Study on spatial diversity and influencing factors of Tunpu settlement in Qianzhong

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Abstract

The Qianzhong Tunpu settlement in China is a historical product of the co-evolution and development of the military defense policies of the Ming Dynasty (1368-1644 AD) such as the station troops and station farms and the unique geographical and cultural environment of Guizhou. In order to explore the evolution of the spatial system of traditional settlements in the process of urbanization and its influencing factors, 10 traditional Tunpu settlements in Qianzhong were studied. Drawing on the relevant theories and methods of community ecology to compare and analyze the spatial characteristics and diversity influence mechanisms of Tunpu settlement. The results show that: (1) On the whole, the spatial diversity of the Tunpu settlement in Qianzhong is manifested as the phenomenon that the military Tunpu and the commercial Tunpu are relatively high, and the residential Tunpu is low. In the change of spatial scale, the spatial diversity of commercial Tunpu and military Tunpu settlements shows a decreasing trend from the inside to the outside, while the residential Tunpu shows a increasing trend from the inside to the outside; The spatial diversity between different settlements shows that there is a strong spatial similarity between commercial Tunpu and military Tunpu, and there is significant heterogeneity between residential Tunpu, while spatial heterogeneity fluctuates to varying degrees in scale changes, showing multiple forms of changes. (2) The spatial network and spatial morphology of the Tunpu settlement have a weak influence on the diversity of the α , which is significantly related to the spatial β diversity of the settlement, and is complementary in the correlation between the whittaker and Bray-curtis indices, and the spatial network controls the spatial difference of the Tunpu settlement. (3) The spatial diversity of the Tunpu settlement is affected by the multiple synergies of the natural environment, policy support, socio-economic and cultural customs, and the socio-economic and cultural customs are the dominant factors control the spatial diversity of the Tunpu settlement. This study applies the theory of urban diversity to the exploration of traditional settlement spatial systems, and focuses on the analysis of internal and external driving factors of traditional settlement spaces. The results show that the theory of urban spatial diversity is also applicable to the study of traditional settlement space systems, enriches the traditional settlement space theory, and provides a theoretical reference for scientifically guiding the planning and development of traditional settlements.

1 Introduction

As an important carrier of tangible and intangible cultural heritage^[1], traditional settlements have important heritage values. But with the process of urbanization, traditional settlements are facing the threat of homogenization and disappearance^[2]Urban and rural settlements as an organic whole, we must emphasize the sustainable development and mutual support of both^[3]. Therefore, the study of traditional settlements has also become a hot topic in the current research on urban and rural development. As the carrier of various activities of the settlement, space is of great significance in the structural protection and cultural inheritance of traditional settlements.

There are certain commonalities with urban spatial theory, and village settlements also have complex and diverse spatial systems. Previous research has systematically elaborated the spatial characteristics of traditional settlements from the dimensions of architectural space, spatial forms, layouts, and distributions of traditional settlements^[4,5,6,7,8]. For example, Hu et al.^[9] constructed a three-dimensional spatial system integrating material space, social space and cultural space in Huizhou's traditional settlement, which verified the rationality of the spatial system and showed that the spatial reorganization of traditional settlements is a qualitative transformation of the positive or passive response of the settlement space system to internal and external environmental changes. Although the research results are rich in traditional settlement space, yet few studies have considered the potential impact of traditional settlement space diversity on the stability and evolution of traditional settlement space systems.

Based on the influence of multiple factors such as natural environment, socio-economic and cultural customs, the spatial forms of settlements have regional heterogeneity that is obviously different from that of cities^[10]. The research framework of the development law of rural settlements based on external factors such as nature, economy, society and culture has been widely used in the study of settlement space. For example, Singh et al.^[11] analyzed the influencing factors of land use in the Galval region of rural India from three aspects: ecological, socio-economic and policy influences. Liu Sheng et al.^[12] explained that natural and human activities are important driving forces that cause the spatial differences in the hollowing out of traditional settlements in Lishui. Beatriz and García-Gómez^[13] argued that population is the main reason for the fluctuation of spatial vitality in traditional cultural regions. Furthermore, some scholars have found that the human-land relationship plays an important driving role in the evolution of the spatial patterns of traditional settlements^[1]. The studies mentioned above showed that the settlement space is driven by multiple aspects. But rural settlements have a law with strong bottom-up and self-organization model, and spatial change is a dynamic process of multiple driving forces affecting multiple dimensions such as material space, economic development and social function^[14]. The exploration of settlement space should not only start from external factors, but also focus on the search for the composition of the village form space itself^[15]. However, only refer external indicators as a way to discuss the development law of traditional settlement space is easy to ignore the driving force of the spatial organization structure law on the evolution and adaptation mechanism of the space system, which has certain limitations. Therefore, it is necessary to study the role of rural settlement spatial networks and spatial forms on the spatial diversity laws of traditional settlements.

