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Study on space diversity and influencing factors of Tunpu settlement in central Guizhou Province of China

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Abstract

The Tunpu settlements are the historical product of the co-evolution development of the unique geographical and cultural environment of Guizhou and the military defense policies of Ming Dynasty (1368–1644 AD), which created products such as the station troops and station farms. In this study, taking 10 Tunpu settlements in central Guizhou as the research objects, the space diversity of the Tunpu settlement and its influencing factors were analyzed based on the theory and calculation method of plant community species diversity. The results showed that: (1) On the whole, the space *α*-diversities of the military Tunpu settlements and the commercial Tunpu settlements were relatively high, with strong spatial similarity, while the residential Tunpu settlements had a lower degree of space *α*-diversity and significant difference. The space *α*-diversity of different types of the Tunpu settlement presents a variety of changes from the core protected areas to coordinated control areas. (2) There was a significant correlation between the spatial network and spatial morphological indicators and space *β*-diversity among the Tunpu settlement, and the stepwise regression showed that spatial morphological indicators had a strong explanatory power for the space *β*-diversity among the Tunpu settlements. (3) The space diversities of the Tunpu settlements were affected by the multiple synergies of natural environment, policy support, social-economic factors and cultural customs. Among them, policy factors and cultural factors were the dominant factors in the space diversity characteristics of the Tunpu settlements. By analyzing the space diversity law and its driving factors of the Tunpu settlements, this study could provide an important scientific basis for the protection planning and management of traditional settlements.

Keywords: Space diversity, Key factors, Tunpu settlement, Central Guizhou

Introduction

As an important carrier of tangible and intangible cultural heritage [1], traditional settlements have important cultural heritage protection value. But with the process of urbanization, traditional settlements are facing the threat of homogenization and disappearance [2]. As an organic whole, urban and rural settlements must emphasize on sustainable development and mutual support [3]. Therefore, the study of traditional settlements has also become a hot topic in 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.

In the 1950s, American scholar Jane Jacobs introduced the theory of Urban Diversity, proclaiming that diversity is nature to big cities [4]. Subsequently, numerous scholars extended the theory further into the diversity of land use, diversity of landscape pattern, and spatial composition diversity [5–7]. And the theory was widely applied to the research on rural settlements diversity [8]. Some researches proved that the theories and methods of species diversity in the taxonomy of plant communities could be used to quantitatively analyze urban space

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diversity [9]. For example, Zheng [10] believed that space diversity included the basic characteristics of urban space, basic elements of urban space and other physical attributes of urban space, and the diversity of spatial types was the most direct criterion for evaluating space diversity; Yang [11] defined space diversity as the diversity of spatial structure, and considered that urban space diversity was the material carrier and spatial appeal of the city's "social ecological chain"; Xu et al. [7] established an urban diversity assessment model based on the diversity of urban spatial composition. However, different from the attribute division of urban mixed plots, traditional settlements are limited by specific cultures and lifestyles, forming a special cultural function space attribute. Therefore, traditional settlement space should be recognized and divided according to spatial functional attributes.

Rural settlements also have complex and diverse spatial characteristics. Previous researches have systematically elaborated the spatial characteristics of traditional settlements from the dimensions of architectural space, spatial morphology, layouts, and distributions of traditional settlements [12–17]. For example, Hu et al. [18] constructed a three-dimensional spatial system integrating material space, social space and cultural space of traditional settlement in Huizhou, verified the rationality of the spatial system and showed that the reorganization of traditional settlements space was the positive effect of the settlement space system on internal and external environmental changes, or a qualitative shift in passive response. Although there are abundant researches on traditional settlement space, few studies have considered the potential value of traditional settlement space diversity in the stability and evolution of traditional settlement space system.

Based on the influence of multiple factors such as natural environment, social-economic and cultural customs, the spatial morphology of settlements has regional heterogeneity that is significantly different from that of cities [19]. The research framework of rural settlements based on influence factors such as nature, economy, society and culture has been widely used in the study of settlement space. For example, Singh et al.[20] analyzed the driving factors of rural land use evolution in the Galval region of India from three aspects: ecological, socio-economic and policy impact. Liu et al. [21] believed that the natural environment and infrastructure were important driving forces for the spatial differences in the hollowing out of traditional settlements in Lishui. Larraz et al. (2020) regarded that population is the main reason for the fluctuation of spatial vitality in traditional cultural areas [22]. In addition, some scholars have found that the human-land relationship played an important driving role in the evolution of traditional settlement morphology [15]. The studies mentioned above showed that the settlement space is a dynamic process driven by multiple dimensions such as physical geography, economic development, and social functions. [23]. However, traditional settlements have a strong bottom-up self-organization pattern. Therefore, it is more meaningful to explore space diversity and its driving factors from within the settlements [24].

