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Quantitative Analysis Village Spatial Morphology Using "SPSS + GIS" Approach: A Case Study of Linxia Hui Autonomous Prefecture

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Abstract: This research comprehensively analyzes the spatial morphology of 177 traditional villages within Linxia Hui Autonomous Prefecture, Gansu Province. The study delineates these characteristics utilizing a combination of five quantitative measured indices—ratio, boundary, saturation, building density, and dispersion coefficients. Leveraging sophisticated analytical techniques facilitated by "SPSS + GIS" integration, the investigation systematically explores the intricate details of village spatial form. Their overarching distribution patterns, and the determinant factors influencing them, provide insights across both granular and broad-scale dimensions. The aim is to establish a robust quantitative data analysis framework, facilitating a precise description of traditional villages' spatial dynamics. The findings categorize the spatial morphology of Linxia's traditional villages into three distinct types: linear multi-point concentration, dense clustering, and irregular dispersion. Common traits among these categories include widespread dispersal, small settlements, and a mix of dwellings. Spatial distribution patterns vary, with dense clusters forming an "olive-shaped" trend in the southeast–northwest direction, while irregularly dispersed villages develop along mountains and valleys, exhibiting multi-core structures. Additionally, linear multi-point concentrated villages display a random, multi-point distribution interspersed with dense clusters. The survival strategies of these commercial, subsistence, and resource-based villages are shaped by a confluence of factors such as elevation, river proximity, ancient road networks, and the interplay between Han Chinese and Tibetan cultural influences. The implications of this study are significant for understanding traditional village dynamics, promoting sustainable development, and refining quantitative methods for rural studies.

Keywords: Linxia Hui Autonomous Prefecture; traditional villages; SPSS; GIS; spatial morphology; village spatial distribution

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1. Introduction

Chinese traditional villages refer to "villages that were formed early, possess rich cultural and natural resources, have certain historical, cultural, scientific, artistic, economic, and social values, and should be protected". This is the definition of traditional villages by the Ministry of Housing and Urban–Rural Development of the People's Republic of China during the national survey of traditional villages in 2012. It is also noted that traditional villages should meet the following criteria: the integrity of traditional architectural features, the preservation of traditional features in location and layout, and the active inheritance of intangible cultural heritage [1]. In alignment with global sustainability efforts, the United Nations ratified "Transforming Our World: The 2030 Agenda for Sustainable Development" in 2015. Within this framework, Sustainable Development Goal 11 (SDG11) is dedicated to the betterment of human settlements, advocating for the development of inclusive, sustainable urban and rural communities, and the conservation of natural and cultural heritage. Reflecting these international aspirations, China's domestic policy has placed significant emphasis on rural development [2]. Since the implementation of the rural revitalization strategy by the 19th National Congress of Communist Party of China, rural development has been consistently prioritized as a significant endeavor. To expedite the modernization of agriculture and rural areas and to contribute to the construction of a beautiful China, the General Office of the Central Committee of the Communist Party of China and the General Office of the State Council issued the 'Five-Year Plan for the Improvement of Rural Human Settlements Environment (2021–2025)' in 2021. This was followed by the 'Rural Construction Action Implementation Plan' in 2022 by the central authorities. These strategies aim to accelerate the modernization of the agricultural sector and the beautification of rural China. The Party's 20th National Congress further reinforced the commitment to comprehensive rural revitalization, prioritizing agricultural and rural progress and enhancing the livability and aesthetic appeal of rural settlements. Exemplifying these ambitions, the "Sustainable Design in China" exhibition at the United Nations Headquarters, which concluded on 13 October 2023, showcased innovative approaches to rural regeneration and minority cultures, reflecting the principles of SDGs. These policies and plans have favorably propelled the continuous enhancement of the rural living environment, bolstering the planning and construction of villages in alignment with the preservation and development of historical and cultural villages and towns as well as traditional characteristic hamlets. This is of significant importance for realizing the sustainable development of China's rural landscapes.

The passage describes the historical significance of Linxia Hui Autonomous Prefecture, which is hereafter referred to as Linxia Prefecture. It served as a critical point along the southern route of the Silk Road, which is a vital town on the Ancient Tang–Tibetan Road, and an important location for the exchange of tea and horses, earning it the nickname the "Dry Port" of western China. The region, situated in the transitional area between Han and Tibetan cultural spheres, has seen frequent ethnic interactions throughout history. From Shang and Zhou dynasties to the Yuan dynasty, various ethnic groups such as Xirong, Qiang, Di, Han, Tuguhun, and Xianbei migrated and settled in this area. By the Qing Dynasty, a complex pattern of cohabitation emerged among multiple ethnic groups, including Han, Hui, Dongxiang, Sala, Bao'an, and Tu communities [3]. As a material carrier that both adapts to complex and diverse natural geographical environments and represents the interaction of multiple ethnic groups and the changes in social culture, traditional villages of Linxia Prefecture have continuously evolved and developed, forming the distribution characteristics of "large heterogeneity and small settlements". Currently, the urbanization process in Linxia Prefecture lags behind compared to most regions in China, and due to the many mountains and valleys within the prefecture, most traditional villages still follow the natural development patterns, maintaining traditional agricultural production methods, and the lives of the villagers remain simple. The complete preservation of the "vernacular authenticity" of traditional villages in Linxia Prefecture allows for a more direct representation of the material culture, intangible culture, and natural culture. These traditional villages serve as witnesses to historical culture and unique spatial memories, and they are a cultural heritage that promotes harmony between people and nature.

Scholarly research on traditional villages has evolved from initially focusing on describing and verifying the characteristics of these villages to encompassing a broader range of topics such as sustainability [4–8], conservation and development [9–11], residential environment [12,13], tourism development [14–16], and spatial morphology and distribution [17–19]. There is now a greater emphasis on studying the overall human habitat environment and the comprehensive value of traditional villages. In terms of research methodology, there has been a continuous expansion of depth and breadth by incorporating interdisciplinary approaches, including geography, ecology, anthropology, history, and ethnology, in addition to the original fields of architecture and sociology. The unique perspectives, methods, and conclusions from these different disciplines provide a more comprehensive understanding of traditional villages compared to a single-discipline approach, which is advantageous for ensuring the scientific and efficient protection of traditional villages. The investigative scope typically spans communities, administrative regions, and broader geographic areas [20–25]. At present, traditional villages are in the process of urbanization, and both the villagers' living conditions and village spatial forms are being significantly affected. Within the opportunities for sustainable development presented by village restructuring and spatial practices, sharp contradictions and issues such as homogenization and alienation have arisen in village construction. Domestic research has reached a consensus on respecting the indigenous essence of traditional villages. Concurrently, influenced by the "quantitative revolution", research has evolved toward quantification, modeling, and systematization. The study of village spatial forms has transitioned from an investigation of static spatial patterns at the village scale to the dynamic forecasting of village system morphologies at a regional scale [26]. In Western research on the quantitative analysis of village forms, the predominant methodologies include numerical analysis, Statistical Package for Social Sciences (SPSS), Geographic Information Systems (GIS), and spatial syntax analysis. Studies are largely focused on analyzing residents' health conditions [27,28], the development of village economies [29,30], and the research on village spatial forms and distribution [31–36]. In the past decade, Chinese scholars have emphasized the use of quantitative analysis methods to investigate the spatial form characteristics, classification, spatial distribution, and causation of traditional villages. Drawing from a compendium of field studies encompassing 320 villages, Sun et al. [37] delineated three distinct spatial configurations of traditional Hakka villages in Meizhou, China, through a nuanced layering and categorization of spatial form elements. Zhou et al. [22] integrated GIS and cluster analysis on 161 traditional village landscapes in Ganjiang River Basin, which facilitated a classification into nine distinct types. This stratification has enabled a deep dive into the geographical distribution and evolution patterns of these types, underpinning targeted strategies for development and preservation. Based on a deeper exploration of regional cultural and geographical differences, Sun [37] further explored the spatial forms of villages. To systematically grasp the regularity of village landscape, Zhou [22] not only scientifically classified village landscape types but also explored the characteristics of their spatial distribution within the region. Pu [38], employing the morphological index method, delved into the two-dimensional general morphology of traditional villages, yielding a refined and quantifiable approach for morphological comparisons, classifications, and analyses. In an illustrative case of 15 traditional villages in southern Anhui, Ye et al. [39] applied a synthesis of morphological index and cluster analysis to scientifically demarcate the spatial morphology of these settlements. The outcome is a precise articulation of the villages' spatial structure, identifying four spatial archetypes: 'regimented and concentrated', 'banded and intensive', 'intensive with a radial tendency', and 'radially dispersed'. Pu [38] and Ye [39] both conducted quantitative analyses of spatial morphology indexes at a smaller and more precise level. They adopted common morphological indices such as aspect ratio [21,40], boundary coefficient [40], and building density [41] to accurately describe the spatial morphology and its characteristics of villages. They further apply clustering statistical analysis methods [39] to scientifically classify the spatial morphology of the village, enabling an accurate grasp of the regular characteristics of the spatial morphology. Most of the aforementioned research studies are concentrated in eastern China and use GIS, clustering, and fractal-based quantitative descriptive indicators to quantify the shape characteristics and distribution of components. They explored the development and change in settlement forms under various influencing factors. The research provided a scientific basis for the planning, redevelopment, and restoration decisions concerning traditional villages. It has become a common model for analyzing settlement spatial form. This research approach is highly relevant to the exploration of traditional villages in Linxia Prefecture.

However, given the region's greater complexity, it is essential to identify traditional village morphological indicators that are more suitable for changing geographic areas and types. Therefore, this study attempts to innovate by combining precise descriptions of traditional village spatial morphology using microstructural quantitative indicators with SPSS + GIS analysis [42]. The proposed approach not only accurately describes the spatial form of traditional villages and grasps its regularity but also allows for a macro-level exploration of regional cultural and geographical differences.

Research on the spatial characteristics of traditional villages in Linxia Prefecture, Gansu Province, has primarily been localized at the provincial level with a focus on individual village studies. Liu et al. [43] point out in "Traditional Villages in Gansu" that Dadun Village in Dahejia Town, Jishishan County, and the "four longitudinal and four latitudinal" street layout of Bafang Shisanhang in Muchang Village, the suburban town of Linxia City, are notable examples of local village structure. Lin [44] categorized villages like these as 'mountain ladder villages', based on their terrain and landforms, while Liu [45] classified them by ethnic settlement patterns into multi-ethnic and minority villages. Yao's quantitative case study [46] on Yaoshui Village revealed a ribbon-like spatial form. The research conducted on traditional villages in Linxia revealed the geographical diversity and different characteristics of their spatial patterns. Simultaneously, these studies underscore the importance of comprehending village spatial morphology in capturing the unique attributes of traditional villages within Linxia Prefecture. However, as tangible spatial representations of ethnic production, living, and social transformation, how can one precisely describe the spatial forms of Linxia Prefecture's villages? Linxia is situated in the transitional zone between Han Chinese and Tibetan cultures and was subjected to the influences and interaction of these two dominant cultural traditions over an extended period. Additionally, it is located at the intersection of the Qinghai–Tibet Plateau and Loess Plateau with distinct vertical climatic and altitude variations. Given the constraints imposed by these limited living conditions, this paper addresses three fundamental scientific questions: (1) How do we accurately describe the spatial morphology of villages in Linxia Prefecture? (2) How do we systematically classify traditional villages and subsequently distinguish and compare their distinctive characteristics? (3) What are the spatial distribution patterns of traditional village types in Linxia Prefecture, and what factors influence these patterns? The revelation of these problems fills the gap in quantifying the spatial forms of traditional villages in Linxia Prefecture, enabling a more comprehensive understanding of the development trends and underlying mechanisms of these villages. Furthermore, this study can be extended to the Longxi ethnic corridor region, which is closely related to the natural and cultural history of Linxia. Such an extension would bear significant implications for promoting the sustainable development of traditional villages in both regions and fostering new sustainable development of human–environment interactions.

The implementation of rural revitalization strategies and the process of rural construction in Linxia Prefecture have raised significant challenges. These include the homogenization of many villages, cultural disruption, and the destruction of human settlements, often neglecting the local rural context. Such issues stem from overlooking the inherent principles of sustainable development and failing to respect the originality of village areas. For this purpose, this research focuses on the spatial form of traditional villages in Linxia Prefecture. It employs a data analysis method based on quantitative morphological indices to provide a more accurate data-driven description of the spatial morphology of Linxia's traditional villages. The study utilizes a systematic clustering methodology to grasp the typologies and differentiation characteristics of traditional village spatial forms. Furthermore, GIS spatial data analysis methods are used to examine the spatial distribution patterns and causes of village types within the regional scope of Linxia Prefecture. The research methods used in this paper for the quantification of traditional village spatial morphology, planning based on village spatial laws, and guidance for the spatial practices and sustainable development of traditional villages hold significant importance.

