	10.192	12.504	East Community Village, West Community Village, Xialin Village, Gusaoshi Village

Table 24. The overall village kernel density(Liaodong).

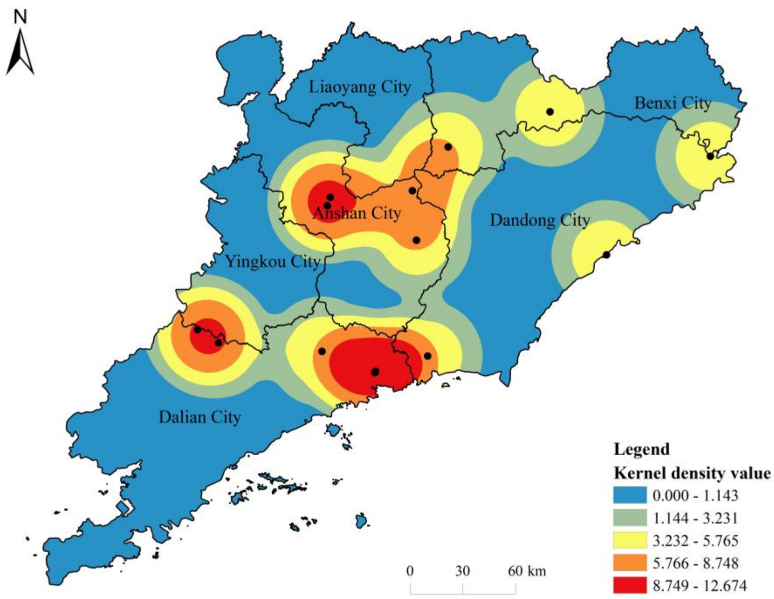

Figure 28. The overall village kernel density map(Liaodong).

The distribution of traditional villages in the Liaodong Peninsula shows a pattern of "high density in some areas and low density overall": the southern coastal and central depressions form clustered areas (high red and orange values), while the northern mountainous and marginal areas are scattered areas (low green and blue values). This distribution pattern reflects the uneven regional infrastructure and development level.

Geographical conditions are an important factor in forming this pattern. The Liaodong Peninsula is mostly mountainous and hilly, with the Qianshan Mountains as its backbone, and the terrain is fragmented. Areas with high core density usually correspond to relatively flat foothills, valleys, or coastal lowlands, while the high-altitude mountainous areas are inconvenient to access and isolated from the outside world, allowing villages to be preserved relatively intact[127]. In contrast, the Liaodong Plain and suburban areas are highly developed, and traditional villages are often fewer. Human and social factors also affect the distribution pattern. Studies have shown that traditional villages are mostly distributed in areas far from the city center, and the degree of transportation convenience is negatively correlated with the number of villages[128]. The southern part of the Liaodong Peninsula has historically had a strong agricultural and fishery base and relatively developed transportation, thus preserving more traditional villages; while the northern mountainous areas are isolated by poor transportation and have a large urban-rural gap, resulting in a sparse distribution of villages. In general, convenient transportation and economic conditions often accompany rapid urbanization, leading to the decline of some villages in plains areas, while remote mountainous areas with poor transportation retain their traditional settlement patterns. In response to these spatial distribution characteristics, planning and protection should adopt a differentiated strategy: for high-density areas, historical preservation and appropriate tourism development should be strengthened to maintain the overall village landscape; for low-density remote areas, infrastructure such as roads and communications needs to be improved, public services enhanced, and the quality of life for villagers improved to prevent village depopulation. Overall, the principle of "adapting to local conditions and prioritizing protection" should be upheld, integrating the protection of traditional villages into the framework of rural revitalization and spatial planning, balancing cultural heritage with ecological protection, and promoting balanced regional development.

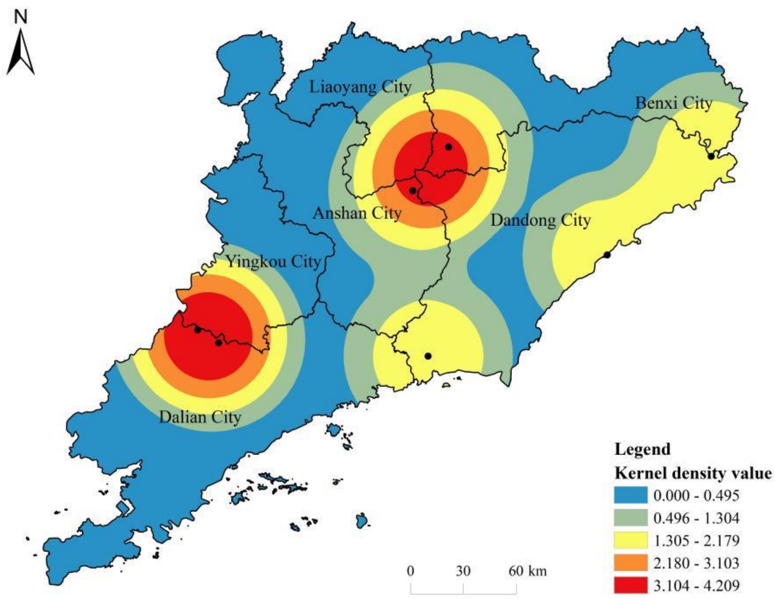

Figure 29. Kernel density distribution map of national-level villages(Liaodong).

As shown in Figure 29, the density distribution of national-level traditional villages in Liaoning Province exhibits a pattern of coexistence of clustering and sparseness, and a clear core-periphery structure. Overall, multiple high-density clusters are formed in the coastal plains and major mountainous and hilly areas, while the inland plains and northern peninsula are relatively sparse [8]. This trend of decreasing density from multiple cores to the periphery is similar to the village cluster patterns found in other watershed studies [129]. Spatially, a core-periphery structure is presented: the clustered areas are often areas with rich historical and cultural resources or excellent transportation conditions, while the peripheral areas have few villages and are scattered. In terms of causes, topography, ecology, and transportation are the main drivers. The western part of the Liaodong Peninsula is mountainous and hilly, while the eastern coastal plain is open. Forests and oceans form natural barriers, so villages are mostly located on moderately sloping, sunny slopes [96]; there are fewer villages on flat coasts and in the Liaohe River valley. Areas with well-developed transportation networks also form significant clusters: the density of villages is highest along the main roads, decreasing with distance [129]. In addition, the integration of immigrants and rich ethnic cultural elements in Northeast China have also led to the formation of secondary clusters in the border areas. Administrative selectivity has also exacerbated spatial differences, with national-level list assessments favoring well-preserved villages, thus benefiting the original core areas more. Studies have shown that high-GDP areas have a larger number of well-preserved traditional villages[129], while areas with complex terrain form natural barriers[129]. This clustered distribution pattern has a significant impact on cultural heritage protection and resource allocation. On the one hand, clustered areas are conducive to the establishment of cultural tourism corridors and centralized protection, achieving efficient management of cultural resources[8,129]; on the other hand, it may also lead to a bias in protection investment towards the core areas, making it difficult for peripheral villages to obtain equal support. Therefore, it is necessary to take into account different regions in protection planning and resource allocation to ensure that traditional villages in each region receive the necessary attention and investment.

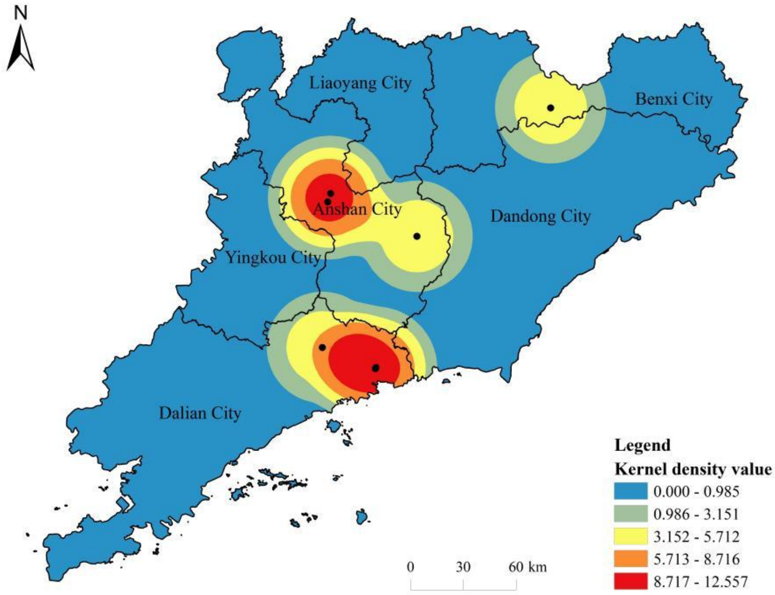

Figure 30. Kernel density distribution map of provincial villages(Liaodong).

As shown in Figure 30, the traditional villages at the provincial level in the Liaodong Peninsula exhibit a mixed pattern of multi-center clustering, zonal extension, and island-like distribution. The core density map shows that continuous high-density cores have formed near the western mountainous areas of Liaoning Province, such as the Chaoyang-Huludao-Jinzhou area; secondary cores surround the main core in ring or zonal patterns, such as the Fuxin-Jinzhou and Huludao-Qinhuangdao edge areas [35]. Overall, the village distribution constitutes a hierarchical structure of "multi-core clustering and gradient transition," similar to the "five major core density areas" morphology of the Loess Plateau region [33]. Furthermore, zonal distributions (e.g., along the coastline or railways) and isolated high-density areas formed after valley separation (similar to the situation in Liulin County, Shaanxi Province [83]) may appear along the Liaoning coast and transportation corridors, indicating that the provincial core density has the characteristics of both zonal distribution surrounding the core and local isolated distribution. Studies on traditional villages at the provincial level in Sichuan also point out that the provincial distribution exhibits a "six-core, five-zone" characteristic [7], corroborating the commonality of multi-core and zonal distributions at the provincial scale.

The formation of this distribution pattern is related to multiple factors such as natural conditions, cultural resources, economic foundation and application pattern. In terms of natural conditions, topography has a significant impact on the preservation of villages. In Liaoning, the mountainous and hilly terrain (such as near Chaoyang, Huludao and Jinzhou) has large topographic relief and closed landforms, which are suitable for the selection of ancient villages and easy to protect. Therefore, the village density in these areas is relatively high[27]. In contrast, the distribution of villages in plains and flat coastal areas is relatively sparse. Climate and hydrology also play a role. For example, annual precipitation affects agriculture and living environment and has a significant impact on the distribution of villages[65]. In terms of cultural resources, the density of cultural heritage sites and traditional characteristic resources determines the degree of village agglomeration. Loess's plateau study shows that cultural heritage density ($q \approx 0.546$) is the primary factor driving the distribution of traditional villages[65], indicating that areas with rich historical and cultural accumulation are more likely to form high-density areas of traditional villages. More provincial traditional villages will also gather around towns with rich cultural resources in Liaoning. In terms of economic foundation, population size, GDP level and urbanization level affect the relationship between people and land, and thus affect the distribution of villages[67]. Generally speaking, remote areas are economically underdeveloped and sparsely populated, but due to lower urbanization and less external influence, traditional villages are better preserved; while economically developed areas have more villages but face greater pressure to renew them, and their clustering patterns are also different. In terms of policy patterns, the application and protection efforts determine the distribution characteristics. The national list of traditional villages is strictly evaluated and usually located in representative areas with high historical value and rich cultural resources, and is supported by national protection funds [98]; provincial villages are evaluated by local governments, are more numerous, and are more dispersed, and are used to fill the gaps in national protection. The Shaanxi case shows that national villages are more likely to receive special support from the central government, which means that in terms of spatial distribution, national villages are more concentrated in policy-favored areas, while provincial villages cover a wider range of provinces [130,131].

5.2 Analysis of Factors Influencing the Distribution of Traditional Villages in the Liaodong Peninsula

Natural geography remains the dominant force, but its structure differs from that of the Liaoxi Corridor. Geographic data analysis shows that precipitation has the highest explanatory power ($q \approx 0.374$, correlation coefficient $R \approx 0.052$), followed by road network density ($q \approx 0.230$, $R \approx -0.227$) and distance from the city center ($q \approx 0.224$, $R \approx 0.167$). Temperature ($q \approx 0.200$, $R \approx -0.110$), humidity ($q \approx 0.149$, $R \approx 0.156$), and NDVI ($q \approx 0.139$, $R \approx 0.199$) are moderately explanatory. Topographic factors have relatively weak explanatory power: DEM ($q \approx 0.096$, $R \approx 0.116$), slope ($q \approx 0.068$, $R \approx 0.141$), and surface relief ($q \approx 0.071$, $R \approx 0.142$). River distance has almost no explanatory power ($q \approx 0.010$, $R \approx -0.054$). Socioeconomic factors are generally weaker than natural factors: GDP ($q \approx 0.085$, $R \approx -0.091$), population density ($q \approx 0.027$, $R \approx -0.082$), and nighttime light ($q \approx 0.067$, $R \approx -0.131$) all show low and mostly negative correlations, indicating that modern economic development and urbanization have a substitution/dilution effect on the preservation of traditional villages.

In summary, traditional villages on the Liaodong Peninsula are mainly constrained by precipitation-vegetation-temperature and humidity conditions, as well as moderate accessibility/distance from cities: the piedmont-coastal transition zone with better precipitation and ecological conditions is more likely to form and preserve traditional settlements; while excessively high road network density and heavily urbanized areas have a significant inhibitory effect on the distribution of traditional villages.

5.2.1 Topographical Factors

Topography is one of the key geological environmental factors influencing the distribution of traditional villages. Elevation affects various environmental elements such as surface water distribution patterns, temperature and humidity, biogeographical boundaries, and land type classification. It also influences the regional environment, village architectural forms, and the cultural customs shaped by the local villagers' production and lifestyle.

This study uses 30-meter resolution digital elevation model (DEM) data provided by the National Geospatial Data Cloud (www.gscloud.cn), combined with a 1:500,000 scale map of Liaoning Province. Based on field surveys and corrections, spatial overlay elevation analysis of traditional villages on the Liaodong Peninsula was conducted using ArcGIS 10.1 software. The DEM data was reclassified using the Natural Breaks method. The analysis results are shown in Figure 31 and Table 25.

	Classification	Quantity	Average	Min	Max	List
1	0-50	3	10.341	5.579	19.737	East Community Village, West Community Village, Dongdayu Village
2	50-100	2	78.817	75.158	82.476	Ronghua Village and Xutun Village
3	100 and above	9	243.898	109.75	407.056	Xinchengzi Village, Tongjiang Village, Xialin Village, Beici Village, Gusaoshi Village, Dingziyu Village, Hekou Village, Dongmatun Village, Lianshanguan Village

Table 25. Elevation(Liaodong).

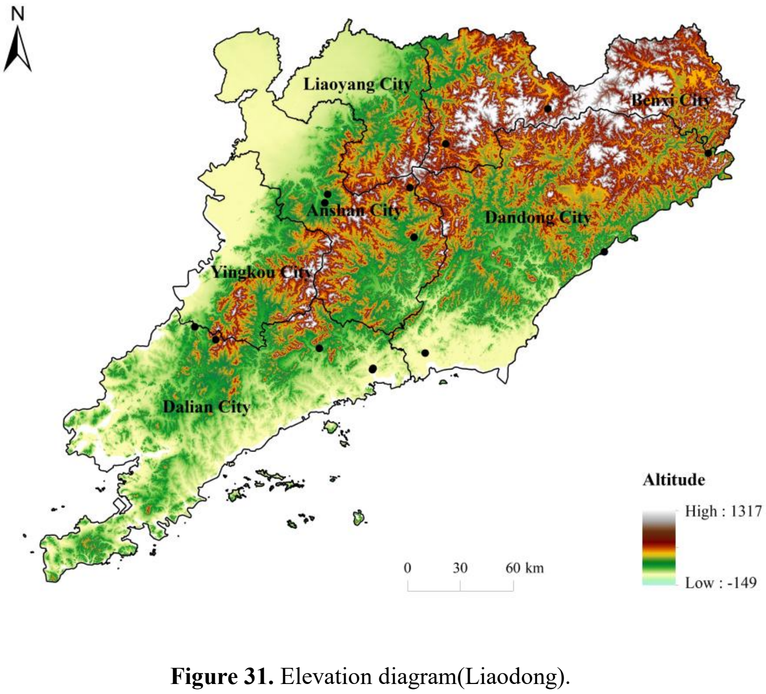

Figure 31. Elevation diagram(Liaodong).

The traditional villages on the Liaodong Peninsula are predominantly situated in hilly and mountainous terrain, exhibiting a spatial pattern of "low in the southwest and high in the northeast" (Figure 31). As can be seen from the elevation map, the eastern areas, including Benxi, Dandong, and northern Liaoyang, are characterized by numerous high-altitude mountains, with some areas exceeding 1000 meters in elevation. In contrast, the Dalian Peninsula and the coastal areas of Yingkou have lower elevations, primarily concentrated in low-lying plains below 100 meters. This topographical pattern creates significant differentiation, directly influencing the site selection and distribution of traditional villages. Limited by the mountainous terrain, climate, and transportation conditions, villages are sparsely distributed in the high-altitude eastern regions, while the low hills and coastal plains in the southwest are more conducive to settlement and agricultural activities, thus attracting more village clusters.

	Classification	Quantity	Average	Min	Max	List
1	0-5	4	2.446	0.636	4.683	East Community Village, West Community Village,Ronghua Village, Dongdayu Village
2	5-10	4	6.859	5.145	7.83	Xinchengzi Village, Xialin Village, Gusaoshi Village, Xutun Village
3	10-15	6	11.713	10.415	12.638	Tongjiang Village, Beici Village, Dingziyu Village, Hekou Village, Dongmatun Village, Lianshanguan Village

Table 26. Slope(Liaodong).

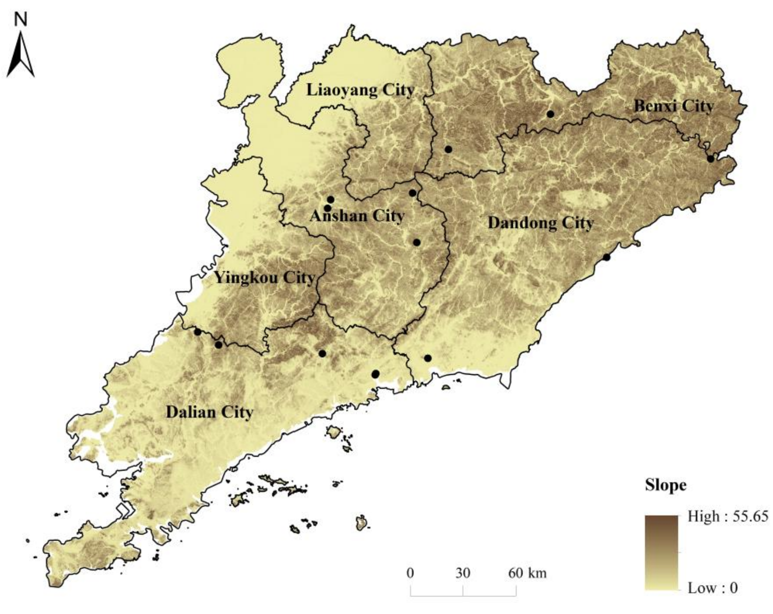

Figure 32. Slope diagram(Liaodong).

Figure 32 and Table 26 further reveal the topographical complexity within the traditional village areas of the Liaodong Peninsula. The overall slope is relatively steep, especially in the mountainous areas of eastern Benxi and Dandong, and the hilly areas of northeastern Liaoyang and Anshan, where slopes generally exceed 25°, hindering transportation accessibility and infrastructure development. In contrast, the terrain in parts of Dalian, Yingkou, and southeastern Anshan is flat, with slopes mostly below 8°, providing favorable conditions for settlement development. Overall, traditional villages on the Liaodong Peninsula are mostly distributed in low- to mid-altitude areas with gentle slopes, primarily in river valleys, hills, and near-shore plains. This site selection pattern avoids geological disasters such as floods while ensuring the sustainability of agricultural production, meeting the dual requirements of traditional settlements for terrain safety and production suitability.

From a spatial planning perspective, attention should be paid to the weak infrastructure in villages in high-slope areas, and zoning protection strategies should be developed based on topographical characteristics. In steep, densely forested border areas, ecological protection and cultural preservation should be prioritized; while in areas with gentle slopes and superior terrain, the integration of traditional villages and new rural development can be promoted to build a multi-type, multi-level settlement spatial network.

	Classification	Quantity	Average	Min	Max	List
1	0-10	2	4.918	4.895	4.941	East Community Village, West Community Village
2	10-20	1	16.263	16.263	16.263	Dongdayu Village
3	20 and above	11	41.798	21.429	59.238	Xinchengzi Village, Tongjiang Village, Xialin Village, Beici Village, Ronghua Village, Gusaoshi Village, Dingziyu Village, Hekou Village, Xutun Village, Dongmatun Village, Lianshanguan Village

Table 27. Topographic relief(Liaodong).