Before the Ming Dynasty, the central area of Guizhou province, or central Guizhou simply, was an area inhabited by ethnic minorities. It was sparsely populated, and the influence of the Central Plains culture and government management was extremely weak.The Tunpu settlements were 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 Weisuo (close to garrison) system (a local military defense system) of the Ming Dynasty (AD 1368–1644) [25]. Part of the people in the lower reaches of the Yangtze River (namely the Jiangnan area) with a highly developed social economy and culture at that time moved to the central region of Guizhou Province in southwest China, forming a settlement landscape with the Jiangnan elements, karst mountain features and military defense integration. Due to the relatively sluggish economy and social development and the closed and self-contained cultural characteristics, the Tunpu settlements in this region have been well preserved in the process of historical development, and have a strong research value in the exploration of traditional settlements. However, the existing studies mainly focused on the spatial characteristics and spatial morphology of the Tunpu settlements [26–28], and there were few relevant reports on the space diversity of Tunpu settlements.

In this study, 10 typical Tunpu settlements in the central area of Guizhou province were selected as research objects, the space diversity and influencing factors of the Tunpu settlements were studied by referring to the theory and measurement method of plant community species diversity. We aimed to explore the following questions: (i) whether the species diversity index system based on plant community taxonomy is suitable for the study of traditional settlement space diversity; (ii) what are the characteristics of the space diversity of the Tunpu settlements; (iii) What are the main factors affecting the space diversity of the Tunpu settlements? This study would provide a basis for revealing the impact mechanism of the space diversity of the Tunpu settlement, as well as a theoretical basis for

the traditional settlement conservation planning and management.

Study areas and objects

Study area

The study area is located in Anshun City, in central Guizhou Province, southwest China (105°13′–106°34′E, 25°21′ ~ 26°38′N) (Fig. 1), with a total area of 9267 km^2, which is a typical karst landform concentration area. According to statistics, there are 229 Tunpu settlements in this area, accounting for 35.5% of the total number of the Tunpu settlements in the province [29]. A total of 67 villages in Anshun have been selected into the list of traditional Chinese villages, of which 36 are Tunpu settlements, accounting for 53.7% of the total number of traditional villages in Anshun.

Research objects

Following the principle of typicality and integrity of traditional settlements, a total of 10 sample Tunpu settlements in the study area were selected in this study: Vil 1 (Shuangtong Village), Vil 2 (Baotun Village), Vil 3 (Chetou Village), Vil 4 (Xiaojia Village), Vil 5 (Gaozhai Village), Vil 6 (Datun Village), Vil 7 (Xiaotun Village), Vil 8 (Yunshan Tun), Vil 9 (Benzhai Village), Vil 10 (Tianlong Village), and the details of the specific settlements are shown in Table 1.

Research methods

Data sources

Obtaining the textual data of traditional villages from Housing and Urban–Rural Development of Guizhou Province, so as to determine the scale range of this study and extract the influencing factors indicators of settlements. Taking the 2019 Pleiades satellite image maps (0.5 m spatial resolution) of the research objects as the basic data source, the two-dimensional vectorized spatial layout map of each sample Tunpu settlement was obtained by visual interpretation based on ArcGIS spatial information technology with reference to the topographic maps of the settlements.The two-dimensional plane data variables of the settlement spatial network (road) and spatial form (overall spatial layout) were extracted.

Space division of the Tunpu settlement

Tunpu settlements have small village area, clear division of spatial functions, and unique military cultural attributes that are different from other traditional settlements in China.Therefore, through field investigation, the internal space of the Tunpu settlement was divided