2. Summary of Cases

2.1. Study Area

Linxia Prefecture, positioned in the southwest of Gansu Province, China, lies within 34°–36° N latitude and 102°–103° E longitude, marking the transitional zone between the Loess Plateau and the Tibetan Plateau (Figure 1). The northeast of this area features a semi-arid climate and consists of gently sloping terrains, while the southwest is characterized by mountainous landforms and a colder, humid climate. The central valley plateau has a moderate climate but is prone to erosion, highlighting the area's ecological vulnerability [47].

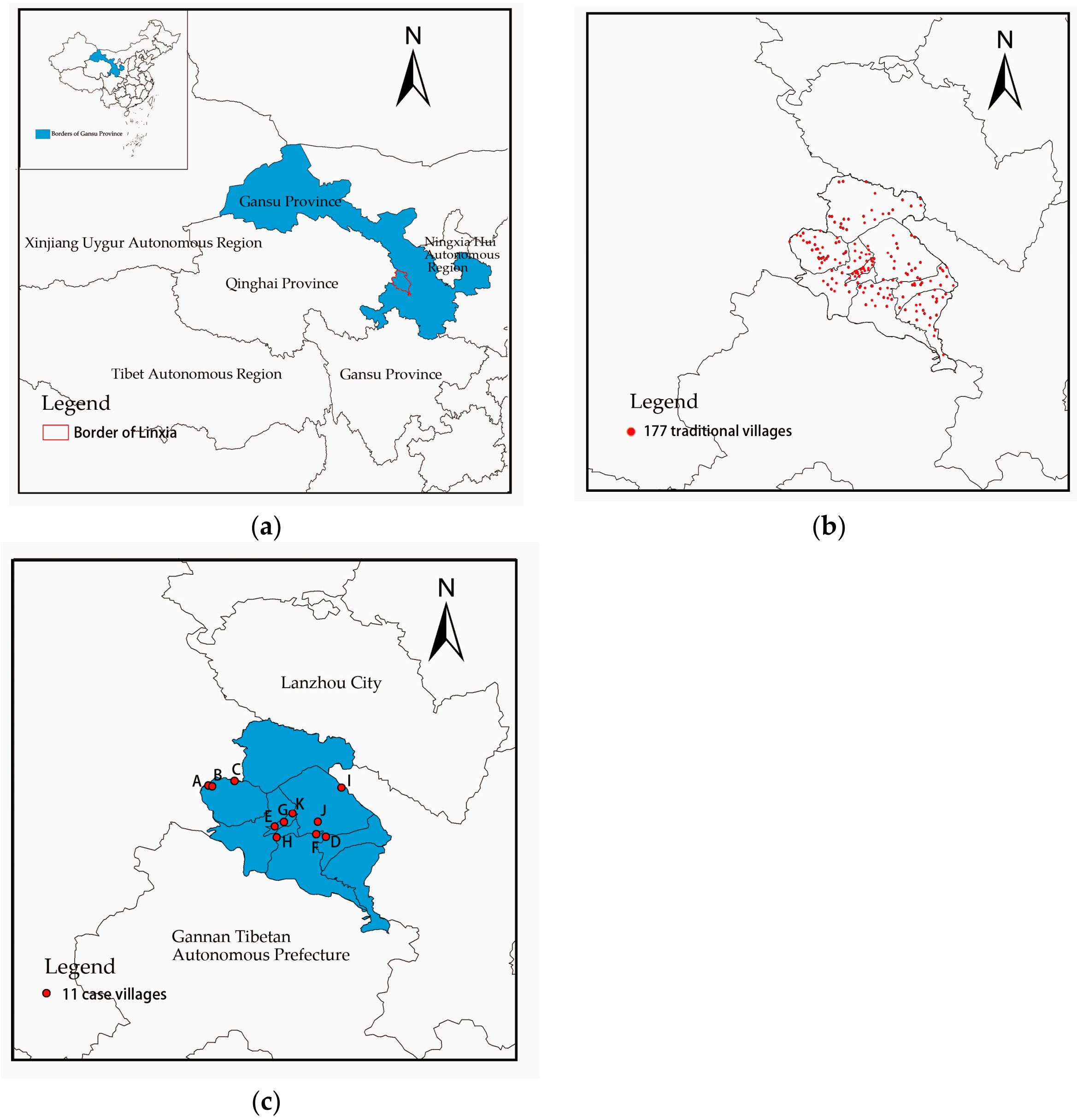


Figure 1. Spatial analysis of the study area. (**a**) Location of Linxia Prefecture; (**b**) Distribution of 177 traditional villages within the region; (**c**) Spatial distribution map of 11 quantified village cases. Developed by the authors.

2.2. Data Sources

The research utilizes data derived from two main sources. (1) Sample selection: Criteria were inclusion in the Directory of Traditional Chinese Villages, characterization as a minority ethnic village or multi-ethnic settlement, status as a national key village for rural tourism, historical and cultural significance, and classification as a beautiful leisure village in China. Liu Jingyun's categorization of minority ethnic and multi-ethnic villages, along with comprehensive field survey data and GIS mapping data conducted by the Gansu Provincial Department of Construction, resulted in the selection of 177 traditional villages samples encompassing both natural and administrative villages. Out of these, 11 typical traditional villages were further chosen for precise quantitative analysis of their spatial morphology. These 11 villages represent the main ethnic groups of Linxia Prefecture, including Han, Hui, Dongxiang, Bao'an, and Tu ethnicities, and they are as follows: Zheqiao, Dadun, Ganhetan, San'erjia, Alimatu, Dahejia, Hanzeling, Yaoshui, Baijia, Muchang, and Yaowan Villages (Table 1). (2) Technical process: The study utilizes Google Earth Pro to define and collect morphological data on village layouts and employs T20 Tianzheng Architecture V6.0 software for consistent scaling. Latitude and longitude coordinates for village locations were batch processed using Map Location tools. Elevation data with 30 m resolution for Linxia Prefecture were acquired from the National Geospatial Data Cloud. Administrative boundary data were sourced from Data V. Geo Atlas platform (http://datav.aliyun.com/portal/school/atlas/area_selector accessed on 20 July 2023). The spatial distribution patterns of the 177 sample villages were then analyzed using ArcGIS 10.7 software.

Table 1. Sample village information table.

Number	Village Name	Topographic Features	Ethnic Information	Aerial Photo of Village Appearance
A	Dadun Village [1]	Mid-elevations platform	Bao'an nationality	
B	Ganhetan Village [1]	Mid-elevations platform	Bao'an nationality	
C	Sanerjia Village [4]	Mid-elevations foothills and valleys	Tu nationality	
D	Alimatu Village [4]	Mountain valley area	Dongxiang nationality	
E	Baijia Village [1]	Valley plain area	Han, Hui ethnic groups	
F	Dahejia Village [4]	High-altitude platform	Dongxiang, Han nationality	

Table 1. *Cont.*

Number	Village Name	Topographic Features	Ethnic Information	Aerial Photo of Village Appearance
G	Muchang Village [2]	Mountain valley	Hui nationality	
H	Yaowan Village [1]	Mid-mountain area	Han and Hui ethnic groups	
I	Yaoshui Village [2]	High-altitude foothills and valleys	Dongxiang nationality	
J	Hanzeling Village [1]	Mountainous region	Dongxiang nationality	
K	Zheqiao Village [3]	River region	Dongxiang, Han, and Hui ethnic groups	

[1] Chinese Ethnic Minority Characteristic Villages; [2] List of Traditional Chinese Villages; [3] National Key Rural Tourism Villages; [4] Administrative Villages. Source: Prepared by the authors.

2.3. Village Spatial Environment

To investigate how traditional villages integrate with their surrounding farmlands, mountainous terrains, and water systems, in-depth field studies were carried out on 11 representative villages. Using drone technology and Google Earth Pro, satellite imagery was captured to support this analysis (Figure 2). In Linxia Prefecture, agriculture forms the backbone of local economies, which influences the spatial arrangement of villages. Linxia Prefecture primarily relies on agriculture as its main mode of production. Due to the relationship between the villages and the surrounding farmland, the villages in Linxia Prefecture exhibit a spatial characteristic where farmland surrounds the settlements on multiple sides. This pattern allows for minimal constraints on the multi-directional development of the villages, providing them with the potential to expand outward, as seen in Dadun and Alimatu Villages. The topography of Linxia Prefecture is predominantly mountainous and hilly. Based on the relationship between the villages and the mountains, the villages can be categorized into patterns such as being bordered by mountains on two sides, three sides, or surrounded by mountains on all sides, as exemplified by San'erjia Village. Water, being an essential resource for human settlements, also plays a critical role in the placement of these villages. Since all rivers in Linxia are part of the Yellow River Basin, encompassing 43 major and minor tributaries, the villages typically align themselves alongside these watercourses. This parallel positioning to rivers indicates that villages not only favor locations near water for practical reasons but also tend to expand along the rivers' flow, highlighting a strip pattern of growth and development.

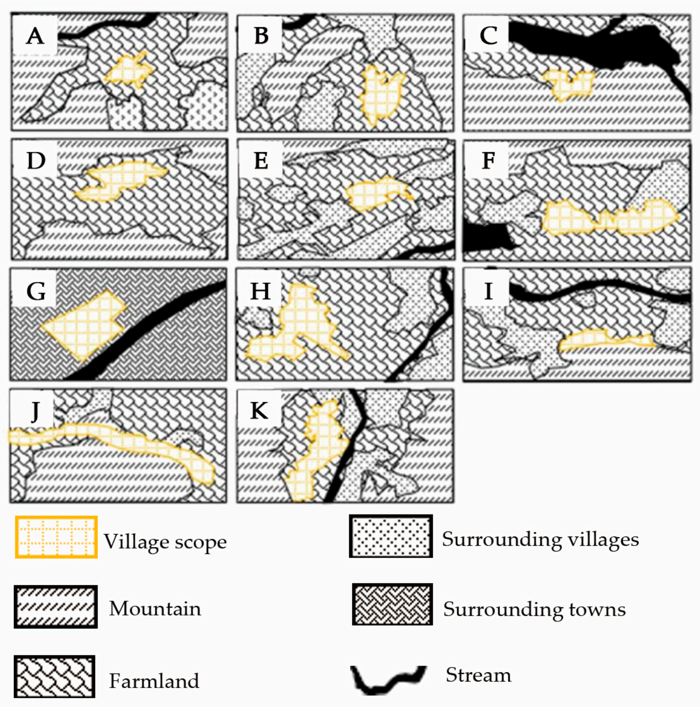


Figure 2. Basic overview analysis of villages. A—Dadun Village; B—Ganhetan Village; C—Sanerjia Village; D—Alimatu Village; E—Baijia Village; F—Dahejia Village; G—Muchang Village; H—Yaowan Village; I—Yaoshui Village; J—Hanzeling Village; K—Zheqiao Village. Developed by the authors.

An analysis of the road networks in relation to the village layouts in Linxia Prefecture reveals a variety of interactions (Figure 3). Villages like Muchang exhibit a dense, closely knit community structure encapsulated within a quadrilateral network of roads. These villages typically have a compact area with higher population density, a relatively stable economy, frequent transportation activity, and are often centrally located, exemplifying classic village planning characteristics. On the other hand, settlements such as Alimatu Village and Dahejia Village have a more open spatial arrangement with road networks that traverse or penetrate the area on one side. This suggests a looser integration with the surrounding road infrastructure. In summary, villages in Linxia Prefecture are predominantly distributed across river valleys and plains, which are areas that are relatively flat and proximate to water sources, and they are influenced significantly by the topographical features of the region. The natural environment plays a pivotal role in shaping the growth of these villages. While the villages are influenced and somewhat restricted by the landform features, they also align themselves according to the available directions for expansion that the landscape affords them.