Studies have been conducted that widely apply biodiversity theories and methods to the joint evaluation of geographical or environmental factors of spatial composition and spatial distribution^[16]. The present studies are based on the α diversity index, with spatial unit division and land use type as the basis for urban and rural settlement diversity research^[17,18,19]. Salvati et al.^[20] defined the urban and rural areas of Athens, Greece according to numerical variations of Shannon-Weiner and Pielou index. Xu et al.^[19] revealed the diversity of urban spatial components and the pattern of urban-rural gradient variations with the α and β diversity index, and verified the applicability of β diversity in the study of urban gradient variation. So, the β diversity index can effectively explain the difference in spatial composition diversity under the spatial distribution gradient. Based on the above research, some scholars have divided the urban space patch to explore the diversity of urban space. For example, Zheng^[21] constructed a spatial diversity evaluation system for spatial diversity, spatial network, environmental system, and the interaction of landscape richness based on the diversity of urban land use, and proved that spatial networks and spatial morphologies have a certain degree of influence on the diversity of spatial land types. Yang^[22] defined spatial diversity as spatial structural diversity, and considered that urban spatial diversity as the material carrier and spatial requirement of the urban "social ecological chain". Whereas, the above research theories all take cities as the research object, and few studies have quantitatively analyzed the spatial diversity of traditional settlements. Different from the high diversity caused by the division of urban mixed patches, the spatial function and type of rural settlements are affected by rural life and production. Therefore, whether urban diversity theory is applicable to the spatial diversity of traditional rural settlements remains to be explored.

Qianzhong area refers to the central part of Guizhou Province in southwest China, which was inhabited by ethnic minorities before the Ming Dynasty with a sparse population. Besides, the influence of Central China culture and government management were extremely weak at that time. The Tunpu settlement is the product of the historical background of the military operations and immigration policies of "transferring the north to conquer the south" and "immigrating the north to the south" under the Ming Dynasty (1368-1644 AD) military defense system^[23]. Relying on the typical karst landform terrain in Qianzhong area, some residents in the Jiangnan region, which had a highly developed socio-economic culture in the lower reaches of the Yangtze River at that time, moved across the region into

the Qianzhong area, forming a settlement landscape with Jiangnan elements, mountain characteristics and military defense. As a legacy of military activities of the Ming Dynasty (1368-1644 AD), the Tunpu settlement has a strong military defense functions and unique cultural values. Because of the relatively lagging economy and social development and the closed cultural characteristics of the self-contained system, the Tunpu settlement in this region can be well preserved in the historical development process, and has strong research value in the exploration of traditional settlements. However, most of the existing research focuses on the spatial characteristics and spatial morphologies of the Tunpu settlement ^[24,25,26], and the spatial diversity of the Tunpu settlement is rarely reported. Based on this, this study selects 10 typical Tunbpu settlements in Qianzhong area as examples, draws on the theory of landscape diversity, and studies the spatial diversity and influencing factors of Tunpu settlements in Qianzhong area. We put forward the following questions: (i) whether the urban spatial diversity index system is applicable to the study of spatial diversity of traditional settlements; (ii) if applicable, what is the law of change in the spatial diversity of the Tunpu settlement; (iii) What are the factors influencing the spatial diversity of the traditional Tunpu settlement and which indicators are significantly correlated? This study will reveal the influencing mechanism of spatial diversity in Tunpu settlement and provide a theoretical basis for the spatial planning and conservation of traditional settlements.

2 Study Areas And Objects

2.1 Study area

This study refers to Qianzhong area is Anshun city of Guizhou province in Southwest China (105°13'~106°34'E, 25°21'~26°38'N) (Figure 1), with a total area of 9267km², which is a typical karst landform concentration area and occupies an important military position along the line of Guizhou and Yunnan. According to statistics, there are 229 Tunpu in the Qianzhong area, accounting for 35.5% of the province's Tunpu ^[27]. According to the list of traditional Chinese villages, a total of 67 villages in Anshun have been selected into the list of traditional villages, of which 33 are Tunpu settlements, accounting for 49.3% of the total number of traditional villages in Anshun.

2.2 Research objects

Following the principle of typicality and integrity of traditional settlements, a total of 10 sample Tunpu settlements in Qianzhong area were selected in this study: Vil1 (Shuangtong Village), Vil2 (Baotun Village), Vil3 (Chetou Village), Vil4 (Xiaojia Village), Vil5 (Gaozhai Village), Vil6 (Datun Village), Vil7 (Xiaotun Village), Vil8 (Yunshan Tun), Vil9 (Benzhai Village), Vil10 (Tianlong Village), and the details of the specific settlements are shown in Table 1.