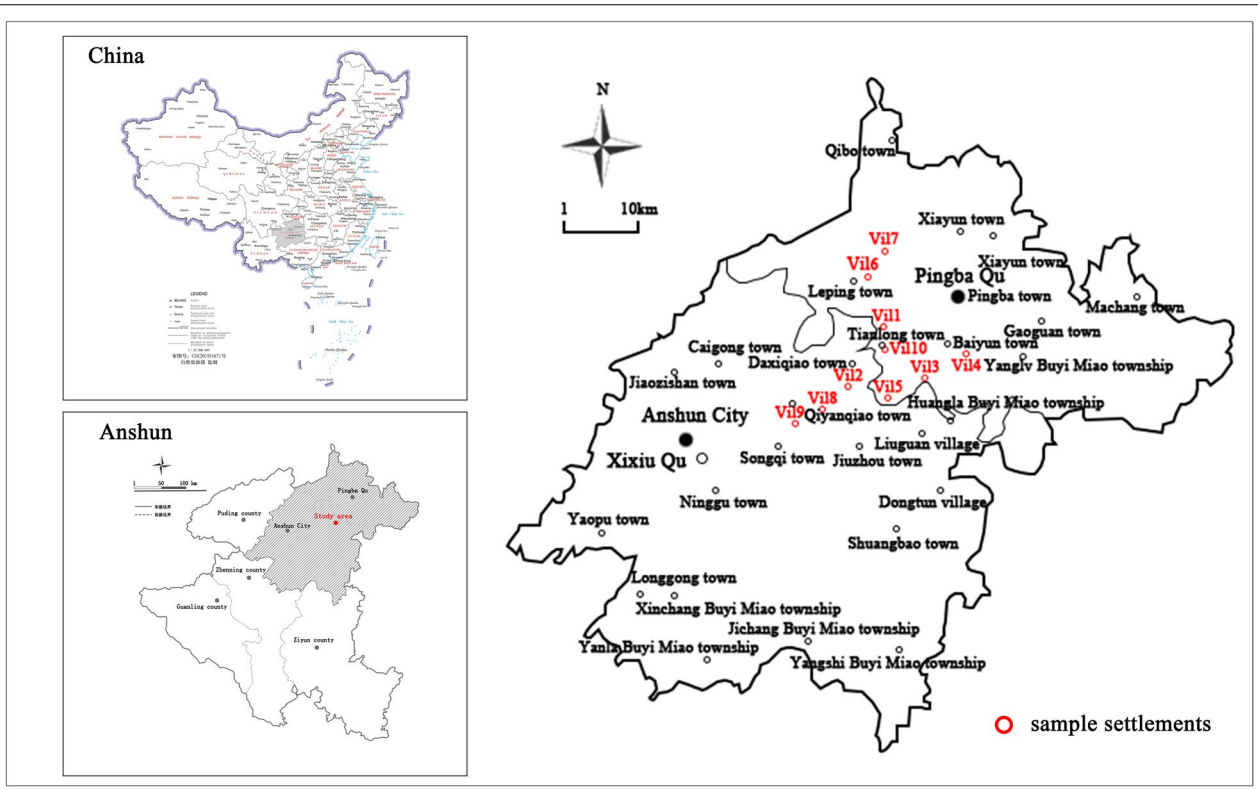

Fig 1. Location map of the study object

Table 1 Basic information of 10 samples(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
Vil 1	Shuangtong	Residential Tunpu	1385	1.34	13.74	106°09′E;26°28′N
Vil 2	Baotun	Military Tunpu	2390	2.62	3.71	106°10′E;26°21′N
Vil 3	Chetou	Residential Tunpu	985	2.27	18.39	106°14′E;26°21′N
Vil 4	Xiaojia	Residential Tunpu	3613	9.36	24.76	106°20′E;26°40′N
Vil 5	Gaozhai	Residential Tunpu	1563	3.35	16.21	106°20′E;26°40′N
Vil 6	Datun	Residential Tunpu	2168	5.02	16.05	106°17′E;26°43′N
Vil 7	Xiaotun	Residential Tunpu	2168	2.60	13.10	106°18′E;26°44′N
Vil 8	Yunshan Tun	Commercial Tunpu	1015	5.32	8.04	106°14′E;26°07′N
Vil 9	Benzhai	Military Tunpu	985	2.29	5.66	106°09′E;26°28′N
Vil 10	Tianlong	Commercial Tunpu	4420	8.12	10.71	106°04′E;26°25′N

into 12 types of unit space (Table 2), following the principle of no repetition and no omission, and based on the specific functional attributes of each plot space. Then spatial attribute database of sample settlements was constructed. To reveal the changes in the space diversity of Tunpu settlement during the later expansion, referring to the historical data of the selected sample settlements and related drawings of conservation planning, the research range of each settlement was divided into two scales: the core protected area with relatively well-preserved traditional landscape characteristics of the settlement and the coordinated control area with later expansion (Table 2).

Space diversity indices of Tunpu settlements

The minimum spatial unit of the 12 spatial types mentioned above was taken as the basic unit for the measurement of space diversity of the Tunpu settlements (just like a plant individual in the measurement of plant community diversity). Through the field survey, the space type and quantity of each settlement were counted, and the species diversity indices [30, 31] were used as measurements for the space diversity of the Tunpu settlement. Three α diversity indices, namely *Margalef*, *Shannon–Wiener* and *Pielou* (Table 3), were selected to measure the richness of space types, the diversity of the space composition and pattern, and the uniformity of space quantity distribution of Tunpu settlement, respectively; Three β diversity indices, *Whittaker*, *Jaccard* and *Bray–Curtis* (Table 3), were used to measure the degree of spatial heterogeneity between the settlements.

Influence factors of space diversity of the Tunpu settlement

Internal influencing factors of Space diversity of the Tunpu settlement

Referring to the research methods of urban space diversity [10, 32], the spatial network and spatial morphology within the settlement were taken as internal factors that directly affect the space diversity of the settlement. The spatial characteristics indicator system (Table 4) of the settlement content was constructed by using space syntax [33] and fractal dimension [34], and each indicator was calculated based on the spatial attribute database of the Tunpu settlement.