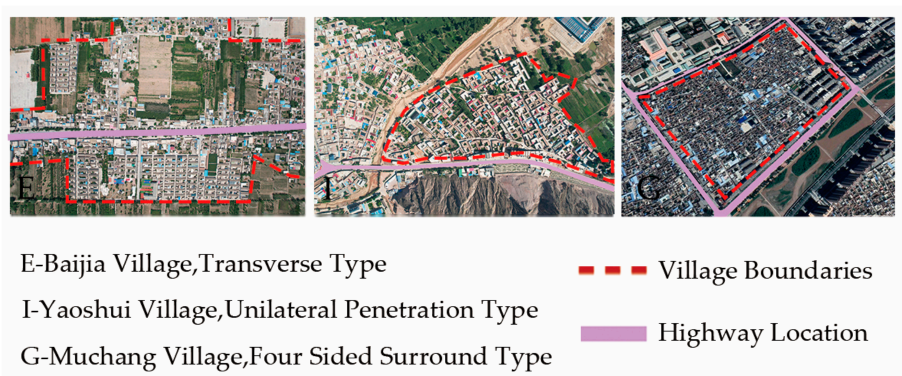


Figure 3. Road network and village spatial location map. Developed by the authors.

3. Research Approach and Methodology

3.1. Conceptual Framework

This study explores the underlying dynamics and principles that are crucial for the rural revitalization of Linxia Prefecture's traditional villages. The research focuses on understanding the intrinsic mechanisms of internal development, prospects for sustainable growth, and the evolving interplay between humans and the land within a multifaceted environmental, social, and cultural context. To achieve this, the study employs field investigations, in-depth interviews, and geographic mapping to analyze the spatial distribution, physical features, and determinants of the region's traditional villages (Figure 4).

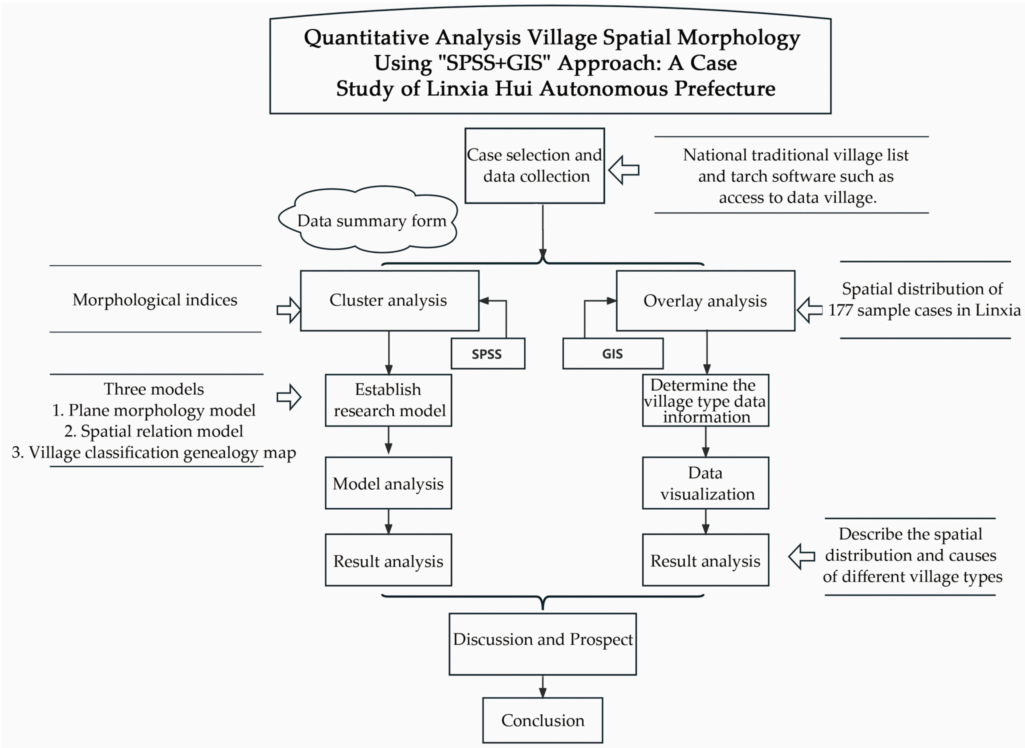


Figure 4. Research thinking analysis diagram. Developed by the authors.

3.2. Research Methodology

The research synthesizes data to formulate various spatial morphological indicators, including the aspect ratio, boundary, saturation, building density, and dispersion coefficients, utilizing CAD and Excel for support. These metrics are subsequently computed and examined to elucidate the spatial morphology and distribution patterns of traditional villages in Linxia Prefecture. The study employs a multi-method approach:

1. A field survey is conducted to gather sample data directly from the source.
2. A morphology index framework is developed to quantify the spatial morphology of traditional villages.
3. Descriptive statistical analysis is performed using IBM SPSS Statistics 26 software, which is complemented by cluster analysis to classify village typologies based on Euclidean distance methods.
4. ArcGIS 10.7 software aids in a layered analysis to investigate the spatial distribution and influencing factors of different traditional village patterns.

3.3. Development and Application of Spatial Morphology Indicators

This section details the use of quantitative metrics to delineate and examine the planar and structural attributes of village spatial morphology. Initially, in terms of index extraction methods, as village boundaries are two-dimensional closed figures formed by different objective physical elements, the academic community has employed the following quantitative metrics for research. Li et al. [48] have noted that the scale of the village boundary directly determines both the size and the spatial morphological traits of the boundary. After fully considering the safe distance for human activity of village space and the accuracy of form quantification, a boundary scale of 90 m has been ultimately established for conducting research on village spatial morphology. Duan [40] suggested that the aspect ratio coefficient and the boundary coefficient, when compared, can reveal patterns in spatial morphology. Li et al. [21] proposed using the aspect ratio coefficient and shape index for a quantitative analysis of a village's overall spatial form, which is complemented by building density and spatial sub-dimensional values for a detailed internal analysis. This dual approach allows for a more nuanced and precise study of village spatial morphology. In essence, a multifaceted examination of various quantitative indices provides a more methodical and dependable approach to assessing the spatial morphology of traditional villages. Drawing on fractal theory [48], the village plans within Linxia Prefecture were simplified, and their geometric characteristics were extracted for quantitative analysis. The study selects five key indicators to quantify spatial morphology: the aspect ratio, boundary coefficient, saturation coefficient, building density, and dispersion coefficient (Table 2).

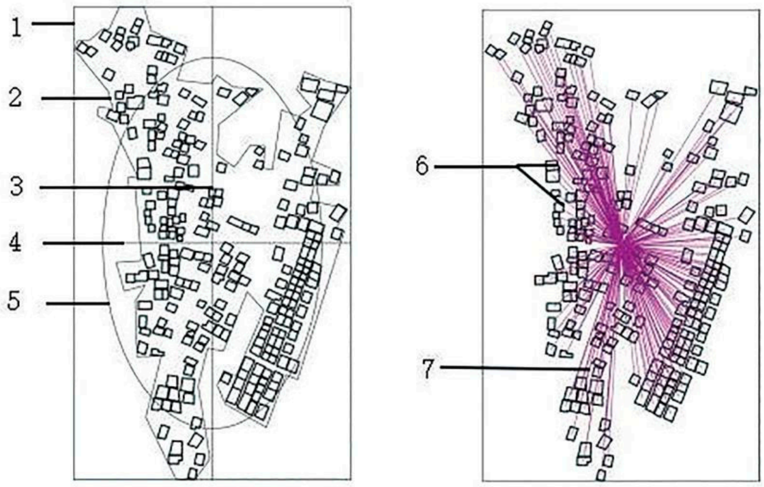
Table 2. Quantitative indicators and algorithms for analyzing the spatial morphology of villages.

Quantitative Index	Algorithm Equation	Independent Variable	Remark
Ratio coefficient of length to width	$\nu = \frac{A}{B}$	A is the length of the long axis of the village area; B is the short axis length of the village area.	The coefficient of length to width ratio, boundary coefficient, and saturation collectively delineate the planar geometry and boundary complexity of village layouts.
Boundary coefficient	$\gamma = \frac{C}{C_0}$	C is the length of the long axis of the village area; C_0 is the circumference of the ellipse.	
Saturation coefficient	$\alpha = \frac{S}{S_0}$	S is the village area; S_0 is the external rectangular area.	
Building density	$\mu = \frac{\sum S_n}{S}$	S_n is the building area; n is the number of dwellings; S is the village area.	Building density and dispersion coefficient are key indicators that define the spatial patterns of village settlements.
Dispersion coefficient	$\theta = \frac{\sqrt{\sum_1^n \left(d_n - \overline{d}\right)^2 / n}}{\overline{d}}$	d_n is the distance between the building center of mass and the village center; $\overline{d}$ is the average distance.	

Source: Prepared by the authors.

Within the scope of the village territory, quantitative indicators are established to delineate the spatial morphology of the village. This involves examining the construction standards for indicators such as the first-level proportion coefficients, boundary coefficients, and saturation coefficients, as well as dual-level indicators like building density and dispersion coefficients (Figure 5). Visual analysis of these quantitative indicators facilitates the study of traditional village spatial morphology at two levels: the planar layout and the residential structure.

At the primary level, the village's layout is quantified using three specific coefficients. The aspect ratio coefficient v quantifies the proportional dimensions of the village, reflecting its foundational geometry by comparing the lengths of its longest and shortest axes. In graph morphology studies, the extent to which a shape occupies a given rectangle is commonly assessed by its area coverage ratio [49]. This concept is encapsulated by the saturation coefficient α, which evaluates the village's spatial expansion and developmental trajectory within a defined rectangular space. The boundary coefficient γ, informed by the work of Sugimoto et al. [50], translates the complexity of the village's periphery. It compares the perimeters of the village boundary with that of an equivalent ellipse, providing a measure of the boundary's regularity or irregularity. These coefficients together offer a comprehensive and nuanced examination of the traditional villages' spatial essence, which is vital for understanding their historical development and guiding future conservation or expansion initiatives.



1-Equal aspect ratio external rectangle
2-Village boundary
3-Village plane long axis
4-Village plane short axis
5-Equal aspect ratio ellipse
6-Village building plan
7-Distance from building center of mass to village center

Figure 5. Index construction standard. Developed by the authors.

The secondary layer of spatial analysis addresses the distribution and arrangement of buildings within the village. Building density μ, a vital metric, indicates the proportion of the village area occupied by buildings, reflecting the intensity of land use and the level of development concentration within the village. The dispersion coefficient is defined as the ratio of the standard deviation of the distances from the centroid of the village to the centroids of the dwellings to the average distance, which is denoted by θ. This coefficient sheds light on the spatial dispersion of dwellings and offers insight into the village's residential layout.

Accompanied by Figure 6, these indicators were meticulously applied to assess 11 traditional villages, providing comprehensive data that encapsulate both the village's planar configuration and the intricacies of its residential architecture, as demonstrated in Table 3.

Table 3. Detailed data table of village spatial form indicators.

Data	Boundary Perimeter/m	External Rectangular Area/m^2	Village Area/m^2	Major Radius of Ellipse/m	Minor Radius of Ellipse/m	Elliptic Perimeter/m
A	4809.16	120	47.7	428	356	2468.2
B	6851.65	136.8	66.3	597	353	3033.94
C	3993.34	62.32	25.3	295	273	1785.09
D	1850.92	19	8.3	186	142	1035.08
E	3008.56	39.4	26.2	387	215	1930.03
F	3684.21	49.8	22.2	441	160	1992.77
G	2840.27	69.7	33.7	331	324	2057.8
H	2412.96	19.8	5.3	131	129	816.82
I	2738.74	41.6	14.7	349	134	1593.53
J	5239.89	124.5	18	398	143	1795.39
K	4245.6	95.8	54.2	465	372	2637.63

Source: Prepared by the authors.

