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Quantitative Analysis of the Evolution of Production–Living–Ecological Space in Traditional Villages: A Comparative Study of Rural Areas in Tibet

Yue Tang [1], Li Zhu [1,*] and Xiaokang Wang [2]

[1] School of Architecture and Art, Central South University, Changsha 410083, China; 211301005@csu.edu.cn
[2] Research Center of Chinese Village Culture, Central South University, Changsha 410083, China; 220501002@csu.edu.cn
* Correspondence: 207131@csu.edu.cn

Abstract: Since the introduction of the rural revitalization strategy by the 19th National Congress of the Communist Party of China in 2017, there have been significant transformations in the production–living–ecological space (PLES) within villages. Evaluating and enhancing villages' PLES are crucial for fostering sustainable development. Therefore, this study utilized a multi-scale environmental assessment model and mathematical approach to conduct horizontal and vertical nested correlation analyses of indicators at different levels through a path analysis, a Spearman correlation analysis, a variance analysis, the entropy weight method, data simulation, and other methods to establish a "three-dimensional" comprehensive evaluation system for traditional village PLES. The findings indicate the following: (1) The ecological space of traditional villages in Tibet significantly impacts the overall environment of the PLES, with the components' impact ranked as follows: ecological space > production space > living space. Furthermore, industry and tourism resources show a significant positive correlation with traditional villages' PLES; (2) There are no significant differences in natural environmental factors, such as air relative humidity, temperature, humidity index, and wind efficiency index among traditional villages in neighboring cities in Tibet. However, they all possess profound ecological and cultural heritage; (3) There are notable disparities in living space between traditional villages in Lhasa and Nyingchi, indicating unbalanced development. It is evident that traditional village construction should not only focus on the development of certain PLES but also pay attention to the balanced development of the overall spatial environment. This study holds great significance for enhancing the living environment of traditional villages in Tibet and promoting sustainable development through protection efforts in these villages.

Keywords: traditional villages; production–living–ecological space; quantitative evaluation; spatial environment; sustainable development

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1. Introduction

Traditional villages are abundant in natural, historical, social, and cultural resources [1,2]. They serve as living remnants of China's agricultural civilization, which spanned thousands of years, and represent a distinct type of village [3]. In comparison to ordinary villages, traditional villages boast a wealth of ancient buildings and folk culture that hold significant historical, cultural, economic, and social value [4]. These unique cultural heritages rely on appropriate preservation methods to be remembered, embodying the integrated wisdom of human production and life alongside the ecological environment. Production–living–ecological space (PLES) is a fundamental space for human activities [5]. Production space (PS) primarily serves as a platform for production functions, including the creation of material products and services. Living space (LS) focuses on meeting the needs of human life, sustainable consumption, and entertainment. Ecological space (ES) plays a key role in providing ecological products and services by maintaining natural conditions necessary for human survival [6]. In 2012, the Ministry of Housing and Urban-Rural Development issued Guiding Opinions on Strengthening the Protection and Development of Traditional Villages [7]. This document emphasized the importance of protecting and developing traditional villages, as well as improving the production, living, and ecological conditions within these villages. As a result, research on traditional villages has become a significant focus within academic circles and throughout society. Relevant studies have not only promoted village construction practices but have also brought about substantial changes in PLES dynamics [8–10]. However, this progress has also led to increasingly intense spatial contradictions within rural areas notably rural overbuilding, which has significantly impacted local human settlements, natural ecosystems, and landscape environments [11]. The repercussions include encroachment on agricultural land, a loss of biodiversity, and the fragmentation of landscapes. Therefore, it is crucial to study current traditional villages' PLES in order to optimize overall village spatial conditions.

The study of PLES can be traced back to the agricultural management model of Taiwan's PLE model in the early 1980s [12]. Subsequently, in 1987, the World Commission on Environment and Development explicitly proposed the concept of PLE, emphasizing the consensus of "sustainable development". This indicates that the objective of rural PLE development is intricately connected to sustainable development. It underscores the importance of rational resource utilization and environmental protection by harmonizing the interplay between production, daily life, and ecological spaces. The ultimate aim is to achieve balanced advancements in economic, social, and ecological dimensions. With the increasing global focus on agricultural development, both developed and developing nations are placing greater emphasis on rural area advancement. Local governments in developed countries prioritize the integrated development of sustainable ecology and rural economies while simultaneously enhancing the quality of life for their citizens [13,14]. Similarly, medium-developed countries aim to improve the production, living standards, and ecological conditions of villages through initiatives such as "rural revitalization plans" and "small subsidy" systems, which closely resemble China's current rural policies [15]. Some scholars have also proposed that ecological sustainability is fundamental to production and living sustainability, as well as key to coordinating human–land relationships and achieving regional sustainable development [16]. In November 2012, the Report of the 18th National Congress of the Communist Party of China officially introduced the concept of "adjusting spatial structure, promoting intensive and efficient production space, livable and moderate living space, and beautiful ecological space", emphasizing coordinated development in these three areas. In 2017, China's rural revitalization strategy emphasized new requirements, such as having prosperous industry, a livable environment, and a rich life along its overall developmental route—pushing PLES concepts to new heights [17]. Therefore, it is an inevitable trend for traditional villages in China to be combined with sustainable development concepts.

Currently, research on traditional village spaces primarily focuses on the following aspects: first, the preservation of both material and intangible cultural heritage within villages [18,19]; second, the distribution characteristics of rural areas within a regional context [20–24], along with an analysis of the factors influencing the evolution of rural spatial forms [25,26]; and third, efforts to enhance the existing built environment in rural regions [27–32] and to foster economic development through rural tourism initiatives [33–35]. The methodologies employed in these studies predominantly involve quantitative analysis [36–38]. Y Sun and Q Ou established a research path of "evaluation—regionalization—zone evolution—comprehensive protection" based on PLES. They proposed three conservation strategies: traditional architectural elements' preservation, parallel conservation and development, and authenticity preservation to protect the traditional relics and cultural landscape of Hakka villages in Meicheng, Guangdong Province [39]. Some scholars also analyze the spatial reconstruction of traditional villages on three levels: material space, social space, and cultural space [40]. Wang H and Chiou S used field survey data and maps from Dai-inhabited areas in Xishuangbanna, Yunnan Province as data sources to analyze the spatial cultural connotation of Dai villages and the concept of "adapting to local conditions and coexisting with nature" through spatial form factors [41]. Kong L and Xu X et al. utilized fuzzy comprehensive assessment methods to build a traditional village life protection evaluation system [42], while Deng C and Huang Z et al. used a one-way ANOVA and Pearson correlation coefficient analysis to study the relationship between vegetation structure and diversity for protecting biodiversity in traditional villages in karst areas [43].

A PLES study was conducted on a traditional village in Tibet, where the population distribution is heavily affected by natural geographical conditions. Relevant data were obtained through open-source databases and software simulations. Various analysis methods including a path analysis, an analysis of variance, non-parametric tests, a correlation analysis, and the entropy weight method were used as the main analytical tools to quantitatively analyze the horizontal and vertical correlations of indicators at different levels.

A comprehensive evaluation framework of Tibetan traditional village PLES was established. Our research is valuable for optimizing and improving the overall environmental comfort of traditional villages in Tibet, as well as for promoting their healthy development. Furthermore, our research is also relevant to the evaluation and enhancement of the ecological environment for production and living spaces in ordinary villages in Tibet. These areas continue to grapple with the tension between preserving cultural traditions and adopting modern lifestyles [44].

2. Materials and Methods

2.1. Study Area

The research team selected four national traditional villages with typical characteristics in Lhasa and Nyingchi in the Tibet Autonomous Region for case study. Xizang Autonomous Region is one of the five ethnic minority autonomous regions in China, located in the southwest part of the Qinghai-Tibet Plateau. It spans between 26°50′ and 36°53′ north latitude and 78°25′ and 99°06′ east longitude, with an average elevation of over 4000 m. Covering an area of 1.2028 million square kilometers, it has jurisdiction over seven prefecture-level administrative units, including six prefecture-level cities and one region. As of the end of 2023, the permanent population of the Tibet Autonomous Region was 3.65 million. The traditional villages selected for this study are Tunda Village (TDV) and Chikang Village (CKV) in Lhasa City, as well as Cuogao Village (CGV) and Zhaxigang Village (ZXGV) in Nyingchi City. The basic information is shown in Figure 1 and Table 1.

