CORRELATION FRACTAL DIMENSION ANALYSIS MOUNTAINOUS TRADITIONAL VILLAGE SETTLEMENT SPATIAL FORM – CASE STUDY OF QIANDONGNAN IN GUIZHOU

Ersilin Wu¹
Boi-yee Liao²

ABSTRACT

Objective: A study carried out in the traditional villages of Qiandongnan in Guizhou province, located in China, to portray 409 traditional villages’ spatial distribution and fractal characteristic, as well as its implications for the preservation of the group of traditional villages.

Theoretical framework: From previous research, traditional village quantitative research on spatial area focuses on the statistics of mathematical models and spatial analyses of GIS, which indirectly reflect the complexity of the spatial patterns of traditional villages. Therefore, applying fractal theory to the spatial complexity of villages can provide a relatively objective and direct assessment for studying traditional villages with different formation backgrounds.

Method: Data were collected in Google Earth map data and spatial data were obtained, which were synthesized and analyzed using spatial, statistical and mathematics analysis to verify the distribution factors and know about villages’ spatial fractal characteristics.

Results and conclusion: The mountain settlements in Qiandongnan are concentrated in Leishan based on the Miao national group and “Liping-Congjiang-Rongjiang” based on the Dong national group. The q values of the explanatory power of each factor for the spatial distribution of traditional villages in the Qiandongnan area are, in descending order, intangible cultural heritage > GDP > distance from roads > height > the proportion of ethnic minorities > urbanization rate > average annual temperature > average annual precipitation > distance to rivers.

Research implications: Villages contribute significantly to the enhancement of traditional Chinese culture, especially the preservation of historical buildings and distinctive local cultures. Furthermore, Knowing the factors of traditional village centralized contiguous protection mode and rural planning based on the policy of rural revitalization in China.

Originality/value: Collected traditional villages’ distribution data from the official website and marked on the Google Earth map. Spatial analysis distribution of villages and emphasizes the importance of spatial correlation analysis in understanding the relationship between land use and rural population distribution.

Keywords: Rural Spatial Pattern, Self-Similarity, Geodetector, Grid Dimension, Spatial Distribution, Correlation Dimension.

¹ International College, Krick University, Bangkok 10220, Thailand. E-mail: ersilin.wu@outlook.com
Orcid: https://orcid.org/0000-0003-2204-4058

² International College, Krick University, Bangkok 10220, Thailand. E-mail: y5708211@ms18.hinet.net
Orcid: https://orcid.org/0009-0002-3393-1701
CORRELAÇÃO ANÁLISE DE DIMENÇÃO FRACTAL FORMA ESPACIAL DE ASSENTAMENTO DE ALDEIA TRADICIONAL MONTANHOSA – ESTUDO DE CASO DE QIANDONGNAN EM GUIZHOU

RESUMO

Objetivo: Um estudo realizado nas aldeias tradicionais de Qiandongnan, na província de Guizhou, localizada na China, retratou a distribuição espacial e a característica fractáltica de 409 aldeias tradicionais, bem como suas implicações para a preservação do grupo de aldeias tradicionais.

Referencial teórico: A partir de pesquisas anteriores, a pesquisa quantitativa tradicional de aldeias sobre área espacial concentra-se nas estatísticas de modelos matemáticos e análises espaciais de SIG, que refletem indiretamente a complexidade dos padrões espaciais das aldeias tradicionais. Portanto, a aplicação da teoria fractal à complexidade espacial das aldeias pode fornecer uma avaliação relativamente objetiva e direta para o estudo de aldeias tradicionais com diferentes formações formativas.

Método: Os dados foram coletados no mapa do Google Earth e dados espaciais foram obtidos, os quais foram sintetizados e analisados por meio de análises espaciais, estatísticas e matemáticas para verificar os fatores de distribuição e conhecer as características fractais espaciais das aldeias.

Resultados e conclusão: Os assentamentos montanhosos em Qiandongnan estão concentrados em Leishan com base no grupo nacional Miao e "Liping-Congjiang-Rongjiang" com base no grupo nacional Dong. Os valores q do poder explicativo de cada fator para a distribuição espacial das aldeias tradicionais na área de Qiandongnan são, em ordem decrescente, patrimônio cultural imaterial > PIB > distância de estradas > altitude > proporção de minorias étnicas > taxa de urbanização > temperatura média anual > precipitação média anual > distância dos rios.

Implicações da pesquisa: As aldeias contribuem significativamente para a valorização da cultura tradicional chinesa, especialmente a preservação de edifícios históricos e culturas locais distintas. Além disso, Conhecendo os fatores da aldeia tradicional centralizado modo de proteção contígua e planejamento rural baseado na política de revitalização rural na China.

Originalidade/valor: Coleta de dados de distribuição das aldeias tradicionais a partir do site oficial e marcados no mapa do Google Earth. Análise espacial da distribuição das aldeias e enfatiza a importância da análise de correlação espacial na compreensão da relação entre uso da terra e distribuição da população rural.

Palavras-chave: Padrão Espacial Rural, Auto-Similaridade, Geodetector, Dimensão da Grade, Distribuição Espacial, Dimensão de Correlação.