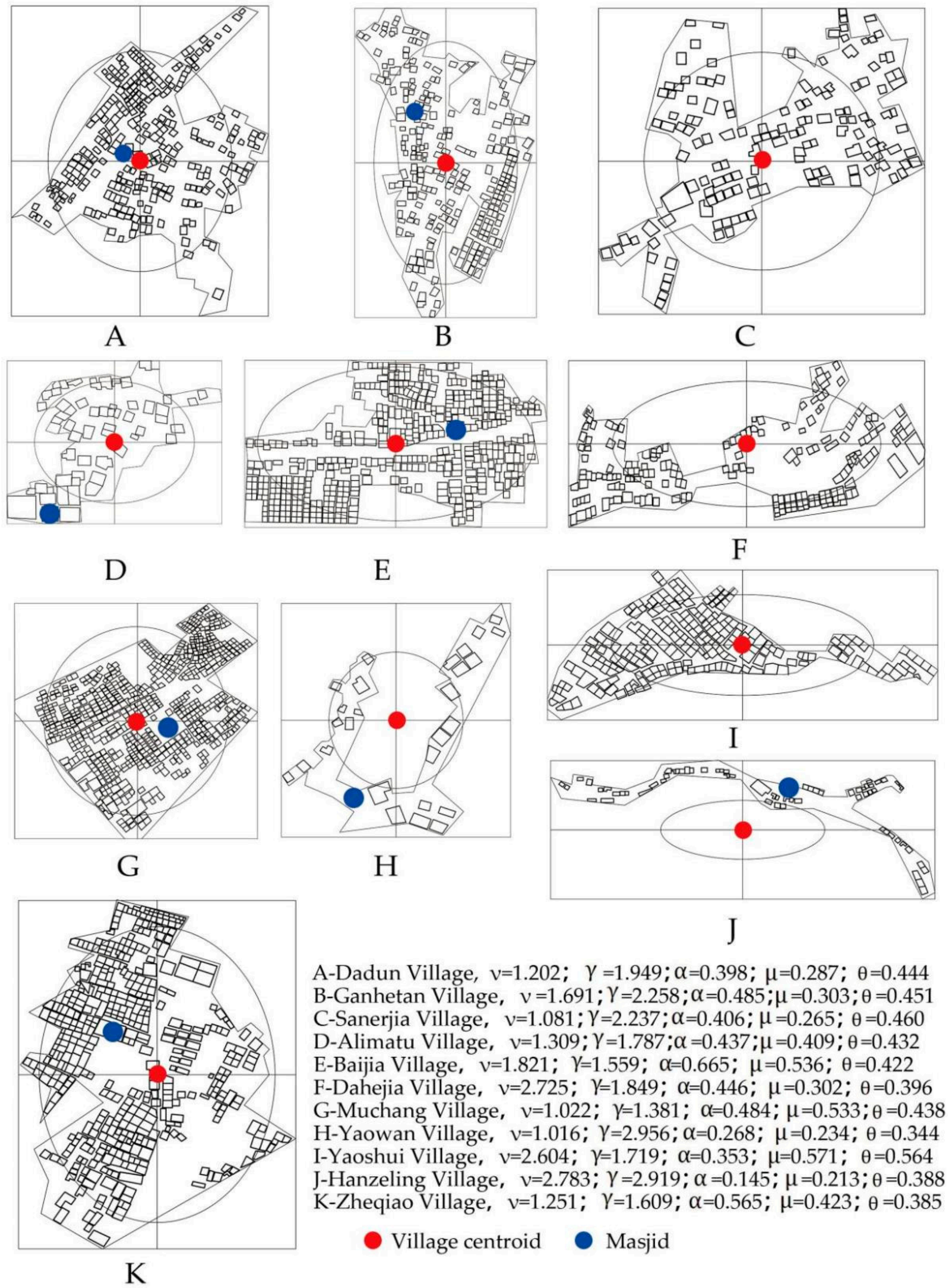


Figure 6. Spatial plan legend and quantitative data analysis of villages. Developed by the authors.

4. Case Study Overview

4.1. Analysis of Quantitative Indicators of Village Plan Form

Section 4.1 delves into the quantitative assessment of traditional village layouts using first-level indicators: aspect ratio, boundary, and saturation coefficients, as depicted in Figure 7. These indicators are pivotal in deciphering the proportional attributes and spatial configurations of the villages. The aspect ratio coefficients for the sampled villages in Linxia Prefecture range from 1.01 to 2.78, with an average value of 1.68 (Table 4). This suggests that the planar morphology of the villages is relatively square and uniform with a general tendency toward a strip-like developmental shape. Specifically, five villages identified as E, I, F, B, and J exceed the average coefficient, implying a pronounced directional expansion in their development, as inferred from their non-linear growth patterns observable in Figure 7. Conversely, villages G, K, D, A, C, and H register aspect ratios at or below the mean, suggesting a more quadrilateral planning form with less apparent directional growth.

G-Muchang Village, in particular, with a coefficient of 1.022, exemplifies a nearly perfect square layout. Historical planning practices, such as the Bafang Shisanhang town street design and the 'living around the temple' concept, have significantly influenced these patterns, fostering a grid-like street network within the 'eight squares' community [51].

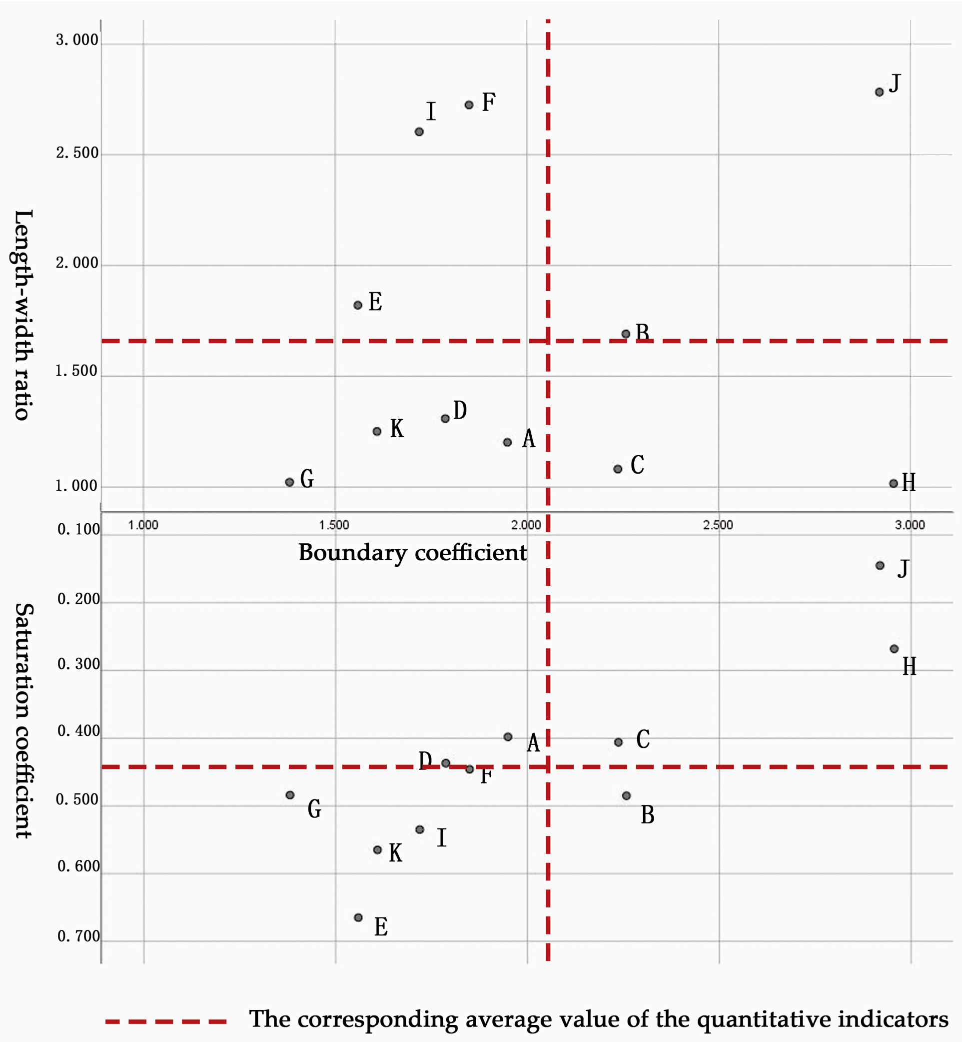


Figure 7. Quantitative analysis model of village plane form. Developed by the authors.

Table 4. Average value of quantitative index of plane form.

	Length–Width Ratio	Boundary Coefficient	Saturation Coefficient
Average value	1.68227	2.02027	0.43945
Number of cases	11	11	11
Standard deviation	0.704640	0.525068	0.140999

Source: Prepared by the authors.

In the context of Linxia Prefecture's traditional villages, the range of boundary coefficients is quite broad, from 1.38 to 2.95, with an average value of 2.02. These coefficients provide insights into the intricacies of the villages' perimeters. A higher boundary coefficient indicates a more complex village boundary, while a lower value suggests simplicity and regularity. G-Muchang Village stands out with the lowest boundary coefficient, which is indicative of its regular and smooth boundary. The village's location in the expansive river valley of Linxia City facilitates its development in multiple directions. Moreover, the village's adherence to the traditional grid street plan contributes to its orderly and less complex boundary. On the other hand, villages J and H exhibit the highest boundary coefficients, at 2.91 and 2.95, respectively. These values reflect the fragmented nature of their development, which is constrained by mountainous terrain. The surrounding mountains, with their steep and varied elevations, impose a high degree of complexity on the boundaries of these villages.

The saturation coefficient in the traditional villages of Linxia Prefecture provides insights into the relationship between village compactness and border complexity. As depicted in Figure 7, there is an inverse relationship between the border coefficient and the saturation coefficient. Villages with complex boundaries tend to have lower saturation coefficients, signifying less compactness or integration. Saturation coefficients among the examined villages vary from 0.14 to 0.66. Villages J and H, situated in the mountainous Dongxiang Autonomous County, show lower saturation coefficients, highlighting the challenging terrain that restricts land use and leads to scattered and uneven residential patterns [52]. In contrast, E-Baijia Village boasts the highest saturation coefficient, reflecting a well-integrated village layout. Its advantageous location in Fuhan Town, with flat terrain, efficient transportation, and surrounded by farmland, has fostered a regular and dense arrangement of homes. The reason for this is that in the process of urbanization and modernization, this village has taken substantial steps to fully implement the directives and requirements of the poverty alleviation campaign. It has focused on the theme of "party building + governance" to establish a modern rural governance structure, persistently advancing initiatives to improve the living environment and sanitation. This includes the renovation and clearance of dilapidated auxiliary buildings, resulting in the creation of a favorable living environment. The combination of favorable geographical conditions and policy support has contributed to the establishment of a highly saturated village layout. Therefore, it can be inferred that in the complex geographic circumstances of Linxia Prefecture, urbanization and modernization is crucial to enhancing the rationality of traditional village spatial planning, enhancing the living environment, and raising land utilization efficiency.

4.2. Analysis of Quantitative Indicators of Spatial Relationship between Houses and Villages

The second-level quantitative analysis of Linxia Prefecture's traditional villages focuses on the building density and dispersion coefficient, which illuminate the clustering intensity of individual buildings and their spatial distribution within villages, as shown in Figure 8. Building density directly correlates with how densely houses are packed in the village: a higher coefficient indicates more tightly packed residences, while a lower one suggests a more spread-out arrangement. From the sampled villages, building density ranged from 0.21 to 0.57, averaging at 0.37 (Table 5). Villages K, E, D, G, and I exceeded this average, signaling that their residential areas take up a significant portion of the village space, leaving less room for open spaces. Specifically, villages G, E, and I have the highest densities, pointing to a compact use of space with limited potential for further spatial development. Conversely, villages J and H have the lowest building density coefficients, indicating through Figure 6 that the base area of the residential buildings is small and the spacing between them is relatively large, presenting a sparse relationship. This pattern suggests that these villages have ample room for growth and development with a considerable amount of space available for future development and utilization.

Table 5. Average value of quantitative index of spatial structure.

	Building Density	**Dispersion Coefficient**
Average value	0.37055	0.42945
Number of cases	11	11
Standard deviation	0.130010	0.056536

Source: Prepared by the authors.

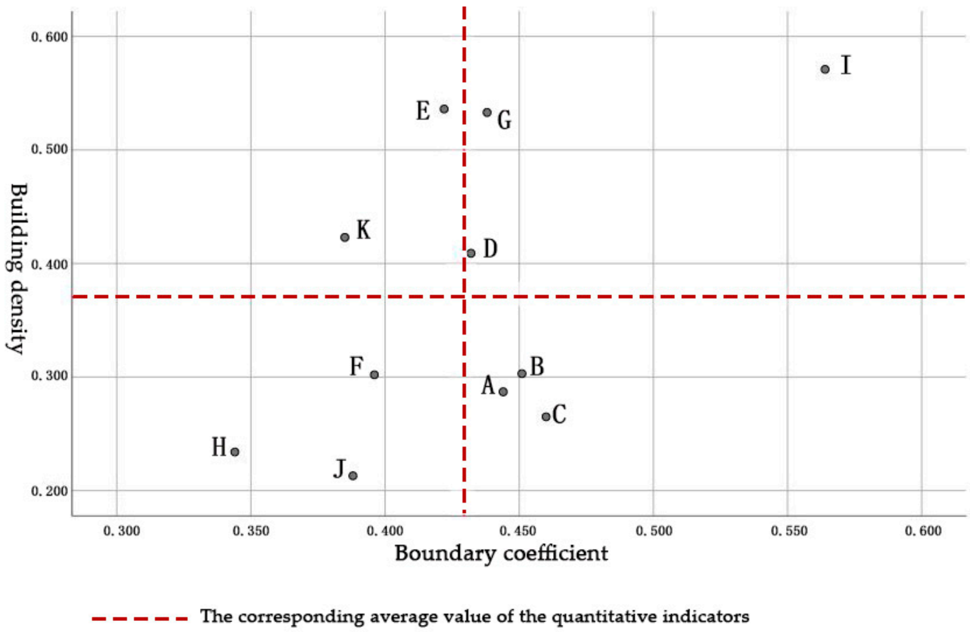


Figure 8. Quantitative analysis model of village spatial structure form. Developed by the authors.