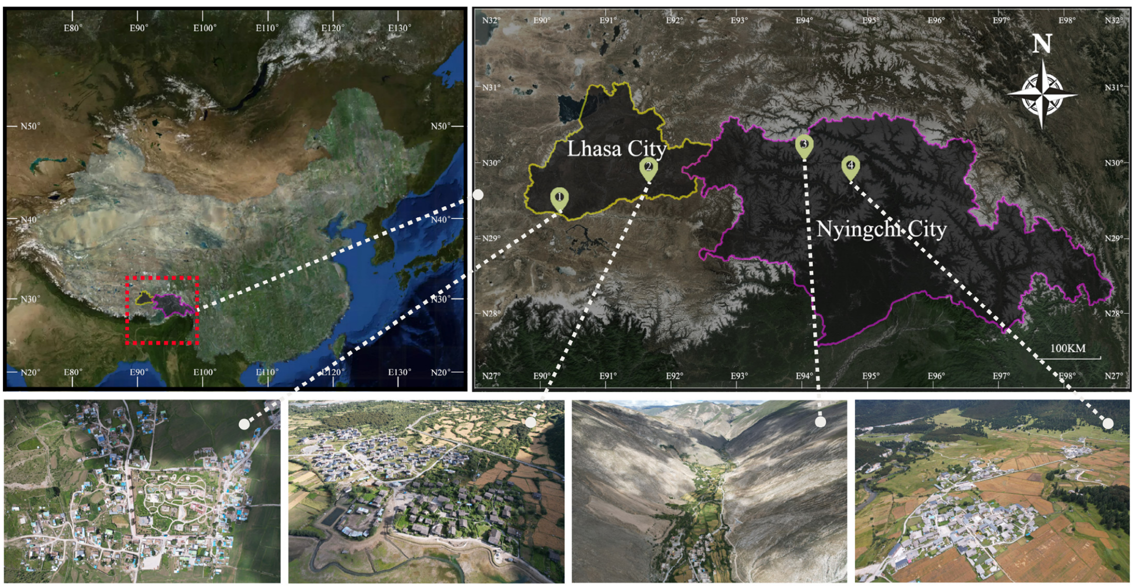


Figure 1. The research object's distribution area in this study.

Table 1. Basic information on traditional villages.

Village Name	Geographical Position	Grade	Basic Information and Features
TDV	Tumba Township, Nimu County, Lhasa City	National level	The village, with a population of 1158 (2022) and covering an area of approximately 97,500 mu, is primarily engaged in Tibetan incense manufacturing and tourism. It boasts a wealth of cultural relics, including the former residence of Tumi Sambuza—a national key cultural relic, as well as Tibetan incense-making skills—recognized as national intangible cultural heritage.
CKV	Jiama Township, Mozhugongka County, Lhasa City	National level	The village, with a population of 1683 people (2022) and an area of approximately 90,000 mu, is primarily engaged in agriculture, animal husbandry, mining, and tourism. CKV is renowned as one of the best-preserved famous estates in Tibet and is also recognized as the birthplace of Songtsen Gampo, the first Tibetan king. The village still retains some of the manor's unique features such as walls, Linka, white towers, temples, and so on.
ZXGV	Lulang Town, Bayi District, Nyingchi City	National level	With a population of 312 (2022), the village covers an area of about 7200 mu, and its primary industry is tourism. ZXGV has a plateau mountain climate, characterized by low annual temperatures, short sunshine hours, and significant temperature differences between day and night. The crops yield fruit once a year.
CGV	Cuogao Township, Gongbujiangda County, Nyingchi City	National level	The village of CGV, located in the Gongbu area, has a population of 437 (2022) and covers an area of approximately 36,060 mu. Its primary industries include mining and tourism. Notably, CGV is the sole village in the Gongbu region that has meticulously preserved the traditional layout of Tibetan villages, encompassing architectural styles of folk houses, customs, culture, and beliefs.

2.2. Data Source

The research data were primarily sourced from open-access databases, software simulation analyses, and comprehensive literature reviews. This study received support from both local government entities and the public.

Index data D1–D8, D29–D32, and D46 were obtained from village committees and the public open platform of the Digital Museum of Traditional Chinese Villages [45]. Data D16–D20, D26–D28, and D42 were acquired from China's National Geographic Information Public Service Open Platform [46] and were simulated in combination with space syntax software Depthmap-Beta 1.0 and Computer Aided Design 2021 (Figures 2 and 3). Data D9–D15 and D21–D24 were obtained through literature review and combined with Baidu Map's public open platform. Data D33–D41 is from the European Centre for Medium-Range Weather Forecasts public open-source database, the Famine Early Warning Systems Network Land Data Assimilation System public open-source database, NASA Earth Observations' public open-source database, and mathematical model calculations. Data D43–D45 and D48 are from publicity reports of Lhasa City Cultural Bureau and Nyingchi City Cultural Bureau, respectively, while D47 is from a publicity report of Traditional Village Protection and Development Research Center [47]. The primary year for collecting the index data was 2022.

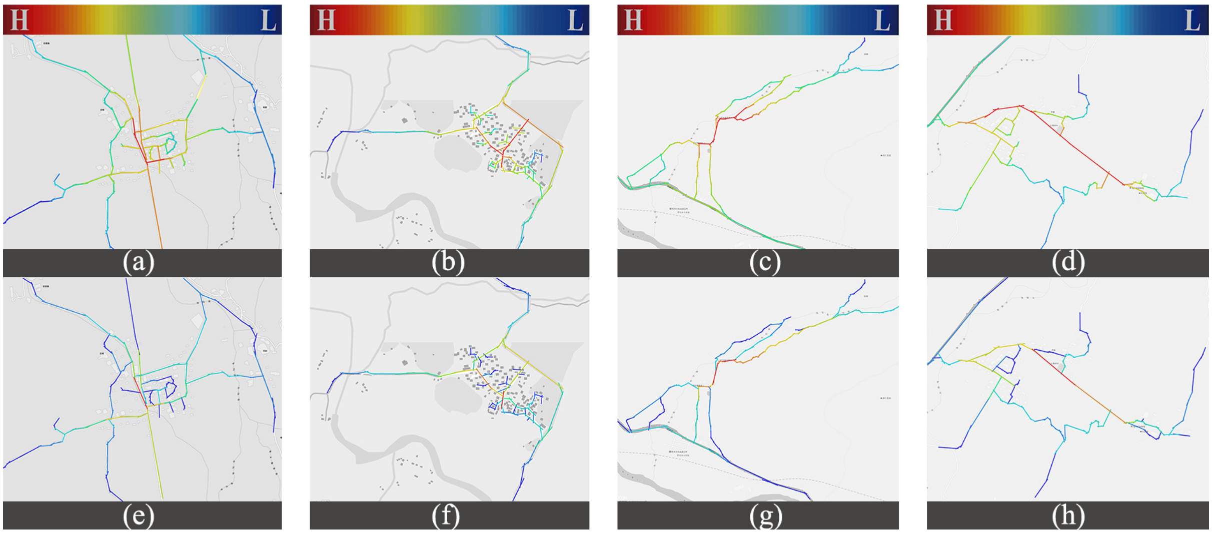


Figure 2. Analysis of the degree of integration and selection in traditional villages within the study area. The integration degrees of CKV, CGV, TDV, and ZXGV are represented by (**a**–**d**), respectively; The choice degrees of CKV, CGV, TDV, and ZXGV are represented by (**e**–**h**), respectively. (If the color of the axis is closer to red, the overall level of integration and selection is higher, indicating increased accessibility. Conversely, if the color is closer to blue, it suggests a lower level of integration and selection).