Table 1

Sample details of the Tunpu settlement in Qianzhong(CPA is core protected area, CCA is coordinated control area).

Tunpu's ID	Name	Type	Population ⌈pop⌋	CPA Size ⌈hm ² ⌋	CCA Size ⌈hm ² ⌋	Latitude and longitude
Vil1	Shuangtong	residential Tunpu	1385	1.34	13.74	106°09'E;26°28'N
Vil2	Baotun	military Tunpu	2390	2.62	3.71	106°10'E;26°21'N
Vil3	Chetou	residential Tunpu	985	2.27	18.39	106°14'E;26°21'N
Vil4	Xiaojia	residential Tunpu	3613	9.36	24.76	106°20'E;26°40'N
Vil5	Gaozhai	residential Tunpu	1563	3.35	16.21	106°20'E;26°40'N
Vil6	Datun	residential Tunpu	2168	5.02	16.05	106°17'E;26°43'N
Vil7	Xiaotun	residential Tunpu	2168	2.60	13.10	106°18'E;26°44'N
Vil8	Yunshan Tun	commercial Tunpu	1015	5.32	8.04	106°14'E;26°07'N
Vil9	Benzhai	military Tunpu	985	2.29	5.66	106°09'E;26°28'N
Vil10	Tianlong	commercial Tunpu	4420	8.12	10.71	106°04'E;26°25'N

3 Research Methods

3.1 Data sources

In this study, through obtaining the textual data of traditional villages of the Department of Housing and Urban-Rural Development of Guizhou Province so as to determine the scale range of this study and extract the influencing factors index of settlements. Taking the 2019 Pleiades high-resolution satellite image map (0.5m spatial resolution) of the research object as the source of image data, referring to the settlement topographic map to drawn up the existing spatial layout map of the Tunpu settlement, and extract the two-dimensional data variables such as the spatial networks and spatial morphologies of the settlement. On the basis of field research, the quantitative statistics of spatial types are carried out.

3.2 Space division of Tunpu settlement

Using typological methods, the Tunpu settlement space is divided from the perspective of functional properties, thereby defining space matter, that is, it refers to the plot space that has a certain functional positioning and is not easily separated by external interference (the two-dimensional land plane). A collection of multiple plot space with a certain function constitutes a spatial population ^[21]. This study is focused on the dense areas of the elements constituting the settlement (neglecting large areas of woodland, rivers and other plots), and based on the functional attributes of each plot space, it can divide into 13 types of space. They are: residential architectural space, street space, courtyard space, Tunpu gate space, Tunpu walls space, watchtower space, temple space, opera house space, ancestral temple space, educational space, square space, ancient well space, commercial space. In order to reveal the spatial diversity changes of the Tunpu settlement in the later period expansion, this study refers to the text of the traditional village planning and design scope of the study area and sets the scale of the scope of this study: That is to say, the core protected area with relatively well-preserved cultural landscape characteristics of the settlement and the planning coordination area of the

later artificial expansion are the scale range(Taking Tianlong Tunpu as an example, Figure 2). According to the formation characteristics of Tunpu settlement, the classification of Tunpu settlement type is the basis for the gradient of diversity differences in β .

3.3 Spatial diversity indicators of Tunpu settlement

The species diversity index is a composite indicator of both richness and uniformity, or heterogeneity index or species heterogeneity ^[28]. In this study, the smallest spatial unit was used as the element of spatial diversity measurement of Tunpu settlement, and the spatial diversity of Tunpu settlement was measured by reference to species diversity index:

Table 2

Calculation and meaning of spatial diversity index of Tunpu settlement

Index category	Index	Calculation method	Description	
α diversity index	<i>Shannon-Weiner index</i> (H')	$P_i = n_i/N$, p_i is the proportion of the i th spatial type in the overall space of the settlement n_i : the number of individuals of the i th species. N : the total number of spatial units in the village		11
	<i>Simpson index</i> (D)	$P_i = n_i/N$, N : the total number of spatial units in the village n_i : the number of individuals of the i th species.		12
	<i>Pielou index</i> (J_h)	H ; spatial diversity index of actual observations, H_{max} ; Maximum possible spatial diversity index. E indicates the distribution of spatial types of different settlements in the overall settlement.		13
	<i>Margalef index</i> (R)	N : is the total number of spatial patch units. $\ln$: the natural logarithm based on e , S : the number of space types.		14
β diversity index	whittaker(β_w)	S : the total number of spatial type units in the research system. ma : the average number of species in each plot or sample.		15
	Coday(β_c)	gh is the number of spatial types that the settlement increases along the differential classification H , $1h$ is the number of spatial types lost by the differential classification H .		16
	Jaccard (C_j)	j is the number of spatial types common in the two settlement study areas, a and b are the number of spatial types of settlement a and settlement b respectively.		17
	Sorenson (C_s)	j is the number of spatial types common in the two settlement study areas, a and b are the number of spatial types of settlement a and settlement b respectively.		18
	Bray-curtis(C_n)	aN is the number of spatial types of settlement space a , bN is the number of spatial types of settlement b , jN is the sum of the smaller number of individuals in the common space of settlement a (jNa) and settlement b (jNb) Taking the sum of the number of spatial individuals that are less than the average of the number of individuals in the common space.		19