In the sample of traditional villages, the dispersion coefficient, which measures the evenness of the residential buildings' distribution, ranges from 0.34 to 0.56, with an average of 0.42 (Figure 8). A higher dispersion coefficient indicates a more irregular and dispersed layout of housing units. Figure 8 shows that 82% of the village samples have dispersion coefficient values mainly concentrated between 0.37 and 0.46. This suggests that the distribution of buildings in the sample villages is relatively uniform and centralized with a clear centripetal orientation toward the village's central area. However, there are still individual differences, such as in villages H and I. Village H has the lowest dispersion coefficient, displaying the typical characteristic of a small village area and a smaller number of buildings. On the other hand, village I exhibits the highest dispersion coefficient, signaling a more spread out and irregular distribution of residences, which is likely influenced by geographical constraints that dictate a strip-like village formation and limit how the village can expand.

4.3. Analysis of Village Spatial Morphology Types Based on Cluster Analysis

To analyze the spatial morphology of traditional villages in Linxia Prefecture, this study utilized quantitative indicators at two levels to enable a precise classification through cluster analysis. The methodology employed statistical techniques to objectively sort the villages into distinct categories based on their spatial configurations. Cluster analysis, an exploratory data analysis tool, was applied when clear categorization criteria were lacking. This technique organizes data by calculating the distances and similarities among various factors. Villages with smaller squared Euclidean distances between them, which indicates a high degree of similarity, are grouped together into the same cluster, suggesting they share more common spatial characteristics [53]. The classification incorporated detailed quantitative assessments such as the aspect ratio coefficient, boundary coefficient, saturation coefficient, building density, and dispersion coefficient. These metrics provided a multifaceted view of the villages' layouts from the overarching plan form to the dispersion of residential buildings relative to the village center. Using IBM SPSS Statistics 26 software to calculate the squared Euclidean distance, the study generated a comprehensive representation of traditional village spatial morphology. The analysis, illustrated in Figure 9, captured both the macro-scale village morphology and the micro-scale distribution of residential units, effectively characterizing the unique planar and spatial attributes of the traditional villages in the prefecture.

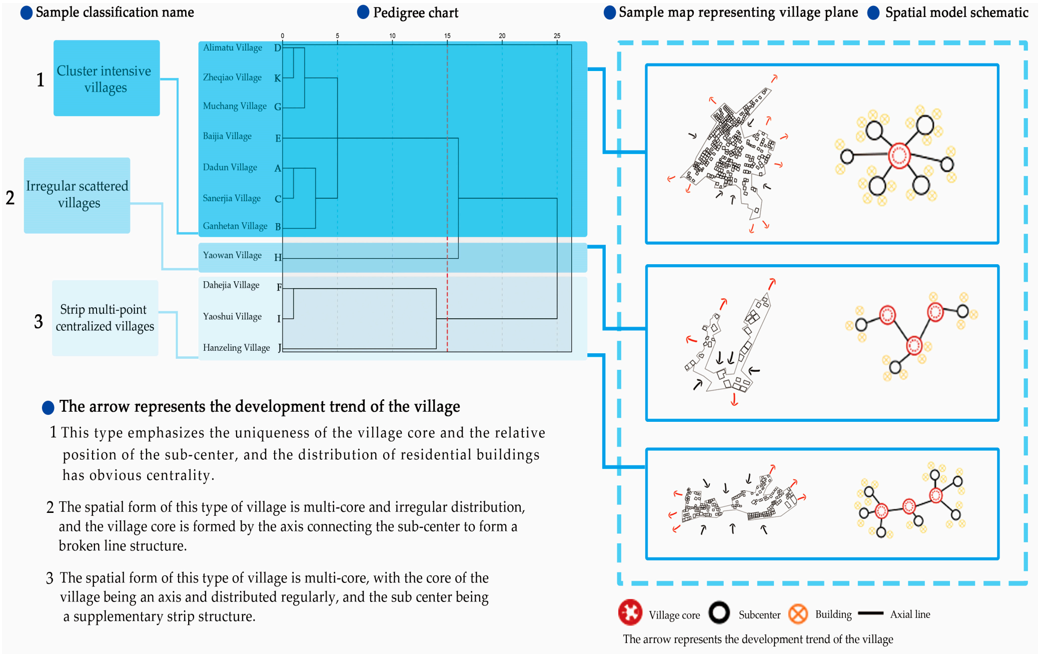


Figure 9. Cluster analysis genealogy and comparative analysis of village types. Developed by the authors.

The Euclidean distance squared equation can be expressed as follows:

$$\mathrm{SEUCLID}(x, y) = \sum_{i=1}^{k} (x_i - y_i)2 \quad (1)$$

Utilizing cluster analysis with a set distance coefficient d = 15, the eleven sampled traditional villages in Linxia Prefecture can be accurately categorized into three distinct morphological clusters, as depicted in Figure 9.

4.3.1. Cluster Intensity

In the classification of cluster-intensive villages, seven villages—D, K, G, E, A, C, and B—have been identified. Villages K and G serve as prime examples within this category, which are characterized by their minimal boundary complexity and heightened building density alongside a reduced aspect ratio and increased saturation coefficients, distinguishing them as quintessential cluster-intensive settlements. These villages are fairly square and typically situated in the relatively flat areas of mountains and river valleys, thus being less influenced by the terrain. This configuration is influenced by the organized, grid-like design characteristic of Linxia's Bafang Shisanhang. "Bafang Shisanhang" in Linxia is a traditional Hui community with a history of several hundred years. It features a unique spatial layout characterized by courtyard-style residences and a network of intersecting streets and alleys organized around eight mosques. The residents in Bafang prioritize the protection of their privacy when building residential houses. The labyrinth layout of streets and alleys provides local residents with a sense of seclusion in their private lives. This reflects the self-organizing growth process that Bafang shisanhang, in the process of community growth, has developed as a protective mechanism for the local residents, ensuring their privacy and well-being. According to human settlement theory, cluster-intensive villages display a pronounced centripetal structure in their spatial organization, which is less disturbed by external environmental factors. The spatial distribution in Linxia Prefecture's cluster-intensive villages reveals a pattern where the village core uniformly extends to peripheral residential clusters, prompting redevelopment around village sub-centers. Consequently, the arrangement of residential buildings follows a clear hierarchical order: from the village core to the village sub-center and then to the individual residential buildings. Figure 6 indicates that the centroid of cluster-intensive villages aligns with the village core. The mosque, central to the village's spiritual life, especially under the influence of Islamic religious beliefs, is typically situated at the heart of the village or at its sub-center. This placement further reinforces the centripetal characteristic of the village's spatial morphology. The distinctive features of the spatial morphology of cluster-intensive villages highlight not only the central role of the village core but also demonstrate how residential units incrementally radiate outward from both the village core and the sub-centers. This emphasizes the orderly expansion of the village's spatial footprint.

4.3.2. Irregular Scatter

Village H is characterized as an irregularly scattered type with the maximum boundary coefficient and smaller values for both building density and dispersion coefficients, representing its typical features. These villages are typically situated in low mountain gullies and ridges with a high degree of fragmentation in the spatial morphology and boundaries. The development of the village form is constrained by natural conditions such as the mountains, and the village and residential buildings are laid out along the contours of the mountains and rivers. The spatial pattern of these villages is shaped by numerous natural elements, resulting in a formation of multiple village clusters. These tend to spread outward from the village core toward the surrounding topographical features like mountains, rivers, and valleys. The layout either follows a two-tier distribution—village core to sub-center to residential buildings or directly from the village core to the residential buildings. The spatial morphology of irregularly scattered villages highlights the presence of multiple village cores, the relatively modest size of the village, and the uneven spread of residential buildings. The village core forms a central axis with the sub-center, creating a zigzag line structure that often aligns with the natural patterns of the landscape. As depicted in Figure 6, there is a considerable distance between the village's center of mass and its core, indicating a weaker centripetal nature in the village's spatial arrangement. Consequently, the overall spatial pattern of the village appears more open and dispersed.

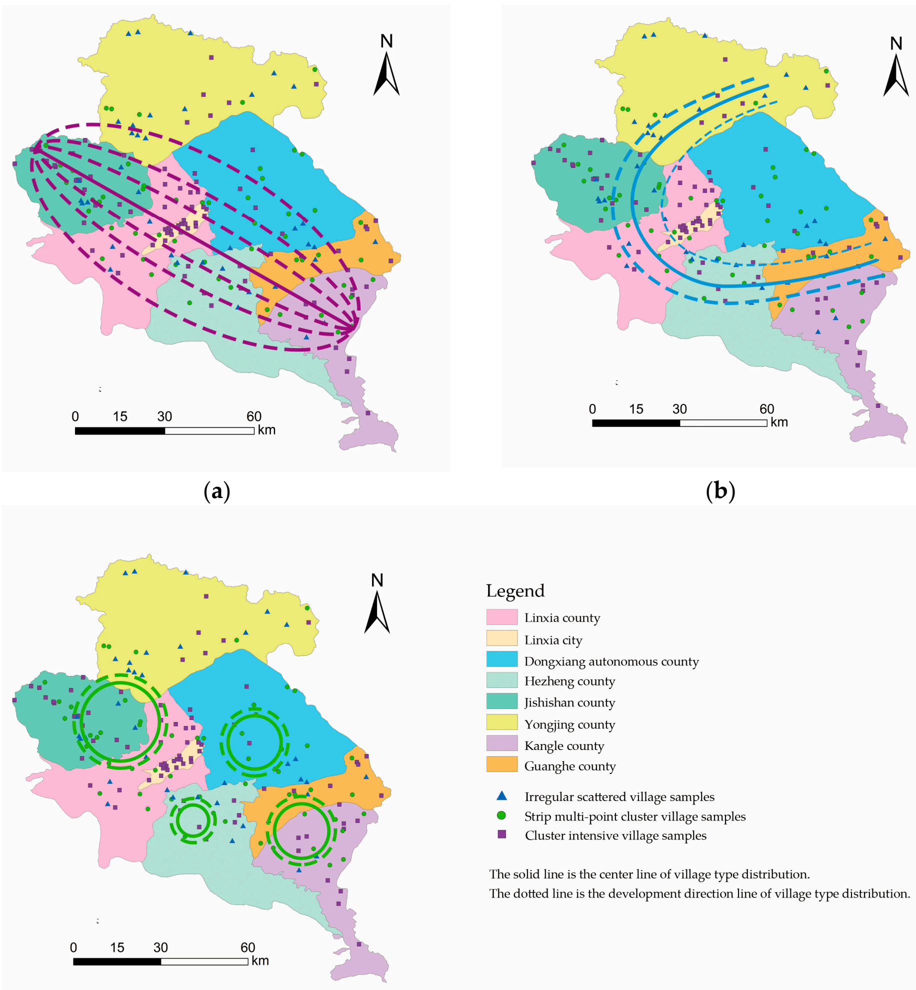
4.3.3. Striped Multi-Point Centralization

The "striped multi-point centralized" category includes villages F, J, and I, with F and J being prime examples. These villages are typically characterized by elongated shapes, indicating large aspect ratios. The strip-clustered type of village spatial morphology is mainly characterized by a non-linear distribution with residential buildings grouped more distinctly within certain zones. From a sociological perspective, group living is a ubiquitous human arrangement [54]. In these villages, the significant longitudinal or latitudinal extension leads to weaker connectivity between residents at opposite ends of the village, gradually leading to a spatial morphology where a single village consists of multiple clusters. The spatial organization of these villages extends along natural and man-made linear features like roads and rivers, manifesting in a layered pattern that progresses from the village core to sub-centers and then to individual residential structures. The spatial structure of these striped, multi-point centralized villages shows a regular arrangement of homes along a main axis defined by the village core with sub-centers forming a secondary, striped pattern. As indicated in Figure 6, the proximity between the village's center of mass and its core suggests a degree of inward focus or centripetal structure. Residential buildings are uniformly aligned along this central axis, influenced by the village's multiple focal points, resulting in a striped spatial morphology.