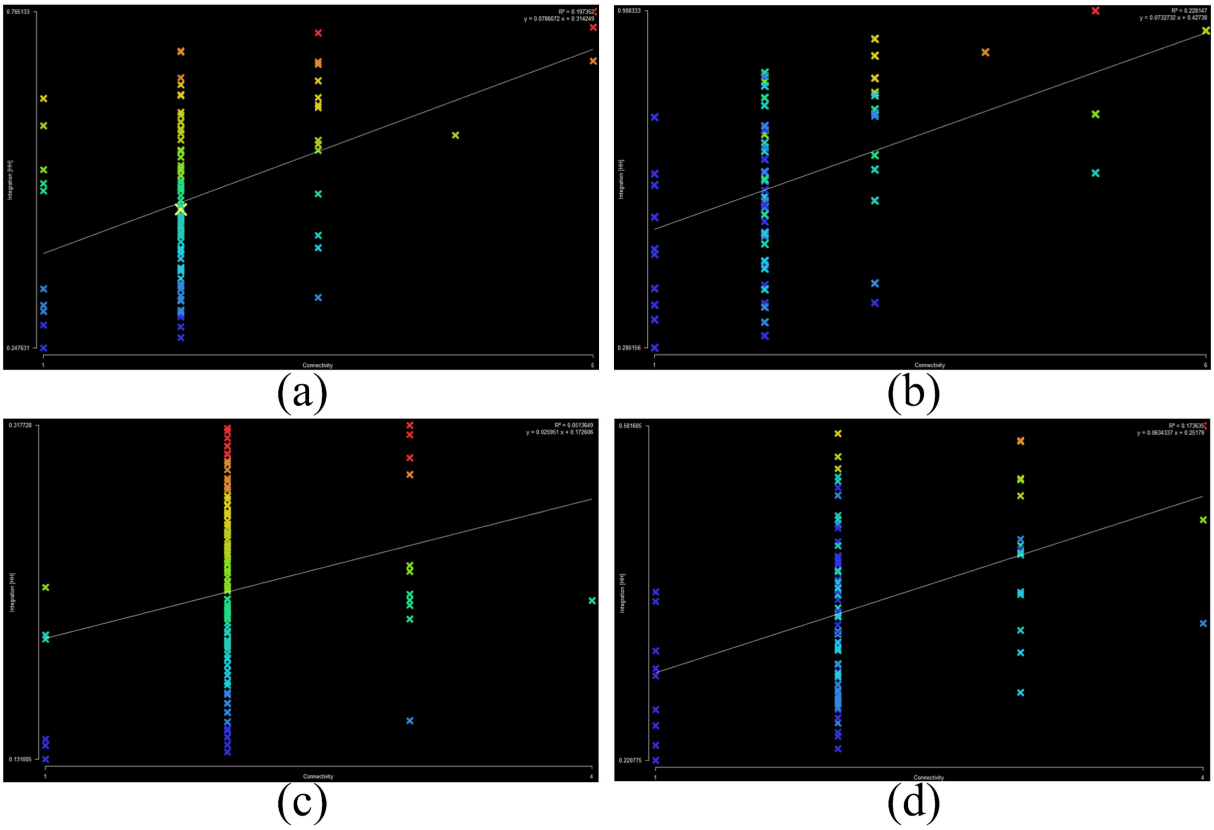


Figure 3. Comprehensibility of the village and its current situation. The comprehensibility values of CKV, CGV, TDV, and ZXGV are represented by (**a**–**d**), respectively. (Comprehensibility refers to the extent to which individuals can understand spatial arrangements while navigating through a village. Generally, when the value of R is less than 0.5, it becomes challenging to discern the non-core areas within the village. Each colored point signifies the connection value of an axis. A deeper red hue indicates a higher connection value, suggesting that the space exhibits greater permeability).

2.3. Methods

The research method of this paper is based on a multi-scale environmental assessment model and mathematical model, and horizontal and vertical nested correlation analyses of indicators at different levels are carried out to build a traditional village PLES comprehensive evaluation system. The main steps are as follows. First, reliability and validity are used to analyze data reliability, and Z-score is adopted for data pre-processing. Secondly, the hypothesis of the model is verified by path analysis, and the correlation of indicators is tested by homogeneity of variance analysis and non-parametric test. In addition, Spearman correlation analysis, independent sample *t*-test analysis and entropy weight method were used to analyze the difference and weight index of evaluation indicators. Finally, the PLES index was calculated by integrating the weighted index coefficients of the above research methods. The research method strictly follows the statistical method of "reliability and validity analysis and Z-score unified standardization" to ensure the objectivity of the analysis.

2.3.1. Construction of Comprehensive Evaluation Framework

The specific evaluation process is shown in Figure 4.

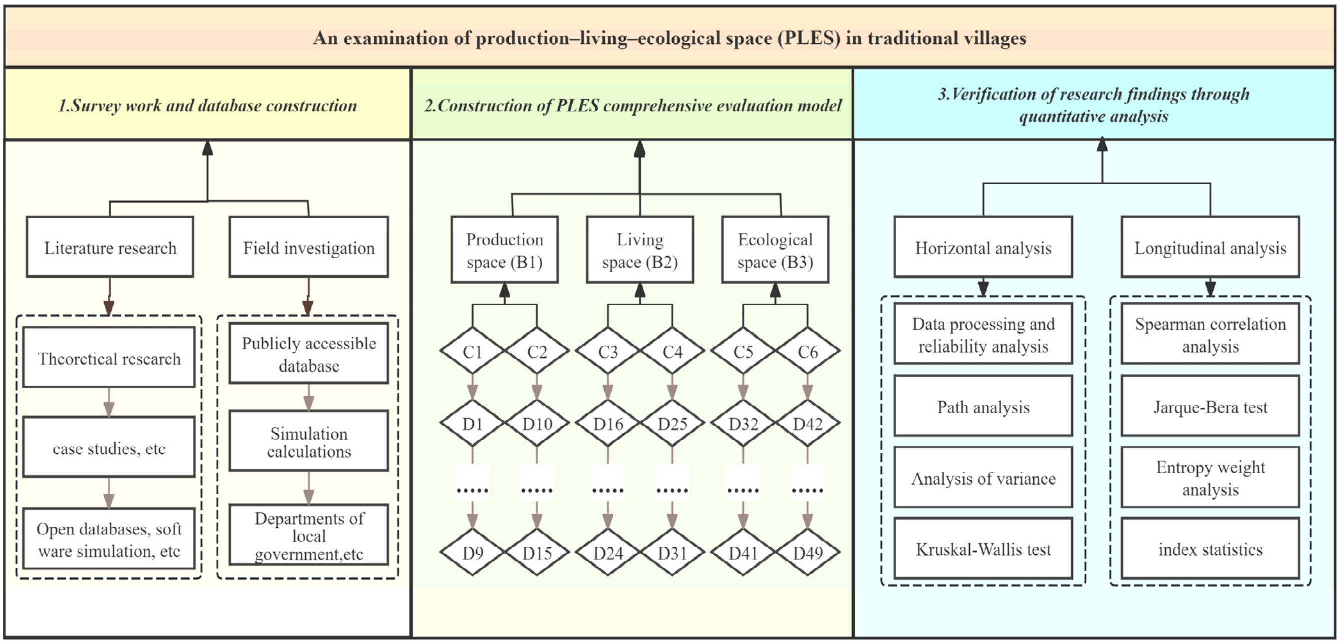


Figure 4. Flowchart for the comprehensive evaluation system.

2.3.2. Index Screening

Through consultation with experts in the field of traditional village research, managers of village management institutions, and representatives of villagers, we conducted an analysis on and categorized the collected data. This was performed in conjunction with relevant evaluation indicators [48–51], such as village economic production [52,53], village living environment [54,55], and village ecological environment [56]. A total of fifty-eight evaluation indicators were finalized, which are derived from three major categories (layer B), six medium categories (layer C), and forty-nine small categories (layer D), as shown in Table 2.

Production space B1 encompasses the economic vitality of village C1 and the surrounding economic potential of C2, which collectively reflect the overall economic development level of the village [57]. Within C1, a larger village area (D1), cultivated land area (D2), total population (D3), and labor force (D4) indicate a stronger potential for agricultural and economical development as well as village expansion. The village collective annual income (D5) and villager per capita annual income (D6) reflect the comprehensive economic income level of the village each year. Additionally, a higher number of leading industries (D7), B&Bs/hotels (D8), and scenic spots (D9) in a village signify more diversified modes of economic development. In C2, proximity to national highways (D10), stations (D11), airports (D12), and scenic spots (D13), as well as an increased number of scenic spots within 20 km (D14) and higher star ratings for nearby scenic spots (D15), all contribute to greater accessibility of the village in terms of its geographical location, enhanced tourism, and increased frequency of potential economic behaviors.

Table 2. Comprehensive assessment system for PLES environment.