External influencing indicators factors of space diversity of the Tunpu settlement

Referring to previous studies [35], and combining with the characteristics and actual conditions of the Tunpu settlement, the external influencing factor indicators were selected from the natural environment, social economy, policy and cultural and other factors related to the Tunpu settlement in central Guizhou. All indicators and their data sources are shown in Table 5. Among them, the values of qualitative indicators were assigned at different levels (see Fig. 2).

Data processing

AutoCAD2014 and Depthmap + Beta 1.0 2012 software were used to process the spatial morphological indicators; the spatial morphological clustering was carried out by the average Euclidean distance. *Spearman* correlation analysis of bivariate correlation was used to compare the correlation between the space diversity of the Tunpu settlement and the internal and external influencing factors. The contribution rate of the influencing factors was analyzed by stepwise linear regression. Excel 2020 and SPSS19.0 software were used to conduct statistical analysis on the data. Origin 2021 software was used for normalization processing of correlation indicators and mapping.

Table 2 The space types and related descriptions of the Tunpu settlement

Space type	Description	Picture
Residential buildings Space	The residential buildings are the living space of villagers, continuing the construction style of Jiangnan dwellingsr, with straight row, L-shaped, courtyard with buildings on three sides, quadrangle, double quadrangle	
Street space	The streets and lanes are the transportation places connecting the internal residents of Tunpu settlement as well as the external contact. Most of them are in the form of network, branch and radial layout, paved with stone slabs	
Courtyard space	Courtyard space, as the gathering place and activity place inside the family, is formed by the building or the elements of the building and the courtyard wall. The ground material is mostly paved with stone	
Outer defense space	The first defense space set at the entrance of the settlement, which is composed of the village gate and the defensive wall. The wall is made of stone, similar to the Great Wall. Various defense activities can be carried out on it, and the space is connected with the village gate	
Watchtower space	Usually set in the center of the settlement, a multi-storey building made of solid stone is the tallest building in the settlement. The main function is to observe the enemy's situation and conduct high-altitude shooting	
Temple space	The places for Tunpu residents to conduct religious activities. Religious beliefs are more popular, and there are various types of religions, but the temple forms are relatively similar. As the core node of Tunpu settlement, temple space is the spiritual dependence of Tunpu residents	
Traditional theatre stage space	The place for the traditional theater performances of the Tunpu settlement. The dramas performed were mainly the themes of ancient Chinese wars, with both cultural entertainment and military drills. The traditional theatre stage is an important carrier of the unique traditional culture of the Tunpu settlement	
Ancestral hall space	The place where residents of a settlement perform sacrificial acts, it plays a role in maintaining the blood relationship between the people and the land of the Tunpu residents	

Table 2 (Continued)

Space type	Description	Picture
Education space	The place for teaching activities. Tunpu settlements were formed by the migration from advanced cultural areas to central Guizhou where cultural and economic development was lagging behind. Most of the Tunpu settlements had set up ancient schools in the Ming and Qing Dynasties, and then evolved into modern schools	
Square space	It refers to the public open place for gathering and distributing, performing and other functions within the settlement. Usually located at settlement entrances, road intersections, bridgeheads, or other place. In ancient times, in order to prevent the invasion of foreign enemies and maintain the combat effectiveness of the army, the square space was used for training. During the transition from the Ming Dynasty to the Qing Dynasty, the function of the army was transformed into the field, and the demand for military defense capabilities was weakened.At present, the residents carry out activities such as drying grain and performing ground plays in the square space	
Ancient well space	The ancient well is the underground water source for production and living of the tunpu residents. In order to prevent the well water from being polluted, the pavement around the well head is hardened and properly enclosed to form the ancient well space	
Commercial space	Commercial space refers to the place where various commercial activities and other economic activities are carried out. Most of them are set up in commercial Tunpu settlements, and they undertake the functions of bazaar and trade activities for the residents of the surrounding villages	

Table 3 Calculation and meaning of space diversity indices of the Tunpu settlements

Index category	Index	Calculation method	Description	
α diversity index	*Shannon–Wiener index(H')*	$H' = -\sum_{i=1}^{s} P_i \log_2 p_i$ $Pi = ni/N$	p_i is the proportion of the ith spatial type in the overall space of the settlement *ni*: the number of individuals of the ith species *N*: the total number of spatial units in the village Higher index represents more diversity of settlement space types	(1)
	Pielou index (E)	$E = H/H\max$	*H*: space diversity index of actual observations, H_{max}: Maximum possiblespace diversity index *E* indicates the distribution of spatial types of different settlements in the overall settlement Representing the allocation of the number of space types	(3)
	Margalef index(R)	$R = (S-1)/lnN$	*N*: the total number of spatial patch units *ln*: the natural logarithm based on e, *S*: the number of space types The higher the index, the richer the types of settlement spaces	(4)
β diversity index	*Whittaker(βw)*	$\beta w = s/ma-1$	*S*: the total number of spatial type units in the research system *ma*: the average number of species in each plot or sample Characterizing the degree of dissimilarity among different settlements	(5)
	Jaccard (Cj)	$Cj = j/(a+b-j)$	*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 Representing the similarity of different settlement spaces	(7)
	Bray–curtis(Cn)	$Cn = 2jN/(aN+bN)$	*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) Representing the spatial composition differences between different settlements	(9)