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1 INTRODUCTION

Traditional mountain village settlements in China exhibit different architectural styles, spatial arrangements, and cultural significance, often characterized by their integration into local ecosystems and interactions with the surrounding natural environment (Wang, 2015). Ancient Chinese architecture, influenced by environmental factors with the availability of construction materials and agricultural tools, has evolved into unique local forms such as Jinggan, Ganlan, and Chuandou (Kim & Park, 2017). These structures enable the development of flexible and diverse forms of living that integrate harmoniously into hilly landscapes and
result in a treehouse-like dwelling. However, the intensification of urbanization and the expansion of urban infrastructure has led to the decline and, in some cases, the disappearance of these village settlements. This process contributes to the degradation of traditional landscapes, lack of investment, mismanagement, and population migration (Alves et al., 2023). Settlements serve as primary hubs for human residence and economic activity. However, the international community has shown a longstanding interest in restoring traditional village settlements amidst new urbanization and rural revitalization. Since the 1950s, traditional territories worldwide have faced threats from improper planning and over-commercialization in tourism, affecting various countries, including the United States, Sweden, Japan, and South Korea (Xi et al., 2015). Historical, environmental, and lifestyle factors influenced farmers' spontaneous decisions and significantly impacted the spatial organization of villages. This has resulted in inefficient land use, a fragmented spatial structure, and haphazard development. Such problems are widespread in many towns. The dual urban-rural form in China requires a balance between social progress and the preservation of cultural heritage. This is further reinforced by the country's shift from historical and cultural villages to traditional villages (J. Zhang & Gu, 2022). Therefore, recognizing these villages' cultural and historical value, the Chinese government has initiated efforts to protect and preserve them.

The term "Traditional Village Settlement (TVS)" refers to multifunctional complexes with many seemingly natural features that go beyond human settlements and raise questions about how society should value people's lives, with an emphasis on historical, cultural, and vernacular architecture and rural tourism (Li et al., 2023). They host tourist activities like sightseeing, relaxation, and cultural learning (Wang, 2019). Investigating the physical and spatial structures of these settlements improves spatial planning and housing design and clarifies the interaction between construction, environment, and settlement form (Alves et al., 2023). The expansion of TVS into rural areas considers local topography, climate, resources, natural materials, architectural styles, and design philosophies. 'Spatial texture,' a concept that denotes the surface composition of material and spatial elements, embodies cultural meaning and social functions (Bhatta, 2023). Understanding the relationship between settlement form, environment, and productivity has advanced land planning and housing design. In summary, traditional village spatial forms in rural areas are influenced by natural environmental factors, human interventions, demographic and socioeconomic elements, natural landscapes, and cultural-economic aspects. These factors determine traditional villages' location, layout, development, maintenance, and protection. Given their importance in rural land use, optimizing the spatial arrangement of rural settlements remains a crucial challenge in land consolidation.
The spatial structure of traditional Chinese village settlements warrants scholarly attention for several reasons. Firstly, it sheds light on these villages' unique architectural design, layout, and cultural significance (Wu et al., 2020). Secondly, it provides insight into the evolution of traditional architecture and its influence across East Asia (Bhatta, 2023). Thirdly, it helps identify the factors sustaining isolated mountain communities and their challenges due to rural depopulation from urbanization and economic growth (Feng et al., 2023). Additionally, it reveals the Chinese government's efforts in protecting and preserving these communities. Understanding these settlements' spatial forms and strategic approaches is crucial for rebuilding a sustainable rural social structure. Studying the spatial organization of traditional Chinese village settlements is imperative for multiple reasons: it tracks the evolution of conventional architecture, identifies preservation challenges, informs preservation strategies, and explores traditional architecture's role in the rural revitalization (Yang & Pu, 2022). Therefore, maintaining traditional villages' original structure and spatial form is vital during preservation or remodelling efforts. Ensuring the continuity and integrity of these villages requires attention to historical features, spatial scale, and regional aesthetics (Zhu & Liu, 2023). From a morphological perspective, spatial texture in villages reflects reality by illustrating the standard characteristics of spatial shapes in groups.

Extensive research demonstrates that rural settlements' spatial configuration and organization, influenced by geographic elements like distribution, size, and layout, are crucial for supporting livelihoods, fostering industrial growth, and enhancing life quality. These variations result from geographical factors, socioeconomic development, and human needs (Li et al., 2017). Additionally, socioeconomic factors, including economic status, sociocultural aspects, and government policies, significantly shape the spatial arrangement of rural settlements (Bi et al., 2021). Geographic elements such as elevation, slope, landforms, and vegetation types profoundly affect rural settlements' spatial distribution and clustering (Xie et al., 2022). The factors influencing the form of rural settlements are multifaceted and diverse, leading to complex interactions that vary by region and context. Consequently, these myriad human and natural factors create intricate, ambiguous, and unpredictable spatial boundaries and textures in villages. The structure of rural settlements, inherent to village existence, evolves alongside their development. This evolution presents unique characteristics during different socio-economic stages and regional contexts. The spatial form of urban and rural areas represents the tangible manifestation of urban-rural relationships, evolving within specific regional contexts (Xiao & Chen, 2012). However, prior research on spatial models and processes in traditional villages often overlooked the interplay between physical space and...
human social activities influenced by socio-economic factors. This study employs mathematical approaches to quantitatively analyze the fractal nature of traditional village spatial forms, offering a more accurate understanding of their configurations.