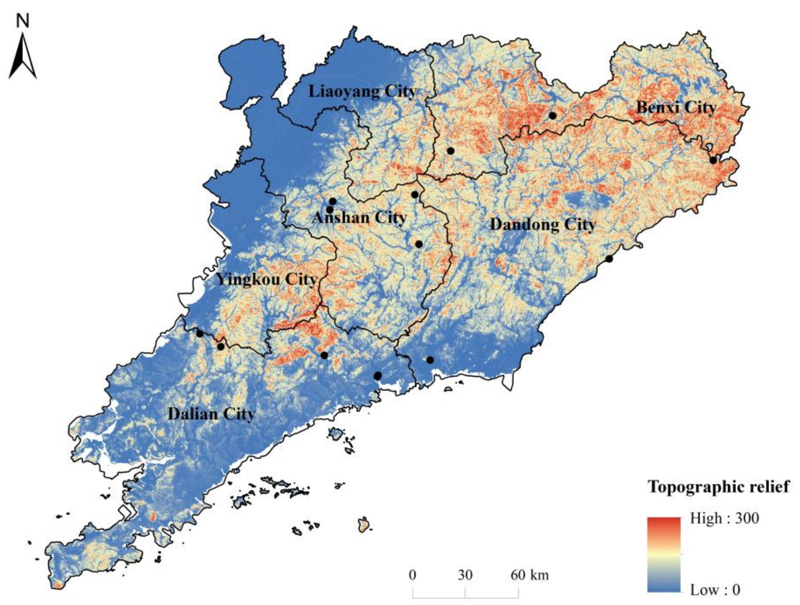

Figure 33. Diagram of topographic relief(Liaodong).

As shown in Figure 33 and Table 27, the traditional villages on the Liaodong Peninsula exhibit a striped pattern of "low undulation along the coast and river mouths—medium undulation in inland hills—high undulation in the northeastern mountains": the southern and southwestern coastal plateaus and river deltas are low-undulation areas (blue), the central low mountain and hilly transition zone is mainly medium-undulation (light yellow), and the northeastern mountain system and the intersection of several mountain ranges form a high-undulation core (orange-red, up to about 300 m). This spatial gradient is determined by the basement topography (coastal deposition/erosion—inland tectonic uplift) and shaped by the long-term effects of river incision and weathering erosion.

5.2.2 Climate and Ecological Factors

	Classification	Quantity	Average	Min	Max	List
1	5-10	10	8.61	6.684	9.953	Xinchengzi Village, Tongjiang Village, Xialin Village, Beici Village, Gusaoshi Village, Dingziyu Village, Hekou Village, Dongmatun Village, Lianshanguan Village, Dongdayu Village
2	10-15	4	10.147	10.003	10.451	East Community Village, West Community Village, Ronghua Village, Xutun Village

Table 28. Temperature(Liaodong).

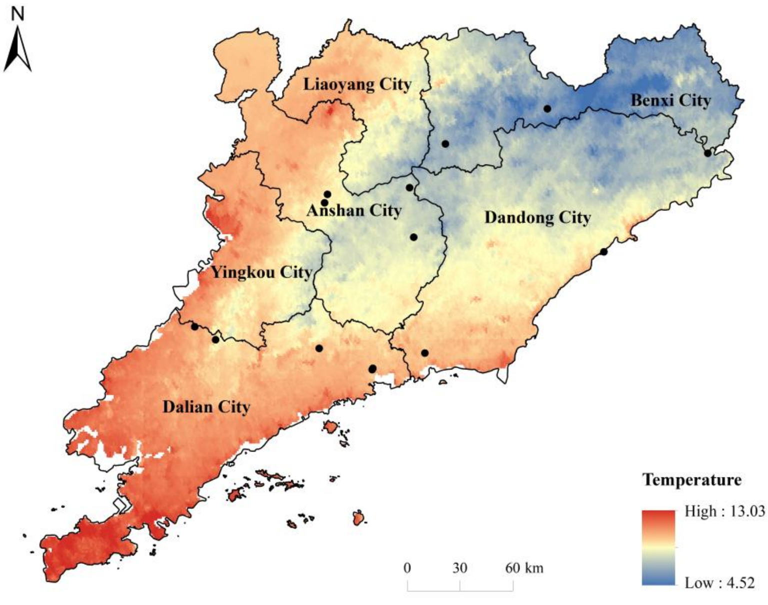

Figure 34. Temperature diagram(Liaodong).

As shown in Figure 34 and Table 28, traditional villages on the Liaodong Peninsula exhibit a decreasing heat pattern from south to north and from the coast to the inland: the southern nearshore and offshore islands are in a high-value zone (high value in the legend is about 13.0°C), the central hills and valleys are a transition zone, and the northeastern mountains (northeast of Benxi and Dandong) form a low-value center (about 4.5–7.0°C). This pattern reflects the combined effect of latitude, ocean regulation, and topographic lifting in temperature rise and fall—the nearshore areas are more significantly buffered by sea temperature and sea breeze, resulting in stable heat conditions; while the northeastern part has a significantly lower average annual temperature due to increased altitude and inlandness. The heat gradient directly affects the livelihood suitability of traditional villages: the mid-temperature to cool-temperate zone (about 8–11°C) is more conducive to dryland farming and fruit and vegetable production, multiple cropping and livestock synergy, and usually forms relatively stable settlement zones; the extreme low-temperature zone has a short agricultural season and high energy consumption, limiting the scale and density of settlements [7,91].

	Classification	Quantity	Average	Min	Max	List
1	500-1000	5	831.34	753.905	981.773	Xialin Village, Ronghua Village, Gusaoshi Village, Xutun Village, Dongmatun Village
2	1000-1500	9	1123.359	1002.221	1357.952	East Community Village, West Community Village, Xinchengzi Village, Tongjiang Village, Beici Village, Dingziyu Village, Hekou Village, Lianshanguan Village, Dongdayu Village

Table 29. Precipitation(Liaodong).

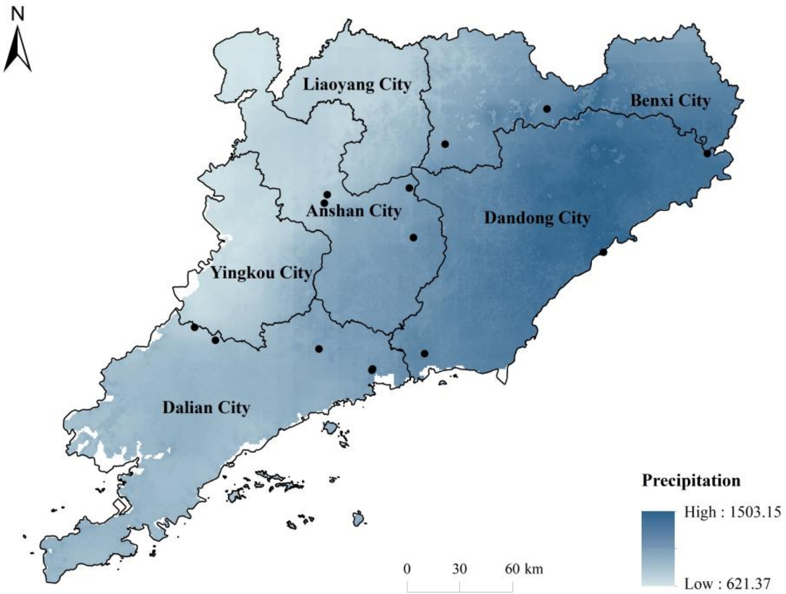

Figure 35. Precipitation diagram(Liaodong).

Figure 35 and Table 29 show that precipitation in traditional villages on the Liaodong Peninsula increases significantly from the southwest inland to the east and northeast. The eastern mountains and coastal zone constitute a high-value area (annual average of about 1,500 mm), while the southwest coast and inner bay plains are low-value areas (about 620–800 mm). This gradient is consistent with the East Asian monsoon path and topographic uplift: when summer monsoon moisture lands from the Bohai-Yellow Sea and is blocked by mountains such as the Qianshan Mountains, precipitation on the windward slope increases significantly, while the leeward side and the inner bay of the peninsula are drier due to the shielding effect. The precipitation pattern has two sides to the distribution of villages: the range of 700–1,200 mm is most conducive to the maintenance of traditional agro-pastoral complexes and small water conservancy systems, thus supporting village agglomeration; although the excessively wet areas have high ecological carrying capacity, we need to be wary of the disturbance of hillside settlements by rainstorms, landslides, and gully erosion [7,35,111].

	Classification	Quantity	Average	Min	Max	List
1	0-65	4	64.216	63.469	64.88	Xialin Village, Gusaoshi Village, Xutun Village, Dongmatun Village
2	65 and above	10	67.417	66.21	68.928	East Community Village, West Community Village, Xinchengzi Village, Tongjiang Village, Beici Village, Ronghua Village, Dingziyu Village, Hekou Village, Lianshanguan Village, Dongdayu Village

Table 30. Humidity(Liaodong).

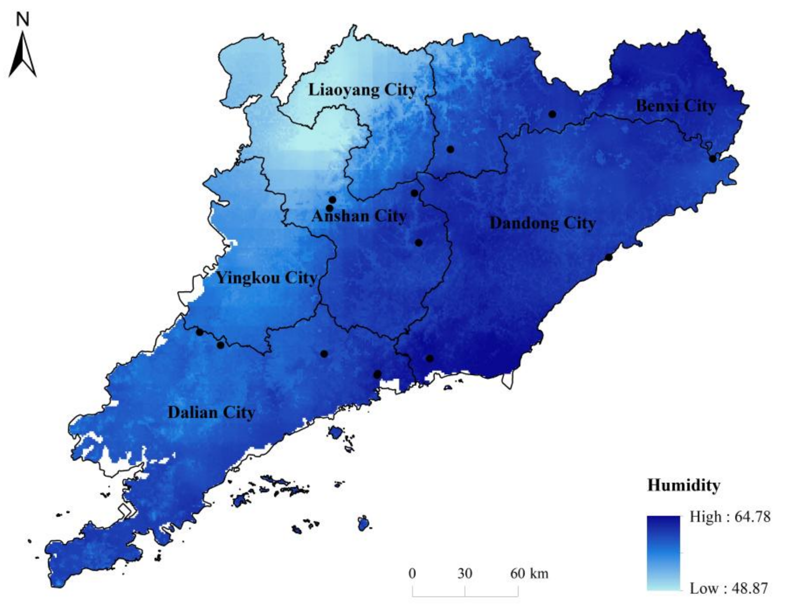

Figure 36. Humidity diagram(Liaodong).

As shown in Figure 36 and Table 30, the spatial distribution of relative humidity in traditional villages on the Liaodong Peninsula is generally consistent with precipitation.

The humidity is relatively high in the eastern coastal and mountainous areas (high value in the legend is about 64.8%), while the relative humidity is relatively low in the central and northern inland areas (about 49%). Humidity is significantly affected by the distance from the sea and the amplification effect of surface water/wetlands: the coastal zone and estuary-tidal flat area have high water vapor flux and vigorous evapotranspiration, maintaining high air humidity, while the inland valleys are affected by dry and cold air masses in winter and spring, resulting in low humidity. For traditional settlements, moderate to high humidity is beneficial to crops and forests, but excessive humidity may increase the risk of corrosion, salt precipitation and mold in wooden buildings, requiring corresponding passive protection measures in building materials, moisture-proof foundations and ventilation patterns [130].

5.2.3 Environmental Factors

	Classification	Quantity	Average	Min	Max	List
1	-1-0	0	0	0	0	None
2	0-0.5	7	0.403	0.295	0.486	East Community Village, West Community Village, Xialin Village, Ronghua Village, Gusaoshi Village, Xutun Village, Dongdayu Village
3	0.5-1	7	0.531	0.515	0.552	Xinchengzi Village, Tongjiang Village, Beici Village, Dingziyu Village, Hekou Village, Dongmatun Village, Lianshanguan Village

Table 31. NDVI (Normalized Difference Vegetation Index)(Liaodong).

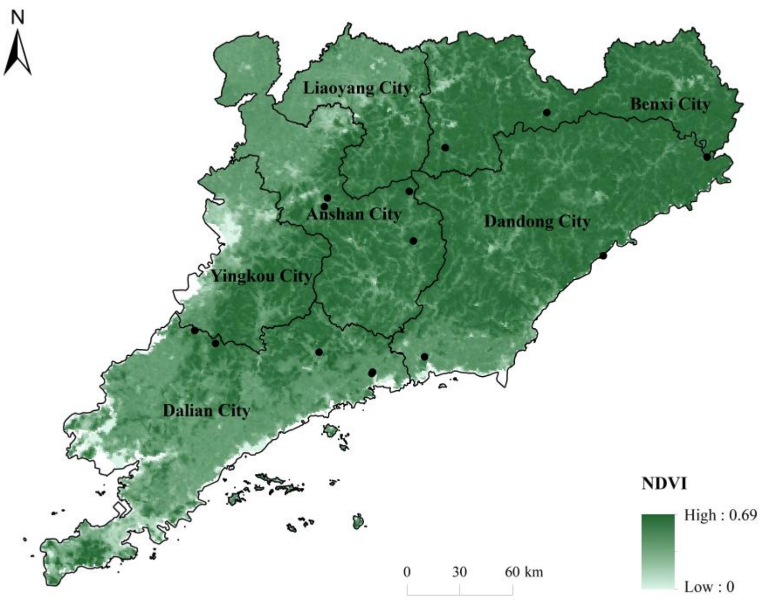

Figure 37. NDVI (Normalized Difference Vegetation Index) diagram(Liaodong).

As shown in Figure 37 and Table 31, the traditional villages on the Liaodong Peninsula are generally at a medium to high vegetation cover level, exhibiting a pattern of "high in the eastern mountains and central-northern hills, and low in the southern coastal and bay areas." The eastern mountains and inland hills, influenced by both marine moisture and orographic uplift, form a continuous high-value zone (≈0.4–0.6+); the central valleys and cultivated areas have a medium value; while the southern peninsula coast, near-shore islands, and some urban built-up areas show low-value patches (≈<0.2–0.3), reflecting the weakening of green coverage due to urban expansion, industrial land use, and transportation corridors. Overall, NDVI is positively correlated with precipitation/humidity and exhibits a "U-shaped constraint" with slope: gentle slopes to slightly undulating terrain are conducive to agroforestry and continuous vegetation, while steep slopes, although having high green coverage (more strongly associated with forest), limit settlement/cultivation; flat but highly urbanized bay areas show a significant decrease in green coverage due to increased impermeability. Existing research indicates that traditional villages tend to be located on ecological backgrounds with medium to high NDVI, and there is a significant coupling between greenness and settlement density, which is consistent with the village agglomeration characteristics of the "high green-medium green belt" in this region.

	Classification	Quantity	Average	Min	Max	List
1	0-0.05	12	0.013	0.007	0.031	East Community Village, West Community Village, Tongjiang Village, Xialin Village, Ronghua Village, Gusaoshi Village, Dingziyu Village, Hekou Village, Xutun Village, Dongmatun Village, Lianshanguan Village, Dongdayu Village
2	0.05 and above	2	0.173	0.169	0.176	Xinchengzi Village and Beici Village

Table 32. Distance to river(Liaodong).

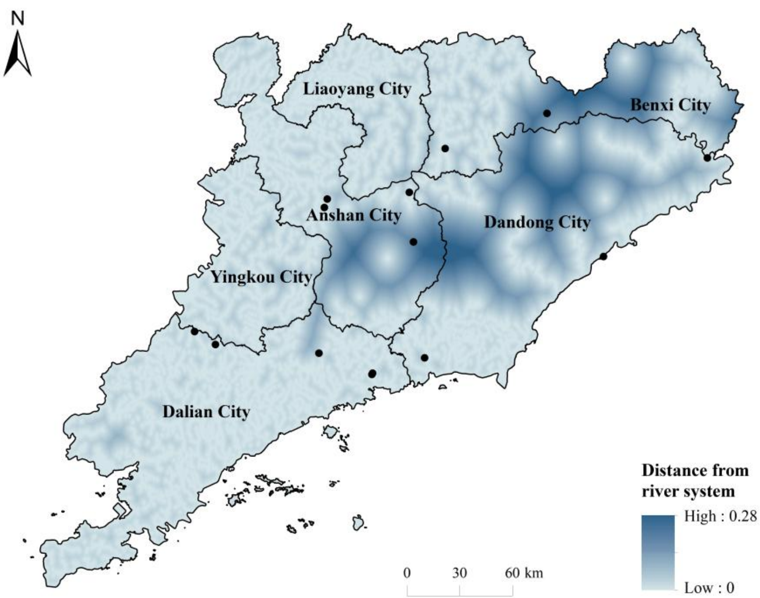

Figure 38. Distance to river diagram(Liaodong).

Figure 38 and Table 32 show a clear dendritic low-value network: continuous low-value zones form along the main stream and its tributaries, increasing towards the watershed and inner bay plateaus. Low-value zones correspond to river valleys and alluvial plains with high water accessibility, convenient irrigation and drainage, and fertile alluvial soil, making them the preferred spaces for traditional agriculture and settlement growth. High-value areas are mostly located in hilly highlands and cape plateaus far from the river network, with weak water supply security, high farmland construction costs, and sparse settlements. International experience also shows that "spatial resistance to the river network" is an important factor explaining traditional settlement patterns; areas near rivers are more likely to form continuous settlement zones and connect with markets. It should be noted that while near-river low-value zones have production advantages, they also face the risks of flooding and riverbank erosion, especially under the combined conditions of strong monsoon years and upstream confluence.

5.2.4 Population and Economic Factors

	Classification	Quantity	Average	Min	Max	List
1	0-50	3	34.222	29.481	39.787	Xinchengzi Village, Beici Village, Dingziyu Village
2	50-100	2	76.66	63.352	89.969	Tongjiang Village and Dongmatun Village
3	100 and above	9	418.662	115.114	1159.253	East Community Village, West Community Village, Xialin Village, Ronghua Village, Gusaoshi Village, Hekou Village, Xutun Village, Lianshanguan Village, Dongdayu Village

Table 33. Population density(Liaodong).

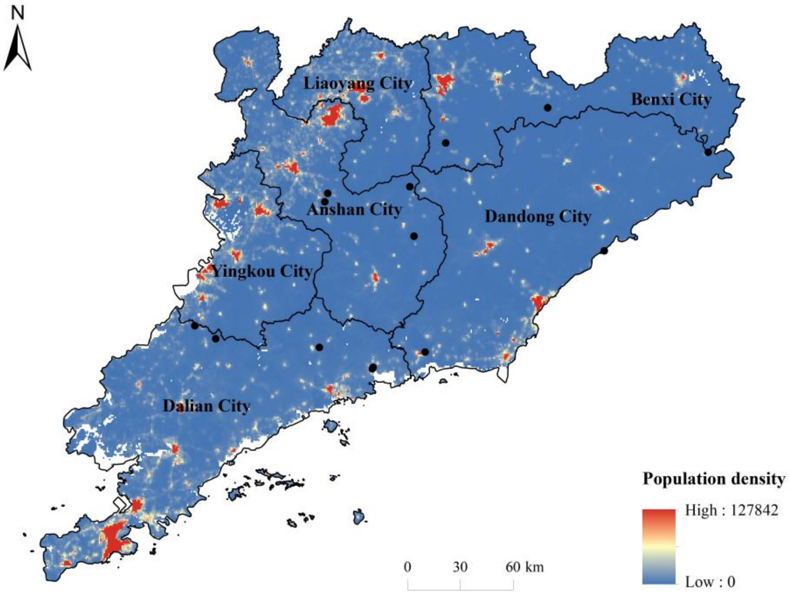

Figure 39. Population density diagram(Liaodong).

Figure 39 and Table 33 show that the population of traditional villages on the Liaodong Peninsula exhibits a significant "core-periphery" pattern: high-value patches and continuous ribbon-like corridors form around several urban cores and ports, rapidly decreasing towards the outlying villages, with only scattered median points appearing along some transportation corridors. Overall, high-density areas are more likely to appear along the coast and near major transportation routes, while the inland hills and offshore capes are sparsely populated. This distribution indicates that the peninsula has long experienced a structural migration of "urban absorption - insufficient rural return": central urban areas and sub-centers absorb rural labor, driving the concentration of public services and resources; relatively remote villages experience population aging and hollowing out, making it difficult for education, medical care, and other facilities to maintain economies of scale, forming a negative cycle of "population - services - attractiveness." For traditional villages, a low-density and low-distraction spatial environment is conducive to the continuation of form and culture, but it also increases the difficulty of daily governance, public service provision, and industrial support.

	Classification	Quantity	Average	Min	Max	List
1	0-0.5	11	0.070	0.0	0.289	Xinchengzi Village, Tongjiang Village, Xialin Village, Beici Village, Ronghua Village, Gusaoshi Village, Dingziyu Village, Hekou Village, Xutun Village, Dongmatun Village, Lianshanguan Village
2	0.5 and above	3	0.711	0.609	0.8831	East Community Village, West Community Village, Dongdayu Village

Table 34. Nighttime lighting(Liaodong).