3.4 Spatial characteristic indicators of Tunpu settlement

3.4.1 Indicators of internal influencing factors of spatial diversity in Tunpu settlement

Spatial networks and spatial morphologies are the spatial organizational structure of settlements reflected in human activities. Space networks and spatial morphologies indirectly reflect the spatial development patterns and historical evolution trajectories of physical space [21,15,29,30,31]. In this study, the following indicators were selected to explore the correlation between the spatial characteristics of the Tunpu settlement and the spatial diversity of the settlement. The specific indicators are as follows:

Table 3

Calculation and meaning of spatial characteristic indicators

Index category	index	Equation	Description	
Spatial network	Road connectivity (Rc)	$\gamma = \frac{L}{3(V-2)}$	L is the number of corridors, V is the number of nodes.	(1)
	Road circularity (Drc)	$\alpha = (L-V) / (2V-5)$	L is the number of corridors, V is the number of nodes.	(2)
	Road density (RD)	$RND=L/A$	L is the total length of the road centerline within the study scope, A is the settlement land use area.	(3)
Spatial morphology	Fractal dimension (Dcf)	$Dc(F) = \lim_{n \rightarrow \infty} \frac{\ln N(\varepsilon)}{\ln(1/\varepsilon)}$	Assuming that F is a bounded set point on a plane, it is always possible to find a rectangle to include F, dividing the rectangle into several small squares with sides long r, and the number of small squares occupied by F is N(r).	(4)
	Patch fragmentation (Pi)	$Pi=Ni/Ai$	Ni is the total number of patches of a certain spatial type, and Ai is the total area of the settlement.	(5)
	Choice (C)		Choice is the choice calculated based on axial map. It measures how often an axial line lies on the shortest topological paths any pair of axial lines. The higher the choice of an axis, the higher the traffic potential for that axis to be traversed.	(6)
	Connectivity (Con)	$Ci = k$	Connectivity is the number of other lines an axial line intersects. In the actual spatial system, the higher the spatial connectivity, the better the permeability of the space. Where, k is the number of nodes directly connected to node i	(7)
	Integration (I)	$Ii = \frac{n-2}{2(MDi-1)}$	Integration is a measure of integration of axial lines. High values means an axial line with a high degree of integration. It characterizes the overall spatial properties of a specific area, reflecting the accessibility of a space, the higher the integration of space, the higher its accessibility. Where, n is the total number of nodes in the network (number of axes); MDi is mean depth	(8)
	Control (Ctrl)	$Ctrl = \sum_i \frac{1}{Ci}$	Control measures the degree to which one axial line controls its immediately neighboring lines, which can indicate the degree of control of a spatial node over the space intersecting it, and reflect the degree of aggregation between local spaces Where, Ci is the integration of roadi	(9)
	Mean depth (MD)	$MDi = \frac{Di}{n-1}$	Mean depth is defend as the arithmetic mean of depths from each line to all others. The higher the value, the lower the convenience of that spatial node. Where, Di is global depth, n is the total number of nodes in the network (number of axes).	(10)

3.4.2 Indicators of external influencing factors of spatial diversity in Tunpu settlement

Combined with data collection and field research, this study established the following indicator system of external influencing factors (table 4).

Table 4

Indicator system of influencing factors

Index category	Index
Natural environment	AltitudeAltForest CoverageFCDistance from Urban AreasDUAHydrographic NetHN
Social economy	Total PoulationTPPermanent Resident PopulationPRPMain TrafficMTPer Capita Cultivated LandPCCLPer capita average incomePCAI
Policies support	Traditional Village List BatchLBInfrastructure InvestmentIIGovernment Support FundsSF
Cultural custom	ReligionRelFolk CultureCulEducationEduType of SettlementST

3.6 Data processing

Excel2020 and SPSS19.0 software were used to perform statistical analysis on the data, the *spearman* correlation analysis of bivariate correlation was used to compare the correlation between spatial diversity and spatial characteristics and influencing factors of Tunpu settlement; stepwise linear regression is used to analyze the contribution rate of influencing factors; adopted mean Euclidean distance to classify spatial patterns; and utilized Origin 2021 software for mapping.