2 THEORETICAL FRAMEWORK

Mountainous regions feature diverse settlements, such as linear, clustered, dispersed, nucleated, terraced, hilltop, valley, ladder, and star configurations (Shahi, 2022). The spatial organization of traditional mountain villages—which encompasses the layout of buildings, streets, and public spaces—is shaped by a confluence of natural, cultural, and historical influences (Zhu & Liu, 2023). Recent studies have employed social network analysis to elucidate the spatial dynamics of rural settlements (Zhao et al., 2022), examine the evolution and determinants of rustic settlement patterns for spatial optimization (Liu et al., 2023), and investigate the distribution and network of traditional village settlements (Liu et al., 2023). The phenomena of rural settlement "hollowing" and the subsequent need for strategic regulation underscore the growing importance of these studies.

Mountainous traditional village settlements exhibit a variety of spatial forms, including aggregation, belt, and dispersion types (Li et al., 2023). These settlements often have a scattered and discrete layout, with small-scale clustering observed in settlement groups (Xu et al., 2018). The spatial structure of these villages is influenced by factors such as geomorphological conditions, population quantity, and land use scale (Wang & Chen, 2022). The development scope of these settlements can be controlled by using a radius of 284.12 m as a measure (Wu & Chen, 2021). The spatial form of traditional villages can vary, with some showing a type of discrete group space with large dispersion and a small settlement. In contrast, others exhibit high integration and concentration in certain regions (Lin et al., 2021). The internal spatial pattern of these villages is often scattered, with low cultural building density and limited spatial passage. The spatial form of traditional settlements plays a crucial role in their sustainable development and can be optimized to combine modern life with traditional village culture.

In the realm of material culture, the spatial morphology of traditional villages encompasses architectural, street, and general spatial configurations. This morphology is delineated by natural features such as forests, water bodies, and human-made elements, including roads, dwellings, and agricultural lands (Zhang et al., 2023). Prior research on traditional villages' spatial texture predominantly utilized qualitative methods, with quantitative studies being less common (Gong et al., 2023). At the macroscopic scale, morphological traits...
of village boundaries are quantified using metrics such as shape index, boundary coefficient, and aspect ratio. The structure and distinctiveness of villages are elucidated via Geographic Information Systems, spatial syntax, and geographic weighted regression analyses. On a more granular level, building layout and land usage are characterized by metrics like building density, dispersion coefficient, spatial gene, and land use stochastic matrix. These methods elucidate spatial patterns and characteristics in rural settings, addressing settlement distribution, land utilization, landscapes, and the peri-urban interface (Söztutar, 2022).

Spatial morphology represents an integrated entity encompassing tangible forms, voids within natural spaces, and perceptual constructs within the cognitive realm, facilitating information exchange in virtual areas (Veiga & Veiga, 2024). The spatial structure of urban and rural systems is intricate, exhibiting self-organizing and fractal qualities (Tong & Murray, 2012). Furthermore, human geographic systems display recursive, self-similar patterns across urban and rural landscapes (Chen, 2015). Research into rural settlements has been primarily concerned with their spatial development, shaped by productivity levels and reflecting the interaction with the natural environment.

The urban spatial form can be analyzed using fractal theory to quantify the characteristics of settlements (Southworth, 2022). Fractal analysis of urban spatial structure can reveal distinct patterns and correlations in the architectural layout (Ali, 2022). The distribution of settlements in different regions can exhibit spatial differences in architectural space forms (Henn et al., 2020). Similarly, the fractal characteristics of rural mountain settlements can be analyzed to understand factors that facilitate the appropriate selection of residential sites. Fractal dimension values can be used to analyze the relationship between elevation, slope, disaster risk, and water-facing levels in rural mountain settlements. The analysis of fractal parameters can provide valuable insights into the spatial organization and growth patterns of slum settlements. Additionally, studying inter-urban structures can help understand similarities between nonlinear pattern formation and settlement patterns.

Previous research in this area has been guided by qualitative methods, relying on field surveys and in-depth interviews to examine physical characteristics, cultural practices, and social dynamics in traditional villages. Researched and conducted in-depth interviews with the Dai Village in Yunnan in terms of physical characteristics, cultural traditions, and social interactions (Wang & Chiou, 2019). Analyzed specific traditional villages to understand their spatial structure, cultural significance, and development challenges from case studies and qualitative interpretation field (Ma & Tong, 2022). However, recent developments have witnessed a paradigm shift towards quantitative analysis, incorporating statistical models,
geospatial techniques, and fractal theory to unravel the intricate spatial patterns characterizing these rural settlements (Chen et al., 2019).

Quantitative interpretation of traditional village settlements involves using statistical models and geospatial techniques to analyze data and identify spatial patterns, such as semantic segmentation for quickly segmenting different objects (Zhang et al., 2021). Researchers are increasingly employing GIS spatial analysis and geographical detectors to dissect the spatial patterns and the factors that influence the quality of life within traditional villages (Duan et al., 2022). This analytical lens is particularly pertinent in less developed regions and holds the potential to inform strategic directions and thoughtful designs for typical rural mountain settlements (Liu et al., 2023). For example, research takes 206 traditional villages in Hubei Province as an example. It proposes a method framework for ‘Feature identification and hierarchical classification (FIHC) that combines field research, spatial geography, and spatial network methods for rural planning in recent years, research on traditional village settlements based on fractal theory has explored the fractal characteristics of village landscapes and the relationship between ethnicisation and village landscapes (Fan et al., 2023). Moreover, these efforts are instrumental in driving rural revitalization endeavors and amplifying the impact of pastoral planning and community reconstruction initiatives.