Results

Characteristics of space network and morphological of the Tunpu settlements

Figure 3 exhibited the differential characteristics of the spatial network of each sample Tunpu settlement. On the whole, the military Tunpu settlements and the commercial Tunpu settlements showed a strong spatial connection, while the spatial network connection of the residential Tunpu settlements was relatively weak. At the core area scale, the Vil 2 spatial network had the highest value of each index, indicating the strongest spatial connection, while the Vil 7 spatial network had the lowest indices and the weakest spatial connection. At the coordinated control area scale, Vil 2 had the highest road density, and Vil 8 had the highest road connectivity and road circulation. Combining the measurement changes of various indicators of spatial network characteristics, it could be seen that the spatial network of the RT varies greatly during the expansion process, with strengthened settlements (such as Vil 4, Vil 5, Vil 6 and Vil 7) and slightly decreased settlements (such as Vil 1 and Vil 3). In contrast, the spatial correlations of the military Tunpu settlements and the commercial Tunpu settlements were mostly weakened to a certain extent. It can be seen from Figs. 4 and 5 that the spatial morphological characteristics of the core protection areas in the Tunpu Settlements presented 4 modes of highly concentrated, moderately concentrated, moderately dispersed and highly dispersed, and presented 3 modes of highly concentrated, moderately concentrated and moderately dispersed in the coordinated control area; each indicator of the spatial morphology fluctuated in different magnitudes at the scale conversion from the core area to the coordinated control area. According to the change of aggregation degree among different settlements, there is no obvious rule between spatial morphological change and Tunpu settlement types.

Space diversities of the Tunpu settlements in central Guizhou

The space α-diversity characteristics at different scales in the Tunpu settlements

Table 6 showed the calculation results of space *α*-diversity of each sample settlement at two spatial scales. It can be seen that there were obvious differences in the space *α*-diversity of different Tunpu settlements in central Guizhou. The space diversity of the military Tunpu settlements and the commercial Tunpu settlements were relatively high. On the scale of core protected areas, the *Margalef* index and

Table 4 Calculation and meaning of spatial characteristic indicators

Indicators category	Indicator	Equation	Description
Spatial network	Road connectivity(*RC*)	$RC = \frac{L}{3(V-2)}$	*L* is the number of corridors, *V* is the number of nodes
	Degree of road circulation(*DRC*)	$DRC = (L - V)/(2V - 5)$	*L* is the number of corridors, *V* is the number of nodes
	Road density (*RD*)	$RD = L/A$	*L* is the total length of the road axis within the study scope, *A* is the settlement land use area
Spatial morphology	Fractal dimension(*FD*)	$FD = \lim_{n\to\infty} \frac{\ln N(\varepsilon)}{\ln(1/\varepsilon)}$	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)*
	Patch fragmentation(*PF*)	$PF = Ni/Ai$	*Ni* is the total number of patches of a certain spatial type, and *Ai* is the total area of the settlement
	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
	Connectivity (*Con*)	$Coni = k$	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
	Integration (*I*)	$I_i = \frac{n-2}{2(MDi-1)}$	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); MD_i is mean depth
	Control (*Ctrl*)	$Ctrl = \sum_{1}^{n} \frac{1}{Ci}$	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, C_i is the connectivity of $road_i$
	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, D_i is global depth, n is the total number of nodes in the network (number of axes)

Table 5 Indicator system of external influencing factors

Influencing factors category	Indicators	Data source
Natural environment	Altitude (*Alt*), Forest Coverage (*FC*), Distance from Urban Areas (*DUA*), Hydrographic Net (*HN*)	Remote sensing images and vectorized topographic maps
Social economy	Total Population (*TP*), Permanent Resident Population (*PRP*), Main Traffic (*MT*), Per Capita Cultivated Land (*PCCL*), Per capita average income (*PCAI*)	The archives of traditional villages in Guizhou Province and the statistical data of relevant departments
Policies factors	Government protect time (*GPT*), Infrastructure Investment (*II*), Investment in traditional landscape maintenance (*ITLM*)	policy documents and materials from the official websites of the Ministry of Housing and Urban–Rural Development of the People's Republic of China and the Guizhou Provincial Department of Housing and Urban–Rural Development
Cultural factors	Number of religious types (*NRT*), Number of folk culture (*NFC*), Number of educational facilities (*NEF*)	The field investigation

Shannon–Wiener index of Vil 1 and Vil 4 were the lowest, and those of Vil 8 was the highest, indicating that settlements with richer space types also have relatively high space diversity; except that the *Pielou* index of Vil 4 showed lower values, the *Pielou* index of all other settlement was between [0.4–0.6], that of Vil 1 performed