Overall, the spatial morphology of the cluster-intensive, irregularly scattered, and striped multi-point centralized villages is deeply influenced by the natural environment, and there are no significant ethnic variations in village layout. All three types exhibit a hierarchical structure with a village core, sub-centers, and residential buildings. The spatial organization is also shaped by cultural practices, as the mosque often occupies a central or sub-central position in the village, reinforcing the centripetal force within the village structure.

4.4. Characteristics of Spatial Distribution of Traditional Village Types

Utilizing ArcGIS 10.7 for overlay analysis, the study identified 177 traditional villages and categorized their spatial morphologies into three major types, allowing for a visualization of their distribution patterns within Linxia. The traditional villages in Linxia Prefecture generally exhibit a distribution characteristic of "divided cores with imbalance" and a spatial distribution of "two concentrated areas with scattered points". The "divided cores with imbalance" distribution characteristic is reflected in the primary distribution of Linxia's traditional villages in two core areas in the central and eastern parts of the prefecture with an imbalanced density—densely populated in the center and sparser in the eastern region. This distribution pattern consists of three distinct geographic arrangements. First, there is an olive-shaped southeast–northwest trending area: Here, the densely grouped villages are predominantly found, clustering mainly within Linxia County, Linxia City, Hezheng County, and Guanghe County, as shown in Figure 10a. Second, there is a U-shaped region opening to the east: This area mainly hosts the irregularly dispersed villages, focusing on Yongjing County, Jishishan Bao'an, Dongxiang, and Salar Autonomous County, Linxia County, Hezheng County, and Kangle County, depicted in Figure 10b. Lastly, there is multi-scattered point distribution: This pattern reflects the random and flexible spatial distribution of the striped multi-point centralized villages, which appear alongside the clustered intensive villages within the geographic space of Linxia State, as illustrated in Figure 10c.



(**a**) (**b**) (**c**)

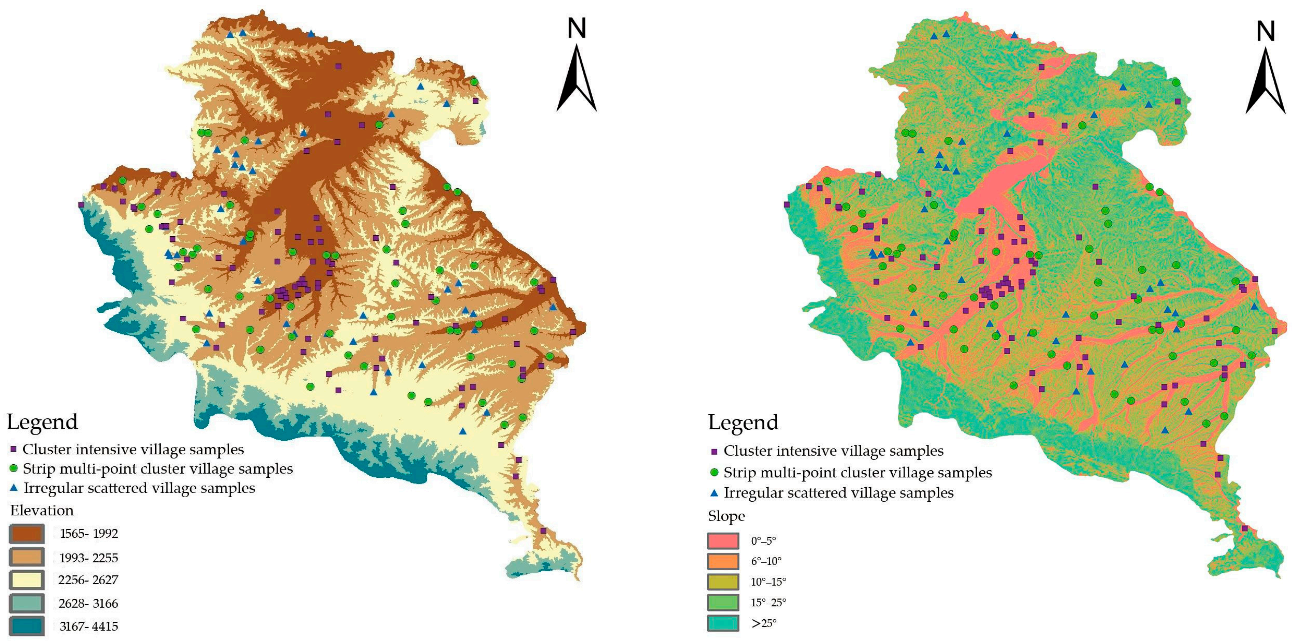
Figure 10. Spatial distribution map of village types. (**a**) Cluster intensive village spatial distribution; (**b**) irregular scattered village spatial distribution; (**c**) strip multi-point cluster village spatial distribution. Developed by the authors.

4.5. Elements Influencing Traditional Village Spatial Distribution

To discern the determinants influencing the typological divergence and developmental dynamics of traditional villages within Linxia Prefecture, this study conducts a GIS overlay analysis. This meticulous analysis overlays the spatial morphology of three distinct village types onto a diverse set of factors, including topographical elevation, slope, fluvial networks, land use patterns, transportation infrastructure, historical routes, and ethnic demographics.

4.5.1. Elevation and Slope

The geographic landscape of Linxia Prefecture is notably diverse; it is characterized by valleys crisscrossing and hills undulating with elevations ranging from 1563 to 4585 m above sea level. Positioned at the transitional juncture between the Qinghai–Tibetan Plateau and the Loess Plateau, the prefecture's topography descends from higher elevations in the southwest to lower in the northeast. The three types of traditional villages within Linxia Prefecture are generally distributed at lower altitude areas conducive to human habitation, particularly in the relatively central and eastern valley and river terrace regions. These traditional villages exhibit spatial morphologies characterized by densely distributed residential buildings, less complex village boundaries, and smaller length-to-width ratios. In the more mountainous areas, the irregularly dispersed village types typically occupy elevations of 2256 m to 2627 m. Conversely, in the river valley terrains, the cluster-intensive and striped multi-point centralized village types are commonly found at altitudes ranging from 1565 to 2255 m. Although less frequently, traditional villages can also be found at higher elevations between 2628 and 4415 m, demonstrating the diversity in settlement patterns across varying topographies within the prefecture (Figure 11a).



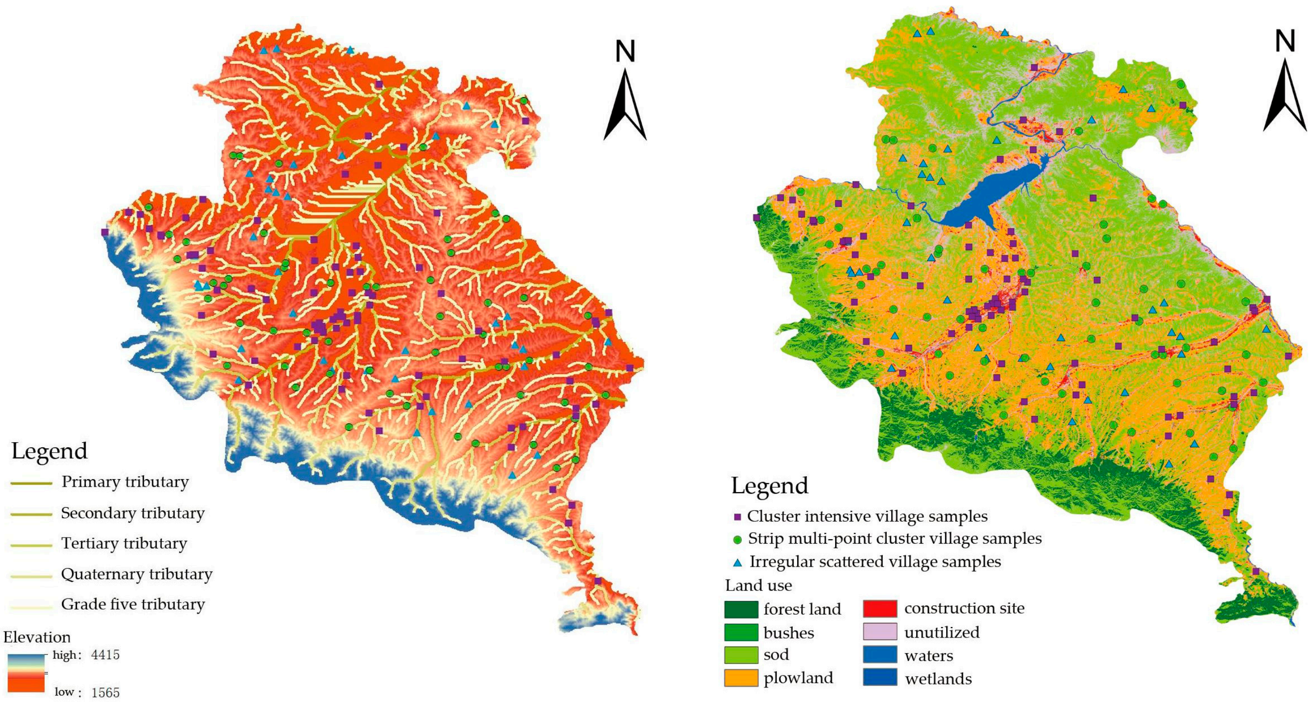
(**a**) (**b**)

Figure 11. Elevation and slope analysis maps. (**a**) Sample village and elevation overlay analysis map; (**b**) sample villages and slope overlay analysis map. Developed by the authors.

Through the overlay analysis of traditional village samples in Linxia Prefecture with slope data (Figure 11b), the traditional villages are clustered within a slope range of 0°–25°. Circular and densely clustered traditional villages are mainly distributed on slopes ranging from 0° to 5°, while linear and closely clustered traditional villages are more commonly found on slopes of 6°–15°. Irregularly dispersed traditional villages tend to be concentrated on slopes between 16° and 25°. A minimal number of traditional villages are distributed on slopes exceeding 25°, highlighting the impact of slope on the spatial characteristics of traditional villages as well as the distribution of village types in Linxia Prefecture. The analysis of elevation and slope confirming the spatial distribution of traditional village types further substantiates the profound influence of the region's topographical features on the formation of traditional village spatial patterns in Linxia Prefecture.

4.5.2. Fluvial Networks and Land Use

The rivers within Linxia Prefecture are all tributaries of the Yellow River system with the region hosting a substantial network of rivers as evidenced by the presence of streams with flows at or exceeding 5000 m^3 (Figure 12a). However, the fertile river valley regions, rich in water resources, constitute only a tenth of the prefecture's land area, which is otherwise characterized by significant soil erosion in the upper Yellow River basin. The rest of the land is dominated by hills and mountains [55]. Consequently, the siting of villages is often strategically determined by the proximity to water sources to fulfill the requirements for drinking, irrigation, and production. An analysis of the central plains depicted in Figure 12a indicates that the cluster-intensive villages are predominantly situated along the primary and secondary tributaries of the Yellow River, including Daxia and Taohe Rivers. The striped multi-point centralized villages tend to be located in the transitional zones of the terrain along the secondary and tertiary tributaries. In contrast, the irregularly dispersed villages mainly settle within the basins and valleys served by the third and fourth-order tributaries. The role of rivers in Linxia Prefecture is integral to the development and distribution of traditional village types. The alignment of villages along these watercourses generates a higher aspect ratio coefficient, influencing the spatial morphology of the villages and constricting their potential development patterns.



(**a**) (**b**)

Figure 12. Fluvial networks and land use analysis maps. (**a**) Sample village and river overlay analysis map; (**b**) sample village and land use overlay analysis map. Developed by the authors.

In Linxia Prefecture, the land is primarily categorized into eight usage types, including forest land, shrubs, grassland, farmland, and construction land (Figure 12b). Construction land constitutes a small proportion, with grassland and farmland jointly occupying around 80% of the total land area. This distribution signifies a relatively low degree of urbanization in the region. Traditional villages are concentrated mainly within the area of grassland and farmland where traditional agricultural practices remain prevalent. An examination of traditional village spatial patterns reveals that the cluster-intensive villages are mainly distributed within cultivated land areas, while linear and closely clustered villages are also prevalent within these cultivated regions. Conversely irregular and dispersed villages tend to be distributed in transition zones between farmland and grassland. The type of farmland has an important influence on the site selection and spatial distribution of traditional villages in Linxia Prefecture.