Furthermore, the study introduces quantitative methodologies to scrutinize spatial texture, employing metrics such as aggregation and capacity dimensions. Quantitative data generated through these measures unveils the intricate interplay between traditional villages and their ecological environments across the development continuum. An evaluation index system tailored to the texture of conventional Miao villages is meticulously crafted to facilitate this quantitative inquiry. These quantitative research methods are a powerful tool to unearth traditional villages nuanced spatial morphological characteristics while dissecting the multifaceted factors that shape their configurations and attributes in a rigorous academic framework.

From previous research, traditional village quantitative research on spatial area focuses on the statistics of mathematical models and spatial analyses of GIS, which indirectly reflect the complexity of the spatial patterns of traditional villages. Therefore, applying fractal theory to the spatial complexity of villages can provide a relatively objective and direct assessment for studying traditional villages with different formation backgrounds. The analytical method of fractal theory is applied to systematically analyze and compare the multiscale spaces in traditional settlements to clarify the mechanism of spatial complexity and its influential features. The Qiandongnan region of Guizhou Province is the primary research area for this study based
on fractal theory. The two objectives of this study are to analyze the fractal characteristics of rural settlements in the Qiandongnan region and to determine the impact of the factors affecting the distribution of rural settlements in this region. Therefore, using geographical detector analysis, fractal dimension analysis and GIS spatial analysis, the authors examined rural settlement data in the Qiandongnan region to investigate the spatial pattern differentiation and its influencing factors. Especially in less developed areas, this can serve as a theoretical basis for the optimisation direction and sensible design of typical rural mountain settlements. It can also lay the foundation for realising rural revitalization, consolidating and expanding rural planning and community reconstruction results.

3 METHODOLOGY

Qiandongnan is located in the transitional zone from the Yunnan-Guizhou Plateau to Xianggui hills and basins in China, with continuous peaks and ridges. Karst is widespread in the territory and forms a particular karst ecosystem. The study area has jurisdiction over 15 county-level units, including Cenggong, Zhengyuan, Shiping, Huangping, Sansui, Majiang, Taijiang, Jianhe, Pingjing, Danzai, Leishan, Rongjiang, Liping, Congjiang, and Kaili. Qiandongnan is a specific area for studying Miao traditional settlements. The total population of Miao in China is 8,940,100, of which 3,799,500 live here. Its geographical location is 107°17′–109°35′ E, 25°19′–27°31′ N, and its land area is 30337 km2.

Four main categories of data sources are included in this study: (1) the list of minority characteristic villages from the official website of the People’s Government of Guizhou province; as of December 2022, 409 settlements in the study area have been selected into the list of ethnic minority villages in Guizhou province; and the geographic coordinates were calibrated using Google Earth; (2) the vector map, elevation, and river system of the administrative boundary of Qiandongnan are provided by the Chinese Resources and Environment Science and Data Center; (3) social and economic data were acquired from statistical yearbooks (Table 1).
The spatial form of traditional mountainous village settlements is a complex and evolving phenomenon, influenced by a range of factors. This research focused on the southeast area of Guizhou, which is a typical Karst Plateau landform area, and the geographical characteristics of nearly 92.5% are mountainous and hilly. Traffic and ecological conditions not only restrict local economic development but also provide a natural barrier to preserving the historical features of villages. The information concerning terrain and surface features can be digitally measured very accurately, facilitating quantitative analysis (Zhang et al., 2023). This allows for a richer, more nuanced understanding of the spatial morphologies of traditional villages, making it an indispensable tool for this study. This research used spatial analysis techniques to analyse and interpret the collected data, possibly including kernel density estimation and other statistical methods.

The table below summarises the social and economic statistics of Qiandongnan:

<table>
<thead>
<tr>
<th>County name</th>
<th>Traditio nal Village Number</th>
<th>Altitude (m)</th>
<th>Temperature</th>
<th>Precipitation</th>
<th>River Network Density</th>
<th>Permanent population of minority nationalities</th>
<th>Intangible cultural heritage</th>
<th>Highway mileage</th>
<th>Per capita GDP</th>
<th>Urbanisation rate</th>
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3.1 RESEARCH THEORY: FRACTAL THEORY

Traditional village spatial form can be analysed through fractal theory. Fractal theory is a nonlinear research method that uses fractal geometry to study complex phenomena (D. Fan et al., 2023). It can be applied to analyse the spatial characteristics of traditional villages, including the individual housing units, spatial environment, and other influencing factors (Yi, 2023). Fractal dimensions can be calculated to evaluate the plane and facade shape of the village, providing important indices for assessing the spatial form (Fan et al., 2020). Fractal theory can also uncover the intrinsic fractal patterns, generative mechanisms, and cultural significance of traditional village landscapes (Yang et al., 2020). By using fractal theory, researchers can analyse the morphological features and generation mechanisms of landscape spatial characteristics in traditional villages, offering a scientific basis for cultural heritage preservation and transmission (Wang & Chen, 2022b). Overall, fractal theory provides a valuable tool for understanding and analysing the spatial form of traditional villages.

Rural spatial form, aggregation, and fractal dimension are related concepts in the study of urban and regional landscapes. The fractal dimension can be used to define various urban form indexes, indicating spatial shape, size, and development. In the context of rural spatial forms, fractal dimensions can help understand the spatial entropy and organization of urban forms. Fractal dimensions can be derived from spatial allometric scaling of urban forms, which is a method used to analyze the spatial structure of urban areas. This method has been applied to study the spatial characteristics and evolution of rural settlement landscapes. The degree of spatial aggregation can be represented by the aggregation fractal dimension. A smaller aggregation fractal dimension indicates a lower level of aggregation, with spatial elements being scattered. Conversely, a higher aggregation fractal dimension indicates a higher level of aggregation and stronger integrity of spatial elements. This approach reveals the texture relationship between the settlements and the surrounding natural environment, providing quantitative data for the study of the texture characteristics of traditional villages.