Layer A	Layer B	Layer C	Layer D
Comprehensive evaluation System for PLES	Production space (B1)	The economic vitality of the village (C1)	Village area (D1); Cultivated area (D2); Total population (D3); Labor force (D4); Village collective annual income (D5); Per capita annual income of villagers (D6); Number of leading industries (D7), B&Bs/hotels (D8), and scenic spots in the village (D9).
		The potential of the surrounding economy (C2)	Distance from the nearest national highway (D10), station (D11), airport (D12), and scenic spot/attraction (D13); Number of scenic spots/attractions within 20 km (D14); Star rating of the nearest scenic spot (D15).
	Living space (B2)	Accessibility of transportation (C3)	Accessibility of public spaces in the village (D16), the hospitals/clinics in the village (D17), the schools in the village (D18), the shops in the village (D19), and the village committees (D20); Distance from the town (D21), the prefecture to which it belongs (D22), the city (D23), and the nearest courier station (D24).
		Comprehensive life services (C4)	Number of public spaces and important nodes (D25); Overall village integration degree (D26); Number of village core areas (D27); Continuity of the village core area (D28); Number of hospitals/clinics in the village (D29), schools in the village (D30), and shops in the village (D31).
	Ecological space (B3)	Characteristics of the natural ecological environment (C5)	Altitude (D32); Mean monthly precipitation (D33); Volume of runoff (D34); Average monthly temperature in degrees Celsius (D35); Monthly average relative air humidity (D36); Temperature and humidity index (D37); Mean monthly wind speed (D38); The average monthly sunshine (D39); Wind efficiency index (D40); Vegetation index (D41).
		Characteristics of the human ecological environment (C6)	The continuity of village living patterns (D42); Number of national cultural inheritors (D43), cultural heritages (D44), cultural heritages at district level (D45), and important people in history (D46). Recognized as a national traditional village (D47); National/district-level cultural heritage types (D48); Number of representative heritage buildings (D49).

Note on indicator units: income is in ten thousand CNY, distance is in kilometers, area is in mu, altitude is in meters, precipitation is in mm, temperature is in °C, wind speed is in m/s, sunshine time is in (peak, h), and runoff is in (m^3).

Living space B2 serves as the primary residential, social, and recreational hub for villagers [58], offering convenient transportation C3 and comprehensive life services C4. C3 encompasses indicators of D16–D24, including higher accessibility to public spaces (D16), hospitals/clinics (D17), schools (D18), shops (D19), and the village committee (D20). Proximity to the township (D21), county (D22), city (D23), and nearest post office (D24) directly impacts the convenience of travel and villagers' access to life services. C4 comprises indicators of D25–D31, with a focus on the number of public spaces and important nodes in the village (D25), overall integration degree (D26), number of village core areas (D27), continuity of village core areas (D28), number of hospitals/clinics in the village (D29), number of schools in the village (D30), and number of shops in the village (D31). These factors collectively contribute to improved access to healthcare, education, and other essential resources for villagers.

Ecological space B3 reflects the highly interconnected relationship between the natural ecological environment C5 of traditional villages and the human ecological environment C6 [59]. C5 encompasses various naturally occurring substances and energies in the vicinity of a village, which directly or indirectly impact the survival and development of its inhabitants. Examples include altitude (D32), average monthly precipitation (D33), average monthly runoff (D34), average monthly temperature in degrees Celsius (D35), average monthly relative air humidity (D36), temperature and humidity index (D37), average monthly wind speed (D38), average monthly sunshine duration (D39), wind efficiency index (D40), and average monthly vegetation index (D41). These indicators directly affect traditional village production, crop yields, and human perception of environmental comfort. Xiaotong Fei posits that the characteristics of the humanistic ecological environment (C6) are closely linked to culture, emphasizing the reciprocal relationship between nature and humanity within the context of human life. The cultural ecology of traditional villages is manifested in their historical and cultural context, as evidenced by indicators such as the continuity of village living patterns (D42), the number of national cultural inheritors (D43), national cultural heritages (D44), district cultural heritages (D45), important historical figures (D46), recognition as a national traditional village (D47), types of national/district cultural heritages (D48), and number of representative cultural relics and buildings (D49). These indicators reflect the historical and cultural significance of villages, playing a crucial role in shaping village social order, emotional identity, and collective memory.

2.3.3. Reliability Analysis

Reliability analysis is divided into two parts: reliability analysis and validity analysis. Reliability analysis, also known as Cronbach's alpha, is used to measure the internal consistency of the PLES comprehensive rating scale. A reliability coefficient below 0.35 indicates the scale data have a low level of reliability, while a coefficient above 0.6 suggests the measuring tool has acceptable levels of internal consistency and reliability (as shown in Formula (1)) [60]. If the reliability of the comprehensive evaluation scale is not high, adjustments should be made according to expert suggestions. Validity research aims to analyze the reasonableness of research items. Comprehensive analysis using KMO value, common degree, variance explanation rate value, factor load coefficient value, and other indicators is conducted to verify the validity level of the data. A KMO value greater than 0.6 indicates that the data are suitable for extracting information [61].

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum S_i^2}{S_x^2}\right) \tag{1}$$

α represents the reliability factor, K denotes the number of test items, S_i^2 signifies the change in scores for all subjects in question i, and S_x^2 stands for the variance in the total score obtained for all subjects.

2.3.4. Standardized Processing of Statistical Data Using Z-Score

In order to ensure the comparability of the results of different dimensions and levels of PLES comprehensive evaluation, it is necessary to perform Z-score standardization by processing the evaluation vector results in SPSS 28.0 software. Standardization involves re-scaling the data so that they have a mean of 0 and a standard deviation of 1, and the conversion formula is shown in Formula (2) as follows:

$$x_{standardized} = \frac{x-\mu}{\sigma} \tag{2}$$

where x represents the raw data, μ denotes the mean of the dataset, and σ signifies the standard deviation of the dataset.

2.3.5. Horizontal Analysis: The Significance of the Assessment Framework and the Differentiation of the Research Object Are Determined

The relevance of the evaluation framework is analyzed using the model path. Path analysis is a special form of structural equation modeling (SEM), which can be used to establish, estimate, and test the causal relationship of the PLES model. The corresponding model expressions are shown in Formulas (3) and (4) [62]. In addition, it is necessary to analyze the distribution pattern of data to determine differences between research objects. If the data are normally distributed and paired with the same variance, parametric tests such as independent samples *t*-test or paired samples *t*-test are used. The Mann–Whitney test is employed when the data are not normally distributed but still paired with similar variances. A significance level of $p < 0.05$ was considered for determining significant differences. If the data exhibit non-normal distribution and do not meet the requirements for homogeneity analysis of variance, non-parametric tests are utilized to analyze differences in index elements among subjects in different groups. Specifically, Mann–Whitney U test was applied for two groups while Kruskal–Wallis test was used for more than two groups [63].

$$Y = \beta_0 + \beta_1 M + \beta_2 X + \varepsilon_3;\ M = \alpha_0 + \alpha_1 X + \varepsilon_2 \tag{3}$$

$$Y = Y_0 + Y_1 X + \varepsilon_1;\ Y_1 = \beta_2 + \alpha_1 \times \beta_1 \tag{4}$$

Y represents the vector of endogenous variables; X represents the vector of exogenous variables directly related to Y; and M represents the intermediate vector between X and Y. α_0, β_0, and Y_0 represent the intercept; ε_1, ε_2, and ε_3 represent the error terms of linear regression; and α_1, β_1, and β_2 are the path coefficients to be estimated, respectively. Y_1 is the total effect; β_2 is a direct effect; and $\alpha_1 \times \beta_1$ is an indirect effect.

2.3.6. Longitudinal Analysis: Correlation of Evaluation Indicators and Determination

The Pearson correlation analysis method was utilized to assess the proximity of two or more variables within the PLES evaluation framework index in order to investigate the interaction mechanism of internal factors [64]. In cases in which the PLES index data did not exhibit normal distribution characteristics, Spearman correlation coefficient analysis was employed. Spearman correlation coefficient analysis serves as the non-parametric counterpart to Pearson correlation coefficient and represents the effect value of non-parametric correlation analysis. The calculation formula is presented in Formula (5) [65].

$$\rho = \frac{\sum_{i=1}^{N} (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{N} (x_i - \overline{x})^2 (y_i - \overline{y})^2}} \tag{5}$$

In the formula, N represents a numerical value; x_i and y_i represent the i values in the x and y rankings, respectively ($1 \leq i \leq N$); $\overline{x}$ and $\overline{y}$ represent the mean values of x and y, respectively.