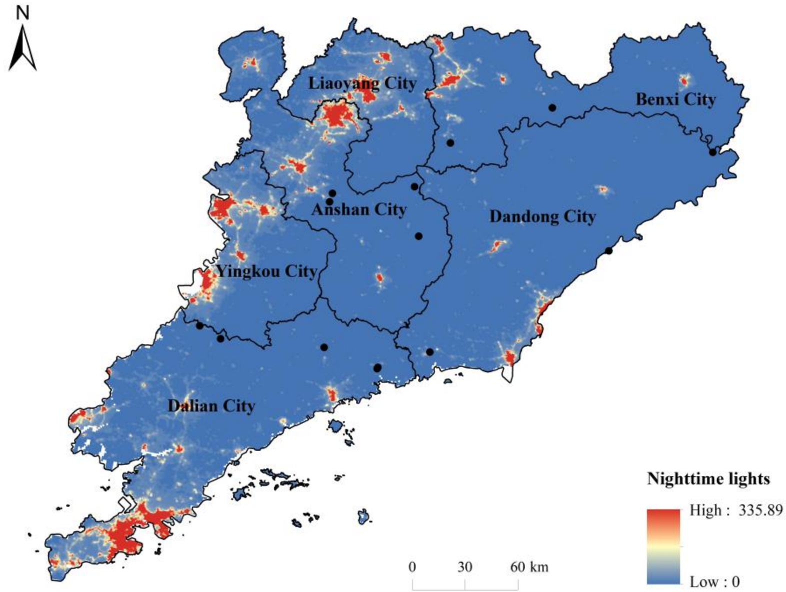

Figure 40. Nighttime lighting diagram(Liaodong).

As shown in Figure 40 and Table 34, the nighttime light patterns of traditional villages on the Liaodong Peninsula are highly consistent with population density, but exhibit a more intuitive continuity and corridor-like structure: luminous patches along the coast and inland cities are connected by main roads, forming a network that outlines nighttime activities and logistics connections; the inland and mountainous areas show large low-value zones, interspersed with small bright spots, indicating localized clusters of small towns and rural centers. The high overlap between the distribution of traditional villages and low-value nighttime light zones indicates weak nighttime economic activity and low human interference, serving as both a "protective umbrella" for cultural heritage preservation and a realistic indication of insufficient development vitality. It is noteworthy that some villages near transportation hubs or tourism corridors show an "increased brightness" phenomenon, suggesting that cultural tourism development or commuter economy is altering the intensity of local nighttime activities, necessitating advance assessment of carrying capacity thresholds and landscape impacts.

	Classification	Quantity	Average	Min	Max	List
1	0-1000	6	276.765	125.0	392.842	Xinchengzi Village, Tongjiang Village, Beici Village, Dingziyu Village, Hekou Village, Lianshanguan Village
2	1000-1500	4	1377.931	1185.579	1458.81	East Community Village, West Community Village, Ronghua Village, Dongdayu Village
3	1500 and above	4	1876.682	1713.526	2101.158	Xialin Village, Gusaoshi Village, Xutun Village, Dongmatun Village

Table 35. GDP distribution(Liaodong).

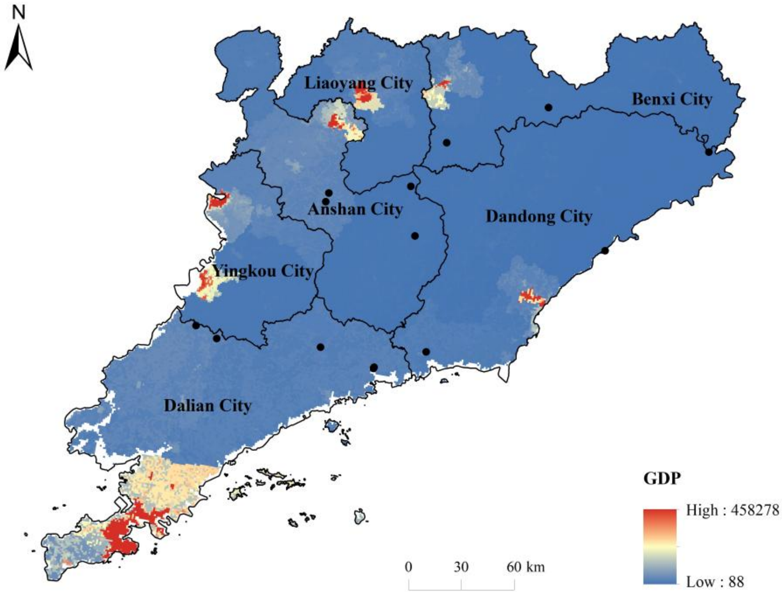

Figure 41. GDP distribution diagram(Liaodong).

As shown in Figure 41 and Table 35, the spatial distribution of GDP in traditional villages on the Liaodong Peninsula is extremely uneven: economic output is significantly concentrated in a few urban cores, ports, and industrial parks, forming "economic highlands"; while the vast rural areas and mountains are "lowlands," essentially isomorphic to the spatial patterns of nighttime light and population density. The coupling of coastal port-manufacturing-service industries has shaped a spatial chain of port-driven production and production-driven population aggregation, leading to deep concentration of economic factors along the coast and main channels. This has a dual meaning for traditional villages: on the one hand, villages near high-GDP areas are more likely to obtain funding, market, and infrastructure support, possessing revitalization potential; on the other hand, these areas also face stronger development and renewal pressures, and land and real estate capital may drive rapid evolution of village landscapes, creating the risk of "cultural landscape alienation." In contrast, villages in low-GDP areas possess better authenticity and integrity, but urgently need appropriate industrial integration and public investment to fill the development gap.

5.2.5 Transportation and Location Factors

	Classification	Quantity	Average	Min	Max	List
1	0-50	2	28.303	27.706	28.900	Tongjiang Village and Hekou Village
2	50-100	5	78.743	60.690	92.152	Xinchengzi Village, Xialin Village, Beici Village, Gusaoshi Village, Dingziyu Village
3	100 and above	7	136.889	106.955	170.960	East Community Village, West Community Village, Ronghua Village, Xutun Village, Dongmatun Village,

	Lianshanguan Village, Dongdayu Village

Table 36. Road network(Liaodong).

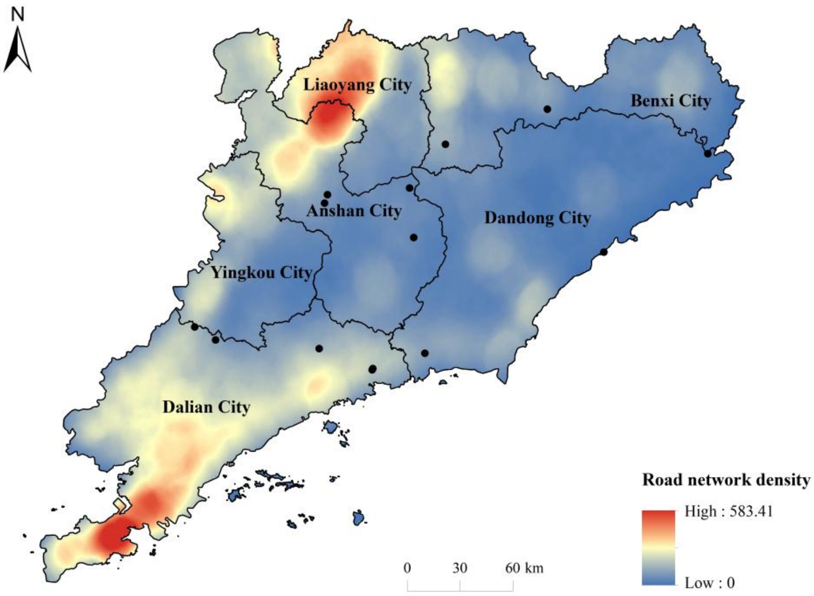

Figure 42. Road network density diagram(Liaodong).

As shown in Figure 42 and Table 36, the road network density map of traditional villages on the Liaodong Peninsula exhibits a typical pattern of diffusion from nodes to corridors and a decrease from the core to the periphery. High-value areas are mainly concentrated in several urban cores and their outward-extending main transportation axes, forming continuous bright bands in a "node-corridor" pattern. The density is particularly high in the port city at the southern tip of the peninsula and its surrounding secondary centers, with local peaks also visible in the north-central region, indicating that urban clusters are interconnected through expressways/high-grade highways. In contrast, the eastern mountainous areas and inner bay plateaus are extensive low-value areas, exhibiting obvious network sparseness and fragmentation, which highly overlaps with spatial units characterized by high undulation, slope, and ecological sensitivity. Overall, road network density is highly isomorphic to population-economic activity: the high-density network along the coast and basin corridors strongly aggregates resources, while the low-density network in the mountainous and hilly areas inhibits resource flow and diffusion.

The impact on traditional villages in the Liaodong Peninsula is dual: on the one hand, villages near dense road networks have stronger market accessibility and access to public services, making them suitable for "light intervention and low impact" revitalization; on the other hand, road spillover effects (traffic flow, noise, visual disturbance) and spatial speculation may lead to landscape fragmentation and homogenization. While low-density areas offer high fidelity and minimal disturbance, they face development bottlenecks such as high logistics costs, difficulty in tourist access, and insufficient public service provision. Therefore, a tiered traffic control and landscape buffer zone should be established along the main corridor: controlling the addition of new paved surfaces and advertising lighting in the core cluster sections, and adopting narrow cross-sections and slow-traffic guidance for branch roads leading to traditional villages to ensure both experience and safety.

	Classification	Quantity	Average	Min	Max	List
1	0-0.5	3	0.380	0.319	0.434	Xialin Village, Gusaoshi Village, Lianshanguan Village
2	0.5-1	7	0.683	0.522	0.819	Xinchengzi Village, Beici Village, Dingziyu Village, Hekou Village, Xutun Village, Dongmatun Village, Dongdayu Village
3	1and above	4	1.174	1.007	1.389	East Community Village, West Community Village, Tongjiang Village, Ronghua Village

Table 37. Distance to city(Liaodong).

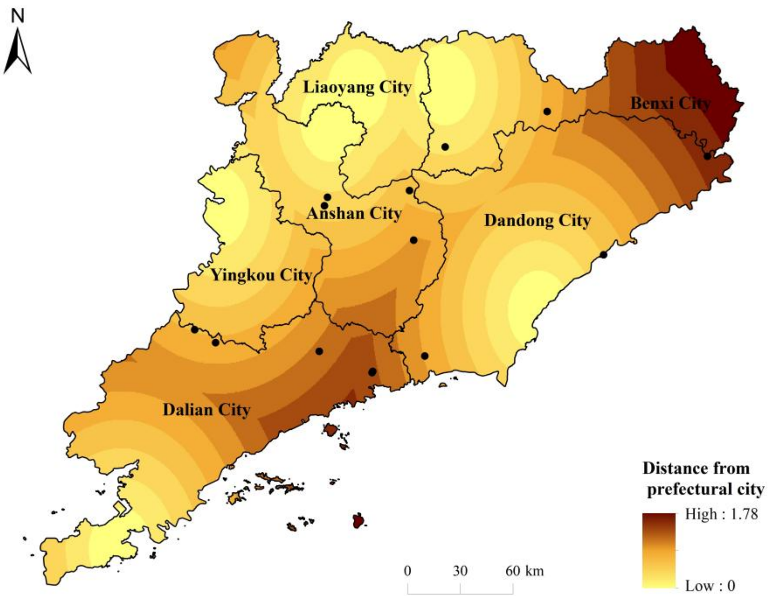

Figure 43. Distance to city center(Liaodong).

Figure 43 and Table 37 illustrate the spatial potential field of urban influence in traditional villages on the Liaodong Peninsula: concentric low-value depressions form around various prefecture-level cities, with multiple potential fields overlapping, confirming the peninsula's multi-center urban system. Distance monotonically increases with outward expansion, reaching high values at mountain edges, offshore capes, and the "blank zones" between cities, indicating significant spatial isolation. These high-value areas typically combine low road network density with high topographic relief, implying relatively weak radiation of public services, employment, and factor flows; they represent a typical space where the vulnerability and authenticity of traditional villages coexist.

For village protection and development, the location potential field creates three differentiated scenarios: Near the center—near the corridor (low distance, high road network density): Easiest to obtain funding and visitor flow, but the village's appearance is under significant development pressure. Constraints such as development intensity caps, visitor carrying capacity quotas, and nighttime lighting limits should be implemented, prioritizing "existing stock renewal and micro-intervention."

Central Corridor-Intersection Area (Medium Distance, Continuous Network): Possessing both agglomeration and radiation conditions, it can serve as the main framework for cultural corridors and rural slow travel, connecting multiple traditional villages and natural-historical nodes to form a cluster-style contiguous protection.

Edge-High Distance-Low Network (High Rise/Far from Cities): Primarily based on public service support and ecological compensation, it is equipped with "central village-radiation point" style education, medical care, and digital infrastructure, developing small-scale, low-intensity, community-led industries (handicrafts, mountain ecotourism) to prevent secondary damage caused by excessive transportation improvements.

5.2.6 Historical and Cultural Factors

Strategic Gateway and Memories of Major Events: The Liaodong Peninsula has historically been a crucial passage connecting the interior of China with Northeast China. Archaeological discoveries show that as early as the late Neolithic period, the Miaodao Islands connected Liaodong and Jiaodong, forming an important maritime exchange route [133-136]. In the early Ming Dynasty, the Ming army crossed the sea from Penglai (Denglai) to conquer Liaodong and incorporated Liaodong into Shandong Province to ensure logistical support via sea transport [133-136]. Liaodong has always been a vital frontier region, witnessing military campaigns against the Wuhuan and Goguryeo during the Han and Jin dynasties, the rise of the Khitan Yelü Abaoji and Wanyan Aguda, and the border struggles between the Ming and Qing dynasties.

Ethnic Convergence and Cultural Integration: The Liaodong Peninsula is at the forefront of multi-ethnic interaction. Since the Han and Jin dynasties, northern nomadic peoples such as the Wuhuan, Xianbei, Khitan, Jurchen, and Mongols have intermingled and frequently interacted with the Han Chinese of the Central Plains [135], forming an inclusive cultural landscape. During the Liao Dynasty, Liaodong was under the rule of the Khitan, and various ethnic groups were under the long-term jurisdiction of a unified regime. Cultural differences gradually decreased, promoting the integration and formation of the Chinese nation [133-136].

Maritime Ties and Coastal Defense Culture: The Liaodong Peninsula faces the Yellow Sea and the Bohai Sea, and has been a vital maritime transportation hub since ancient times. In 908, Emperor Taizu of Liao built the "Zhendong Haikou Great Wall" along the line from Dalian Bay to Jinzhou Bay [134-137]. Archaeological discoveries show that this Great Wall starts at the shore of Dalian Bay in Ganjingzi and ends at the shore of Jinzhou Bay in Tuchengzi, with a total length of about 6 kilometers [133-138]. This fortress served as both a coastal defense line and a gateway for foreign exchanges [133-138]. Subsequently, the Liao, Jin, and Ming dynasties all established fortresses, beacon towers, and other defensive facilities along the coast, forming a unique maritime

Great Wall cultural landscape.

Cultural Heritage and Archaeological Resources: The Liaodong region has numerous important cultural heritage sites and archaeological sites, providing material evidence for regional historical research. For example, numerous tombs dating from the Bronze Age to the Han Dynasty have been discovered around the Muyangcheng site in Lushunkou, proving that the area was a long-term center of human activity and a key military and coastal defense location [133-138]. The Shenyang Imperial Palace, the Qing Dynasty imperial tombs, and the Liao Dynasty Great Wall ruins in Dalian, among other sites, reflect the inheritance and diverse interweaving of Liaodong culture throughout history.

5.3 Discussion

5.3.1 Consistency and Differences between Research Results and Existing Studies

This study found that traditional villages on the Liaodong Peninsula are mainly clustered in habitable areas such as foothills and river valleys, exhibiting a "core-periphery" distribution structure, with the foothill-river valley area as the core and the highly urbanized coastal plain as the periphery. This is consistent with existing studies that emphasize the limiting role of topography and water systems on village site selection [35,57,90]. Nationwide studies have shown that traditional villages are mostly distributed in low-altitude, warm and humid areas, and are concentrated near rivers in areas with relatively underdeveloped populations and economies [57,90]. This study also shows that climate conditions and ecological environment are key influencing factors. However, there are also significant differences in the spatial distribution pattern of the Liaodong Peninsula: unlike the significant clustering patterns found in many regional studies, our nearest neighbor index (NNI>1) results show that traditional villages in the entire region generally exhibit a relatively uniform distribution, which may be related to the peninsula's long and narrow geographical shape and the history of coastal development. In contrast, in areas such as the Liaoxi Corridor, villages are clustered in a corridor-like manner due to the narrow mountain-sea corridor [35]; while the mountains (Qianshan) of the Liaodong Peninsula run north-south, causing villages to expand along a northeast-southwest direction (the main axis of the standard deviation ellipse in this study is consistent with the direction of the Liaoning mountain range [35], and the urbanization process in the coastal areas has led to the discrete distribution of marginal villages ("island-like" preservation). Overall, the results of this study, consistent with national and other regional studies, confirm the dominant role of the natural environment (such as climate, topography, and water system) in the distribution of traditional villages. However, in terms of spatial organization, the Liaodong Peninsula shows a more dispersed and point-and-zone combined pattern, which reflects the uniqueness of urban-rural evolution under the special coastal-mountain coupling background of this region [35,57,90].

5.3.2 Relative Importance and pattern of Influencing

Factors

Geographic detector analysis shows that natural geographical factors have the greatest explanatory power for the distribution of traditional villages in the Liaodong Peninsula, followed by factors such as accessibility. Annual precipitation has the highest explanatory power, followed by climatic indicators such as vegetation cover (NDVI) and temperature. This is consistent with the results of studies across the country: Su et al. found that annual precipitation (26.06%) and annual average temperature (19.50%) are the most important influencing factors in the distribution of traditional villages nationwide [7,10]. In this study area, sufficient precipitation and suitable temperature and humidity conditions are conducive to the maintenance of agro-pastoral complex and small-scale water conservancy systems. Therefore, traditional villages are concentrated in the rain-rich piedmont-coastal transition zone; while excessively high or low precipitation and temperature conditions are not conducive to the preservation of villages [7]. NDVI, as an indicator of ecological carrying capacity, also shows a positive effect - areas with high NDVI values (forests or cultivated land) often provide a better natural environment, which is conducive to the formation of settlements. The low q-values of topographic factors (such as altitude and slope) in the model may be due to the large proportion of low-to-medium altitude areas within the peninsula, thus making the differential effect of climatic gradients such as precipitation on village distribution more significant.

Conversely, socioeconomic factors are generally negatively correlated with the number of traditional villages: areas closer to the city center, with higher GDP, greater population density, and brighter nighttime lights have fewer traditional villages. This indicates that urbanization and modern economic development have, to some extent, "diluted" the pattern of traditional villages, consistent with findings from studies in multiple locations. For example, studies in the upper Yellow River Basin found that areas with high density of traditional villages often correspond to low population density and low urbanization rates [90]; Chen et al.'s national analysis also showed that traditional villages are mostly distributed in areas with relatively underdeveloped populations and economies [138]. In the Liaodong Peninsula, the impact of convenient transportation (road network density) on villages is dual: on the one hand, moderate transportation can promote tourism and industrial development; but excessively high road network density often corresponds to plains with high urbanization levels, leading to the renewal or disappearance of traditional villages. Overall, climate-ecology and moderate accessibility have jointly shaped the traditional village pattern of the Liaodong Peninsula, and the more economically developed the region, the more difficult it is for traditional villages to be preserved [7,10,92,93,94,95,96].

5.3.3 Suggestions on Cultural Protection and Coordinated Development in the Liaodong Peninsula

Given the characteristics of the distribution of traditional villages in the Liaodong Peninsula and the profound historical and cultural background of the region, the concept of regional linkage and overall protection should be emphasized. Some scholars have pointed out that the protection of “individual villages” should be transformed into the protection of “regional communities”, breaking through the single-village thinking and realizing cross-administrative region cultural linkage protection[35]. In the Liaodong Peninsula, a cross-city (county) collaborative protection pattern should be constructed. For example, the traditional villages in the foothills and valleys of Dandong-Benxi should be divided into contiguous protection zones and cultural corridors should be formed with the villages of coastal cities such as Dalian and Anshan. At the same time, local exchanges and cooperation should be encouraged, such as carrying out cross-regional traditional cultural festivals and tourism route planning, highlighting regional cultural resources such as coastal defense culture and ethnic minority culture. In addition, the synergistic effect of rural revitalization and ecological protection policies should be fully utilized. Under the premise of prioritizing cultural protection, the economic vitality of traditional villages should be stimulated through tourism development and the inheritance of characteristic handicrafts. However, excessive commercialization should be avoided, and a sustainable development model of “small scale and community-led”should be advocated[35].

5.4 Summary

This study found that the spatial pattern of traditional villages in the Liaodong Peninsula presents a“core-periphery”structural feature: they are mainly clustered in relatively suitable terrain such as foothills and river valleys, while the density of villages is low in coastal plains and highly urbanized areas. Overall, the distribution of traditional villages presents a “point-belt combination and local clustering” pattern, forming obvious clustered core belts and discrete edges, such as the intermingling of contiguous settlements in river valleys and low mountain areas with isolated distributions in coastal towns. This pattern is consistent with the “dense core-sparse periphery”pattern of traditional Chinese villages [139], that is, villages extend in contiguous areas along areas with abundant resources and good accessibility, while coupling with natural barriers such as mountains and coastlines to form a dispersed trend. Standard deviation ellipse analysis shows that the main axis of the overall distribution of villages is basically consistent with the topographic direction, extending in a northeast-southwest direction, reflecting the guiding role of the Qianshan mountain range and major river corridors in the layout. Kernel density analysis further points out that the southern hilly areas and central river valleys of the peninsula form a high-density core area of villages, while the northern mountainous areas and coastal plains have a lower kernel density, reflecting the uneven regional development and the gradient difference in natural resource conditions.