3.2 KERNEL DENSITY ANALYSIS

Traditional village distribution patterns can be analyzed using kernel density estimation techniques. The characteristics of traditional village distribution were investigated using spatial analysis methods, Geodetector, and mathematical statistics. Factors such as annual precipitation, annual average temperature, river density, and road density were found to influence the
distribution of traditional villages (Li et al., 2022).

\[ f_n(x) = \frac{1}{nh} \sum_{i=1}^{n} k \left( \frac{x-x_i}{h} \right) \]  

\[ n \in \text{Equation (1), f is the traditional village density distribution function, n is the traditional village distribution, } k \left( \frac{x-x_i}{h} \right) \text{ is the kernel function, and h is the set broadband.} \]

### 3.3 AVERAGE NEAREST NEIGHBOR INDEX

The traditional settlement spatial Average Nearest Neighbor Index is a technique used in geography to measure the departure from randomness in the distribution of a two-dimensional point pattern. It calculates the distance from each point to its nearest neighbor and compares the mean observed distance with the expected distance if the same number of points were distributed randomly. The resulting statistic, R, indicates the degree of departure from randomness, either towards clustering or towards uniformity. This technique has been applied to study settlement patterns and spacing along lines in various geographical areas (Chiu et al., 2018).

\[ R = \frac{\bar{r_1}}{rE} 2\sqrt{D} \]  

\[ \text{In the Equation (2), } \bar{r_1} \text{ is the nearest distance, and } rE \text{ is the theoretical nearest distance. Quantitatively determines the type of distribution of point features within an area. When } R > 1, \text{ the distribution of point elements is uniform; when } R = 1, \text{ the dotted features are random; when } R < 1, \text{ the dotted features tend to agglomerate and distribute.} \]

### 3.4 GEODETECTOR

Traditional settlement spatial GeoDetector is a method used to analyze the spatial distribution characteristics and influencing factors of traditional settlements (B. Li et al., 2022). It involves the use of spatial analysis techniques such as GIS, kernel density analysis, and standard deviation ellipse. The GeoDetector model is then applied to detect the influencing factors of traditional settlements, considering both natural and socio-economic factors.
\[ q = 1 - \frac{\sum_{h=1}^{H} N_h \sigma_h^2}{N \sigma^2} \]  

In the Equation (3), the q value is a measure of the detection force of the independent variable—the value is \([0, 1]\), and the closer to 1, the greater the influence of the factor. \(L\) is the stratification of the independent or dependent variable, \(N_h\) and \(\sigma_h^2\) are the number of elements and the variance of layer \(h\), respectively, and \(N\) and \(\sigma^2\) are the number of units and the variance of the whole, respectively.

3.5 SPATIAL CORRELATION DIMENSION

A range of studies have explored the spatial correlation dimension in rural areas. Emphasizes the importance of spatial correlation analysis in understanding the relationship between land use and rural population distribution. Builds on this by using both the aging population ratio and density to identify different types of aging communities in urban and rural settings (Shiode et al., 2014). Investigates the impact of geophysical parameters on rural settlement density and size in China, highlighting the influence of topography and climate. Further explores the correlation between village settlement distribution and the net income of rural residents in poverty-stricken counties, emphasizing the need for systematic planning to improve economic development (H. Liu & Wang, 2014). These studies collectively underscore the significance of spatial correlation analysis in understanding the complex dynamics of rural areas. Within the framework of urban systems, the interplay among settlements is present, and the spatial correlation dimension serves to characterize the mutual interactions and spatial linkages among rural settlements in the area. Initially, the spatial function within the settlement system is identified as Equation 4:

\[ C(r) = \frac{1}{N^2} \sum_i^N \sum_j^N \theta(r - d_{ij})(i \neq j) \]  

In Equation 4, \(C(r)\) represents the spatial correlation function of rural settlements, \(r\) is the given distance scale, \(d_{ij}\) is the Euclidean distance between the \(i\) and \(j\) rural settlements, and \(\theta\) is the Heaviside function, which is:

\[ \theta(r - d_{ij}) = \begin{cases} 1 & (d_{ij} \leq r) \\ 0 & (d_{ij} > r) \end{cases} \]  

In Equation 4, \(C(r)\) represents the spatial correlation function of rural settlements, \(r\) is the given distance scale, \(d_{ij}\) is the Euclidean distance between the \(i\) and \(j\) rural settlements, and \(\theta\) is the Heaviside function, which is:
If the spatial distribution of rural settlements is fractal, then it should exhibit scale invariance, that is:

\[ C(r) \propto r^{D_1} \quad (6) \]

In practical calculations, for ease of computation, the formula for \( C(r) \) can be modified to:

\[ C(r) = \sum_{i,j=1}^{N} H(r - d_{ij}) \quad (7) \]

Within this, equation 7 denotes the spatial correlation dimension, \( D_1 \), whose values generally lie between 0 and 2. As \( D_1 \) tends towards 0, it signifies a high concentration of settlements in a single location, indicating tighter links between rural settlements in the area; Conversely, as \( D_1 \) nears 2, the distribution among rural settlements becomes more scattered, reflecting a more even spatial distribution. The distinctive application of the spatial correlation dimension is its capacity to represent the connectivity of the transportation network among different components of the urban system, thus signifying the interconnectedness among settlements.