The PLES index requires verification of the difference in analysis index data and its combination with the index weight coefficient. Firstly, after confirming the normal distribution of the research data, a *t*-test was used to analyze the significance of differences between the index data. Then, following forward or backward data processing, the index weight coefficients with significant differences are calculated using the entropy weight method. The specific calculation steps and formulas are outlined below.

1. Build the original index data matrix;
2. Perform data standardization;
3. Calculate the entropy of the evaluation index;
4. Calculate the coefficient of variation of the evaluation index;
5. Define the weight of the evaluation index;

6. Calculate the value of the sample.

Please refer to Equations (6)–(11) for the calculation formula [66]. Finally, the PLES index for different research objects is calculated, and comparisons are made and analyses are conducted regarding the differences in and causes of the results.

$$X = \{x_{ij}\}_{m\times n} 0 \le i \le m,\ 0 \le j \le n) \tag{6}$$

$$x'_{ij} = \begin{cases} \frac{x_{ij}-x_{ij\min}}{x_{ij\max}-x_{ij\min}} \\ \frac{x_{ij\max}-x_{ij}}{x_{ij\max}-x_{ij\min}} \end{cases} \tag{7}$$

$$y_{ij} = \frac{x'_{ij}}{\sum x'_{ij}}, 0 \le y_{ij} \le 1 \tag{8}$$

$$e_j = -k\sum(y_{ij} \times \ln y_{ij}) = \left(\frac{1}{\ln m}\right)\sum(y_{ij} \times \ln y_{ij}) \tag{9}$$

$$g_j = 1 - e_j;\ w_j = g_j/\Sigma g_j \tag{10}$$

$$f_{ij} = w_j \times x'_{ij};\ f_i = \Sigma f_{ij} \tag{11}$$

where x_{ij} is the indicator value of the jth indicator of the ith program to be evaluated. The product of the weight w_j of the jth indicator and the proximity x'_{ij} of the jth evaluation indicator of the ith sample in the standardized matrix are used as the evaluation value f_{ij} of $x_{ij}j$ and the evaluation value f_i of the ith sample, respectively.

3. Results

3.1. Result of Reliability Analysis

The research data demonstrate good levels of reliability and validity. The Cronbach's alpha reliability analysis indicates that the CITC values of all analysis items were greater than 0.4, suggesting a strong correlation between the analysis items. Furthermore, the data reliability coefficient is 0.699, exceeding the threshold of 0.6 and indicating the research data have an acceptable level of reliability. Additionally, the KMO and Bartlett test results reveal that the common degree value for all research items is higher than 0.4, with a KMO value of 0.717, surpassing the threshold of 0.6 and indicating the effective extraction of information from the research items (Tables 3 and 4).

Table 3. Cronbach's alpha reliability analysis.

Name	Total Correlation of Correction Items (CITC)	Cronbach's Alpha If Item Deleted	Cronbach's α Coefficient
CKV	1.000	0.716	0.699
ZXGV	1.000	0.711	
TDV	1.000	0.628	
CGV	1.000	0.709	
AV	1.000	0.578	
MV	1.000	0.459	
SD	1.000	0.710	

The cronbach's α coefficient exceeding 0.6 suggests that the results of the analysis are valid.

Table 4. KMO and Bartlett tests.

KMO Value		0.717
Bartlett sphericity test	Approximate chi-square	5855.771
	df	21
	p-value	0.000

3.2. Results of Horizontal Analysis: Correlation Analysis Between the Assessment Framework and the Study Object

The results of the path analysis conducted on the evaluation frameworks indicate a significant positive relationship between these frameworks. Specifically, when PS (B1) has an impact on PLES (A), the standardized path coefficient value is 0.000 > 0, and the path demonstrates a significance level of 0.01 (z = 88.694, p = 0.000 < 0.01), suggesting that PS will indeed have a significant positive impact on PLES (A). Similarly, when LS (B2) impacts PLES (A), the standardized path coefficient value is 0.000, with a significance level of 0.01 (z = 88.440, p = 0.000 < 0.01), indicating that LS will also have a significant positive impact on PLES (A). Furthermore, when ES (B3) affects PLES (A), the standardized path coefficient value is 0.704 > 0, with a significance level of 0.05 (z = 1.980, p = 0.048 < 0.05), demonstrating that ES significantly positively influences PLES (A) as well (Figure 5). These findings suggest that an evaluation framework centered around the four traditional villages of TDV, CKV, CGV, and ZXGV has been established, and village PS, LS, and ES all exert significant positive impacts on the overall performance of PLES (Table 5).

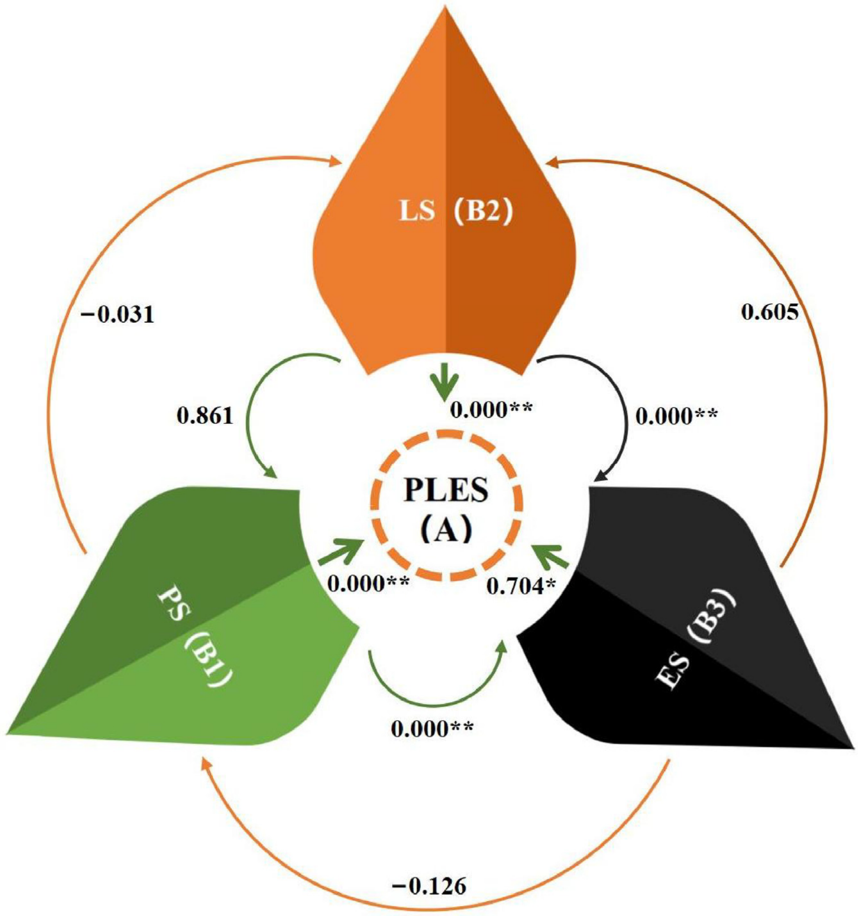


Figure 5. Relationship between PS, LS, ES, and PLES. (Numbers marked with * indicate a general correlation, while numbers marked with ** signify a strong correlation).

Table 5. Model regression coefficient.

X→Y	Non-Standardized Path Coefficient	SE	z (CR Value)	p	Standardized Path Coefficient
PS→PLES	0.000	0.000	88.694	0.000	0.000
LS→PLES	0.000	0.000	88.440	0.000	0.000
ES→PLES	0.364	0.184	1.980	0.048	0.704

Note: → Indicates path influence.

Then, we conducted a homogeneity test of variance to analyze the results of C1–C6 in four traditional villages. The test showed significance ($p < 0.05$), indicating that the volatility of the different sample data varies and does not meet the prerequisite requirements for an ANOVA. Therefore, we utilized the Kruskal–Wallis test statistics to analyze the level of significance of C1–C6 in four traditional villages. The results revealed that the level of significance of TDV was $p = 0.003$, of CKV was $p = 0.009$, of CGV was $p = 0.006$, and of ZXGV was $p = 0.015$—all less than 0.05. This suggests significant differences among the four traditional villages in economic vitality (C1), economic potential (C2), transportation convenience (C3), comprehensive life services (C4), natural ecological environment characteristics (C5), and human ecological environment characteristics (C6) (Tables 6 and 7).

Table 6. Results of the analysis for homogeneity of variance.