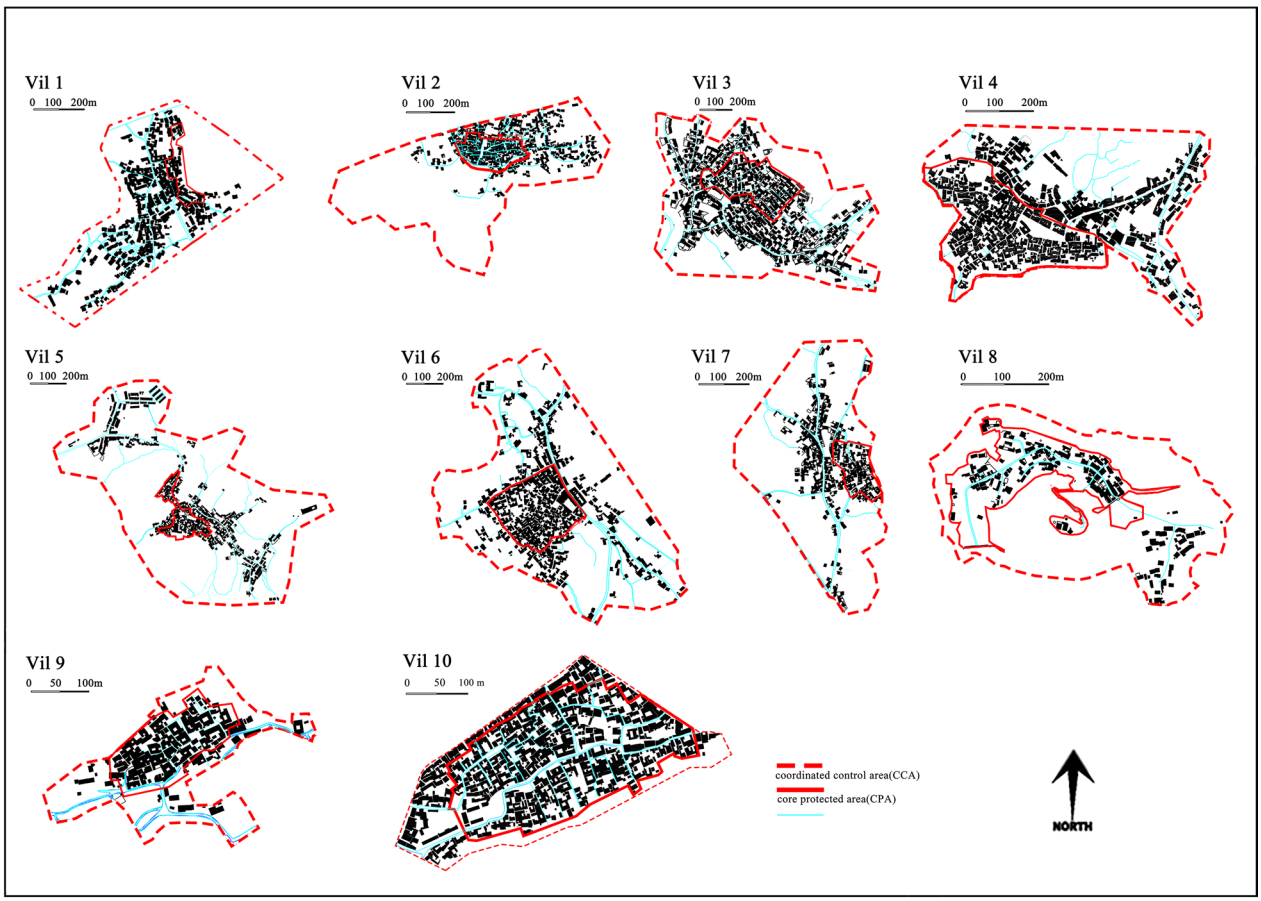

Fig. 2. The research scale of each sample Tunpu settlement

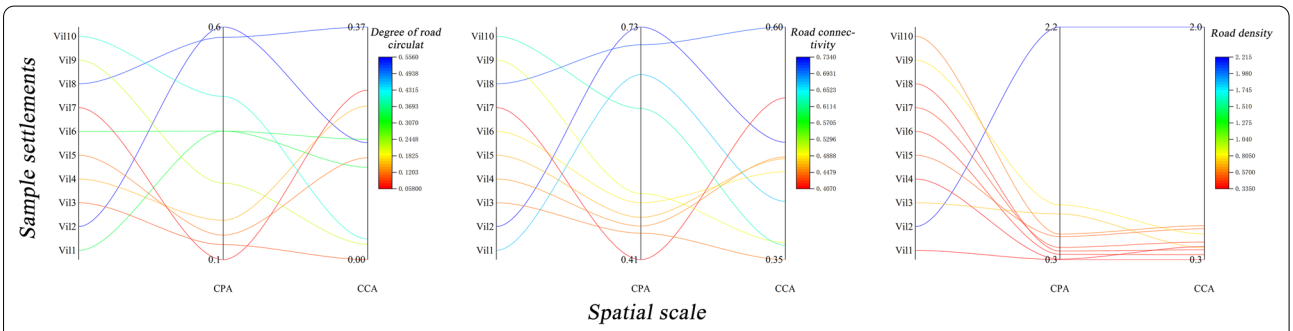

Fig. 3. Characteristics of the space network of the sample Tunpu settlements

the highest. In the transformation from the core protected area to the coordinated control area, almost all the space α-diversity indices of the military Tunpu settlements and the commercial Tunpu settlements were slightly reduced, indicating that their spatial complexity of the coordination area was lower than that of the core area; while the space α-diversity indices of the residential Tunpu settlements presented that *Margalef* index all showed an upward trend, the *Shannon–Wiener* index increased and the *Pielou* index decreased slightly.

Space β-diversity characteristics among the Tunpu settlements

The space β-diversity between the Tunpu settlements were shown in Table 7. Both the dissimilarity index (*whittaker* index and *Bray–curtis* index) and the similarity