3.6 GRID DIMENSION

The grid dimension \( D_2 \) is primarily used to reflect the balance of distribution of traditional villages in the region. When investigating the spatial distribution of the system, the number of grids \( N(r) \) occupied by the villages is related to the grid size \( r \). Assuming that the distribution of traditional villa is a scaleless property, the relationship holds:

\[ N(r) \propto r^{\alpha} \quad (8) \]

Where:

\( \alpha = D_0 \) is the capacity dimension, \( r \) is the grid size. When \( 0 < D < 2 \), it means that traditional villages in the system are relatively evenly distributed; when \( D \) tends to be closer to 0, traditional villages tend to be concentrated in one place; when \( D = 2 \), it means that traditional
villages are extremely well-distributed, which is compatible with the central place model. Afterwards, we can ignore the difference in number of villages in the grid, assuming that the number of “traditional villages” in the grid of row i and column j is \( N_{ij} \), and the total number of traditional villages in the whole domain is \( N \). Its formula is as follows:

\[
P_{ij} = \frac{N_{ij}}{N} \quad (9)
\]

Next, we can obtain information dimensions, whose expression is as follows:

\[
I(r) = -\sum_i \sum_j P_{ij(r)} \ln P_{ij(r)} \quad (10)
\]

In the formula, \( K = \frac{1}{r} \) represents the number of segments on each side of the region. If the traditional village spatial distribution system is fractal, the expression is as follows:

\[
I(r) = I_0 - D_2 \ln r \quad (11)
\]

Where:

\( I_0 \) is a constant, and \( D_2 \) is an information dimension.

\[
K = \frac{D_2}{D_0} \quad (12)
\]

Where:

The geographical significance of the \( K \) value is that connectivity increases as the \( K \) value grows closer to 1. When \( K = 1 \), the traffic line between traditional village is a straight line, and the connectivity worsens as the value grows closer to 0.
4 RESULTS AND DISCUSSION

4.1 RESULT

4.1.1 Spatial Distribution Density Analysis

To visually analyze the density distribution of traditional villages in the Mountain area in Qiandongnan, based on several experiments and the relevant research of previous scholars, a 50 km bandwidth was used as the search radius and a nucleus density analysis map of traditional villages in the Qiandongnan area was derived (Figure 1). The analysis concluded that the traditional villages in Qiandongnan two key features that the central area are densely distributed that Leishan based on Miao nations, and “Lipingr-Congjiang-Rongjiang” based on Dong nations, the rest area with a scattered distribution.

Figure 1

Nuclear-density density-map of traditional villages in Qiandongnan

The nearest neighbor analysis of the traditional villages in the mountainous areas of Qiandongnan in Guizhou was carried out by using ArcGIS. For the traditional villages in the mountainous areas of Qiandongnan, we observed a theoretical average nearest neighbor
distance of $r_E = 3523.21 \text{ m}$, an actual average nearest neighbor of $r_1 = 4779.44 \text{ m}$, and a nearest neighbor index of $R = 0.74$ $R < 1$, $Z = \frac{-10.17}{0.00}$ (Figure 1). The results show that the traditional villages in the mountainous areas of Qiandongnan are clustered or dispersion.

**Figure 2**

*Average nearest neighbor index map of traditional villages*

![Image of average nearest neighbor index map](image)

<table>
<thead>
<tr>
<th>$r$ (km)</th>
<th>$r_1$ (km)</th>
<th>$Z$</th>
<th>$P$</th>
<th>$R$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.523</td>
<td>4.780</td>
<td>-10.16957</td>
<td>0.000</td>
<td>0.737159</td>
</tr>
</tbody>
</table>

**4.1.2 GeoDetector**

The $q$-values of the explanatory power of each factor on the spatial distribution of traditional villages in the Qiandongnan area are, in descending order, the intangible cultural heritage > GDP > distance from roads > elevation > the proportion of ethnic minorities > urbanization rate > average annual temperature > average annual precipitation > distance from rivers (Table 3). This indicates that the intangible cultural heritage is the main driving factor affecting the spatial distribution of traditional villages in the Qiandongnan area, with an
explanatory power of 0.68. Among the social factors, GDP had the strongest explanatory power of 0.66; elevation had the strongest explanatory power among all the natural factors, with an explanatory power of 0.39. Here, the topography is suitable for agricultural production, and the water supply is adequate, which were the primary conditions of site selection to ensure the villagers’ livelihood, as opposed to being on a sunny slope. Furthermore, the minority group spatial location with complex geological conditions, they have the strong road network density may base on urbanization development.