	Group (Standard Deviation)						F Value	p Value
	C1 (n = 9)	C2 (n = 6)	C3 (n = 9)	C4 (n = 7)	C5 (n = 10)	C6 (n = 8)		
CKV	0.00	0.00	0.00	0.00	2.21	0.00	3.848	0.006 **
ZXGV	0.01	0.00	0.00	0.00	2.21	0.00	3.844	0.006 **
TDV	0.00	0.00	0.00	0.00	2.21	0.00	3.850	0.006 **
CGV	0.00	0.00	0.00	0.00	2.21	0.00	3.848	0.006 **

** $p < 0.01$.

Table 7. Results of non-parametric test analysis.

	Group Median M, 25% and 75% Quantiles						Kruskal–Wallis Test Statistic H Value	*p* Value
	C1 (n = 9)	C2 (n = 6)	C3 (n = 9)	C4 (n = 7)	C5 (n = 10)	C6 (n = 8)		
CKV	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	15.447	0.009 **
ZXGV	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	14.055	0.015 *
TDV	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	18.279	0.003 **
CGV	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	−0.143 (−0.1, −0.1)	16.429	0.006 **

* $p < 0.05$ ** $p < 0.01$.

3.3. Results of Longitudinal Analysis: The Difference in Evaluation Indices, Calculation of Weight Coefficients, and Analysis of PLES Index

A Spearman correlation analysis was conducted to examine the relationship between CKV, ZXGV, TDV, and CGV. The results indicated a significant association among the four traditional villages. The phase relationship between CKV and ZXGV, TDV, and CGV is 0.911, 0.709, and 0.900, respectively. Similarly, the phase relationship between ZXGV and TDV, CGV, and CKV is 0.690, 0.929, and 0.911, correspondingly. Furthermore, the phase relationship between TDV and CGV, CKV, and ZXGV is 0.719, 0.709, and 0.690, while the phase relationship between CGV and CKV, ZXGV, and TDV is 0.900, 0.929, and 0719, respectively. The phase relation values of the four villages are all greater than 0, and the *p*-value is less than 0.01, indicating a significant positive correlation (Figure 6).

Then, the results of the Jarque–Bera test we conducted showed that none of the research data exhibited significance ($p > 0.05$), indicating the null hypothesis is accepted and the data conform to a normal distribution (Figure 7). Subsequently, a single-sample *t*-test was performed to analyze differences in indicator data among the four traditional villages. The findings revealed statistically significant variances among D4, D6, D7, D12, D14, D19, D23, and D24 in PS (B1). Additionally, there were statistically significant disparities between

D25, D26, D28, and D31 in LS (B2), as well as among D32, D36, D37, D38, D39, D40, D41, D42, D47, and D49 in ES (B3) (Table 8).

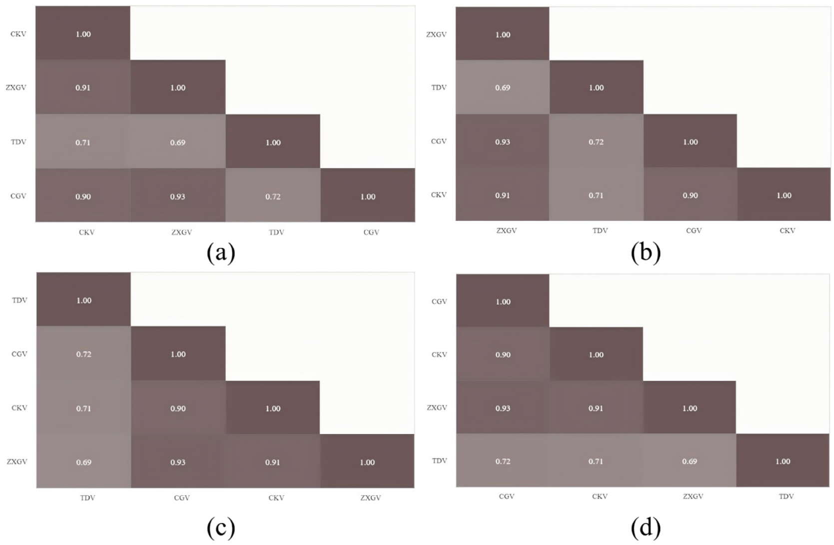


Figure 6. Results of the Spearman correlation analysis conducted among four traditional villages. (**a**) Spearman correlation analysis of CKV with ZXGV, TDV, and CGV; (**b**) Spearman correlation analysis of ZXGV with CGV, TDV, and CKV; (**c**) Spearman correlation analysis of TDV with CGV, CKV, and ZXGV; (**d**) Spearman correlation analysis of CGV with CKV, ZXGV, and TDV.

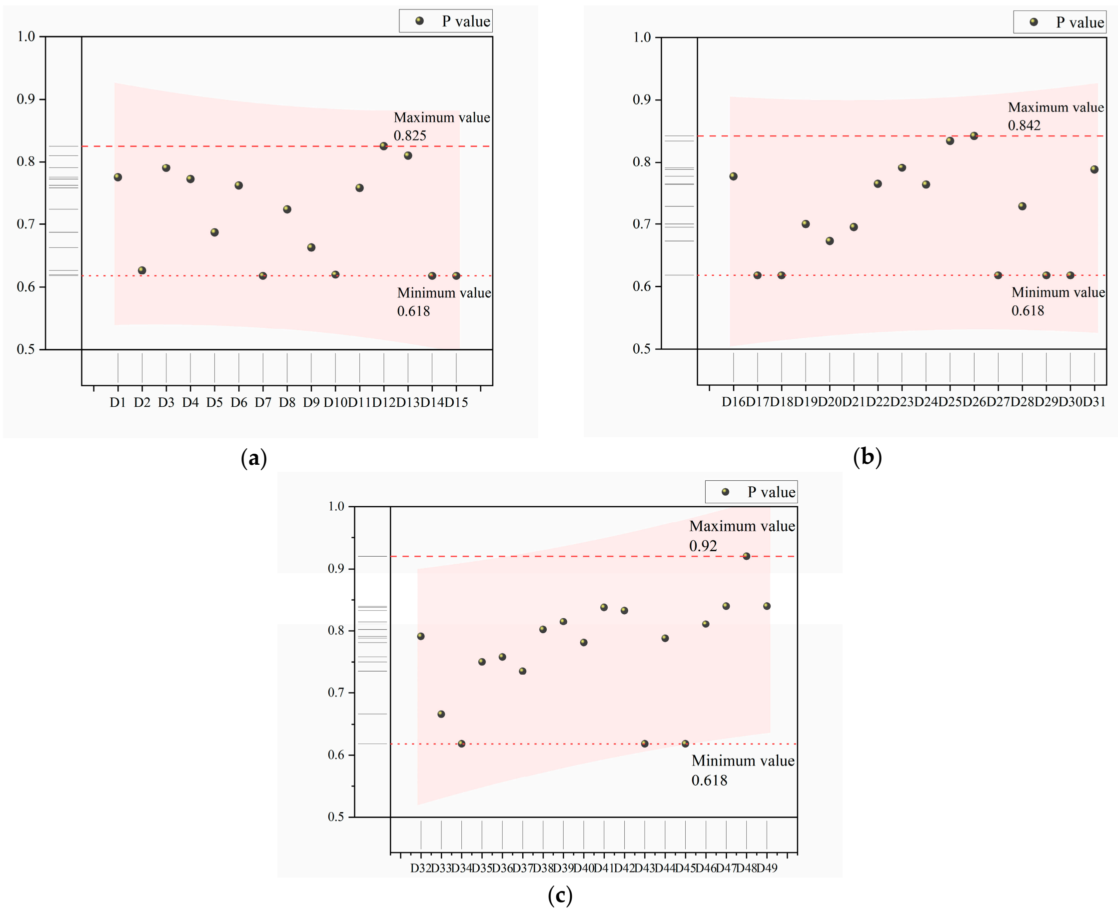


Figure 7. The results of the Jarque–Bera test. (**a**) Analysis results of D1–15 indicators in PS; (**b**) Analysis results of D16–31 indicators in LS; (**c**) Analysis results of D32–49 indicators in ES. (The pink regions illustrate the overarching trend observed in the data).

Table 8. Results of single-sample *t*-test analysis.