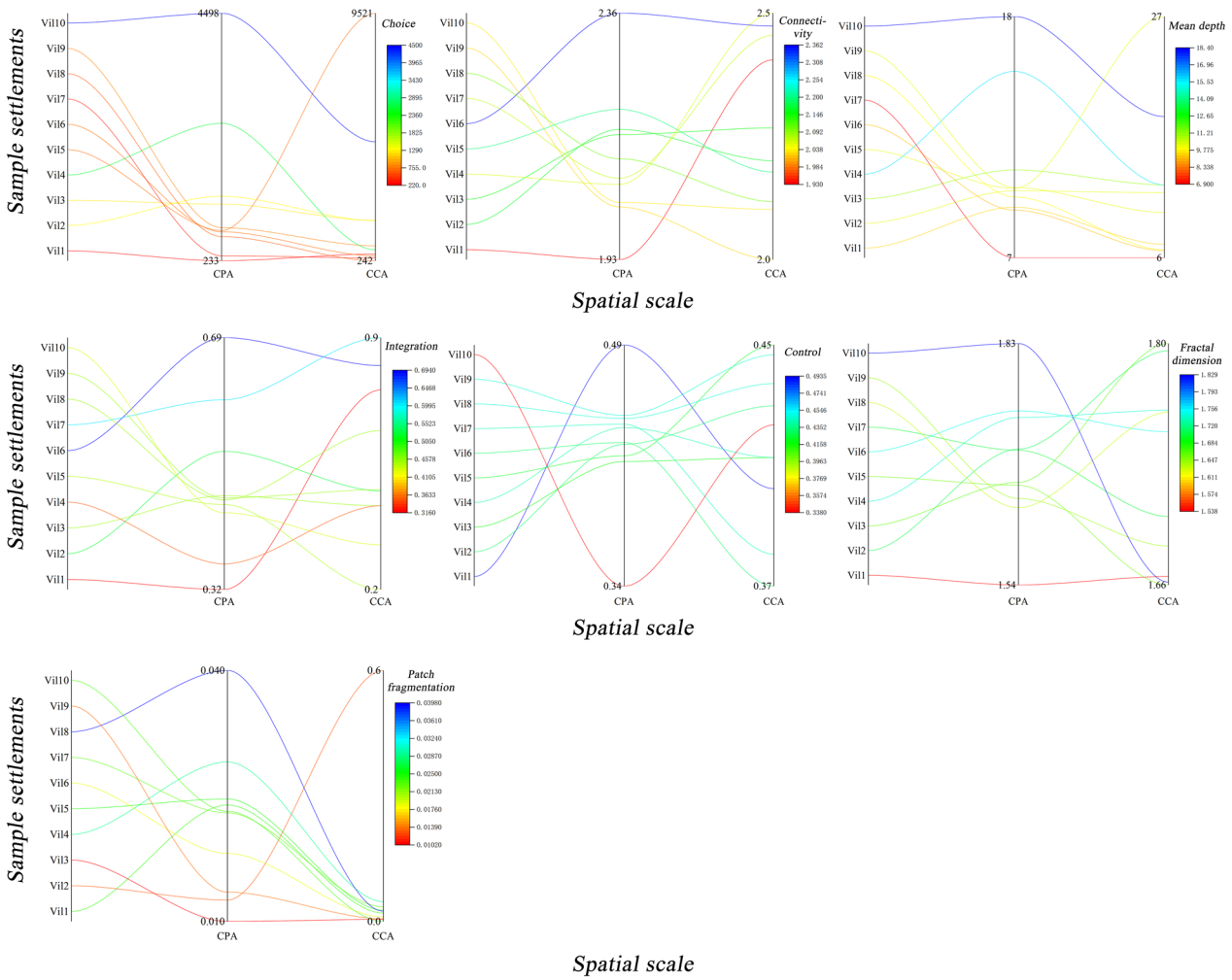

Fig. 4. Spatial morphological characteristics of the sample Tunpu settlements

index (*Jaccard* index) show that the similarity level between the military Tunpu settlements and the commercial Tunpu settlements was higher than other Tunpu settlements, and the difference among the residential Tunpu settlements was higher than that of the other settlements. On the scale of the core protected area, the *whittaker index* (dissimilarity index) was the highest among the residential Tunpu settlements, and the lowest among the commercial Tunpu settlements; the *Jaccard* index (similarity index) was the highest among the commercial Tunpu settlements, higher between the commercial Tunpu settlements and the military Tunpu settlements, and the lowest between the commercial Tunpu settlements and the residential Tunpu settlements; the highest *Bray–curtis* index (dissimilarity index) presented among the residential Tunpu settlements, and the lowest was between the commercial Tunpu settlements and the military Tunpu settlements. On the scale of the coordinated control area, the order