Natural geographical factors play a dominant role in the distribution of traditional villages in Liaodong. Precipitation, temperature, vegetation and other ecological elements constitute the "production base" for the survival of traditional settlements[7]. Overall research in my country shows that annual precipitation, average annual temperature and river density have the highest explanatory power for the distribution of traditional villages[7]. The Liaodong Peninsula also shows a similar trend: the coastal areas and river alluvial areas with sufficient precipitation are more conducive to farming and the continuation of villages; in terms of topography, traditional villages are generally located in areas with moderate altitude and moderate slope, which avoids the disadvantages of high mountains and steep slopes, and takes into account the accessibility of water and soil resources. Vegetation cover (NDVI) is often positively correlated with village distribution, and the "high NDVI-high village" phenomenon is obvious[7,42,43,44]. Studies show that most traditional villages are surrounded by abundant vegetation and water bodies, with rivers nourishing fertile soil, providing excellent conditions for agricultural production [7,42,43]. However, villages are scarce in the high-altitude, cold, and sparsely vegetated areas of the northeast and northwest. In short, climatic comfort and ecological environment determine the "base color" of village spatial layout, forming a distribution gradient on the peninsula that gradually shifts from warm and humid in the south to dry and cold in the north.

In contrast, the influence of human and social factors on the distribution of traditional villages is relatively limited and complex. Geographical survey analysis shows that socioeconomic indicators (such as population density, GDP, and nighttime light intensity) are negatively correlated with village distribution or have a weak correlation [7,10,68]. Generally, traditional villages are mostly located in sparsely populated and relatively economically underdeveloped areas: densely populated and economically developed areas are often accompanied by urbanization and industrial development, leading to a decline in the number and integrity of traditional villages [2,7]. Accessibility plays a dual role: moderate road network convenience can promote rural tourism and public services, but excessive transportation development is often linked to urban expansion, exacerbating the homogenization and disappearance risks of villages. Historical and cultural factors also profoundly influence village patterns: as a multi-ethnic convergence area and a key border region, the Liaodong Peninsula saw many villages formed along historical post roads, border trade routes, and migration routes. Rich cultural relics (such as ancient castles along the coast and Manchu cultural villages) are spatially highly coupled with the villages, demonstrating the shaping role of regional cultural context in village clustering. Thus, natural factors lay the foundation for the distribution of traditional villages, while human and economic processes shape the details and variations of this distribution, making the villages in this region both ecologically dependent and exhibiting the dual influence of "innovative industrial development" and "historical inheritance."

The spatial distribution of traditional villages on the Liaodong Peninsula also shows a close connection with arable land, ecology, and cultural heritage. On the one hand, most traditional villages are located near fertile farmland and riverside irrigation areas, reflecting a high degree of dependence between humans and the land; on the other hand, a favorable ecological environment (such as mountain forests and water networks) often corresponds to better-preserved villages [7,10,68]. Furthermore, rich traditional architectural complexes, folk landscapes, and historical sites are commonly found around these villages, reflecting a high degree of coupling between cultural elements and spatial distribution. These findings validate the applicability of the "production base-environmental constraint" theory to the Liaodong Peninsula, namely, that natural resources provide the conditions for village survival, while cultural history adds to the village's attractiveness and cohesion.

The conclusions of this study have important implications for the protection and utilization of traditional villages in the Liaodong Peninsula and even Northeast China. It is recommended that the core areas of traditional villages connected by mountains, rivers and fields be included in the key protection corridors in spatial planning, and that the integrated management of ecological and cultural landscapes be strengthened; in terms of infrastructure construction, the accessibility of remote villages and the supply of public services should be improved, while controlling the damage to the village landscape caused by transportation development; in terms of humanistic policies, the identification and classification protection of multi-ethnic cultural villages should be strengthened, and the coordinated development of traditional village protection and rural revitalization strategy should be promoted. In general, the principles of "adapting to local conditions, prioritizing protection, and inheriting and developing" should be adhered to, so as to achieve the organic integration of traditional village heritage protection and regional economic and social development, in order to preserve local memories and promote sustainable rural revitalization in the process of modernization [2,68].To provide a comprehensive overview, a qualitative comparison of all influencing factors is presented in Appendix Table A1, based on the spatial pattern analysis of individual variables.

Chapter 6 Comprehensive Analysis of the Influence Patterns on the Distribution of Traditional Villages in Liaoning Province

6.1 Introduction

At the beginning of this chapter, to provide a structured overview of the inter-regional differences identified in the preceding analyses, Table 38 summarizes the key contrasts between the Liaoxi Corridor and the Liaodong Peninsula across spatial patterns, dominant factors, and interaction characteristics.

	Liaoxi Corridors	Liaodong Peninsula
Overall Pattern	Core–edge structure	Local core – wide edge structure
NNI Result(total)	R = 0.871 < 1 → significantly clustered	R = 1.243 > 1 → dispersed
SDE Direction	Rotation:63.03° → SW–NE corridor direction	Rotation:63.87° → NE–SW, similar trend but weaker directionality
KDE Hotspot pattern	bead-like corridor pattern	Overall low clustering; scattered hotspots in southern hills
Distribution of Villages	Villages survive better in mild terrain, near water, moderately remote	Villages depend on ecological suitability; strongly affected by development
Summary	Terrain–water constrained, corridor-shaped, clustered along valleys	Climate–ecology dominated, dispersed, eco–culture sensitive

Table 38. Summary of Inter-Regional Differences in the two regions

While Table 38 summarizes the structural and spatial differences between the two regions, it does not directly represent the quantitative relationships between variables and village distribution density. In this study, such relationships are examined using SHAP-based marginal effect analysis derived from the XGBoost model.

Unlike conventional scatter plots, SHAP captures both nonlinear effects and interaction mechanisms, thereby providing a more robust and comprehensive validation of variable–density relationships.

This chapter, as an integration and enhancement chapter, aims to compare and analyze the differences in the influence patterns of the spatial distribution of traditional villages in the two regions of Liaoxi Corridor and Liaodong Peninsula, based on the research results of the previous chapters, and to provide a unified and integrated explanation at the provincial scale. Previous chapters used methods such as GeoDetector and Geographically Weighted Regression (GWR) to quantitatively assess the strength and spatial variability of various influencing factors, revealing the driving characteristics of natural environment and human social factors on the distribution patterns of traditional villages in the two regions. In simple terms, GeoDetector was used to identify which factors have stronger explanatory power and whether the interaction between two factors enhances that explanatory power, while GWR was used to examine whether the influence of these factors varies across locations.However, since GeoDetector and GWR mainly capture linear or quasi-linear influence patterns, they are insufficient in revealing nonlinear effects and complex interactions [140,141].

To address this limitation, this chapter further introduces an interpretable nonlinear machine learning framework, namely XGBoost combined with SHAP (SHapley Additive exPlanations), in order to establish a unified comparative analytical framework for the two regions. In simple terms, XGBoost-SHAP is used here to explain how multiple factors jointly shape village distribution when their effects are nonlinear, threshold-dependent, and interactive. Compared with conventional statistical models, the XGBoost-SHAP framework can better capture complex relationships among variables and thus provides a stronger basis for comparing regional differences in influencing patterns [140,141]. In other words, based on the previous GeoDetector and GWR analyses, this chapter will use the unified modeling framework XGBoost+SHAP to conduct a horizontal comparison and comprehensive analysis of the dominant factors and their interaction effects in the distribution of traditional villages in the Liaoxi Corridor and Liaodong Peninsula.

At the same time, it should be emphasized that the two study regions share a consistent data foundation and preprocessing procedure, which ensures the fairness and scientific rigor of the comparison. This chapter uses the same sample data and the same driving-factor system as the previous chapters; the main difference lies in the analytical method. By applying a nonlinear interpretable model on a unified analytical platform, this chapter is able to explore influencing patterns more comprehensively, including potential threshold effects, nonlinear contributions, and coupling relationships between factors that are difficult to detect through conventional methods [140,141].

The remainder of this chapter is organized as follows. First, the principles and validation procedure of the XGBoost-SHAP model are introduced. Second, the model results for the Liaoxi Corridor and the Liaodong Peninsula are presented, including variable importance rankings and factor interaction characteristics (corresponding to Figures 44-49 and Table 39). Third, the common and region-specific dominant factors and interaction patterns are compared in depth in relation to differences in topography, transport accessibility, and cultural context. Finally, policy-oriented implications for regionally differentiated protection and development are discussed, and the methodological compliance and reproducibility of the results are clarified. Through this integrated analysis, the chapter aims to more comprehensively reveal the differences in the influencing patterns of traditional village distribution across different regions of Liaoning Province, and to provide a scientific basis for more targeted protection and development strategies [138,139].

6.2 Unified Comparison of Machine Learning Methods

(1) Overview of Model Methods: XGBoost (Extreme Gradient Boosting) is a gradient boosting algorithm based on decision tree ensembles, possessing efficient parallel computation and regularization capabilities. Compared to traditional GBDT, XGBoost performs second-derivative approximation optimization on the loss function and introduces strategies such as shrinkage [140,141], thereby improving the model's ability to fit complex relationships while suppressing overfitting. However, machine learning models are often criticized as "black boxes," making it difficult to explain their internal patterns [140,141]. To improve model transparency, game theory-based interpretation methods such as SHAP (Shapley Additive Explanations) have emerged in recent years. SHAP quantifies the interpretability of the model's decision-making process by calculating the marginal contribution of each feature to the model's prediction [142,143].

(2) XGBoost+SHAP Interpretation Framework: Combining the XGBoost model with SHAP can achieve high-precision fitting while extracting the direction of influence, nonlinear response characteristics and interaction effects of each influencing factor on the distribution of traditional villages[41]. Specifically, XGBoost is first used to fit and predict the spatial distribution of traditional villages (such as village density or existence), and then the SHAP value of each feature under each sample is calculated. These SHAP values reflect the degree of positive and negative influence and contribution of the features to the prediction results[40]. By taking the mean or summing of the SHAP values of the whole sample, the global influence ranking of each feature (i.e., variable importance) can be obtained; in addition, the interaction decomposition of SHAP can also quantify the interaction strength between two factors and draw an interaction influence "heat map" to reveal the synergistic or inhibitory effect on the distribution of traditional villages when two factors work together[40]. Compared with traditional linear models, the XGBoost+SHAP method can identify implicit nonlinear relationships and interaction effects, such as finding the threshold inflection point of a certain environmental factor or the "double-edged sword" effect of transportation accessibility on village distribution. This is crucial for a deeper understanding of complex human-land relationships [140,141].

In summary, the unified machine learning framework of XGBoost+SHAP allows for a fair comparison of the influencing patterns of traditional villages in the Liaoxi Corridor and Liaodong Peninsula based on the same data. This method possesses both strong nonlinear fitting capabilities and provides clear interpretability, demonstrating significant advantages in comprehensively revealing the differences in the spatial patterns of traditional villages driven by multiple factors [51,140-143].

Reason for Adopting the Unified XGBoost-SHAP Framework:

The purpose of introducing XGBoost+SHAP in this chapter is not simply to add another analytical model, but to construct a unified and interpretable comparative framework for the two regions under the same variable system(input variables → model training → SHAP calculation → feature ranking → interaction heatmap →

cross-regional comparison). While previous methods such as GeoDetector and GWR have already revealed factor explanatory power and spatial heterogeneity, they do not directly provide a common metric for comparing nonlinear effects, contribution magnitude, and interaction patterns across regions. Given that the distribution of traditional villages is likely shaped by threshold effects, nonlinear responses, and factor coupling, a tree-based ensemble model is more appropriate than relying solely on linear specifications. XGBoost is therefore used to capture complex relationships, while SHAP is employed to translate the model output into comparable feature contributions, directional effects, and interaction structures. This combination makes the inter-regional comparison more consistent, transparent, and analytically robust.

It should be noted that SHAP is used in this study as an explanatory tool for interpreting model outputs. The results indicate the contribution and direction of association between each variable and the modeled spatial distribution, but they should not be interpreted as strict causal effects.

6.3 Research Results: Comparison of XGBoost+SHAP Analysis in Two Regions

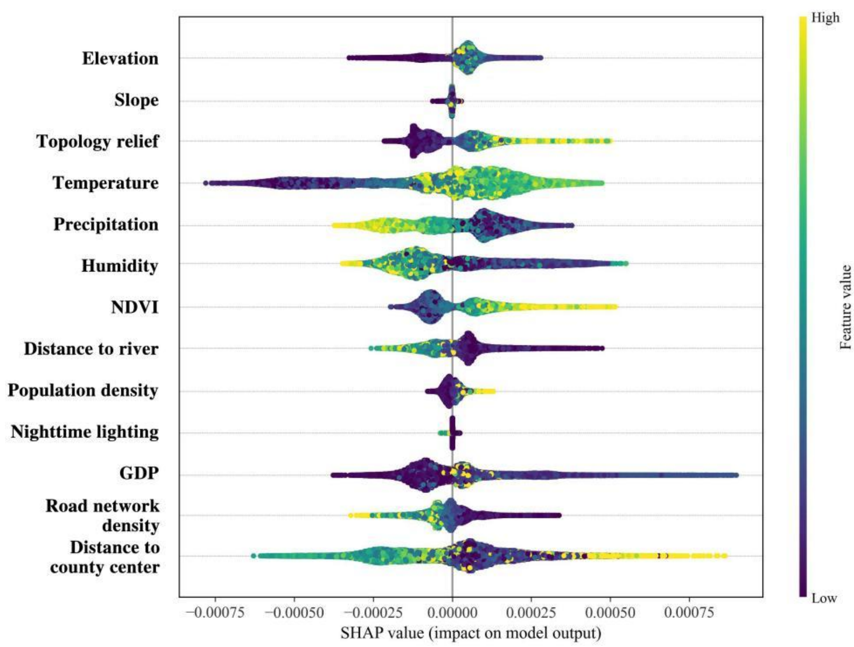

Figure 44. Overview map of the Liaoxi Corridor region SHAP

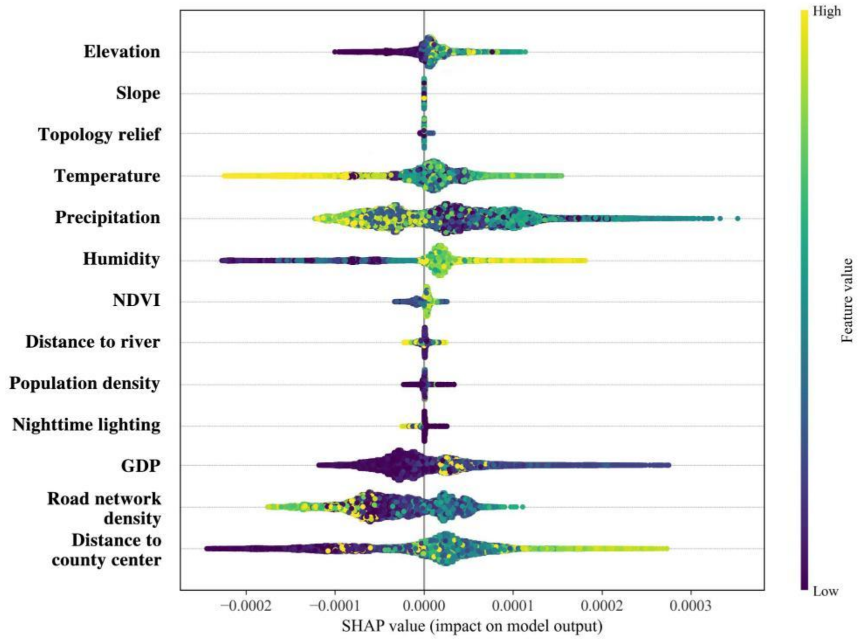

Figure 45. Overview map of the Liaodong Peninsula region SHAP

Factor	Liaoxi Rank	Liaodong Rank	Dominant Effect	Pattern Type	Interpretation
Temperature	1	3	↑	Nonlinear	Climatic suitability supports settlement persistence
Distance to city center	2	2	↓ (Liaodong) / ↑ (Liaoxi)	Bipolar	Accessibility vs urban pressure dual effect
Humidity	3	5	↑	Monotonic	Moisture conditions support habitation
Precipitation	4	1	↑	Threshold	Water availability constrains distribution
GDP	5	4	↓	Monotonic	Development pressure reduces village survival
Topographic relief	6	12	↑	Threshold	Terrain constraint effect (stronger in Liaoxi)
NDVI	7	2	↑	Clustered	Ecological suitability
Distance to river	8	11	↓	Monotonic	Water accessibility advantage

Table 39. Global SHAP importance and effect characteristics of variables in two regions

Note：↑ indicates positive influence; ↓ indicates negative influence.

Figures 44 and 45 present the SHAP-based feature importance rankings derived from the XGBoost models for the Liaoxi Corridor and the Liaodong Peninsula, respectively. The results indicate that the factors influencing the spatial distribution of traditional villages in the two regions show both shared tendencies and clear regional differences. In both regions, natural environmental variables occupy the highest positions in the overall importance ranking, confirming that environmental suitability provides the basic background for the survival and persistence of traditional villages. However, the specific dominant factors and their relative contributions differ between the two study areas.

In the Liaoxi Corridor, temperature, distance to city center, humidity, precipitation, and GDP show the highest global contributions in the SHAP ranking, followed by variables such as topographic relief, NDVI, and distance to rivers. Overall, the importance pattern suggests that the distribution of traditional villages in this region is jointly shaped by climatic conditions, locational accessibility, and terrain-related environmental constraints. In particular, the relatively high contributions of topographic relief, elevation-related variables, and distance to rivers indicate that traditional villages in the Liaoxi Corridor are still closely associated with valley settings, moderate terrain conditions, and water-accessible environments. This result is consistent with the broader spatial pattern identified earlier, in which villages are concentrated along the east–west valley corridors of the Yanshan Mountains and near major river systems such as the Laoha River, Daling River, and Xiaoling River [35,53,140–143].

By contrast, in the Liaodong Peninsula, precipitation ranks first in global SHAP importance, followed by distance to city center, road network density, GDP, and humidity. Compared with the Liaoxi Corridor, the explanatory power of precipitation, transport accessibility, and economic intensity is more prominent in this region, while the contribution of terrain-related variables is relatively weaker. This pattern suggests that the spatial distribution of traditional villages in the Liaodong Peninsula depends more strongly on hydrothermal conditions, accessibility, and the broader socio-economic environment. Areas with sufficient precipitation, suitable humidity, and convenient transportation conditions appear to provide more favorable settings for long-term settlement continuity and village preservation. At the same time, the relatively lower ranking of elevation, slope, and local relief implies that topographic differentiation plays a more limited role here than in the Liaoxi Corridor, possibly because much of the Liaodong Peninsula is characterized by comparatively moderate topographic variation, whereas climatic and accessibility gradients are more spatially influential.

A further comparison of the two SHAP overview plots shows that distance to city center is highly important in both regions, indicating that locational relation to administrative and service centers is a shared explanatory factor in the distribution of traditional villages. Nevertheless, the two regions differ in the balance between natural and human-related drivers. The Liaoxi Corridor exhibits a stronger association with terrain-water-climate coupling, reflecting the constraint of local habitat conditions on village persistence. In contrast, the Liaodong Peninsula shows a more pronounced role of precipitation-accessibility-development coupling, highlighting the combined influence of ecological suitability and human activity intensity.

Overall, the XGBoost + SHAP results further support the conclusion that the distribution of traditional villages in both regions is fundamentally conditioned by the natural environment, but the dominant dimensions of influence are not identical. The Liaoxi Corridor places greater emphasis on local environmental constraints related to terrain, river proximity, and climatic adaptation, whereas the Liaodong Peninsula is more strongly characterized by the combined effects of precipitation conditions, accessibility, and socio-economic development. These differences reveal clear regional heterogeneity in the influencing patterns of traditional village distribution and provide further empirical support for differentiated protection and management strategies.

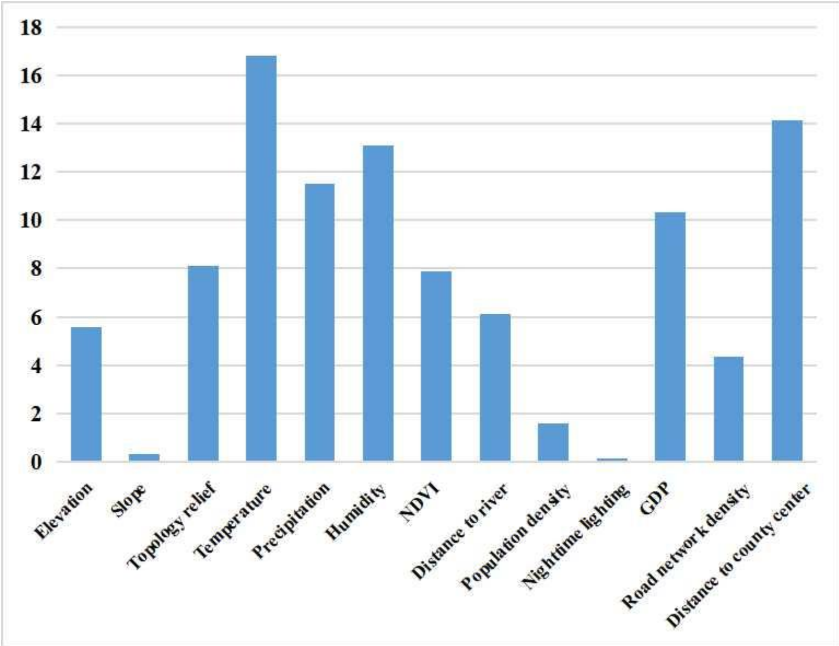

Figure 46. Global Importance of XGBoost–SHAP in the Liaoxi Corridor Region.