4. Results

4.1 Spatial diversity analysis of Tunpu settlement in Qianzhong

4.1.1 Diversity characteristics α at different scales in the Tunpu settlement space

Table 5 shows that there are significant differences in spatial diversity between different Tunpu settlements in Qianzhong. The Margalef and Shannon indexes of military Tunpu and commercial Tunpu are relatively high, the Margalef and Shannon indexes of residential Tunpu are relatively low, and the Pielou index of each settlement is quite different. On the whole, the spatial diversity index of Vil8 in the core protected area is relatively high, and the spatial diversity index of Vil4 is relatively low; From the perspective of different scale ranges, there was a slight decrease in the diversity of military Tunpu and commercial Tunpu indicators. Residential Tunpu was characterized by an increase in the Margalef and Shannon indexes and a slight decline in the Pielou index, meanwhile, a relatively high spatial diversity in the coordinated control area as vil8 and vil1 as the lowest.

Table 5

α diversity of Tunpu settlement space (CPA is core protected area, CCA is coordinated control area.)

Tunpu's	<i>Margalef</i>		<i>Simpson</i>		<i>Shannon</i>		<i>Pielou</i>	
ID	CPA	CCA	CPA	CCA	CPA	CCA	CPA	CCA
Vil1	0.7453	1.2102	0.4343	0.3153	0.7702	0.6720	0.5556	0.3232
Vil2	1.6908	2.0237	0.5122	0.4398	1.0496	0.9368	0.4558	0.3652
Vil3	0.9262	1.2325	0.3948	0.4276	0.7297	0.8073	0.4073	0.3674
Vil4	0.8654	1.1870	0.2003	0.4260	0.4609	0.8760	0.2573	0.4213
Vil5	1.0178	1.2046	0.4437	0.4661	0.8863	0.9053	0.4947	0.4353
Vil6	1.2463	1.4583	0.5057	0.5371	0.9204	1.0155	0.4426	0.4410
Vil7	0.8461	1.2852	0.4760	0.4742	0.8849	0.9320	0.5498	0.4482
Vil8	2.2459	2.1621	0.6085	0.5658	1.4309	1.3279	0.5758	0.5344
Vil9	2.1493	2.0881	0.6157	0.5632	1.3765	1.2763	0.5539	0.5136
Vil10	1.8778	1.7941	0.5356	0.5153	1.1561	1.1237	0.4652	0.4522

4.1.2 Spatial types β diversity characteristics of Tunpu settlements

Based on the diversity results of the Tunpu settlement β classification as a difference gradient (Table 6), the Jaccard and Sorenson indexes between commercial Tunpu and military Tunpu were higher than those of other settlements, and the Whittaker and Bray-curtis indexes between residential Tunpu showed a relatively high performance, and the Cody index of military Tunpu/commercial-residential Tunpu showed a higher trend. The fluctuation of the β diversity index between settlements is relatively small, the β diversity of commercial Tunpu-commercial Tunpu and military Tunpu-military Tunpu at different scales is relatively stable, while the fluctuation range of military Tunpu-commercial Tunpu and commercial Tunpu-residential Tunpu is relatively large.

Table 6

Diversity of β between different types of Tunpu(MT is military Tunpu, CT is commercial Tunpu, RT is residential Tunpu).

SM	<i>whittaker(β_w)</i>		<i>Coday(β_c)</i>		<i>Jaccard (C_j)</i>		<i>Sorenson (C_s)</i>		<i>Bray-curtis(C_n)</i>	
	CPA	CCA	CPA	CCA	CPA	CCA	CPA	CCA	CPA	CCA
MT-RT	2.2726	2.2100	3.0833	2.3750	0.4665	0.6341	0.6293	0.7731	6.7528	6.2722
MT-MT	2.2000	2.2000	2.0000	2.0000	0.6923	0.6923	0.8182	0.8182	5.5455	5.5455
CT-CT	2.1818	2.1818	1.0000	1.0000	0.8462	0.8462	0.9167	0.9167	7.7500	9.4167
RT-RT	2.4205	2.2654	1.9000	1.4333	0.5112	0.7160	0.6736	0.8304	10.7021	10.0475
MT-CT	2.1885	2.1818	1.3750	0.5000	0.7953	0.9231	0.8794	0.9583	4.3696	6.5417
CT-RT	2.2503	2.2168	3.7083	2.4167	0.4187	0.6191	0.5857	0.7628	9.2184	8.9528