Table 3

<table>
<thead>
<tr>
<th>No.</th>
<th>Variable</th>
<th>q</th>
<th>sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Elevation</td>
<td>0.390822</td>
<td>0.345507</td>
</tr>
<tr>
<td>2</td>
<td>Average Temperature</td>
<td>0.153226</td>
<td>0.84104</td>
</tr>
<tr>
<td>3</td>
<td>Average Precipitation</td>
<td>0.070599</td>
<td>0.94220</td>
</tr>
<tr>
<td>4</td>
<td>Distance from Rivers</td>
<td>0.044590</td>
<td>0.97389</td>
</tr>
<tr>
<td>5</td>
<td>Proportion of Ethnic Minorities</td>
<td>0.241935</td>
<td>0.74012</td>
</tr>
<tr>
<td>6</td>
<td>Intangible Cultural Heritage</td>
<td>0.678815</td>
<td>0.05226</td>
</tr>
<tr>
<td>7</td>
<td>Distance From Roads</td>
<td>0.530512</td>
<td>0.19774</td>
</tr>
<tr>
<td>8</td>
<td>GDP</td>
<td>0.662507</td>
<td>0.12269</td>
</tr>
<tr>
<td>9</td>
<td>Urbanization Rate</td>
<td>0.165970</td>
<td>0.78893</td>
</tr>
</tbody>
</table>

4.1.3 Spatial Correlation Dimension

The use of Formulas (4) and (5) resulted correlation dimension $D_1 = 1.3556$, $R^2 = 0.9658$. The correlation dimension $D$ tend to 1 means that the traditional village spatial distribution is relatively evenly clustered along the geographical line, which makes the spatial distribution conducive to constructing the traditional villages system. When the spatial correlation dimension $D$ trend to 2, it indicates that the spatial distribution of traditional villages in Qiandongnan is quite balanced.
4.1.4 Grid Dimension

The grid dimension reflects the traditional villages' spatial distribution rate in Qiandongnan. The selection of a rectangle on the vector map of the spatial distribution, which contains 409 samples, changes the visible rectangular area into a unit, and each side of K is divided equally. The calculation of the probability $P_{ij}(r)$, with a change in the $r$ value, enables the determination of the corresponding $K(r)$ and $P_i$ values, and the corresponding $I(r)$ can be obtained using Equation (9) (Table 4). Next, the grid dimension calculation data were obtained from Equation (9) and (10), and $(\ln K, \ln N)$ and $(\ln K, \ln I(r))$ were drawn, leading to the transformation of $(\ln K, \ln N)$ and $(\ln K, \ln I(r))$ into a double logarithmic coordinate. The grid capacity dimension $D_0$ and grid information dimension $D_2$ are then determined (Table 5).

Table 2
The determining dates of grid dimension of the Qiandongnan traditional village spatial distribution

<table>
<thead>
<tr>
<th>K</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>4</td>
<td>8</td>
<td>14</td>
<td>19</td>
<td>25</td>
<td>32</td>
<td>38</td>
<td>47</td>
<td>53</td>
</tr>
<tr>
<td>$I(r)$</td>
<td>0.2</td>
<td>0.5</td>
<td>0.8</td>
<td>0.9</td>
<td>1.0</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Figure 3
The log-log plot for the correlation dimension of traditional villages in Qiandongnan

$y = 1.3556x - 16.099$
$R^2 = 0.9658$
Table 3

The determining dates of grid dimension of the Qiaandongnan traditional village spatial distribution

<table>
<thead>
<tr>
<th>Type</th>
<th>Capacity Dimension</th>
<th>Information Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>1.6014</td>
<td>0.6511</td>
</tr>
<tr>
<td>R²</td>
<td>0.9974</td>
<td>0.9912</td>
</tr>
</tbody>
</table>

Figure 2

The log-log plot for capacity dimension of traditional village spatial form in Qiaandongnan

Figure 3

The log-log plot for the information dimension of traditional village spatial form in Qiaandongnan

Figure 4 and Figure 5 indicates that the spatial structure of the traditional village is
mathematically significant when measured on a scaleless range \((\ln K 0.7–2.3)\) with grid dimension D. The capacity dimension \(D_0 = 1.6014, R_0^2 = 0.9559\), the grid information dimension \(D_2 = 0.6511, R_2^2 = 0.9912\).

4.2 DISCUSSION

4.2.1 Factors of Spatial Distributions

In this study, research showed that the spatial distribution and morphological characteristics of traditional settlements were a survival process of constant adaptation to the harsh natural environment and coping with changes in internal and external conditions in different periods of time, which was an external manifestation of the common effect the natural environment, the social environment and the economic environment. Table 3 shows that the spatial distribution of traditional villages is influenced by a variety of factors, including natural environment, social ties, historical culture, economic development, and topographic features. These factors play a crucial role in shaping the spatial shape and distribution patterns of traditional villages. The spatial distribution of traditional villages in Qiandongnan of Guizhou Province is influenced by both intangible culture and socioeconomic factors, with intangible cultural heritage factors having a greater influence. In addition, social and historical factors, including social ties, cultural symbols and historical cultural values, have been identified as influencing the spatial distribution of traditional villages. Natural environment such as topography, temperature, annual rainfall and river basins were found to have a significant impact on the distribution of traditional villages. Furthermore, economic development and urbanization have been shown to influence the spatial distribution of traditional villages, without there being a necessary relationship between the level of economic development and the rise and fall of traditional villages. The spatial distribution of traditional villages includes two spatial dimensions, which distribute the mountain settlements in Qiandongnan concertedly on Leishan based on the Miao national group and “Liping-Congjiang-Rongjiang” based on the Dong national group, and the spatial distribution characteristics of existing rural tourism villages show an agglomeration distribution tendency.
4.2.2 Traditional Settlements Fractal Characteristics

The spatial correlation dimension of traditional villages is influenced by a combination of natural, social, historical and economic factors that contribute to the unique spatial distribution and shape of traditional villages. The spatial correlation dimension of traditional villages is also influenced by the evolutionary process, characteristics and driving factors from the cultural ecosystem perspective. The fractal dimension of rural macromorphology can follow a morphological oscillatory order around the equilibrium level, indicating a dynamic spatial evolutionary process. In addition, the grid dimension of traditional villages is influenced by factors such as adaptability as tourist destinations, industrial change, and village interaction and spatial structure. The results of the network planning algorithm have been proven to have a significant impact on the required network capacity and highlight the importance of efficient network sizing in the context of traditional villages.