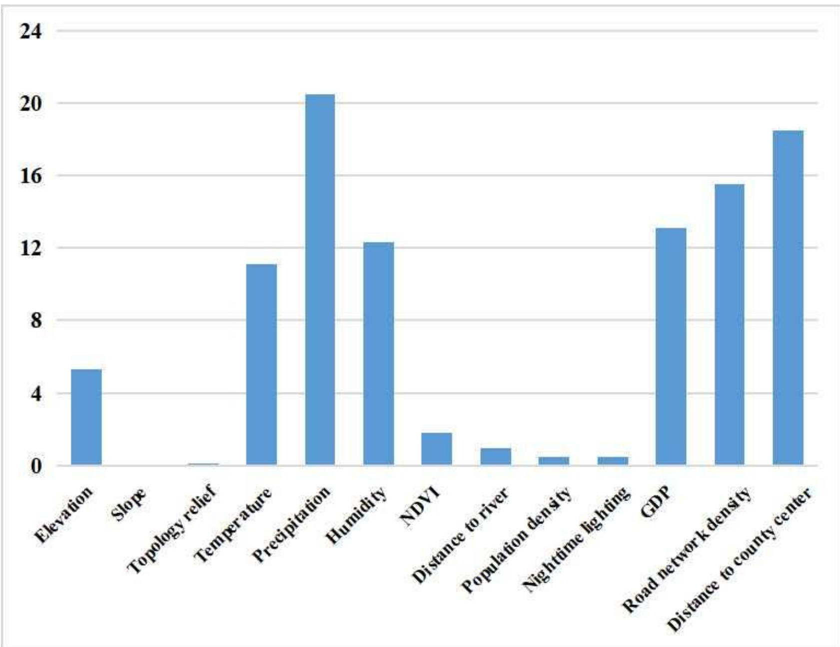

Figure 47. Global Importance of XGBoost–SHAP in the Liaodong Peninsula Region.

Rank	Liaoxi's factors	Liaodong's factors	Comparative Insight
1	Temperature	Precipitation	Climate dominates both regions but with different dimensions
2	Distance from city center	Distance from city center	Opposite urban influence patterns
3	Humidity	Road network density	Accessibility more critical in Liaodong
4	Precipitation	GDP	Socio-economic pressure stronger in Liaodong
5	GDP	Humidity	Development suppresses villages in both regions

Table 40. Top-5 key influencing factors and their dominant roles

Meanwhile [140,141], humanistic and social factors ranked second in importance in both regions, and their effects were largely opposite to those of natural environmental factors. In the Liaoxi Corridor, historical and cultural factors (such as migration history and the density of border defense and reclamation remains) may serve as proxy variables and have a positive effect on village distribution: some locations with deep cultural heritage and multi-ethnic integration backgrounds are more likely to preserve traditional settlements, reflecting the importance of cultural attractiveness and cohesion [34,36]. The Liaoxi Corridor has been a "cultural corridor" since ancient times, and factors such as migration and military defense have shaped the formation and distribution of villages. For example, traditional villages are more concentrated in areas near ancient post roads, the Great Wall defense line, or ethnic integration zones [34,36,66]. In contrast, humanistic factors in the Liaodong Peninsula are mainly reflected in the negative impact of modern socio-economic and locational transportation factors on village distribution: model results show that in the Liaodong Peninsula, the closer to the city center, the higher the population density, the higher the GDP and the higher the nighttime light intensity, the fewer traditional villages there are (SHAP value is negative). This phenomenon reflects the ebb and flow between modernization and the protection of traditional settlements. In other words, the faster the urbanization and economic development in a region, the more likely traditional villages are to undergo renewal, demolition, or functional transformation, resulting in fewer remaining villages. This pattern is consistent with studies in other regions of China: for example, studies in the upper reaches of the Yellow River show that areas with high density of traditional villages usually have lower population density and urbanization levels; and Bian et al. (2022)[5] found in their nationwide analysis that traditional villages are mostly distributed in relatively underdeveloped remote areas. Thus, although the two regions have different levels of socio-economic development, they both show a general trend of "the faster the development, the fewer traditional settlements," reminding us that we need to balance the protection of cultural heritage while promoting urbanization.

Comparison of Factor Interaction Characteristics: Figures 48 and 49 present SHAP-based effect heatmaps for the Liaoxi Corridor and Liaodong Peninsula models, respectively. In these matrices, off-diagonal cells represent the strength of pairwise interaction effects between two variables, whereas diagonal cells represent the main effect (self-contribution) of each variable rather than "self-interaction." Darker colors indicate stronger contributions to model output. To ensure comparability, the two figures were plotted using the same variable order, color scale range, font settings, and legend format. Therefore, cross-regional comparison should focus primarily on the distribution and concentration of darker off-diagonal cells, while the diagonal cells are used to identify variables with relatively strong individual contributions.

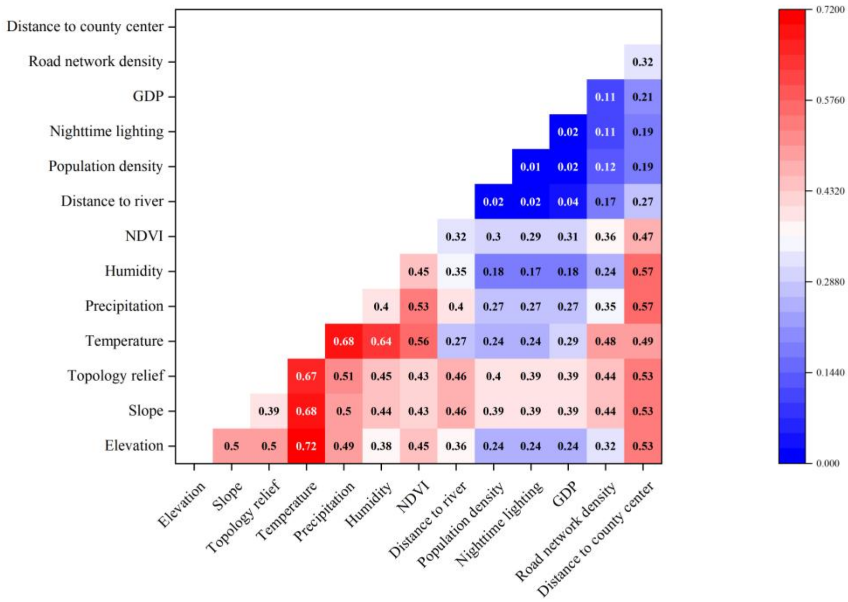

Figure 48. SHAP-based main-effect and interaction-effect heatmap for the Liaoxi Corridor region.

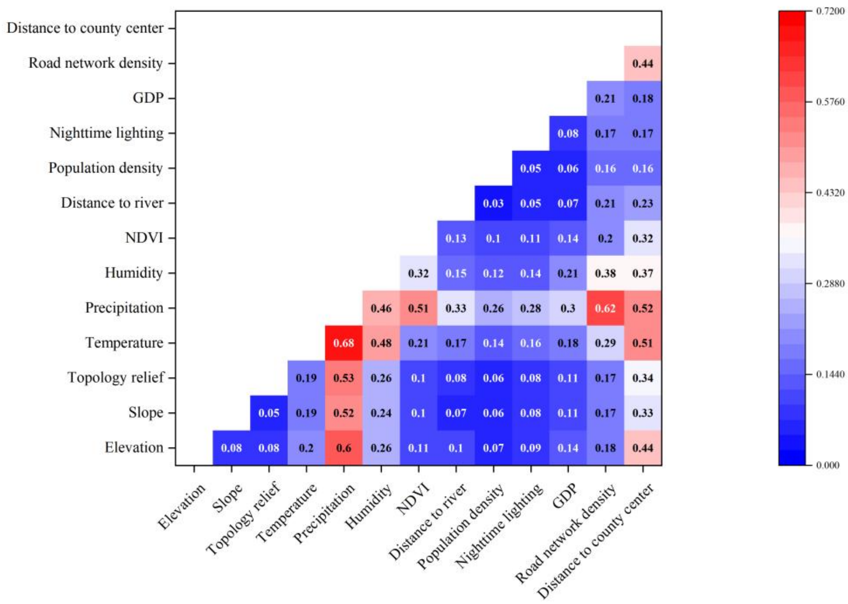

Figure 49. SHAP-based main-effect and interaction-effect heatmap for the Liaodong Peninsula region.

Aspect	Liaoxi	Liaodong
Off-diagonal intensity distribution	Concentrated in limited variable pairs	More widely distributed across multiple pairs
Dominant interaction pairs	Slope × Road density; Elevation × River distance	Precipitation × Road density
Clustering pattern of strong interactions	Localized clusters (few strong hotspots	More dispersed clusters (multiple moderate－strong cells)
Diagonal (main effect) prominence	Several variables show strong individual contributions	Strong contributions also present but less concentrated
Cross-factor interaction tendency	Primarily among terrain and accessibility-related variables	Frequently involves climatic variables combined with accessibility
Overall visual pattern	More structured and concentrated	More diffuse and cross-combined

Table 41. Visual comparison of SHAP interaction heatmaps(Figure 48-49)

Overall, the two regions exhibit distinct effect structures. In the Liaoxi Corridor, stronger off-diagonal contributions are concentrated mainly among natural environmental factors and between natural and accessibility-related factors, indicating a pronounced synergy among topography, hydrology, and transportation conditions. By contrast, in the Liaodong Peninsula, darker off-diagonal cells appear more frequently in combinations involving climatic/ecological variables and transportation/socioeconomic variables, suggesting that village distribution is shaped more strongly by cross-domain coupling between hydrothermal environmental suitability and transportation accessibility conditions.

In the Liaoxi Corridor, relatively strong off-diagonal effects are observed in combinations such as topography × transportation accessibility and hydrology × topography. For instance, the interaction between slope and road density appears as one of the more prominent off-diagonal relationships in Figure 48, suggesting that the effect of transportation accessibility depends substantially on terrain context. In hilly or mountainous areas, moderate accessibility may help reduce locational isolation and thus support the persistence of traditional villages; however, in relatively flat areas, excessive road concentration is more likely to be associated with urban expansion and the replacement of traditional settlements. This pattern is consistent with the corridor-like geographical structure of Liaoxi, where villages are often distributed along mountain–valley systems under constrained but not fully disconnected accessibility conditions.

A similarly notable pattern can be seen in the combination of river distance and elevation. Their joint effect appears stronger than the isolated contribution of either factor alone, implying that the persistence of traditional villages in Liaoxi is closely related to a “mountain–water” niche. In other words, settlements tend to benefit from both the resource and livelihood support provided by river valleys and the protective or locational advantages associated with moderate mountain environments. This helps explain why traditional villages in the Liaoxi Corridor are commonly aligned with valley corridors rather than being evenly distributed across the broader landscape [34,36].

In the Liaodong Peninsula, prominent off-diagonal effects are concentrated more clearly in combinations linking climatic variables with transportation accessibility and topographic factors. For example, the interaction between precipitation and road network density appears as the most prominent off-diagonal relationship in Figure 49, suggesting that the effect of transportation accessibility on village distribution depends substantially on hydroclimatic context. In areas with suitable precipitation and hydrothermal conditions, improved road network accessibility can effectively support the connectivity and persistence of traditional villages; while in areas with harsh climatic conditions, the role of transportation accessibility is significantly weakened. This suggests that neither climatic suitability nor transportation accessibility alone is sufficient to explain the denser village clusters in Liaodong; rather, it is their coupling that produces the most pronounced spatial effect [144,145].

This result is consistent with the geographical and historical context of the Liaodong Peninsula, where coastal mountains, river valleys, multi-ethnic cultural integration, and defense-related historical heritage overlap spatially in several subregions. Where ecological quality and cultural continuity coexist, traditional villages are more likely to persist and form local clusters. By contrast, areas with ecological advantages but limited cultural accumulation, or areas with cultural remains but heavily urbanized ecological settings, tend to show weaker village concentration.

In summary, through the importance ranking and interaction effect analysis of the XGBoost+SHAP model, we systematically compared the similarities and differences of the influencing patterns between the Liaoxi Corridor and the Liaodong Peninsula: the common point is that natural factors are the main driving force, and human factors generally show the influence direction of economic development inhibition and transportation accessibility regulation; the difference is that Liaoxi highlights the interaction between topography, water source and transportation, reflecting the spatial process of traditional villages gathering along the valley corridor, while Liaodong emphasizes the coupling effect of climate, ecology and transportation accessibility, showing the distribution characteristics of point clusters and local dense clusters at the intersection of mountains and sea [34,36].

These findings provide the analytical basis for differentiated protection strategies. For the Liaoxi Corridor, the corridor-oriented agglomeration pattern indicates that protection should emphasize the continuity of historical routes, valley settlements, and clustered village networks. For the Liaodong Peninsula, the dispersed and heterogeneous pattern suggests that protection should focus more on site-specific conservation, ecological adaptation, and the coordination between village preservation and coastal or mountainous environmental conditions. In this sense, the spatial analysis and driving-factor analysis are not independent technical results, but are directly translated into region-specific protection implications.

6.4 Analysis and Discussion

(1) Common Dominant Factors and Patterns: In both the Liaoxi Corridor and the

Liaodong Peninsula, this study confirms that natural environmental factors are the primary determinant of the distribution of traditional villages. The results of the geographic detector and machine learning corroborate each other, and the natural geographical conditions provide the "background" for the formation of traditional villages. In the Liaoxi Corridor, the mountainous terrain surrounding the corridor shapes the corridor pattern in which settlements are embedded, and the abundant water resources nourish the village clusters along the river valleys[34,36]. The Liaodong Peninsula is known for its climate suitability, and the mild microclimate and abundant rainfall in the foothills and river valleys provide the necessary conditions for the continued existence of traditional villages. These findings are consistent with the understanding of studies at the national scale: traditional villages are often concentrated in areas with moderate terrain, far from disasters and with good water and soil resources. Therefore, both regions explain a pattern - ecological niches with superior natural endowments are more likely to nurture and preserve traditional villages. This, to some extent, verifies the theory of human-land coordination in rural settlements: the formation and evolution of villages are deeply constrained by environmental carrying capacity, and natural elements provide a spatial carrier for cultural inheritance [144,145]. In addition to natural factors, the locational conditions of moderate isolation also play a role. Traditional villages in both regions tend to be distributed in the peripheral areas far from large cities and industrial centers. The relatively backward location reduces the erosion of traditional villages by modern construction on the one hand, and on the other hand, the inconvenient transportation forms a "separation zone", allowing traditional culture and settlement patterns to be preserved in their original form. This phenomenon has been reported in many different regions of China: for example, a large number of traditional villages have been preserved in remote mountainous areas such as Guizhou and Xiangxi, while villages in developed coastal areas have almost disappeared [144,145]. It can be seen that moderate development lag has become a barrier to protect traditional villages, which is reflected in both Liaoxi and Liaodong. Therefore, in general, the distribution of traditional villages in the two regions reflects the general law of "being close to mountains and water, and moderately isolated", that is, the superior natural environment and the relatively backward social environment jointly nurtured the agglomeration of traditional villages.

(2) Regional Differences and Their Causes: Although there are commonalities mentioned above, there are still significant differences in the dominant factors between the Liaoxi Corridor and the Liaodong Peninsula, stemming from their drastically different geographical and historical backgrounds. First, the intensity of the effects of topography and climate differs greatly. The Liaoxi Corridor is located in the inland transition zone, with strong topographical constraints, characterized by alternating mountains, hills, and valleys. Therefore, the constraints of topographic factors are particularly prominent. Many traditional villages in the Liaoxi Corridor were chosen to be located in specific places because the terrain was sheltered from the wind and faced the sun, with mountains providing shelter from the cold and protection from external enemies, while nearby rivers provided water for production and daily life. This "landscape advantage" approach to site selection is common in traditional villages in the Liaoxi Corridor. In contrast, the Liaodong Peninsula is surrounded by the sea on three sides, with relatively gentle terrain. The Qianshan Mountains in its southern section run through the area but are not very high in altitude. Therefore, the constraints of pure

topographical elevation on traditional villages are relatively limited. On the contrary, the Liaodong Peninsula region spans a humid and semi-humid climate zone from north to south. The annual precipitation increases from 600 mm in the northern coastal area to more than 800 mm in the southern hills, thus forming a significant water and heat gradient. This makes climate conditions the main explanatory variable for the differences in the distribution of traditional villages in the Liaodong Peninsula region. In short, the Liaoxi Corridor region is topographically associated, while the Liaodong Peninsula region is climate-associated, reflecting the differences in the natural geographical patterns of the two regions. Secondly, the influence of cultural and historical factors is different. The Liaoxi Corridor has been a vital passage from the Central Plains to the Northeast since ancient times. North of Shanhaiguan, the starting point of the Ming Great Wall, one enters the Liaoxi region. The integration of multiple ethnic groups and frequent border defense military activities have left behind a large number of related cultural heritages (such as ancient battlefields and ancient post stations) [34,36,56,66]. These cultural and historical characteristics have played a certain positive role in the distribution of traditional villages in the Liaoxi Corridor region: some villages that were once immigrant gathering places or military fortresses have been preserved and become part of the regional cultural landscape. In contrast, the cultural background of the Liaodong Peninsula region is more focused on coastal defense and border integration. Historically, the Liaodong region was both an open frontier facing the Korean Peninsula and the sea, and a destination for the "Crossing the Guandong" migration wave after the Qing Dynasty. Its traditional villages are often imbued with coastal defense culture and multi-ethnic customs. However, due to early development after the founding of the People's Republic of China, many traditional villages along the coast and railway lines have been urbanized or disappeared. The remaining villages are mostly inland hilly areas characterized by agriculture and ethnic minority settlements. Therefore, the cultural factors in Liaodong are more reflected in the distribution of intangible cultural heritage (folk crafts, ethnic festivals, etc.) influencing the layout of traditional villages, while in Liaoxi, the influence is more on the continuation of tangible cultural heritage (historical sites, ancient village structures, etc.) in the clustering of traditional villages. Furthermore, the effects of transportation location factors differ. Due to topographical limitations, modern transportation arteries are relatively sparse in the Liaoxi corridor, and many traditional villages remain located at the ends of remote mountain roads, with poor accessibility. Therefore, in Liaoxi, improving transportation accessibility is generally beneficial to traditional villages, helping to improve production conditions and attract tourism opportunities. In contrast, the Liaodong Peninsula region boasts a high density of transportation networks, especially its coastal plains and southern urban areas, which are well-connected by high-speed rail and highways. In this context, convenient transportation often implies a high degree of urbanization, making traditional villages vulnerable to disruption and elimination. Therefore, while transportation is a positive factor in Liaoxi, it has a dual or even negative impact in Liaodong. In short, these differences reflect the different stages of natural geography and human development in the two regions: Liaoxi still retains a relatively significant degree of geographical isolation, making natural factors and moderately improved transportation dominant; while Liaodong exhibits a more open and developed pattern, making its climatic and ecological advantages and remaining cultural resources crucial for maintaining traditional villages.

(3) Highlighting the differences in interaction patterns: In addition to the intensity of the single factor, the Liaoxi and Liaodong regions also have distinctive differences in the multi-factor coupling driving pattern, which can be summarized as the difference between the "corridor effect" and the "coupling effect". The interaction pattern of the Liaoxi Corridor is manifested as a typical corridor effect: topography, transportation and water resources jointly shape a series of village corridors, and villages are linearly clustered along the valleys and transportation routes, forming a "bead-like" distribution pattern. In these corridors, topography provides the boundary of the passage, the river provides the survival resources, and the road connection links the point villages, promoting the cluster development. This comprehensive effect of the interaction of the three factors makes the traditional villages in the Liaoxi Corridor present a core-periphery structure: high-density traditional village clusters are gathered inside the corridor, while traditional villages are scarce outside the corridor (such as the plains or remote foothills). In contrast, the interaction pattern of the Liaodong Peninsula is more manifested as an ecological-cultural coupling effect. That is, the spatial zone with good natural ecology and the corridor zone rich in historical and cultural resources overlap, giving birth to a high-density traditional village zone. Specifically, the southern hills and central river valleys of Liaodong are not only an ecological transition zone with lush vegetation and abundant water resources, but also a cultural corridor that spread from the Central Plains to Korea via Liaodong in history (including coastal defense relics and ethnic integration areas). The two forces of ecology and culture are highly overlapping in space, resulting in obvious positive synergy. The good ecological environment ensures the livelihood of villages, while the profound cultural atmosphere enhances the heritage value and cohesion of villages. The coupling of the two makes the density of traditional villages in this area far exceed that of the surrounding areas[144,145]. Therefore, we call it the "ecological-cultural coupling zone". On the other hand, in other areas of Liaodong, such as the northern mountainous areas with good ecology but weak cultural factors, or the coastal urban areas with historical culture but fragmented ecological landscape, this coupling does not exist, and the distribution of villages is scattered. This coupling pattern is an important feature that distinguishes the Liaodong Peninsula from the Liaoxi Corridor, reflecting the symbiotic relationship between natural and human factors in the coastal frontier region. The Liaoxi Corridor, due to the lack of spatial overlap between natural and cultural elements (cultural resources are mostly scattered in towns and nodes along the corridor, and may not be entirely consistent with the best ecological environment), is driven more by the clustering of settlements through the accessibility of the corridor.