4.5.3. Transportation

Linxia Prefecture's rugged terrain, characterized by numerous gullies and ravines, has historically shaped its transportation infrastructure to be relatively undeveloped. A comparative analysis of vector data on historical roadways and modern national, provincial, and county highways reveals about a 60% overlap in their routes [56]. Consequently, the buffer zones around these highways have been categorized into three ranges: less than 1000 m, 1000–2000 m, and 2000–3000 m, as presented in Figure 13. Overlaying these transportation buffer zones onto the map of sampled villages shows that a substantial number of cluster-intensive villages fall within the national and provincial highway buffer zones, as shown in Figure 13a,b. This pattern correlates with the zones' positioning within the state's lower elevation and flatter landscapes, which are more easily accessible via these major roadways. Historically, exposure to external influences and threats prompted villagers to cluster together for security and stability. This, in turn, gave rise to a concentrated arrangement of residential buildings and the emergence of densely packed and orderly villages. Moreover, over 90% of the identified village types are situated within the buffer zone of county roads, as indicated in Figure 13c. This finding suggests that traditional villages are commonly established along significant roadways, and the trajectories of road development seem to have a substantial influence on the spatial distribution of these villages. Consequently, this influence impacts their spatial form and aspect ratio coefficients.

4.5.4. Trade Routes and Ethnic Integration

In Linxia Prefecture, the historical overlay of stagecoaches and ancient trade routes with the sampled villages unveils the relationship between village types and these historical pathways. Villages exhibiting a clustered pattern align with an "olive-shaped" spatial distribution that extends from southeast to northwest, which is in congruence with the historical Tang–Tibetan Road. Linxia City, historically known as Hezhou, was a station along Silk Road as early as Han and Tang dynasties and a thoroughfare of the Ancient Tang–Tibetan Road. The Song dynasty government established a customs post here for tea and horse trade as well as silk transactions. At the beginning of the Ming dynasty, the government set up a "Tea-Horse Division" in Hezhou and other places to facilitate commodity circulation activities. Consequently, Linxia Prefecture historically formed an important commercial node and ancient route that entered the state through Kangle County and went directly up to Jishishan Autonomous County into Tibet. This route has served as a long-standing bridge for communication between Tibetan and Han Chinese areas [57]. The traditional villages that evolved along this historic thoroughfare naturally adapted to the ebbs and flows of trade. Communities, particularly those of Hui ethnicity, have historically emphasized privacy, influencing the gradual formation of a physical layout that supports both commercial activities and secluded living spaces. Presently, Linxia Prefecture stands as a paradigm of multi-ethnic integration. The settlement patterns of "large mixed residence and small clustered residence" reflect the peaceful coalescence and progressive development of diverse ethnic groups under a canopy of shared religious convictions. According to Figure 14b, it is observed that there is no significant correlation between traditional village types and their spatial distribution with ethnicity. This indicates that the ethnic mosaic of Linxia Prefecture has evolved as a complex yet integrated system independent of the spatial arrangements of its traditional villages.

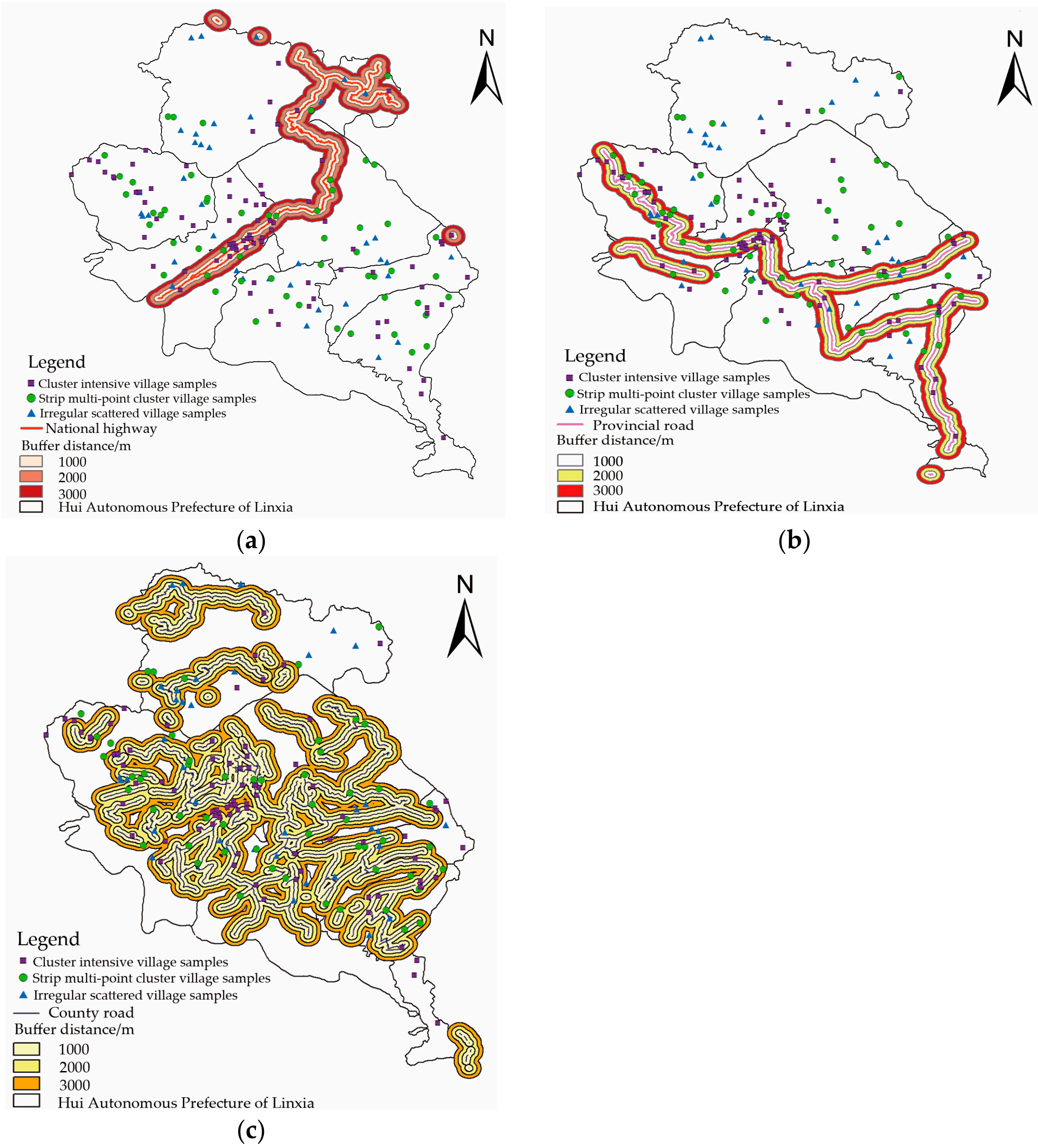
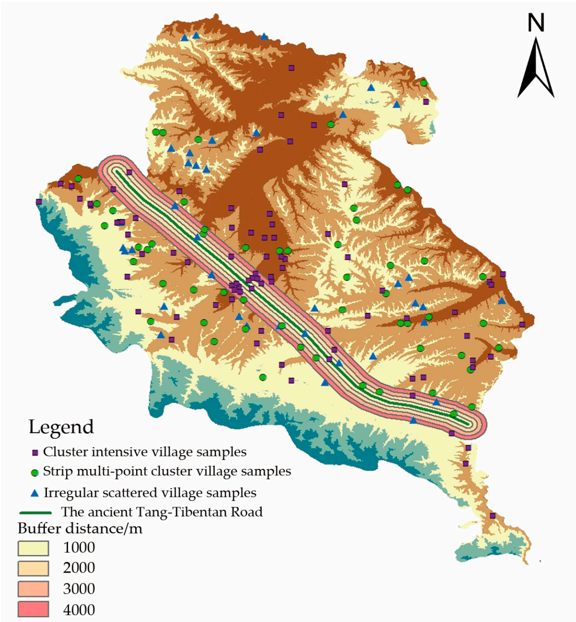


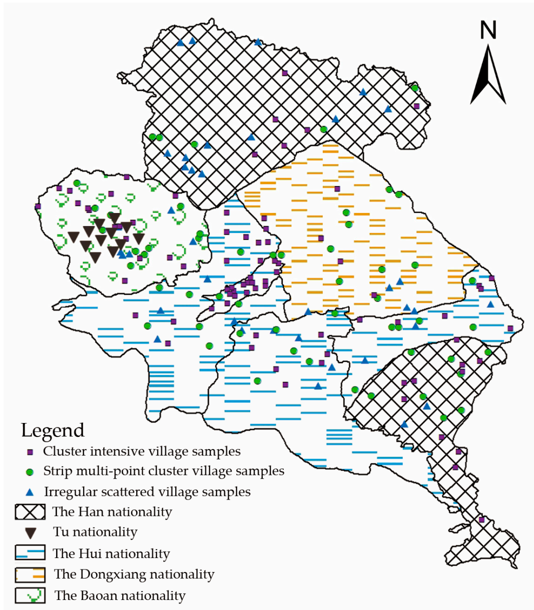
Figure 13. Traffic analysis map. (**a**) Superimposed map of village type and national road; (**b**) superimposed map of village type and provincial road; (**c**) superimposed map of village type and county road. Developed by the authors.

4.6. Spatial Patterns of Villages

At the extremes of Linxia Prefecture reside Han Chinese and Tibetan ethnic groups, the former in the east representing the agrarian culture, and the latter in the west embodying the plateau pastoral culture [58]. Thus, under the overarching influence of Han-Tibetan cultural dynamics, the traditional villages of Linxia Prefecture have evolved into three types of village forms and spatial distribution characteristics. These transformations have been influenced by a combination of factors including altitude, fluvial systems, and transportation. This further reveals that the clustered, irregular dispersed, and strip-clustered village types correspond to commercial, subsistence, and resource-based survival models, respectively.



(**a**)



(**b**)

Figure 14. Ancient roads, ethnic analysis map. (**a**) Superimposed map of village type and ancient road; (**b**) superimposed map of village type and nationality. Developed by the authors.

The commercial archetype of traditional villages in Linxia Prefecture has its roots in Han and Tang dynasties with Hezhou emerging as a pivotal trade center leveraging the ancient Tang–Tibetan routes for exchanging commodities like tea and horses. Throughout the Tang era and later solidified during the Ming dynasty's national consolidation, Linxia evolved into a crucial conduit for trade, culturally and economically bridging Han interior with Tibetan peripheries. During the Qing dynasty, the number of trading firms increased, leading to heightened competition. Consequently, Hui merchants shifted their focus toward Gannan and Qinghai Tibetan regions [57]. Linxia Prefecture's longstanding role as a commercial nexus has been sustained by a legacy of trade and commerce, which is now manifested along historic and modern economic corridors as well as tourist routes. Influences on this survival mode extend beyond mere trade, encompassing historic population movements, cultural interchanges, and the contemporary dynamics of urban–rural progression. The traditional villages following this survival model display a strong sense of order, which gradually diminishes from the center of Linxia City toward both ends.

The subsistence mode of traditional villages is primarily observed among the smaller ethnic minorities residing within the ethnic corridors of Linxia Prefecture. These groups, which are interspersed among the larger populations of Han, Tibetan, and Hui peoples, are often found in narrow strips of land nestled between the foothills and mountains. Such areas offer a mosaic of secluded spaces and natural mountainous pathways, providing both refuge and strategic routes for transportation. Villages adopting this survival mode utilize the terrain to facilitate movement and to serve as bastions during times of conflict, leveraging these geographical advantages for protection and the preservation of their cultural practices. The topography thus not only enables these communities to thrive in isolation but also fortifies their cultural resilience and continuity [59].

Resource-based traditional villages in the autonomous prefecture attract inhabitants due to the region's bounty of natural and commercial resources. Communities that settle around these resources not only enjoy the direct benefits they offer but also the secondary economic and social cohesion that arises from them. These villages serve as pivotal points for the movement of diverse ethnic groups and are strategically located in the transitional zone between the dominant cultural realms of Han Chinese and Tibetans. Consequently, these communities often choose to establish themselves in areas of political stability and economic vitality to capitalize on the available resources. With the advantages of a flatter terrain, better access to transport and waterways in the central and eastern areas, and proximity to historical trade routes, these villages are well-positioned to maximize resource utilization.