4.2 Spatial characteristics of The Tunpu settlement in Qianzhong

4.2.1 Characteristics of space network in Qianzhong Tunpu settlement

It can be seen from figure 3 that the overall level of military Tunpu and commercial Tunpu shows the characteristics of a space network with strong connections, and the spatial network connection of residential Tunpu is relatively weak, but there are different amplitudes of changes in the spatial network indicators of Tunpu settlements under artificial expansion. Among the spatial network indicators in the core area, Vil2 has the strongest spatial connection, and in the coordinated control area, Vil2 has the highest performance in road density and Vil8 has the highest performance in road connectivity and road circularity; On the whole, the expansion of the regional spatial network of residential Tunpu is characterized by a strengthening or slight decrease in ties, and most of the spatial relevance of military Tunpu and commercial Tunpu is weakened to a certain extent, while the slight increase in Vil8 may be related to the strengthening of external links with its original closed geographical conditions in the process of urbanization.

4.2.2 Spatial morphological characteristics of the Tunpu settlement in Qianzhong

It can be seen from figures 4 and 5 that the spatial morphological characteristics of the core area of tunpu settlement are manifested in four levels: high concentration, moderate concentration, moderate dispersion and high dispersion. The coordination area is characterized by the spatial morphological characteristics of three levels: high concentration, moderate concentration and moderate dispersion; The spatial formative indicators fluctuate by different amplitudes in the scale change, and according to the change of the degree of aggregation between different settlements, there is no obvious law between the spatial morphological changes of the Tunpu settlement and the type of the Tunpu settlement.

4.3 Analysis of influencing factors of spatial diversity in Qianzhong Tunpu settlement

4.3.1 The relationship between the internal influencing factors of the Qianzhong Tunpu settlement and the spatial diversity

Figure 6 is the correlation analysis results of the spatial network, spatial morphology and α , β diversity of the Tunpu settlement. The results showed that the internal influencing factors had no obvious correlation with the spatial diversity of the Tunpu settlement α , and there was a significant correlation between the whittaker and Bray-curtis indices of β diversity, and the correlation with other indices was weak. Among them, the whittaker index has a very significant negative correlation with the road connectivity and road circularity indexes, a very significant positive correlation with the degree of connection and integration, and a significant negative correlation with the intelligibility, a very significant negative correlation between the Bray-curtis index and the road density, a significant negative correlation with the fractal dimension, and a significant positive correlation with the depth value and selectivity.

4.3.2 External influencing factors of spatial diversity in Qianzhong Tunpu settlement

Figure 7 shows that the indicators of α diversity and β diversity show different degrees of correlation with external influencing factors. The Margalef Index is significantly correlated with the type of Tunpu, and correlated with the degree of government support and religious. The Shannon index was significantly positively correlated with the Tunpu type; the whittaker index was significantly negatively correlated with altitude, significantly positively correlated with cultivated land per capita, and significantly negatively correlated with religion. The Bray-curtis index has a significant positive correlation with the distance from the urban area, per capita annual income, and infrastructure investment. It also has a significant negative correlation with water systems and customs, and a significant correlation with the amount of government support and education.

4.3.3 Analysis of control factors influencing spatial diversity in Tunpu settlement

It can be seen from figures 6 and 7 that the spatial richness of the Tunpu settlement is significantly related to the natural environment, cultural customs and government support. There is a significant correlation between the Shannon index and cultural customs; The whittaker and Bray-curtis indices were significantly correlated with the spatial characteristics and external influencing factors of the Tunpu settlement, as well as with the natural environment, socio-economic, policy support and cultural customs. Through stepwise linear regression, exclude variables that are not significant in spatial type α indexes and influencing factors, so as to conclude the regression equation for the spatial α diversity and influencing factors of the Tunpu settlement.

$$Y_R = 0.905 + 0.385ST - 2.016PCCL \quad R^2 = 0.850$$

$$Y_H = 0.698 + 0.234ST + 0.005MT \quad R^2 = 0.802$$

In the equation, ST is the Tunpu type, PCCL is the per capita cultivated land, and MT is the main transportation.

Through the stepwise linear regression equation, the regression equation for the spatial β diversity and influencing factors of the Tunpu settlement is obtained.

$$Y_w = 2.48 - 0.459Rc \quad R^2 = 0.910$$

$$Y_n = 1.508 + 6.639PCAI \quad R^2 = 0.888$$

In the equation, Rc is road connectivity and PCAI is annual per capita income.