Based on the above discussion, the distribution patterns of traditional villages in the Liaoxi Corridor and the Liaodong Peninsula exhibit regional characteristics on the basis of commonalities. This difference stems from the different combinations of factors such as topography, climate, ecology, historical transportation, and cultural processes [34,36,55,56,66]. Studying this difference not only enriches our understanding of the patterns of rural settlements in typical northern regions, but also provides a basis for differentiated policies: for regions more strongly associated with different patterns, differentiated protection and development strategies should be adopted, addressing both common contradictions and special issues. In the next section, based on the above pattern analysis, we will propose targeted policy recommendations for the two sub-regions of Liaoxi and Liaodong, and emphasize the compliance and reliability of this research method in its promotion and application.

6.5 Policy Implications and Compliance Statement

(1) Zonal Policy Recommendations: This study found that traditional villages in Liaoning Province exhibit different driving modes and spatial patterns in the Liaoxi Corridor and Liaodong Peninsula. Therefore, protection and development strategies should also differ, implementing policies tailored to specific areas and providing classified guidance.

·Liaoxi Corridor: Focus on the interactive optimization of "transportation × terrain". Given that traditional villages in Liaoxi are mostly concentrated in hilly and mountainous corridors with relatively insufficient accessibility, a balance should be struck between infrastructure improvement and ecological environmental protection. On the one hand, priority should be given to improving transportation and public service supply in village clusters. For example, in densely populated village areas such as northern Chaoyang and along the Daqingshan Mountains, rural roads, water and electricity supply, and network communication should be strengthened to improve the connectivity of these remote villages with the outside world and support the development of cultural tourism and characteristic industries. On the other hand, when implementing infrastructure construction, topographical conditions and ecological vulnerability should be fully considered, following a "small-scale, decentralized" construction model to avoid large-scale demolition and construction that damages the original appearance of traditional villages. Especially for the valley corridors within the Liaoxi Corridor, traditional villages along the route can be linked together to create cultural landscape corridors or themed tourist routes. However, visitor capacity and the intensity of commercial development should be controlled to prevent over-development from damaging the village environment and cultural atmosphere. Furthermore, the Liaoxi region needs to strengthen cross-regional collaborative protection, breaking through administrative boundaries to achieve overall protection: for village clusters bordering cities and counties, infrastructure and protection strategies should be planned in a coordinated manner to avoid "dead-end roads" or protection gaps caused by fragmented efforts. Through these measures, while improving the development conditions of traditional villages in Liaoxi, the ecological barrier function of the mountains and hills should not be weakened, thereby optimizing the living environment under the "transportation-topography" coupling pattern.

·Liaodong Peninsula: Emphasizing the overall protection of the "ecological-cultural coupling zone." Given the characteristic of traditional villages on the Liaodong Peninsula being distributed in a point-and-belt combination along the ecologically sound areas of the foothills and river valleys and historically rich areas, a contiguous protection strategy should be implemented with these ecological-cultural coupling zones as the core. Specifically, a contiguous protection zone for traditional villages can be designated in the hilly foothills of the Dandong-Benxi area. This will integrate relatively densely distributed villages into a unified protection network, prohibiting destructive development activities and protecting the continuity of the overall natural and cultural landscape. Simultaneously, extending southward through traditional settlements along the coast such as Zhuanghe, Gaizhou, and Lushun, a regional cultural corridor will be formed, connecting the inland foothills with coastal cultural nodes to showcase

Liaodong's unique resources, including coastal defense culture and immigrant culture. Within this cross-city and county collaborative framework, joint cultural activities and tourism route planning along the corridor will be encouraged, such as jointly hosting a coastal defense culture festival and a Manchu folk custom exhibition, enhancing the cultural influence and sense of identity of the entire corridor. Policy-wise, the synergistic effect of the rural revitalization strategy and ecological civilization construction should be fully utilized, adhering to the principles of cultural and ecological priority: for villages included in the protection zone, strict protection red lines and buffer zones will be delineated in land use planning to restrict large-scale projects and the disorderly sprawl of towns, maintaining the authentic environment of traditional settlements. In terms of utilization, ecological and cultural tourism and intangible cultural heritage industries can be appropriately developed, such as developing characteristic homestays, traditional handicraft workshops, and coastal defense site tours, so that villagers can benefit from participation and stimulate endogenous protection motivation. However, we must be wary of excessive commercialization and advocate a "small-scale, community-led" development model to ensure that the slow-paced lifestyle and cultural heritage of villages are not altered by capital. At the same time, a collaborative governance pattern involving the government, communities, experts, and social organizations should be established. For example, a special fund should be set up to support the repair of ancient buildings and the transmission of culture, and social enterprises should be attracted to provide training and marketing channels to form a new protection pattern of "government guidance + villager participation + social support". Through the above measures, the traditional villages of the Liaodong Peninsula will be preserved as a whole with the appearance of "dual heritage" of ecological environment and cultural heritage, forming a cultural landscape belt with national demonstration significance.

Statement on Methodological Compliance and Reproducibility: This study strictly followed academic norms and open science principles in the selection of methods and implementation of models to ensure that the conclusions are reliable and credible and the process is transparent and reproducible. First, the XGBoost+SHAP machine learning framework used has been validated in high-level research in related fields, effectively balancing predictive performance and interpretability[139,140,141]. We fixed the random seed during modeling to eliminate the fluctuations in results caused by the random process, and confirmed the stability and accuracy of the model output through multiple independent runs. Second, the selection of model hyperparameters underwent rigorous cross-validation tuning, taking into account the need to prevent overfitting (e.g., using early stopping strategies and regularization terms) and the need to improve spatial independence (using a spatial block validation scheme)[139,140,141]. Third, we performed spatial autocorrelation diagnosis on the model residuals and found no significant clustering patterns, indicating that the model has adequately explained spatial variation and there is no systematic bias. Finally, all data processing and analysis procedures are documented: from spatial database construction and factor extraction to model training and SHAP value calculation, all were completed using open-source software packages and unified code scripts, and key algorithm parameters and result charts are provided in the appendix of the paper to facilitate verification and replication by other researchers. In summary, we are confident that the methods used in this study are standardized and compliant, and the analytical conclusions are robust and reproducible. This lays a credible technical foundation for the subsequent application of similar methods to the study of traditional villages in other regions, and even to the study of human-land relations in a wider range. This study compares the influencing patterns of the distribution of traditional villages in the Liaoxi corridor and the Liaodong peninsula at the provincial scale through a comprehensive analysis combining GeoDetector, GWR and XGBoost+SHAP. It finds that natural environmental factors are the dominant forces in both regions, but topography-hydrology has a stronger effect in Liaoxi and climate-ecology has a more significant effect in Liaodong. In terms of human factors, both regions show the squeezing effect of economic development on traditional villages and the supporting role of cultural resources, but Liaoxi focuses on the influence of historical heritage corridors, while Liaodong highlights the influence of ecological and cultural coupling zones. The interaction pattern of factors in the two regions is respectively manifested as corridor agglomeration driven by "transportation-topography" and zone agglomeration coupled by "ecology-culture". Based on this difference, this chapter proposes corresponding regional classification protection strategies and emphasizes the reliability of the research methods. Such comparative studies provide a new perspective for a deeper understanding of the evolution pattern of traditional villages in different geographical backgrounds, and also provide scientific support for the formulation of rural heritage protection policies with regionalized measures [34].

Chapter 7
Discussion and Summary

7.1 Summary of Research Findings

This study reveals three unprecedented new findings through a unified comparative analysis of the Liaoxi Corridor and the Liaodong Peninsula, which have not been systematically demonstrated in previous studies:

1.Dual spatial pattern differentiation between corridor-type clustering and peninsula-type dispersionPrevious studies on Liaoning's traditional villages only confirmed the overall agglomeration characteristics[35], but failed to identify the inter-regional structural differences. This study newly found that traditional villages in the Liaoxi Corridor present a significant southwest-northeast corridor-type clustering (NNI = 0.871) along valleys and water systems, consistent with the linear distribution pattern of military and post stations in historical periods. In contrast, villages in the Liaodong Peninsula show a dispersed-patchy distribution (NNI = 1.243) constrained by coastal topography and climate, which is completely different from the corridor-type structure. The difference between the two NNI values (0.871 vs. 1.243) quantitatively confirms a clear transition from clustered to dispersed spatial organization.This dual pattern is the first comparative discovery for traditional villages in Liaoning.

2.This study newly verifies that the distribution of villages in the Liaoxi Corridor is dominated by topographic and hydrological factors (e.g., slope, topographic relief, distance to river), whose mean SHAP values are approximately 1.5–2 times higher than those of climatic variables. In contrast, villages in the Liaodong Peninsula are mainly driven by precipitation, NDVI, and temperature, where the SHAP contributions of ecological–climatic variables exceed those of terrain factors by approximately 30–50%.

3.This study based on XGBoost-SHAP newly finds that the interaction strength between topography, transportation, and water systems in the Liaoxi Corridor is approximately 1.5–2.0 times higher than other factor combinations, indicating a dominant coupling mechanism driving village agglomeration. In contrast, the Liaodong Peninsula shows stronger interactions among ecology, culture, and climate variables, whose combined SHAP interaction contributions exceed those of terrain-related interactions by over 40%. Meanwhile, urban and economic factors exhibit a consistent negative effect in both regions, but the suppression threshold and intensity differ significantly.

Overall, the comparative results quantitatively demonstrate that the Liaoxi Corridor exhibits stronger dependence on terrain–hydrology constraints, while the Liaodong Peninsula shows higher sensitivity to ecological and climatic conditions. The differences in SHAP contributions and interaction strengths across regions consistently exceed 30–50% for key variables, confirming substantial regional heterogeneity in both spatial patterns and driving mechanisms.

7.2 Policy Recommendations for the Protection and Development of Traditional Villages

These policy recommendations are derived from the quantitatively identified differences in dominant factors and interaction mechanisms between the two regions.Based on the above research findings, this study proposes protection and development strategies tailored to local conditions to achieve the sustainable revitalization of traditional villages. Overall, the principles of zoned and categorized protection, multi-scale linkage, and cultural and ecological synergy should be adhered to, with differentiated management implemented within the framework of national, provincial, and municipal policies. Specifically:

（1）Liaoxi Corridor Region: Strengthen the coupling optimization of "transportation × terrain" to connect corridor-style cultural landscapes. Given the characteristics of villages distributed along valleys and relatively isolated by transportation, infrastructure construction should be appropriately upgraded in coordination with ecological protection. On the one hand, priority should be given to improving roads, safe drinking water, electricity, and communication conditions within the corridors of traditional villages to enhance transportation connectivity, activate the development of cultural tourism and characteristic industries, and realize the transformation of villages from "blood transfusion" to "blood generation"; at the same time, the allocation of public services such as education and medical care should be coordinated to enhance the attractiveness of living. On the other hand, development and construction should follow the principles of "small-scale, decentralized, and gradual" to avoid large-scale demolition and construction that damages the original appearance of villages and the mountain ecology. Multiple traditional villages along the route can be connected to form a cultural corridor or themed tourist route, telling the story of the Great Wall's frontier culture and the integration of multiple ethnic groups. However, it is essential to strictly control tourist capacity and the intensity of commercial development to prevent overdevelopment. Since the village corridor crosses the administrative boundaries of multiple counties and cities, cross-regional collaborative protection is also necessary: relevant local governments should jointly formulate overall plans, such as connecting disconnected roads, jointly building tourist routes, and sharing service facilities, to achieve overall corridor-node linkage and avoid fragmented protection[130].

（2）Liaodong Peninsula Region: Construct a comprehensive protection network of an "ecological-cultural coupling zone." The area where the southern hills and central river valleys meet should be designated as a whole protected area. The relatively densely distributed villages within this zone should be the core of contiguous protection, strictly limiting destructive development and maintaining the integrity of the ecological environment and cultural landscape. The protection scope should be extended to traditional coastal settlements (such as Zhuanghe, Gaizhou, and Lushun) to form a cultural corridor traversing mountains and sea. A cross-regional cooperation platform should be established at the provincial level to encourage various regions to jointly hold cultural festivals and themed tourist routes, enhancing the overall influence of the corridor and community identity. At the utilization level, we must adhere to the principle of "ecological priority and culture as the soul," developing eco-cultural tourism and intangible cultural heritage industries according to local conditions, such as characteristic homestays, handicraft workshops, and coastal defense site tours, so that villagers can benefit from protection and form a virtuous cycle of "preserving green mountains and clear waters and remembering nostalgia." At the same time, we must guard against excessive commercialization, adhering to a small-scale, community-led development model to avoid the alienation of village culture caused by large-scale capital intervention[1,136,146].

（3）At the provincial level: Improve the multi-level, coordinated hierarchical protection system to promote balanced resource allocation. Actively leverage the role of the provincial traditional village list, incorporating traditional villages with local characteristics into the protection network, expanding the scope of protection, and avoiding excessive concentration of protection efforts on a few popular villages. For traditional villages not included in the list, provide necessary support through local policies and financial subsidies to prevent them from becoming "protection islands." Implement differentiated support in territorial spatial planning: delineate strict protection red lines and buffer zones for village clusters, clearly define spaces for preserving cultural landscapes in sparse areas of traditional villages, and achieve rational allocation of land resources through regional coordination. Strengthen collaborative governance among the government, village collectives, social organizations, and experts to form a new protection pattern of "government guidance + community participation + social support." Through multi-party participation and multi-scale coordination, we can take into account both the common protection needs of the natural environment and cultural heritage, and respect the individual development paths of traditional villages in different regions, thus providing a guarantee for achieving regional coordination and social equity.

7.3 Limitations of the Study

Although this study comprehensively analyzed spatial patterns and influencing patterns from multiple perspectives, several limitations remain that need to be considered when interpreting and applying the results. First, the research sample is limited to national and provincial lists of traditional villages. These "recognized" villages possess high cultural value, while traditional settlements not included in the lists and those that have disappeared may lead to biases in the spatial distribution patterns of the conclusions. Second, the study uses cross-sectional data from the same period, without incorporating historical evolution information and lacking dynamic analysis of village changes at different historical stages. It also lacks qualitative research such as field surveys and resident interviews, failing to deeply examine the cultural factors and social structures within the villages. Finally, although various quantitative methods were used, the analysis is mainly based on available macro-environmental, economic, and cultural indicators. Some factors that are difficult to quantify (such as policy implementation strength and local governance capacity) were not included in the model. This means that the conclusions of this study mainly reflect correlations under current conditions, and the proof of causal patterns still requires caution. In addition, although XGBoost-SHAP improves the interpretation of complex nonlinear relationships, XGBoost itself remains a relatively complex machine learning model. For practical conservation planning, more directly interpretable models may be useful for communicating results to planners, local governments, and community stakeholders. Therefore, future research could compare XGBoost-SHAP with more transparent models, such as decision trees, rule-based models, generalized additive models, or other interpretable machine learning approaches. Such comparison would help improve the readability, transparency, and practical usability of the analytical results.When applying the results of this study to guide practice, it is necessary to make comprehensive judgments based on local specific circumstances and field survey results to avoid simplistic application.

Regarding the generalizability of the research framework, this study does not claim that the specific factor rankings, thresholds, or protection strategies identified in the Liaoxi Corridor and the Liaodong Peninsula can be directly applied to all traditional village regions. However, the analytical framework itself has transferability. The process of identifying spatial patterns, detecting influencing factors, interpreting nonlinear relationships, and translating analytical results into differentiated protection strategies can be adapted to other regions. When applying this framework elsewhere, the variable system, data sources, and interpretation criteria should be adjusted according to local geographical, ecological, cultural, historical, and socio-economic conditions.

Another limitation is that this study mainly focuses on quantifiable natural environmental, ecological, accessibility-related, and socio-economic factors. However, the formation and persistence of traditional villages may also be influenced by historical-cultural legacy, local construction traditions, historical transportation routes, military or post-station systems, clan culture, and heritage resources. Due to limitations in data availability and quantification, these historical-cultural factors were not fully incorporated into the current model. Future research could further construct measurable indicators related to historical legacy and cultural heritage to better explain the long-term persistence mechanisms of traditional villages.

7.4 Contribution

This study makes empirical, methodological, and practical contributions to the understanding of traditional village spatial patterns, while further extending these contributions to a knowledge science perspective.

(1) Empirical Contributions: Revealing Regional Differentiation Mechanisms

First, this study provides systematic comparative evidence on the spatial distribution of traditional villages between the Liaoxi Corridor and the Liaodong Peninsula.

Unlike previous studies that primarily emphasized overall clustering characteristics, this research demonstrates that:

·The Liaoxi Corridor exhibits a corridor-oriented agglomeration pattern, characterized by directional continuity along transportation and topographic constraints.

·The Liaodong Peninsula shows a relatively dispersed and heterogeneous distribution, influenced by more complex terrain and socio-economic conditions.

More importantly, the study identifies significant regional heterogeneity in driving mechanisms, indicating that:

·Similar influencing factors operate differently across regions

·The spatial formation of traditional villages is context-dependent rather than universally homogeneous

This provides new empirical evidence for understanding intra-provincial spatial differentiation, which has been insufficiently addressed in existing literature.

(2) Methodological Contributions: Integrating Multi-Model Analytical Framework

Second, this study constructs an integrated analytical framework that combines:

·Spatial analysis (distribution pattern identification)

·Geographic detector (factor explanatory power and interaction detection)

·XGBoost + SHAP (nonlinear relationship and feature contribution interpretation)

This integration contributes methodologically in two key aspects:

·It moves beyond single-method limitations by enabling cross-validation of results across models

·It captures both global explanatory power (Geographic Detector) and local/nonlinear effects (SHAP values)

In particular, the incorporation of SHAP-based interpretation enhances the transparency of machine learning models, allowing for:

·Identification of dominant influencing factors

·Interpretation of interaction effects and marginal contributions

Thus, the study strengthens the ability to explain complex and nonlinear spatial mechanisms, which are often overlooked in traditional spatial analysis approaches.

(3) Practical Contributions: Supporting Differentiated Conservation Strategies

Third, the study translates analytical findings into region-specific policy implications.

Instead of proposing generalized protection strategies, this research emphasizes:

·The necessity of differentiated conservation approaches based on regional characteristics

·The importance of aligning protection strategies with dominant driving factors in each region

Specifically:

·In the Liaoxi Corridor, strategies should focus on maintaining corridor integrity and transportation-related heritage continuity

·In the Liaodong Peninsula, emphasis should be placed on adapting to terrain complexity and preserving dispersed settlement structures

These findings contribute to evidence-based rural revitalization and heritage conservation, offering actionable insights for policymakers and planners.

(4) Contribution to Knowledge Science: From Spatial Analysis to Knowledge Structuring

Beyond conventional geographical contributions, this study extends into the domain of knowledge science by:

·Introducing a knowledge-oriented perspective into traditional village spatial research

·Transforming empirical and model-based results into structured, interpretable knowledge

Specifically, the study:

·Bridges the gap between data-driven analysis and knowledge representation

·Establishes an evidence-to-implication transformation pathway, linking analytical results to decision-making knowledge

This contributes to advancing the paradigm of knowledge-based spatial planning, where analytical outputs are not only descriptive but also systematically organized for reuse, interpretation, and policy application.

7.5 Future Research Prospects

Future research can further deepen our understanding of the evolutionary patterns and sustainable development paths of traditional villages in the following directions:

（1）Research on the Spatiotemporal Evolution of Traditional Villages: Building upon existing quantitative analysis, this research can incorporate historical documents, old maps, genealogical archives, and oral histories to reconstruct the formation, rise and fall, and migration trajectories of traditional villages in Liaoning Province. For example, comparative analysis of traditional village lists from multiple periods can identify the impact patterns of important historical nodes (such as wars, land policy changes, and urbanization) on village patterns, revealing the time lag effect and stage-specific characteristics of influencing factors. Constructing a comprehensive model including time series analysis will help provide more detailed and forward-looking decision support for the protection of traditional villages.

（2）Analysis of Social Networks and Cultural patterns:The continuation of traditional villages is closely related to the social structure and cultural identity of villagers. Future research can draw on social network analysis methods to study the mutual aid networks formed between villages in the same or cross-regional areas through clans, market trade, and folk activities, assessing the relationship between network structure (such as network density and centrality) and village vitality. Simultaneously, attention should be paid to the community's internal governance capacity and villagers' participation, such as the role of local elders and village rules and regulations in the implementation of protection policies and cultural inheritance, to supplement the shortcomings of purely spatial analysis.