5. Discussion

5.1. Effectiveness of "SPSS + GIS" Research Approach

The "SPSS + GIS" research methodology proves valuable for analyzing the traditional villages of Linxia Prefecture, given the region's diverse topography, ethnic mix, historical layers, and social fabric. This approach prioritizes the accurate interpretation of spatial patterns, distinguishing features, and distribution, as well as the factors driving these aspects. It blends both detailed and broad quantitative analysis techniques. Firstly, it allows for the detailed quantification and description of the villages' spatial morphology by establishing a two-tier morphological index for plane shapes and spatial structures. Secondly, the integration of SPSS cluster analysis aids in sorting these indicators to showcase both the similarity within groups and diversity between them, capturing the complex interplay of spatial patterns. Building upon the results of this study, GIS technology can be utilized to explore the spatial distribution characteristics of villages' spatial morphological variations and to investigate the influencing factors and causes. This comprehensive inquiry into the spatial dynamics and influencing factors of traditional villages in Linxia reveals the patterns of geographic distribution and clustering properties of various attributes. Employing the "SPSS + GIS" technique facilitates the discernment of the fundamental forces shaping the spatial configuration of the villages and offers insights into their future development trajectories and environmental adaptability, focusing on the internal drivers of development.

5.1.1. "SPSS + GIS" Research Methodology SWOT Analysis

The integrated "SPSS + GIS" methodological framework is distinguished by several advantages in spatial morphology research. Contemporary focus in this field has shifted from merely describing physical forms to probing the interplay between spatial forms and external influences. The framework employs a morphological index to articulate the spatial configuration of villages. It then pairs this index with cluster analysis to enable precise classifications, distinguishing between highly homogeneous categories within the same group and the significant heterogeneity between different groups. This process unveils intricate patterns and varying compositions within village structures. Through SPSS system, similarities and complex, non-linear differences in spatial patterns are more accurately identified, going beyond mere shapes to include geographic, humanitarian, and other relational variables. This insight helps to dissect the nuances of spatial distribution and communal clustering traits. The Arc GIS platform is used to delve into the spatial distribution variations of village characteristics, facilitating a deeper understanding of group aggregations and the dynamics of spatial morphology. This research approach surpasses the quantitative stage of spatial form analysis and marries the "cause" with the "shape". It lays a foundation for dynamic simulations of spatial forms and informs future spatial practice and reconstruction efforts. The method underscores the significance of accurately interpreting spatial laws to guide the spatial practice of villages. The cultural value orientations of the villages are important, but it is the efficacy and precision in understanding spatial patterns that direct rural planning and development decisions. This facilitates addressing the core issues of spatial practices in Chinese villages and helps conceptualize a new spatial relationship between people and land in rural settings. However, the utilization of the "SPSS + GIS" research method itself presents certain challenges in the selection of quantitative indicators. First of all, it is imperative to thoroughly consider the study purposes, the logical relationship among variables, and the level of comprehensiveness and representativeness of the chosen quantitative indicators, as they constitute the basis of the entire study. It is essential to acknowledge that SPSS software may introduce errors in data processing results, necessitating validation and filtering procedures. In the case of ArcGIS, which is employed for spatial analysis, the overlay and manipulation of diverse data layers can be intricate, adding to the complexity of data acquisition. Furthermore, the "SPSS + GIS" approach, when applied to the study of traditional village spatial forms, represents a multidisciplinary intersection of statistics, geography, and architecture. Therefore, effectively managing the relationship between disciplines is crucial. Secondly, the application of "SPSS + GIS" in the study of traditional village spatial patterns remains relatively limited. This limitation is attributed to the intricate nature of factors such as sample selection, data acquisition, and processing. Overcoming these constraints holds substantial real-world significance for advancing research on the development of traditional villages in China.

5.1.2. Suitability of "SPSS + GIS" Research Approach in Linxia Prefecture's Traditional Villages

The "SPSS + GIS" framework is well-suited for the study of Linxia Prefecture's traditional villages, which are embedded in a multicultural landscape with complex spatial arrangements. This region straddles the Qinghai–Tibet and Loess Plateaus, featuring a diverse terrain with significant altitude variations from 1563 to 4585 m, which includes mountains, valleys, and plains. In Linxia, the ongoing evolution of village forms has been influenced by this rich environmental diversity, resulting in a variety of village layouts. Geographically and culturally, the area serves as an intermediary between Han and Tibetan cultures, historically playing a pivotal role in trade and the coexistence of diverse ethnic groups. The villages here are characterized by large multi-ethnic settlements with intricate, overlapping living spaces. The spatial structures of these villages are complex, exhibiting both uniformities and intricate differences that demand a nuanced analysis. By integrating SPSS cluster analysis with detailed morphological indexing, a scientific approach is enabled for classifying the spatial morphology of these traditional villages. GIS spatial mathematical analysis enhances this by depicting the relationship between spatial forms and the dynamic interplay of natural and cultural factors in Linxia Prefecture. It also permits the examination of the variations in spatial distribution of village attributes and the patterns of community clustering. In essence, the application of the "SPSS + GIS" analytical approach to Linxia's traditional villages is advantageous for revealing the spatial regularities that emerge from the fusion of similarity and diversity within the region's multi-ethnic context.

5.1.3. Expanding the Value of "SPSS + GIS" Research Approach

The "SPSS + GIS" research method, effective for investigating traditional villages in Linxia, has broader applicability to multi-ethnic regions in China where cultural diversity and geographical specificities intertwine. With the acceleration of China's urbanization since 1979, the contrast between urban and rural development has become increasingly significant, underscoring the complexity of China's urban–rural dynamics. The focus of spatial research has been shifting from urban centers to rural landscapes, aligning with the central government's efforts to modernize ethnic regions. Prioritizing the sustainable development of traditional villages within these ethnic territories has emerged as a critical task. Central to this process is the need to understand the unique spatial phenomena of traditional villages. The analytical capability of the "SPSS + GIS" method is particularly suited to unpacking the non-linear and complex spatial patterns of these villages. It facilitates a nuanced understanding of the distinctive spatial arrangements and can discern the advantages and challenges presented by the spatial morphology and structure of village areas. Moreover, this method can be instrumental in detecting the intricate and non-linear properties of rural spatial systems, offering valuable insights into their complexity. As such, the "SPSS + GIS" research method holds potential for widespread application across

China's diverse multi-ethnic landscapes, enabling a deeper comprehension and informed approach to rural planning and development.

5.2. Sustainable Development of Traditional Villages

5.2.1. Integrity of Historical Villages

The sustainability of traditional villages entails respecting and maintaining their historical integrity. Villages with a dense, regimented layout often originated as protective enclaves shaped by historical ethnic conflicts. These settlements adapted to the Hui people's commercial needs by developing distinct zones for public commerce and private living. The strip-clustered and irregular dispersed types of villages, which are primarily agricultural and pastoral in production, are distributed in topographically complex areas of mountains, rivers, and valleys. These villages are often located in areas with convenient access to transportation and water. Additionally, the strip-clustered and irregular dispersed village types exhibit resource-based and subsistence-based survival models, respectively. For sustainable land use, the evolution of these villages' spatial forms must align with local features, adapting to natural conditions and utilizing the terrain judiciously [60]. The design of village streets, particularly those facilitating trade and religious activities, should harmonize with the natural environment and the commercial acumen of Hui people. Addressing the spatial practice in Chinese villages fundamentally requires a focus on accurately interpreting spatial laws. Effective guidance on spatial practice, informed by an understanding of spatial regulations, should take precedence over merely preserving cultural value orientations within these communities.

5.2.2. Resilience of Traditional Village Form

The spatial configuration of Linxia's traditional villages is a product of historical, economic, and cultural factors as well as the complex terrain and ethnically diverse backdrop. The pattern of densely ordered villages tends to follow an "olive-shaped" trajectory from southeast to northwest, a spatial orientation influenced by the ancient Tang–Tibetan Road, local transport routes, and variations in elevation. In contrast, villages with a more scattered, "U-shaped" distribution typically lie in the east, their layout determined largely by the region's physical geography. These villages, often ensconced in challenging mountainous areas, are reliant on agriculture and pastoralism, with ample grasslands and agricultural spaces to support livestock rearing. The striped, multi-point concentrated village type demonstrates a unique adaptability to the environment with a spatial pattern that can be described as "stochastically dispersed". Additionally, these villages often co-exist with cluster-intensive communities, where agricultural–commercial hybrid economies have taken root. Recognized as a pivotal transitional structure within Linxia, the striped multi-point villages bridge the gap between the densely regimented and the more freely dispersed village types. These villages typically possess a degree of social isolation with an economy dominated by independent smallholders. As such, the evolution of their form and expansion follows an intrinsic logic that can sometimes be at odds with contemporary spatial planning practices, which are often prescriptive and top–down. Planners must, therefore, acquire a deep comprehension of the governing principles behind the spatial patterns of these villages and devise development strategies in alignment with this understanding. Such an approach can reconcile planning efforts with the inherent development logic of the villages, fostering their sustainable growth and resilience.

5.3. Limitations and Prospects

This study has applied the "SPSS + GIS" quantitative approach to dissect the complexities of spatial reconfiguration in the context of rural revitalization and urbanization with a focus on traditional villages. This methodological framework has proven valuable in addressing multifaceted issues such as the multifarious spatial patterns of villages, cultural dislocations, environmental degradation, and internal development dynamics, ultimately informing spatial decision making in rural planning. The approach facilitates a reimagining of the rural human–land spatial relationship. However, traditional villages in Linxia Prefecture present a complex geographical landscape and a rich tapestry of ethnic cultural diversity as it is a multi-ethnic region. This research aims to elucidate spatial characteristics and comprehend spatial patterns. Building upon a mathematical analysis of precise morphological indexes, combined with the preliminary attempts and explorations involving statistical and spatial data analysis using "SPSS + GIS", the spatial morphology of villages is the result of intricate interplay between numerous factors, encompassing natural resources and human activities. It is, in itself, a dynamic and intricate developmental process. The spatial pattern of villages exhibits complex statistical, fractal, and distribution characteristics. Precise description along with SPSS + GIS integration allows the selection of quantitative indicators at different levels, such as single village, geographical area, and even cross-geographical scales. This facilitates the exploration of multiple aspects, including village spatial shape features, typologies, distribution characteristics of elements, and the dynamic evolution of spatial morphology over time. However, due to the multitude of hierarchical village components and sub-systems, and the inherently spatial and dynamic characteristics of the data, the selection of indexes and the consideration of relationship variables between the villages and the external environment factors require further improvement and rationalization in the subsequent stages of the research.

6. Conclusions

Linxia Prefecture stands as a paradigmatic illustration of the spatial patterning of multi-ethnic traditional villages in China, which are characterized by their indigenous developmental trajectories. Honoring intrinsic spatial configurations and understanding underlying spatial dynamics addresses the central issues of spatial practice in China's villages, enhances rural planning, and fosters a nuanced understanding of rural human–land relations. This research selected 177 traditional villages within Linxia Prefecture for analysis, deploying quantitative morphological indicators such as aspect ratio coefficients, boundary coefficients, saturation coefficients, and building densities to elucidate the spatial morphology through precise mathematical analysis. The findings are shown as follows:

(1) Based on the precise description from the quantitative morphological analysis, the spatial layout of traditional villages in Linxia Prefecture predominantly manifests as more square-shaped configurations. These configurations feature complex boundaries, low residential density, and smaller settlements, reflecting a hierarchical structure from village core to sub-center to residential buildings.
(2) Using cluster analysis, a statistical classification of the spatial morphology of traditional villages in Linxia Prefecture yields three types: cluster intensive, irregularly scattered, and strip multi-point concentrated. Further combined with GIS spatial analysis unveils the spatial distribution characteristics of each village type. Cluster-intensive villages show the spatial distribution pattern resembling an "olive-shaped southeast to northwest trending areas". Irregularly scattered villages are located in relatively flat areas, such as mountains, hills, gullies, and river valleys, transitioning vertically from the southwestern highlands to the northeastern lowlands. This indicates the development trend characterized by multi-core villages along the valleys and mountains. Strip multi-point concentrated villages show the tendency toward random distribution, often featuring multi-point focal points that are accompanied by cluster-intensive villages.
(3) The study reveals the spatial operational patterns that underlie the spatial morphology of traditional villages in Linxia Prefecture. The characteristics of the three spatial form types—clustered, irregularly dispersed, and strip-clustered—are a result of the complex interplay between the region's intricate geographical patterns and the diversity of its ethnic cultures. This amalgamation has given rise to three distinct traditional village survival modes, each characterized by its orientation toward commerce, subsistence, or resource utilization.

In conclusion, the intricate and distinctive spatial formations of Linxia Prefecture's traditional villages encapsulate a profound spatial memory and cultural legacy, embodying rich historical narratives and natural evolutionary patterns. To align with China's rural revitalization strategy, traditional villages in Linxia Prefecture must prioritize sustainable development pathways. These pathways should respect natural spatial laws, promote multi-ethnic integration, and honor their autonomous heritage all while thoroughly examining the historical and cultural dimensions of their human environments.

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