Name	Minimum Value	Maximum Value	Mean Value	Standard Deviation	t Value	*p* Value
D4 (labor force)	172.000	707.000	428.750	253.970	3.376	0.043 *
D6 (villager per capita annual income)	0.984	3.300	2.390	0.988	4.839	0.017 *
D7 (number of leading industries)	1.000	2.000	1.250	0.500	5.000	0.015 *
D12 (distance from the nearest airport)	75.800	187.400	123.100	47.433	5.191	0.014 *
D14 (number of scenic spots/attractions within 20 km)	1.000	2.000	1.250	0.500	5.000	0.015 *
D19 (accessibility of the shops in the village)	1836.000	5625.000	3165.250	1691.379	3.743	0.033 *
D23 (distance from the city)	72.000	140.000	99.425	32.006	6.213	0.008 **
D24 (distance from the nearest courier station)	5.500	19.900	14.725	6.686	4.404	0.022 *
D25 (number of public spaces and important nodes)	2.000	9.000	5.000	2.944	3.397	0.043 *
D26 (overall village integration degree)	0.318	0.908	0.643	0.255	5.047	0.015 *
D28 (continuity of the village core area)	0.051	0.228	0.163	0.077	4.199	0.025 *
D31 (number of the shops in the village)	1.000	3.000	1.750	0.957	3.656	0.035 *
D32 (altitude)	3300.000	3850.000	3622.500	258.588	28.018	0.000 **
D36 (monthly average relative air humidity)	40.493	74.757	55.244	17.358	6.365	0.008 **
D37 (temperature and humidity index)	36.052	46.217	41.589	5.354	15.535	0.001 **
D38 (mean monthly wind speed)	2.391	4.308	3.258	0.875	7.449	0.005 **
D39 (the average monthly sunshine)	177.714	214.772	198.460	16.570	23.954	0.000 **
D40 (wind efficiency index)	748.315	1074.216	949.754	148.933	12.754	0.001 **
D41 (vegetation index)	0.208	0.491	0.365	0.122	5.964	0.009 **
D42 (the continuity of village living patterns)	0.310	0.819	0.596	0.221	5.393	0.012 *
D47 (recognition as a national traditional village)	2012.000	2016.000	2013.750	1.708	2358.263	0.000 **
D49 (number of representative heritage buildings)	1.000	5.000	2.750	1.708	3.220	0.049 *

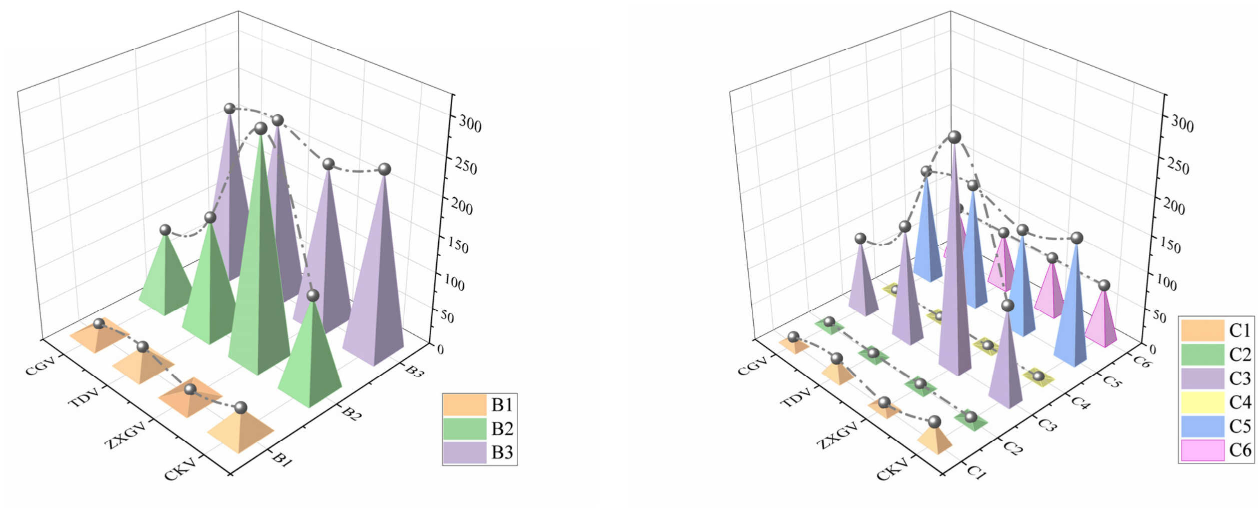
* $p < 0.05$ ** $p < 0.01$.

Therefore, following the forward and reverse processing of the aforementioned indicator data, the results of the entropy weight analysis indicate that the weight coefficients of each index are as follows in descending order: (D7 = D14) > D31 > D36 > D24 > D19 > D38 > D37 > D4 > (D49 = D47) > D25 > D32 > D39 > D41> D23 > D26 > D42 > D40 > D12 > D6 > D28 (Table 9).

Table 9. The entropy method is utilized for computing the weight outcomes.

Item	Information Entropy	Information Utility	Weight Coefficient
D4	0.6861	0.3139	4.12%
D6	0.7989	0.2011	2.64%
D7	0.1171	0.8829	11.58%
D12	0.7893	0.2107	2.76%
D14	0.1171	0.8829	11.58%
D19	0.6006	0.3994	5.24%
D23	0.7699	0.2301	3.02%
D24	0.5453	0.4547	5.96%
D25	0.7170	0.2830	3.71%
D26	0.7750	0.2250	2.95%
D28	0.7999	0.2001	2.62%
D31	0.5108	0.4892	6.42%
D32	0.7571	0.2429	3.19%
D36	0.5295	0.4705	6.17%
D37	0.6808	0.3192	4.19%
D38	0.6721	0.3279	4.30%
D39	0.7593	0.2407	3.16%
D40	0.7788	0.2212	2.90%
D41	0.7662	0.2338	3.07%
D42	0.7779	0.2221	2.91%
D47	0.7140	0.2860	3.75%
D49	0.7140	0.2860	3.75%

According to the index weight coefficient, we combined the data of four traditional villages, CKV, ZXGV, TDV, and CGV, and conducted a statistical analysis of the PLES index. The results of the PLES (Layer A) and (Layer B) dimensional analysis showed that the four traditional villages could be ranked according to the total index of PLES (A) from high to low as follows: ZXGV (522.4204484) > TDV (420.2742258) > CKV (399.0147645) > CGV (344.7955538). The average index was 421.6262481. The PLES indices of B1, B2, and B3 for the four traditional villages were as follows: ZXGV (B1 = 10.38644776, B2 = 297.6562107, B3 = 214.3777899); TDV (B1 = 26.18824982, B2 = 154.3080713, B3 = 239.7779047); CKV (B1 = 32.88163228, B2 = 126.2392135, B3 = 239.8939188); and CGV (B1 = 16.18756997, B2 = 101.8796099, B3 = 226.7283739) (Figure 8a).



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

Figure 8. Analysis of the index for Layer B and Layer C. (**a**) Analysis of the index for Layer B; (**b**) Analysis of the index for Layer C. (The cones of the same color signify the same indicator across the four villages, while the spheres denote the values associated with each indicator. The curves that connect these spheres illustrate the trends corresponding to this set of indicators).

The results indicate that the B1 index for TDV's and CKV's production spaces in Lhasa is significantly higher than those of ZXGV and CGV in Nyingchi City, suggesting that traditional villages in Lhasa have more favorable production spaces. There are substantial differences in the B2 index among the four traditional villages, with the disparities in living space comfort being particularly prominent when compared to B1 and B3. The ecological spatial B3 indices of the four traditional villages are relatively similar, indicating that there is not a significant difference in ecological environment between the different villages.

The index for the village PLES is significantly influenced by various factors (Figure 8b). The C2 index of CGV was found to be the highest, although the overall index was the lowest among all villages. However, when compared with the other three villages, CGV demonstrated superiority in terms of proximity to the nearest airport (D12) and number of scenic spots (D14) within a 20 km radius. Additionally, ZXGV exhibited the highest C3 index, indicating better accessibility to shops in the village (D19), a shorter distance from the city (D23), a closer proximity to the nearest express station (D24), and more convenient travel options for daily life. Furthermore, both ZXGV and TDV had higher C4 indices, suggesting that they have a more reasonable distribution of public space and more important nodes (D25), a greater overall integration degree (D26), an increased continuity of the village core area (D28), and a larger number of shops offering comprehensive life services (D31). The C5 index of ZXGV is the lowest, while that of CKV is the highest. This indicates significant differences in altitude (D32), monthly average relative air humidity (D36), temperature and humidity index (D37), monthly average wind speed (D38), monthly average sunshine time (D39), wind efficiency index (D40), and monthly average vegetation index (D41) between the villages of ZXGV and CKV, highlighting the distinct characteristics of their natural environments. The C6 index of the four villages is close, indicating little difference in the continuity of village residence patterns (D42), recognition as a national traditional village

(D47), and the number of representative cultural relics and buildings (D49). Furthermore, all villages have profound cultural heritage.