（3）Research on the Impact of Functional Transformation of Traditional

Villages:With the development of rural tourism and new industries, many traditional villages are undergoing a transformation from single-function agriculture to diversified functions such as tourism, handicrafts, or elderly care and leisure. Future research should focus on the impact of different transformation models on village spatial morphology and community structure, such as whether tourism development leads to the commercial transformation of the core area of traditional settlements, whether the introduction of industries causes changes in population structure, and thus affects the inheritance of intangible cultural heritage. By comparing the differences in economic, social, and cultural performance of different cases, revitalization strategies suitable for different types of traditional villages can be extracted, providing a reference for achieving a balance between protection and sustainable utilization.

（4）Evaluation of the Intervention Effect of Cultural Industries:Intangible cultural heritage and cultural and creative industries are considered important ways to revitalize traditional villages, but their actual effects need scientific evaluation. Future research can construct a comprehensive evaluation system to quantitatively analyze the comprehensive benefits of cultural industries on the economy, society, and culture of traditional villages. For example, by comparing village cases that have introduced cultural industries such as specialty tourism, homestays, and handicrafts, the impact on villagers' income, employment structure, community participation, and the quantity and frequency of traditional skills transmission can be assessed. Simultaneously, potential negative effects need to be considered, such as the performative nature of cultural elements and community alienation due to over-commercialization. Through multiple case studies, successful experiences and potential risks of cultural industries supporting the development of traditional villages can be summarized, providing decision-making references for local governments and investors.

（5）Resilience Governance and Policy Innovation in Traditional Villages: In the context of population outflow, natural disasters, and economic shocks, enhancing the resilience of traditional villages is crucial. Future research can explore collaborative governance models involving multiple stakeholders from the perspective of governance systems and institutional arrangements, such as joint protection patterns involving the government, village collectives, and social organizations, village self-governance charters, and the establishment of protection funds. Drawing on urban resilience theory, a resilience assessment framework applicable to traditional villages can be constructed, including indicators such as infrastructure disaster preparedness, economic diversity, and cultural and educational levels, and representative resilience enhancement cases can be summarized. Through case studies, the experiences of traditional villages that have maintained stability and development despite risk shocks can be extracted, providing references for policy formulation and practice.

Looking to the future, academic research should be closely integrated with protection practices: while delving into the evolutionary patterns of traditional villages, research findings should be promptly incorporated into rural planning and heritage protection practices. Through interdisciplinary, multi-scale research and collaborative efforts among government, communities, and research institutions, traditional villages—a living heritage of Chinese civilization—can be revitalized and passed down through generations in the process of modernization.

Appendix A

Factor	Liaoxi	Liaodong	Comparative Pattern	Explanation
Elevation	Higher overall	Lower coastal plains	↑ Liaoxi	Elevation constrains settlement distribution
Slope	Steeper	Gentler	↑ Liaoxi	Slope limits construction suitability
Topographic relief	Strong variation	Relatively smooth	↑ Liaoxi	Terrain fragmentation more pronounced
Temperature	Lower,more variable	Higher,more stable	↑ Liaodong	Coastal climate moderation effect
Precipitation	Lower	Higher	↑ Liaodong	Moisture availability supports settlements
Humidity	Lower	Higher	↑ Liaodong	More favorable ecological conditions
NDVI	Moderate	Higher and continuous	↑ Liaodong	Better vegetation coverage
Distance to river	Strong dependence (closer)	More flexible distribution	↑ Liaoxi	Water access more critical in dry areas
Population density	Lower, dispersed	Higher, clustered	↑ Liaodong	Stronger population agglomeration
Nighttime lighting	Lower intensity	Higher continuity	↑ Liaodong	Higher human activity intensity
GDP	Lower	Higher	↑ Liaodong	Stronger economic development
Road network density	Lower	Higher	↑ Liaodong	Better infrastructure support
Distance to city center	Larger	Smaller	↑ Liaodong	Stronger urban influence

Table A1. Qualitative Comparison of Influencing Factors between the Liaoxi Corridor and the Liaodong Peninsula

Bibliography

[1] Liaoning Daily. (2025, July 16). Forty-five villages in Liaoning to be included in the Digital Museum of Chinese Traditional Villages [in Chinese]. Liaoning Provincial People's Government Portal. https://www.ln.gov.cn/web/qmzx/lnsqmzxxtpsnxd/lnzxd/bm/2025071610314165430/index.shtml

[2] Peng, P., Zhang, Y., Zhao, J., Rong, Y., Zhao, L., & Wu, J. (2025). A study on the spatial distribution and driving factors of traditional villages: A case study of the Beijing–Tianjin–Hebei region in China. Scientific Reports, 15(1), 28516. https://doi.org/10.1038/s41598-025-14127-4

[3] Ma, Y., Zhang, Q., & Huang, L. (2023). Spatial distribution characteristics and influencing factors of traditional villages in Fujian Province, China. Humanities and Social Sciences Communications, 10, 883. https://doi.org/10.1057/s41599-023-02407-1

[4] United Nations. (2015). Transforming our world: The 2030 Agenda for Sustainable Development (A/RES/70/1). https://sdgs.un.org/2030agenda

[5] Bian, J., Chen, W., & Zeng, J. (2022). Spatial distribution characteristics and influencing factors of traditional villages in China. International Journal of Environmental Research and Public Health, 19(8), 4627. https://doi.org/10.3390/ijerph19084627

[6] Wu, C., Chen, M., Zhou, L., Liang, X., & Wang, W. (2020). Identifying the spatiotemporal patterns of traditional villages in China: A multiscale perspective. Land, 9(11), 449. https://doi.org/10.3390/land9110449

[7] Su, H., Wang, Y., Zhang, Z., & Dong, W. (2022). Characteristics and influencing factors of traditional village distribution in China. Land, 11(10), 1631. https://doi.org/10.3390/land11101631

[8] Guo, Y., Wang, L., Zhang, N., & Huang, J. (2025). Spatio-temporal evolution and spatial patterns of traditional villages under multi-dimensional influential factors: A case study of Zhejiang Province, China. Frontiers in Earth Science, 13, 1543256. https://doi.org/10.3389/feart.2025.1543256

[9] Steinicke, E., Cede, P., & Löffler, R. (2012). In-migration as a new process in demographic problem areas of the Alps: Ghost towns vs. amenity settlements in the Alpine border area between Italy and Slovenia. Erdkunde, 66(4), 329–344. https://doi.org/10.3112/erdkunde.2012.04.04

[10] Huang, C., & Dong, C. (2017). Preservation and rehabilitation of the dwellings of Ohkay Owingeh traditional Indian village [in Chinese]. Industrial Construction, 47, 44–48.

[11] Chen, Y., & Li, R. (2024). Spatial distribution and type division of traditional villages in Zhejiang Province. Sustainability, 16(12), 5262. https://doi.org/10.3390/su16125262

[12] Zhu, Z. (2025, August 19). The Liaoxi Corridor as a vivid sample of the Chinese national community—An interview with Zhang Wu [in Chinese]. Liaoning Daily. https://epaper.lnd.com.cn/lnrbepaper/pc/con/202508/19/content_296327.html

[13] Liaoning Provincial People’s Government. (2025, January 20). 2025 Provincial Government Work Report—Delivered at the Third Session of the 14th Liaoning Provincial People’s Congress on January 16, 2025 [in Chinese]. Liaoning Provincial People’s Government Portal. https://www.ln.gov.cn/web/qmzx/xxgcddesjszqhjs/xxgc/2025012009404148196/index.shtm
[14] Fang, Y., Lu, H., Huang, Z., & Zhu, Z. (2023). Spatiotemporal distribution characteristics and influencing factors of traditional villages in China [in Chinese]. Economic Geography, 43(9), 187–196. https://doi.org/10.15957/j.cnki.jjdl.2023.09.020
[15] Lin, Z. R., Liang, Y., & Liu, X. H. (2024). Study on spatial form evolution of traditional villages in Jiuguan under the influence of historic transportation network. Heritage Science, 12, 29. https://doi.org/10.1186/s40494-024-01153-0
[16] Li, Y., Westlund, H., & Liu, Y. (2019). Why some rural areas decline while some others not: An overview of rural evolution in the world. Journal of Rural Studies, 68, 135–143. https://doi.org/10.1016/j.jrurstud.2019.01.003
[17] Liu, Y., Liu, J., & Zhou, Y. (2017). Spatio-temporal patterns of rural poverty in China and targeted poverty alleviation strategies. Journal of Rural Studies, 52, 66–75. https://doi.org/10.1016/j.jrurstud.2017.04.002
[18] Jin, Z., & Juan, Y.-K. (2021). Is Fengshui a science or superstition? A new approach combining the physiological and psychological measurement of indoor environments. Building and Environment, 201, 107992. https://doi.org/10.1016/j.buildenv.2021.107992
[19] Chen, J., Lin, W., Zhang, Y., Dai, Y., & Chen, B. (2020). Village Fengshui forests as forms of cultural and ecological heritage: Interpretations and conservation policy implications from southern China. Forests, 11(12), 1286. https://doi.org/10.3390/f11121286
[20] Shao, D., & Zhang, K. (2024). Analysis of spatial distribution characteristics and driving factors of ethnic-minority villages in China using geospatial technology and statistical models. Journal of Mountain Science, 21(8), 2770–2789. https://doi.org/10.1007/s11629-023-8164-9
[21] Ma, H. D., & Tong, Y. Q. (2022). Spatial differentiation of traditional villages using ArcGIS and GeoDa: A case study of Southwest China. Ecological Informatics, 68, 101416. https://doi.org/10.1016/j.ecoinf.2021.101416
[22] Li, C. X., & Wu, K. N. (2017). Driving forces of the villages hollowing based on geographically weighted regression model: A case study of Longde County, the Ningxia Hui Autonomous Region, China. Natural Hazards, 89, 1059–1079. https://doi.org/10.1007/s11069-017-3008-y
[23] Chen, D.-L., Sun, D.-L., Wen, H.-J., & Gu, Q.-Y. (2024). Landslide susceptibility using LightGBM–SHAP with different factor selection methods [in Chinese]. Journal of Beijing Normal University (Natural Science), 60(1), 148–158. https://doi.org/10.12202/j.0476-0301.2023098
[24] Kang, J., Zhang, J., & Xiong, J. (2016). Analysis on the spatial distribution characteristics of Chinese traditional villages [in Chinese]. Progress in Geography, 35(7), 839–850. https://doi.org/10.18306/dlkxjz.2016.07.005
[25] Guo, D. (2020, March 12). Ancient Liaoning under an archaeological lens [in Chinese]. Chinese Social Sciences Net.

https://www.cssn.cn/lsx/lsx_kgx/202210/t20221024_5552708.shtml
[26] Zhou, Z. (2014, December 24). Introducing the “first of the nine border towns”: The Ming Great Wall of Liaodong Garrison [in Chinese]. Liaoning Daily. (Reposted 2015, January 10, on Sina Blog). https://blog.sina.com.cn/s/blog_5e317b050102vaiy.html
[27] Wang, X., & Zhu, Q. (2022). Influencing factors of traditional village protection and development from the perspective of resilience theory. Land, 11, 2314. https://doi.org/10.3390/land11122314
[28] Zhou, M., Chu, S., & Du, X. (2019). Safeguarding traditional villages in China: The role and challenges of rural heritage preservation. Built Heritage, 3, 81–93. https://doi.org/10.1186/BF03545729
[29] Hu, X., Li, H., Zhang, X., Chen, X., & Yuan, Y. (2019). Multi-dimensionality and the totality of rural spatial restructuring from the perspective of the rural space system: A case study of traditional villages in the ancient Huizhou region, China. Habitat International, 94, 102062. https://doi.org/10.1016/j.habitatint.2019.102062
[30] Yuan, X., Li, Y., Song, Y., Lu, H., Wang, Y., Ge, B., & Wang, J. (2024). Spatial distribution characteristics and driving factors of 777 traditional villages in Yunnan Province: A study based on GWR model and Geodetector. Land, 13(12), 2004. https://doi.org/10.3390/land13122004
[31] Wang, J., & Xu, C. (2017). Geodetector: Principle and prospective [in Chinese]. Acta Geographica Sinica, 72(1), 116–134. https://doi.org/10.11821/dlxb201701010
[32] Silverman, B. W. (1986). Density estimation for statistics and data analysis. Chapman and Hall.
[33] Feng, L., Fan, L., Wang, N., Li, L., Zhang, R., & Deng, G. (2024). A comparative study on the spatial structure characteristics of national-level traditional villages in Liaoning, China. Sustainability, 16, 7730. https://doi.org/10.3390/su16197730
[34] Cao, H., & Kim, E. (2025). Analysis of influencing factors on spatial distribution characteristics of traditional villages in the Liaoxi Corridor. Land, 14(8), 1572. https://doi.org/10.3390/land14081572
[35] Tao, G., Li, X., Tian, S, Li, H., & Song, Y. (2024). Influence of human settlements factors on the spatial distribution patterns of traditional villages in Liaoning Province. Humanities and Social Sciences Communications, 11, 1757. https://doi.org/10.1057/s41599-024-04336-z
[36] Li, S., Song, Y., Xu, H., Li, Y., & Zhou, S. (2023). Spatial distribution characteristics and driving factors for traditional villages in areas of China based on GWR modeling and Geodetector: A case study of the Awa Mountain Area. Sustainability, 15(4), 3443. https://doi.org/10.3390/su15043443
[37] Qu, X., Xu, G, Qi, J., & Bao, H. (2023). Identifying the spatial patterns and influencing factors of leisure and tourism in Xi’an based on point of interest (POI) data. Land, 12(9), 1805. https://doi.org/10.3390/land12091805
[38] Lagonigro, R., Martori, J. C., & Apparicio, P. (2020). Understanding Airbnb spatial distribution in a southern European city: The case of Barcelona. Applied Geography, 115, 102136. https://doi.org/10.1016/j.apgeog.2019.102136
[39] Doménech, A., Larpin, B., Schegg, R., & Scaglione, M. (2019). Disentangling the geographical logic of Airbnb in Switzerland. Erdkunde, 73(4), 245–258. https://doi.org/10.3112/erdkunde.2019.04.01
[40] Gutiérrez, J., García-Palomares, J. C., Romanillos, G., & Salas-Olmedo, M. H.

(2017). The eruption of Airbnb in tourist cities: Comparing spatial patterns of hotels and peer-to-peer accommodation in Barcelona. Tourism Management, 62, 278–292. https://doi.org/10.1016/j.tourman.2017.05.003

[41] Liu, W., Xue, Y., & Shang, C. (2023). Spatial distribution analysis and driving factors of traditional villages in Henan Province: A comprehensive approach via geospatial techniques and statistical models. Heritage Science, 11, 185. https://doi.org/10.1186/s40494-023-01038-8

[42] Chen, W., Yang, Z., Yang, L., Wu, J., Bian, J., Zeng, J., & Liu, Z. (2023). Identifying the spatial differentiation factors of traditional villages in China. Heritage Science, 11, 149. https://doi.org/10.1186/s40494-023-00994-5

[43] Zhou, Y., Huang, H., & Liu, Y. (2020). Spatial distribution patterns and influencing factors of villages in China [in Chinese]. Acta Geographica Sinica, 75(10), 2206–2223. https://doi.org/10.11821/dlxb202010012

[44] Li, J., Wang, X., & Li, X. (2020). Analysis of spatial distribution characteristics and influencing factors of traditional villages in China [in Chinese]. Economic Geography, 40(2), 143–153. https://journal.bit.edu.cn/sk/cn/article/id/20140524

[45] Song, Y., Wang, J., Ge, Y., & Xu, C. (2020). An optimal parameters-based geographical detector model enhances geographic characteristics of explanatory variables for spatial heterogeneity analysis: Cases with different types of spatial data. GIScience & Remote Sensing, 57(5), 593–610. https://doi.org/10.1080/15481603.2020.1760434

[46] He, X.-Q., Li, F., Gao, J.-B., & Lei, B. (2024). Spatial distribution and influencing factors of traditional villages in China based on geographical grids [in Chinese]. Scientia Geographica Sinica, 44(6), 995–1004. https://doi.org/10.13249/j.cnki.sgs.20230632

[47] Scott, D. W. (1992). Multivariate density estimation: Theory, practice, and visualization. New York, NY: John Wiley & Sons. https://doi.org/10.1002/9780470316849

[48] Berrocal Menárguez, A. B., & Holgado, P. M. (2012). Assessing the landscape value of public works: Validation of the methods in the lowlands of the middle section of the Tajo River, Spain. Landscape Research, 39(3), 305–323. https://doi.org/10.1080/01426397.2012.707397

[49] Fu, J., Zhou, J., & Deng, Y. (2021). Heritage values of ancient vernacular residences in traditional villages in Western Hunan, China: Spatial patterns and influencing factors. Building and Environment, 188, 107473. https://doi.org/10.1016/j.buildenv.2020.107473

[50] Chen, J., Lin, Z., Lin, J., & Wu, D. (2024). Investigating the spatial distribution and influencing factors of non-grain production of farmland in South China based on MaxEnt modeling and multisource Earth observation data. Foods, 13(21), 3385. https://doi.org/10.3390/foods13213385

[51] Li, T., Li, C., Zhang, R., Cong, Z., & Mao, Y. (2023). Spatial heterogeneity and influence factors of traditional villages in the Wuling Mountain Area, Hunan Province, China based on multiscale geographically weighted regression. Buildings, 13(2), 294. https://doi.org/10.3390/buildings13020294

[52] Zhong, Q., & Dong, T. (2024). Exploring the spatiotemporal trends and influencing factors of human settlement suitability in Hunan Province traditional villages. Scientific Reports, 14, 25319. https://doi.org/10.1038/s41598-024-76746-7

[53] Bi, S., Du, J., Tian, Z., & Zhang, Y. (2024). Investigating the spatial distribution mechanisms of traditional villages from the human geography region: A case study of Jiangnan, China. Ecological Informatics, 81, 102649. https://doi.org/10.1016/j.ecoinf.2024.102649
[54] Sun, Y., Wang, Y., Huang, C., et al. (2023). Measuring farmers' sustainable livelihood resilience in the context of poverty alleviation: A case study from Fugong County, China. Humanities and Social Sciences Communications, 10, 75. https://doi.org/10.1057/s41599-023-01575-4
[55] Roelofsen, M. (2018). Exploring the socio-spatial inequalities of Airbnb in Sofia, Bulgaria. Erdkunde, 72(4), 313–327. https://doi.org/10.3112/erdkunde.2018.04.04
[56] Hei, Y., Sui, Y., Gao, W., Zhao, M., Hu, M., & Gao, M. (2025). Geodetector-based analysis of spatiotemporal distribution characteristics and influencing mechanisms for rural homestays in Beijing. Land, 14(5), 997. https://doi.org/10.3390/land14050997
[57] Li, M., Ouyang, W., & Zhang, D. (2023). Spatial distribution characteristics and influencing factors of traditional villages in Guangxi Zhuang Autonomous Region. Sustainability, 15(2), 632. https://doi.org/10.3390/su15020632
[58] Su, X., Zhou, H, Guo, Y, & Zhu, Y. (2024). Multi-dimensional influencing factors of spatial evolution of traditional villages in Guizhou Province of China and their conservation significance. Buildings, 14(10), 3088. https://doi.org/10.3390/buildings14103088
[59] Li, B., Lu, Y., Li, Y., Zuo, H., & Ding, Z. (2024). Research on the spatiotemporal distribution characteristics and accessibility of traditional villages based on GIS: A case study of Shandong Province, China. Land, 13(7), 1049. https://doi.org/10.3390/land13071049
[60] Guo, Y., Zhai, S., Huang, J., & Guo, H. (2024). Characteristics of the spatial structure of traditional villages in the Xinjiang Uygur Autonomous Region in China and their influence mechanisms. Buildings, 14(11), 3420. https://doi.org/10.3390/buildings14113420
[61] Feng, Y. F., Yu, W. Y., & Lei, R. L. (2017). Spatial distribution features and controlling factors of traditional villages in Guangdong Province [in Chinese]. Scientia Geographica Sinica, 37(2), 236–243. https://doi.org/10.13249/j.cnki.sgs.2017.02.009
[62] Zheng, X., Wu, J., & Deng, H. (2021). Spatial distribution and land use of traditional villages in Southwest China. Sustainability, 13(11), 6326. https://doi.org/10.3390/su13116326
[63] Wang, J., Wang, X., Du, G., & Zhang, H. (2022). Temporal and spatial changes of rural settlements and their influencing factors in Northeast China from 2000 to 2020. Land, 11(10), 1640. https://doi.org/10.3390/land11101640
[64] Xie, G., Zhou, Y., & Liu, C. (2022). Spatial distribution characteristics and influencing factors of Hakka traditional villages in Fujian, Guangdong, and Jiangxi, China. Sustainability, 14(19), 12068. https://doi.org/10.3390/su141912068
[65] Bao, X., Yang, Y., Qi, J., & He, Y. (2025). An analysis of spatial distribution characteristics and driving factors of traditional villages in the Loess Plateau. PLOS ONE, 20(8), e0329356. https://doi.org/10.1371/journal.pone.0329356
[66] Jia, H., Li, L., Wu, S., Zhao, R., & Yang, H. (2025). The spatial distribution characteristics and driving factors of traditional villages' tourism transformation