Based on the above regression analysis and the integrated results and the value of R^2 , it can be concluded that when the R^2 of the spatial type Y_R and Y_H of the Tunpu settlement is 0.85 and 0.802 respectively, then the degree of fitting is perfect. The Tunpu type has a strong influence on the richness and diversity of the Tunpu settlement space type. Arable land per capita and major traffic have a negative correlation effect on the spatial diversity of Tunpu settlements. When the R^2 of the Y_w and Y_n spatial types of Tunpu settlement were 0.91 and 0.888 respectively, then the degree of fitting was relatively high. Per capita annual income has a large contribution rate to the spatial difference of Tunpu settlement, and road connectivity has a negative correlation with the spatial difference of Tunpu settlement. The above results also reflect from the side that the space network has an important responsible position for the spatial diversity of the Tunpu settlement, and the socio-economic and cultural customs are the main influencing factors for the spatial diversity of the Tunpu settlement.

5. Discussion

5.1 Spatial diversity of Tunpu settlements in different scales/types

The diversity of urban spatial types is an important indicator to reflect urban vitality^[21], and the changing trend of spatial diversity reveals the law of urban expansion. Usually, in the scale change of urban spatial, urban diversity changes significantly along the population density gradient, as the distance from the central city^[20,32], resulting in significant differences in urban-rural gradient diversity^[14]. Previous studies have pointed out that the urban-rural gradient decreases in a pattern of physical decay from the inside to the outside, resulting in the hollowing out of rural industry and population^[33]. However, this study showed that the ranges of different spatial scales, military Tunpu and commercial Tunpu was in line with the law of urban diversity change. They all performed as decreasing from the inside to the outside, which is different from the diminishing law of diversity of the expansion of the urban center to the periphery. The diversity of residential Tunpu α shows a trend of increasing from the core area to the expansion area, which is obviously different from the single diversity characteristics under the urban and rural gradient, which confirms that the expansion of the Tunpu settlement has a variety of spatial evolution mechanisms^[25]. Through the results of β diversity, it can be concluded that the spatial similarity between military Tunpu and commercial Tunpu is relatively high, and the dissimilarity between residential Tunpu is larger, which may be related to the more prominent defensive cultural characteristics and rich spatial functions of military Tunpu and commercial Tunpu. It also reflects from the side that due to the stricter defensive guard needs and scale requirements of military Tunpu and commercial Tunpu, the strict spatial hierarchy and the same or similar defense system different from that of residential Tunpu are characterized^[26,34], explaining that the spatial type differences of Tunpu settlements have significant cultural dependence. Through field research, it was found that the public landscapes such as streets, alleys, watchtowers, and Tunpu walls with extremely obvious defensive functions in military Tunpu and commercial Tunpu were relatively well preserved in historical style, while the damage to the landscape of residential Tunpu was relatively serious. It shows that the Tunpu types with strict military needs are less affected by the homogenization and destructiveness of urbanization expansion, which further indicates that the defensive function dominates the spatial representation of Tunpu settlements, and the

hierarchy of the defense system is inseparable from the formation and development of Tunpu settlements ^[35,36]. Comparing the study areas of the sample settlements, it was found that unlike the decreasing trend of human activity along the urban and rural gradient in urban expansion ^[13], the Tunpu settlement showed a strong anthropogenic vitality in the expansion area under the influence of urbanization, which was contrary to the law of urban spatial diversity, and to a certain extent, it reflected that the intensity of anthropogenic activities had a counter-effect on the spatial diversity of Tunpu settlements. Although the Tunpu settlement as a whole shows low spatial diversity compared with the urban spatial diversity, but its diversity index shows certain laws, which explains the applicability of the diversity index system based on ecological theory in the study of spatial diversity of traditional settlements at home and abroad.

5.2 The driving mechanism of spatial diversity between the spatial network and spatial morphology of the Tunpu settlement

In the evaluation system of urban spatial diversity, spatial network and spatial morphology indicators have a strong correlation with urban spatial diversity ^[21,29]. The spatial morphological characteristics changed under social and political influences, which directly or indirectly determine the endogenous logic of traditional settlements ^[38]. The results show that the spatial characteristics of Tunpu settlement have no obvious influence on the degree of spatial diversity, and there is a significant correlation in the spatial difference of Tunpu settlement, and complement each other. Among them, the contribution rate of road connectivity in the spatial difference is relatively large, and the defensive road system structure of the Tunpu settlement is indirectly described as an important influencing factor leading to the difference in the spatial performance of the settlement. It is demonstrated that the spatial network and spatial morphology indicators also have an important impact on the traditional settlement space system ^[40,41]. However, there are still some weaknesses in the theoretical and practical research on the spatial organizational structure of traditional settlements and the influence mechanism of spatial diversity. Therefore, the research on in-depth quantification of spatial diversity and spatial organizational structure is an urgent need for the rational planning of traditional settlement spaces.