4. Discussion

In this section, we present a thorough analysis of the research findings, examine the influencing mechanisms and related issues concerning the Tibetan traditional villages' PLESs, and propose suitable strategies for improvement.

Through the analysis, it is found that the traditional villages' PLESs in Tibet are jointly determined by PS, LS, and ES, which is consistent with the existing research results in other regions and verifies the rationality of the evaluation model constructed in this research. The ranking of the influence of PS, LS, and ES on PLES is ES > PS > LS, respectively, which is consistent with the existing research results in other regions [67,68]. This means that ES between traditional villages has the most significant impact on the overall environment. Special attention should be paid to improving the ecological environment of villages when optimizing village space, and the concept of green development should lead the governance and optimization of rural ecological environments. For example, we should prevent pollution and reduce emissions at the source of production to reduce the damage to natural resources such as air, water, land, and trees. In addition, we should instruct villagers to dispose of garbage and implement the integrated treatment measures of "household collection, village collection, township transportation and county office" in the treatment process. Additionally, we suggest evaluating the grazing bearing capacity of agricultural and pastoral sites, implementing controlled grazing measures, and avoiding excessive grazing to lower damage to the ecological environment. For instance, a pasture can be segmented into multiple plots, and grazing activities can be systematically rotated among these plots to ensure that each area receives adequate rest and recovery time. Grazing is restricted during the spring greening period and the autumn fruiting period of grasses to facilitate optimal grassland recovery.

Even though ES has the strongest influence on PLES, the B3 index of the four villages is relatively close, which means that the average air relative humidity, temperature and humidity index, wind efficiency index, and other natural environment influencing factors between the four villages are not significantly different, and all of them have profound human and ecological heritage. This indicates that the ESs among the four villages did not exhibit a markedly pronounced disparity. Therefore, CKV, TDV, ZXGV, and CGV should pay attention to the optimization of PS and LS while improving ESs in future rural construction.

The development of industry and tourism has significantly impacted traditional Tibetan villages. For instance, TDV primarily focuses on the production of handmade Tibetan incense and rural tourism. It is important to note that the foundation for this industrial development is the avoidance of serious environmental pollution in rural areas. This finding aligns with existing research conducted in other regions [69]. Our research found that compared with other influencing factors, the proportion of traditional village industry and surrounding scenic area resources in Lhasa and Nyingchi was the highest. This finding is also consistent with our field research results. The field research revealed that all four villages have leading industries, while relying on surrounding scenic spots to develop tourism. Therefore, the development of rural tourism in traditional villages should not be limited to a single village itself, but should be combined with the surrounding scenic spots' resources to achieve integrated and comprehensive development.

The index of the traditional village PLES in Lhasa is lower than that of Nyingchi City, which has not been included in existing research. According to the data from the Tibet Statistical Yearbook 2022, Lhasa City exhibits a higher degree of urbanization compared to Nyingchi City. However, the index of PLES for traditional villages in Lhasa does not significantly surpass that for traditional villages in Nyingchi City. This indicates a mismatch between the overall development level of Lhasa and traditional villages, highlighting the need for more attention to be paid to the development of traditional villages through policies and financial support.

When the LS of a traditional village is well constructed and the PS and ES environment are relatively ordinary, it can significantly affect the overall environment. This finding aligns with existing research from other regions [70]. The highest index among four traditional villages is that of ZXGV. Compared with the other three villages, ZXGV's B1 and B3 indices are lower, but its B2 index is higher. This suggests that there is a significant difference in LS development between traditional villages in Lhasa and Nyingchi, leading to unbalanced overall development within ZXGV's PLES. Therefore, this also emphasizes that traditional village construction should not only focus on developing certain spaces but should prioritize balanced development across all areas.

The current research findings exhibit several shortcomings, including a limited focus on the comfort of villagers' daily lives, inadequate attention on rural areas facing harsh environmental conditions, and an insufficient systematic application of research methodologies. Firstly, most studies focus on the protection of historical and cultural heritage in traditional villages, while paying little attention to the convenience of villagers' daily travels, the village's economic production potential, and the livable ecological environment. Secondly, the majority of relevant studies concentrate on traditional villages in low-altitude plain areas with a comfortable climate, neglecting high-altitude areas with fewer traditional villages, an unfavorable ecological environment, and low levels of livability. Thirdly, despite diverse research methods being used, there is a lack of a systematic and comprehensive evaluation framework. These deficiencies will be corrected in a future study.

Further Research

Accordingly, there is still room for further progress. Firstly, the sample size of research objects can be further supplemented. Due to the lack of existing research on traditional villages in Tibet and the vast area of Tibet, the number of traditional villages is small and their distribution is relatively scattered, which present certain obstacles to the collection of research samples. Secondly, the comfort of the indoor space of village dwellings can be included in relevant research. Due to a large number of village dwellings and the fact that indoor spaces belong to private villagers, it is difficult for researchers to enter these areas to collect data. As a result, there is a relatively small amount of indoor spatial data collected in this study, and these data have not been included. Therefore, future studies will aim to increase sample sizes and incorporate residential environment data from traditional villages in Tibet so as to further explore the influencing factors on the overall environmental conditions within traditional Tibetan villages, ultimately guiding better protection and development strategies for village spaces.

5. Conclusions

The main conclusions are as follows:

(1) The impact of PS and LS on the PLESs in traditional villages in Tibet is lower than that of ES. This suggests that traditional villages should prioritize the improvement of their environment during development and construction. Although ES has a more significant impact on PLES, the small difference in the ES index between villages indicates that there is no significant difference in natural ecological features such as temperature, humidity, and wind efficiency between traditional villages in Lhasa and Nyingchi City. Both villages have a wealth of cultural heritage. Therefore, improving ES remains an important issue for traditional villages in Tibet.

(2) Relying on industry and tourism is a typical feature of traditional villages in Tibet. The proportion of traditional village industry and surrounding scenic area resources in Lhasa and Nyingchi is the highest, with leading industries present in both areas. These villages also rely on surrounding scenic areas to develop tourism. This provides inspiration for the development of rural tourism in other traditional villages. Rural tourism should not only focus on the village itself, but also integrate surrounding tourist resources to create

interconnected tourist routes and diverse scenic experiences. It is important to acknowledge the potential conflict between industry and tourism and prioritize traditional industries that depend on manual skills, which tend to have a lesser environmental impact compared to industrial sectors. Concurrently, local governments and enterprises must implement appropriate measures for the real-time monitoring of industrial impacts on the environment in order to mitigate any adverse effects that industry may have on tourism.

(3) There is a significant disparity in the index for living space (LS) between traditional villages in Lhasa and Nyingchi. This indicates that the development of LS in traditional villages is unbalanced between the two cities. When the development of LS in a traditional village surpasses that of PS and ES, it significantly impacts the overall PLES. Therefore, this research result prompts us to reflect on the fact that the development and construction of traditional villages should not solely focus on individual aspects such as PS, LS, and ES, but rather emphasize balanced development across all aspects of the traditional villages' PLESs. It is important to emphasize that, in the context of balanced rural PLES development, the primary objective of PS advancement should be to minimize ecological impacts while achieving a synergistic outcome that benefits both economic and ecological interests. Industries characterized by high levels of pollution, such as chemical manufacturing and heavy metal smelting—which are particularly likely to cause soil and water contamination—should not be prioritized. If the development of PS is in conflict with ES or LS, it is imperative to implement an ecological compensation mechanism. This should involve providing economic compensation to farmers and enterprises that prioritize the protection of ecological spaces, thereby encouraging them to adopt more environmentally sustainable production methods.

This study not only offers a comprehensive understanding of the optimization of the human settlement environment in traditional villages in Tibet, but also presents effective methods and suggestions for further research and practical applications. In addition, the sustainable development of rural areas in various countries and regions holds significant importance. On one hand, rural construction must prioritize the balanced development of PS, LS, and ES. On the other hand, during the developmental process, it is essential to actively cultivate industries that are characteristic of the local context while being mindful of potential conflicts between industrial activities and the ecological environment.

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