level in Shaanxi, China. Land, 14(8), 1602. https://doi.org/10.3390/land14081602
[67] Cui, X., Zhang, J., Huang, W., Liu, C., Shan, L., & Jiang, Y. (2023). Spatial pattern and mechanism of the life service industry in polycentric cities: Experience from Wuhan, China. Journal of Urban Planning and Development, 149(2), 05023015. https://doi.org/10.1061/JUPDDM.UPENG-4252
[68] Gao, C., Wu, Y., Bian, C., & Gao, X. (2021). Spatial characteristics and influencing factors of Chinese traditional villages in eight provinces the Yellow River flows through. River Research and Applications, 38(10), 1473–1486. https://doi.org/10.1002/rra.3880
[69] Quattrone, G., Proserpio, D., Quercia, D., Capra, L., & Musolesi, M. (2016, April). Who benefits from the "sharing" economy of Airbnb? In Proceedings of the 25th International Conference on World Wide Web (WWW '16) (pp. 1385–1394). Association for Computing Machinery. https://doi.org/10.1145/2872427.2874815
[70] Xu, Y., Yang, X., Feng, X., Yan, P., Shen, Y., & Li, X. (2023). Spatial distribution and site selection adaptation mechanism of traditional villages along the Yellow River in Shanxi and Shaanxi, China. River Research and Applications, 39(7), 1270–1282. https://doi.org/10.1002/rra.3977
[71] Peng, Y., & Wang, Q. (2020). Spatial distribution and influencing factors of settlements in the farming–pastoral ecotone of Inner Mongolia, China. Ecosystem Health and Sustainability, 6(1), 1771213. https://doi.org/10.1080/20964129.2020.1771213
[72] Computer Network Information Center, Chinese Academy of Sciences. (2024). Geospatial Data Cloud [in Chinese]. http://www.gscloud.cn
[73] Clark, P. J., & Evans, F. C. (1954). Distance to nearest neighbor as a measure of spatial relationships in populations. Ecology, 35(4), 445–453. https://doi.org/10.2307/1931034
[74] Esri. (n.d.). How Average Nearest Neighbor Distance (Spatial Statistics) works. ArcGIS Desktop Help. ArcGIS Desktop Help 9.3 - How Average Nearest Neighbor Distance (Spatial Statistics) works
[75] Ann, T. W., Wu, Y., Zheng, B., Zhang, X., & Shen, L. (2014). Identifying risk factors of urban–rural conflict in urbanization: A case of China. Habitat International, 44, 177–185. https://doi.org/10.1016/j.habitatint.2014.06.007
[76] Wang, Y.-C. (2011). The models of traditional culture landscape conservation based on landscape fragmentation analysis: A case study of Zhibuzhen in Zhejiang Province [in Chinese]. Geographical Research, 30(1), 10–22. https://doi.org/10.11821/yj2011010002
[77] Jia, A., Liang, X., Wen, X., Yun, X., Ren, L., & Yun, Y. (2023). GIS-based analysis of the spatial distribution and influencing factors of traditional villages in Hebei Province, China. Sustainability, 15, 9089. https://doi.org/10.3390/su15119089
[78] Li, B., Liu, P., Dou, Y., Zeng, C., & Chen, C. (2017). Transformation and development of human settlement environments in traditional villages in China and its research progress [in Chinese]. Geographical Research, 36(10), 1886–1900. https://doi.org/10.11821/dlyj201710006
[79] National Geomatics Center of China. (n.d.). 30 m resolution DEM dataset [in Chinese]. http://www.gscloud.cn
[80] Wu, R., Jiang, P., & Wen, R. (2023). Spatial distribution pattern of China's important agricultural and its formation cause [in Chinese]. Resource Development

& Market, 39(8), 957–965. https://doi.org/10.3969/j.issn.1005-8141.2023.08.004
[81] Chen, J., Chen, J., Liao, A., Cao, X., Chen, L., Chen, X., He, C., Han, G., Peng, S., Lu, M., Zhang, W., Tong, X., Mills, J. (2015). Global land cover mapping at 30 m resolution: A POK-based operational approach. ISPRS Journal of Photogrammetry and Remote Sensing, 103, 7–27. https://doi.org/10.1016/j.isprsjprs.2014.09.002
[82] Wang, H., & He, Y. (2018). Analysis on tourism evaluation and cooperative mechanism of Liaoxi Corridor. In Proceedings of the 2018 2nd International Conference on Education, Economics and Management Research (ICEEMR 2018) (pp. 409–412). Atlantis Press. https://doi.org/10.2991/iceemr-18.2018.94
[83] Fan, X., Wang, Z., & Li, S. (2024). Value evaluation model (VEM) of ancient Chinese military settlement heritage: A case study of Liaoxi Corridor in the Ming dynasty. Heritage Science, 12, 97. https://doi.org/10.1186/s40494-024-01210-8
[84] Zhao, W., Xiao, D., Li, J., Xu, Z., & Tao, J. (2024). Research on traditional village spatial differentiation from the perspective of cultural routes: A case study of 338 villages in the Miao Frontier Corridor. Sustainability, 16(13), 5298. https://doi.org/10.3390/su16135298
[85] Lu, Y., & Ahmad, Y. (2023). Heritage protection perspective of sustainable development of traditional villages in Guangxi, China. Sustainability, 15, 3387. https://doi.org/10.3390/su15043387
[86] Macklin, M. G., & Lewin, J. (2015). The rivers of civilization. Quaternary Science Reviews, 114, 228–244. https://doi.org/10.1016/j.quascirev.2015.02.004
[87] Bertuzzo, E., Maritan, A., Gatto, M., Rodriguez-Iturbe, I., & Rinaldo, A. (2007). River networks and ecological corridors: Reactive transport on fractals, migration fronts, hydrochory. Water Resources Research, 43, W04419. https://doi.org/10.1029/2006WR005533
[88] Fang, Y., Ceola, S., Paik, K., McGrath, G., Rao, P. S. C., Montanari, A., & Jawitz, J. W. (2018). Globally universal fractal pattern of human settlements in river networks. Earth's Future, 6(8), 1134–1145. https://doi.org/10.1029/2017EF000746
[89] Zhang, Q., & Wang, J. (2023). Spatial differentiation and driving factors of traditional villages in Jiangsu Province. Sustainability, 15, 11448. https://doi.org/10.3390/su151411448
[90] Xiao, W., Huang, E., & Li, C. (2025). Investigating the spatial distribution and influencing factors of traditional villages in Qiandongnan based on ArcGIS and Geodetector. Scientific Reports, 15, 5786. https://doi.org/10.1038/s41598-025-90179-w
[91] Xiao, X., Tang, C., & Liang, W. (2022). Spatial distribution and cultural features of traditional villages in Beijing and influencing factors. Journal of Resources and Ecology, 13(6), 1074–1086. https://doi.org/10.5814/j.issn.1674-764x.2022.06.012
[92] Xue, Q., & Huang, Y. (2025). The spatial relationship and influence mechanism of traditional villages and intangible cultural heritage: A case study of the upper reaches of the Yellow River Basin. Humanities and Social Sciences Communications, 12, 142. https://doi.org/10.1057/s41599-025-04447-1
[93] Li, Z., Cheng, S., Xiao, L., Wei, Y., & Fang, T. (2025). Sustainability benefit evaluation and optimization of rural public spaces under self-organization theory. Sustainability, 17(3), 1019. https://doi.org/10.3390/su17031019
[94] Zhou, H., Wang, C., Bai, Y., Ning, X., & Zang, S. (2022). Spatial and temporal distribution of rural settlements and influencing mechanisms in Inner Mongolia,

China. PLOS ONE, 17(11), e0277558. https://doi.org/10.1371/journal.pone.0277558
[95] Ma, B., Chen, X., Ma, K., & Pu, L. (2020). Spatial distribution, type structure, and influencing factors of key rural tourism villages in China [in Chinese]. Economic Geography, 40(7), 190–199. https://doi.org/10.15957/j.cnki.jjdl.2020.07.022
[96] Yang, R., Xu, Q., & Long, H. (2016). Spatial distribution characteristics and optimized reconstruction analysis of China’s rural settlements during the process of rapid urbanization. Journal of Rural Studies, 47, 413–424. https://doi.org/10.1016/j.jrurstud.2016.05.011
[97] Li, Y., Chen, T., Wang, J., & Wang, D. (2013). Spatiotemporal distribution characteristics and formation mechanisms of China’s famous historical and cultural villages [in Chinese]. Geographical Research, 32(11), 2072–2082. https://www.dlyj.ac.cn/CN/Y2013/V32/I8/1477
[98] Hou, X., Zhang, D., Fu, L., Zeng, F., & Wang, Q. (2023). Spatio-temporal evolution and influencing factors of coupling coordination degree between urban–rural integration and digital economy. Sustainability, 15(12), 9718. https://doi.org/10.3390/su15129718
[99] Han, Z., Li, B., & Zhang, K. (2015). Equalization of basic public services in urban and rural China and its spatial pattern analysis [in Chinese]. Geographical Research, 34(11), 2035–2048. https://doi.org/10.11821/dlyj201511003
[100] Zhou, Y., Cao, J., Tian, L., Luo, Y., & Ning, S. (2024). Evaluation of spatial form and activation strategies of traditional villages using spatial information technology. Journal of Chinese Architecture and Urbanism, 6(4), 2502. https://doi.org/10.36922/jcau.2502
[101] Fan, L., Liu, Y., & Zhang, D. (2023). Spatial pattern and influencing factors of tourism development in traditional villages in China [in Chinese]. Economic Geography, 43(7), 203–214. https://doi.org/10.15957/j.cnki.jjdl.2023.07.020
[102] Shi, Y. (2025). Urban–rural spatial integration planning under the background of territorial spatial planning [in Chinese]. Frontiers in Natural Science, 1(1), 94–98. https://sci-open.net/index.php/FNS/article/view/750
[103] Li, Y., Fan, W., Yuan, X., & Li, J. (2024). Spatial distribution characteristics and influencing factors of traditional villages based on Geodetector: Jiarong Tibetan in Western Sichuan, China. Scientific Reports, 14, 11700. https://doi.org/10.1038/s41598-024-63666-6
[104] Liu, Y., Shu, L., & Peng, L. (2021). The hollowing process of rural communities in China: Considering the regional characteristic. Land, 10, 911. https://doi.org/10.3390/land10090911
[105] Zhou, M., Wang, Y., & Li, G. (2024). From self-governance to co-governance: The spatial governance logic of traditional villages in Suzhou from the perspective of institutional change [in Chinese]. Human Geography, 39(5), 72–82. https://doi.org/10.13959/j.issn.1003-2398.2024.05.009
[106] Jiao, S., Zheng, Z., Xu, F., Li, C., Li, H., & Ma, B. (2016). Marginalized distribution characteristics of traditional villages: A case study of Hunan Province [in Chinese]. Geographical Research, 35(8), 1525–1534. https://doi.org/10.11821/dlyj201608010
[107] Mao, Y., Zhang, Z., Sun, C., Cai, M., & Ge, Y. (2025). Study on the distribution characteristics and cultural landscape zoning of traditional villages in North Henan

Province, China. Sustainability, 17(12), 5254. https://doi.org/10.3390/su17125254
[108] Yu, H., Deng, W., & Liu, S. Q. (2013). The impact of relief amplitude on population and economic development in Three Gorges Reservoir [in Chinese]. Research of Environmental Sciences in the Yangtze Basin, 22, 686–690. https://yangtzebasin.whlib.ac.cn/EN/abstract/abstract10425.shtml
[109] Liaoning Provincial Bureau of Statistics. (2023). Liaoning statistical yearbook 2023 [in Chinese]. China Statistics Press. https://tjj.ln.gov.cn/tjxx/xxcx/tjnj/otherpages/2023/zk/indexch.htm
[110] Ren, Z., Dong, S., Xiao, W., Sang, M., Zhang, Y., Chen, X., et al. (2025). Cretaceous evolution of the northeastern Asian continent: Insights from the Pikou strike-slip fault zone of the Liaodong Peninsula, NE China. Tectonics, 44, e2024TC008639. https://doi.org/10.1029/2024TC008639
[111] Yang, J., Huang, Y., Luo, L., & Li, Y. (2023). The role of Changbai Mountain in an extreme precipitation event in Liaoning Province, China. Remote Sensing, 15(18), 4381. https://doi.org/10.3390/rs15184381
[112] Zhang, L., Yan, J., Zhao, B., Lin, X., Wang, P., Zhang, C., Yu, Y., & Zhang, P. (2021). The rapidly evolving Fudu Estuary sandbar lagoon landform on the east coast of the Bohai Sea: Recent changes and mechanism. Journal of Marine Science and Engineering, 9(12), 1350. https://doi.org/10.3390/jmse9121350
[113] Chen, S., Mehmood, M. S., Liu, S., & Gao, Y. (2022). Spatial pattern and influencing factors of rural settlements in Qinba Mountains, Shaanxi Province, China. Sustainability, 14(16), 10095. https://doi.org/10.3390/su141610095
[114] Long, F., Liu, J., Zhang, S., Yu, H., & Jiang, H. (2018). Development characteristics and evolution mechanism of homestay agglomeration in Mogan Mountain, China. Sustainability, 10(9), 2964. https://doi.org/10.3390/su10092964
[115] Wu, K., Su, W., Ye, S., Li, W., Cao, Y., & Jia, Z. (2023). Analysis on the geographical pattern and driving force of traditional villages based on GIS and Geodetector: A case study of Guizhou, China. Scientific Reports, 13, 20659. https://doi.org/10.1038/s41598-023-47921-z
[116] Wang, Z., E, S., Du, T., Zhang, L., Islam, M., & Li, J. (2022). Spatial distribution characteristics and influencing mechanism of rural settlements in mountainous areas [in Chinese]. Transactions of the Chinese Society of Agricultural Engineering, 38(10), 277–285. https://doi.org/10.11975/j.issn.1002-6819.2022.10.033
[117] Liu, H.-H., Liu, X.-C., & Zhao, X.-H. (2006). Characteristics of distribution of rural settlements in hilly area, Northeast China [in Chinese]. Journal of Ecology and Rural Environment, 22(1), 15–19. http://www.ere.ac.cn/en/article/id/8882
[118] Liaoning Provincial People’s Government. (2024, June 20). Our province adds 40 new provincial-level traditional villages [in Chinese]. Liaoning Provincial People’s Government Portal. https://www.ln.gov.cn/web/zwgkx/tzgg/2024062009065624264/index.shtml
[119] Sohu History Team. (2021, February 2). Liaoning Great Wall Chronicle (21) | Discovery and history of the Liao-dynasty Great Wall [in Chinese]. Sohu.com. https://www.sohu.com/a/448314176_355221
[120] Lattimore, O. (1962). Inner Asian frontiers of China. Beacon Press.
[121] Barfield, T. J. (1989). The perilous frontier: Nomadic empires and China. Blackwell.

[122] Mote, F. W. (1999). Imperial China 900–1800. Harvard University Press.
[123] Nie, Z., Chen, C., Pan, W., & Dong, T. (2023). Exploring the dynamic cultural driving factors underlying the regional spatial pattern of Chinese traditional villages. Buildings, 13(12), 3068. https://doi.org/10.3390/buildings13123068
[124] Liu, Y., Li, Y., & Yang, Y. (2018). Strategic adjustment of land use policy under the economic transformation. Land Use Policy, 74, 5–14. https://doi.org/10.1016/j.landusepol.2017.04.034
[125] Wang, D., Zhu, Y., Zhao, M., & Lv, Q. (2021). Multi-dimensional hollowing characteristics of traditional villages and its influence mechanism based on the micro-scale: A case study of Dongcun Village in Suzhou, China. Land Use Policy, 101, 105146. https://doi.org/10.1016/j.landusepol.2020.105146
[126] Mao, Q., Xie, L., & Fan, L. (2025). Spatial characteristics and determinants of traditional village distribution in Guizhou Province. PLOS ONE, 20(5), e0324275. https://doi.org/10.1371/journal.pone.0324275
[127] Wang, Z., Zhu, J., & Wu, Z. (2024). Study on the spatial distribution characteristics of traditional villages and their response to the water network system in the lower Yangtze River Basin. Scientific Reports, 14, 22586. https://doi.org/10.1038/s41598-024-74363-y
[128] Chen, X., Xie, W., & Li, H. (2020). The spatial evolution process, characteristics and driving factors of traditional villages from the perspective of the cultural ecosystem: A case study of Chengkan Village. Habitat International, 104, 102250. https://doi.org/10.1016/j.habitatint.2020.102250
[129] Xing, Y., Leng, J., & Zhou, H. (2025). Cognitive preferences for architectural renovation strategies in traditional villages combining subjective evaluation and eye tracking. Frontiers of Architectural Research, 14(4), 1017–1034. https://doi.org/10.1016/j.foar.2024.10.003
[130] Liu, X., Wu, T., Xie, Z., Yuan, W., & Yang, H. (2025). Creating the spatial utilization pattern of traditional villages in the Yellow River by connecting the heritage corridors system with the assessment of tourism potential. Land, 14(7), 1402. https://doi.org/10.3390/land14071402
[131] Li, B., Wang, J., & Jin, Y. (2022). Spatial distribution characteristics of traditional villages and influence factors thereof in hilly and gully areas of northern Shaanxi. Sustainability, 14(22), 15327. https://doi.org/10.3390/su142215327
[132] Chen, L., Zhong, Q., & Li, Z. (2023). Analysis of spatial characteristics and influence mechanism of human settlement suitability in traditional villages based on multi-scale geographically weighted regression model: A case study of Hunan Province. Ecological Indicators, 154, 110828. https://doi.org/10.1016/j.ecolind.2023.110828
[133] Liu, P., Zeng, C., & Liu, R. (2023). Environmental adaptation of traditional Chinese settlement patterns and its landscape gene mapping. Habitat International, 135, 102808. https://doi.org/10.1016/j.habitatint.2023.102808
[134] Zhu, L., Li, Z., Su, H., et al. (2021). Temporal and spatial distribution of ancient sites in Shaanxi Province using geographic information systems (GIS). Heritage Science, 9, 121. https://doi.org/10.1186/s40494-021-00598-x
[135] Liu, L., Liu, F., Zhang, W., & Xu, Z. (2022). Spatial distribution and evolution of ancient settlements from the Neolithic to the Bronze Age in Dalian area, China. Frontiers in Earth Science, 10, 917520. https://doi.org/10.3389/feart.2022.917520

[136] Yu, H. (2024, December 31). The pivotal status of the Muyangcheng city-site and its port from the Warring States to the Han dynasty [in Chinese]. FX361. https://www.fx361.com/page/2024/1231/25566058.shtml
[137] Haijiaoshi. (2023, December 31). Liaodong as an important area of the northern defense system in the Ming dynasty [in Chinese]. Haijiaoshi.com. https://www.haijiaoshi.com/archives/513
[138] Haijiaoshi. (2023, December 31). The consolidation of the southeastern maritime frontier during the Liao dynasty and the cultural integration of Liaodong [in Chinese]. Haijiaoshi.com. https://www.haijiaoshi.com/archives/13539
[139] Ding, Y., Shi, B., Su, G., Li, Q., Meng, J., Jiang, Y., Qin, Y., Dai, L., & Song, S. (2021). Assessing suitability of human settlements in high-altitude area using a comprehensive index method: A case study of Tibet, China. Sustainability, 13(3), 1485. https://doi.org/10.3390/su13031485
[140] Du, P., Huai, H., Wu, X., Wang, H., Liu, W., & Tang, X. (2025). Using XGBoost-SHAP for understanding the ecosystem services trade-off effects and driving mechanisms in ecologically fragile areas. Frontiers in Plant Science, 16, 1552818. https://doi.org/10.3389/fpls.2025.1552818
[141] Batunacun, B., Wieland, R., Lakes, T., & Nendel, C. (2020). Using SHAP to interpret XGBoost predictions of grassland degradation in Xilingol, China. Geoscientific Model Development Preprints. https://doi.org/10.5194/gmd-2020-59
[142] Guidotti, R., Monreale, A., Ruggieri, S., Turini, F., Giannotti, F., & Pedreschi, D. (2019). A survey of methods for explaining black box models. ACM Computing Surveys, 51(5), 1–42. https://doi.org/10.1145/3236009
[143] Gao, S., Hu, Y., & Li, W. (Eds.). (2023). Handbook of geospatial artificial intelligence (1st ed.). CRC Press. https://doi.org/10.1201/9781003308423
[144] Li, X., Sun, W., Zhang, D., Huang, J., Li, D., Ding, N., Xie, Y., & Wang, X. (2021). Evaluating water provision service at the sub-watershed scale by combining supply, demand, and spatial flow. Ecological Indicators, 127, 107745. https://doi.org/10.1016/j.ecolind.2021.107745
[145] Yuan, L., Xu, L., Zhang, Z., et al. (2025). Traditional village clustered protection and utilization methods based on network science. npj Heritage Science, 13, 140. https://doi.org/10.1038/s40494-025-01705-y
[146] Tencent News. (2024, November 12). Historical records of Liaoshi: The construction of the Great Wall at Zhendong estuary during the Liao dynasty [in Chinese]. Tencent News. https://news.qq.com/rain/a/20241112A085UE00