5.3 Analysis of external influencing factors of spatial diversity in Qianzhong Tunpu settlement

A settlement space is a system built by the interconnection, influence and action of different elements ^[39]. The specific socio-cultural and natural environment allows the material space of traditional settlements to manifest itself in a diverse form ^[42]. The diversity of spatial patch types as functional division units can also effectively reflect the spatial variation law of traditional settlements. This study shows that the spatial diversity of The Qianzhong Tunpu settlement is a comprehensive response under the synergy of multiple driving factors such as natural environment, social economy, policy support and cultural customs, which confirms the inevitable impetus of external influencing factors on the evolution of the spatial system of traditional settlements ^[13,26,43,44,45,46,47]. From the perspective of influencing factors, the gradual regression equation is further analyzed, and the correlation between cultural customs and social economy on the spatial diversity index of Tunpu settlement is more significant, which indicate that cultural customs and social economy have a strong guiding effect on Tunpu settlement. It was confirmed that socio-economic and cultural practices played an important role in maintaining stable spatial systems and evolution of traditional settlements ^[42,48,49,50]. Through the survey, it is found that the qianzhong Tunpu settlement area lacks the necessary economic development factors, and there is a significant weakening trend in the cultural identity of the settlement residents. Therefore, in the process of protection and development of the Tunpu settlement, it is necessary to attach

importance to the guiding role of culture in spatial diversity, develop economic factors that conform to the endogenous logic of the settlement, and improve the economic level of the settlement residents in order to carry out effective protection and development.

6. Conslusions

The traditional settlement space system is the carrier of settlement activities formed by social development and cultural factors, which is directly affected by traditional culture and social development, and has multiple forms of expression. Quantifying the spatial diversity of traditional settlements and their influencing factors has a certain scientific value. In this study, the spatial diversity law of Tunpu settlement was analyzed by using the ecological diversity index, and by analysis the spatial network and spatial morphology to explore the spatial diversity of Tunpu settlement influenced by spatial network, spatial morphology and external factors, so as to draw the conclusion the following preliminary results: (1) On the whole, the spatial diversity of the Tunpu settlement in Qianzhong is manifested as the phenomenon that the military Tunpu and the commercial Tunpu are relatively high, and the residential Tunpu is low. In the change of spatial scale, the spatial diversity of commercial Tunpu and military Tunpu settlements shows a decreasing trend from the inside to the outside, while the residential Tunpu shows a increasing trend from from the inside to the outside; The spatial diversity between different settlements shows that there is a strong spatial similarity between commercial Tunpu and military Tunpu, and there is significant heterogeneity between residential Tunpu, while spatial heterogeneity fluctuates to varying degrees in scale changes, showing multiple forms of change. (2) The spatial network and spatial morphology of the Tunpu settlement have a weak influence on the diversity of the α , which is significantly related to the spatial β diversity of the settlement, and is complementary in the correlation between the *whittaker* and *Bray-curtis* indices, and the spatial network controls the spatial difference of the Tunpu settlement. (3) The spatial diversity of The Tunpu settlement is affected by the multiple synergies of the natural environment, policy support, socio-economic and cultural customs, and the socio-economic and cultural customs are the dominant factors control the spatial diversity of the Tunpu settlement. This study applies the theory of urban diversity to the exploration of traditional settlement spatial systems, and focuses on the analysis of internal and external driving factors of traditional settlement spaces. The results show that the theory of urban spatial diversity is also applicable to the study of traditional settlement space systems, enriches the traditional settlement space theory, and provides a theoretical reference for scientifically guiding the planning and development of traditional settlements.

Declarations

Availability of data and materials:

The data that support the findings of this study are available from [Department of Housing and Urban-Rural Development of Guizhou Province in China] but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of [Department of Housing and Urban-Rural Development of Guizhou Province in China].

Competing interests:

The authors have no competing interests.

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Authors' contributions:

All authors contributed to the entire paper, although Hongyi Ge curated the data, writing the paper and all authors was involved in data acquisition and processings. All authors read and approved the final manuscript.

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Figures

Figure 1

Location map of the study object

Figure 2

The defined range of study scope (A is the area where the landscape features are relatively well conserved; B is an area that is destroyed or altered by human-expanded landscape features. In this study, A is the core protected area, and the entire settlement planning area after the expansion from A to B is the coordinated control area)

Figure 3

Characteristics of the space network of the Tunpu settlement

Figure 4

Spatial morphological characteristics of Tunpu settlement

Tree diagram of average connections

Figure 5

Spatial morphological cluster of Tunpu settlement

Figure 6

Results of *spearman* correlation analysis between spatial characteristics and spatial diversity of Tunpu settlement

Figure 7

Spatial diversity of Tunpu settlement and correlation of influencing factors