4.2.3 Natural Environment Factors

When comparing villages in flat areas with those in mountainous regions, it is clear that mountain villages have a stronger connection to their natural surroundings. The topography, water systems and climate play an important role in shaping the structure and appearance of these villages, as well as determining their livelihoods and spatial layout. Due to the limited availability of flat land suitable for agriculture in mountainous regions, residents often choose environments conducive to their survival and growth. The existence of these villages is the result of internal and external factors that have adapted to each other. The fluctuating terrain can affect the layout and architectural style of these villages. For example, villages in areas such as valley terraces and loess plateaus with minimal terrain differences tend to cluster together, and independent troglodyte dwellings are the predominant architectural form. Conversely, villages in hilly areas with pronounced relief extend predominantly linearly along rivers, with mountain-style troglodyte dwellings being the predominant building type. Residents design their homes by adapting and changing nature to suit their needs. Access to water, light, heat and suitable land is essential for the sustainable development of these traditional villages.

4.2.4 Social and Economic Factors

In Qiandongnan, after a long period of development and construction, there are few
areas left that have not been affected by human activities, as people build settlements according to various natural conditions. Over time and adversity, people are influenced by social, economic and behavioral choices. As a result, they are gradually changing the use and function of their villages, creating ecological wisdom appropriate to the region. China's rapid social and economic growth since its reform and opening-up has had a significant impact on rural development, and many regional characteristics of rural areas have disappeared. A cultural crisis due to the rapid disappearance of villages has led to the development of measures to preserve traditional villages in the context of the rural revitalization plan. With a strong social character, traditional villages are recognized and implemented based on natural and humanistic values. The traditional villages in the hill and ravine regions of northern Shaanxi are mainly located in places that have been less affected by industrialization and modernization, meaning that these areas have high population densities, low urbanization rates, and low GDP per capita. In the past, the location and layout of a village were primarily determined by the surrounding landscape. However, in today's times when the outside world is changing significantly, the social and economic environment plays a crucial role in the survival and growth of traditional villages.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This research takes 409 national and provincial traditional villages in the hill and ravine areas of Qiandongnan in Guizhou as the research object and analyzes the spatial distribution characteristics and influencing factors of these traditional villages. The research results on the spatial distribution and characteristics of traditional villages have wide application in rural revitalization, regional development and sustainable management. By analyzing the external forces and internal motivations behind the renewal and development of traditional villages, the research deepens the understanding of these settlements and their cultural significance, enabling traditional societies to better adapt to contemporary challenges. In addition, the results provide a quantitative basis for studying the adaptability of site selection and provide operational technical guidance for village renewal, planning and construction. This has implications for ongoing discussions about how local cultural and historical experiences can influence the renewed design of traditional settlement areas and how digital means can facilitate the updating of the design of traditional buildings. The spatial distribution and characteristics of traditional
villages also have implications for tourism development and spatial planning. Empirical research on the spatial distribution of rural tourism development provides a guide for future spatial planning and construction of all-for-one tourism in other areas, thereby contributing to the sustainable development of tourism and the preservation of cultural heritage. Furthermore, the results highlight differences in relevant geographical and environmental factors, levels of economic development and local political support, which can inform policy making and regional development strategies. In addition, the research results can be used in the assessment and management of traditional village systems. The research contributes to assessing the extent to which the traditional village system supports socio-cultural dimensions of sustainable land use management and provides insights into the role of traditional village systems in implementing sustainable land use management practices.

5.2 RECOMMENDATION

The findings can serve as a guide for rural revitalization and regional development, helping policymakers and planners make informed decisions to address unbalanced development and revitalize traditional villages in the face of global urbanization challenges. The research results can also contribute to environmental resource management and the vitality of traditional village communities, and highlight the importance of positive political organization as a guarantee for realizing the integration of traditional villages. In addition, the results provide a quantitative basis for studying the adaptability of site selection and provide operational technical guidance for village renewal, planning and construction, which may be valuable to urban planners and community stakeholders. Policymakers should promote rural electrification to improve the welfare of people in rural areas, which have larger populations and households than urban areas, by implementing electrification with renewable energy. Urban planners and policymakers can use the empirical research on spatial distribution to guide future spatial planning and construction for all-for-one tourism and rural tourism development in various areas.

5.3 LIMITATIONS

The research findings on the spatial distribution and characteristics of traditional villages may have limitations in terms of data collection, methodological issues and the generalizability of the results. These limitations should be considered by policymakers, urban
planners, and community stakeholders when interpreting and applying the research findings. First, policymakers and researchers should recognize the potential limitations in data collection, such as data corrections that may affect the validity and generalizability of the results. Second, urban planners and researchers should be aware of methodological issues, such as the lack of real-world conditions in experiments, which may affect the applicability of research findings to complex real-world environments. Furthermore, when planning for sustainable development and urban ecosystem services, policymakers should consider the potential constraints related to community engagement, municipal liability and public safety.

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