of *Jaccard* index (similarity index) values from high to low was among the military Tunpu settlements, between the commercial Tunpu settlements and the military Tunpu settlements, and between the commercial Tunpu settlements and the residential Tunpu settlements; the highest values of *whittaker* index and *Bray–curtis* index were among the residential Tunpu settlements, and the lowest values were between the commercial Tunpu settlements and the residential Tunpu settlements. Between the scales of the same type Tunpu settlement, the space β-diversity among the commercial Tunpu settlements was the most stable; and among the other settlements, the *Jaccard* index (similarity index) showed an upward trend; the *whittaker* index (dissimilarity index) presented a small decline; the *Bray–curtis* index (dissimilarity index) showed a rise and a decline of different magnitudes.

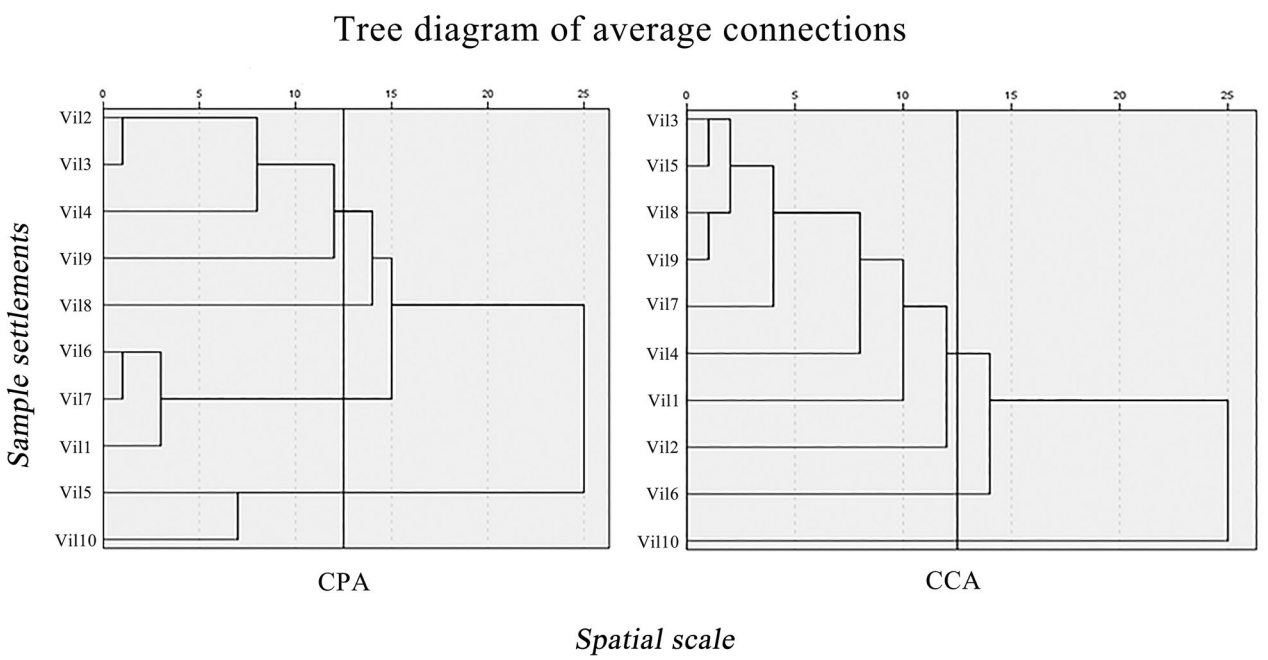

Fig. 5. Analysis of spatial morphological cluster of the sample Tunpu settlement

Table 6 The space α diversity of the Tunpu settlements (CPA is core protected area, CCA is coordinated control area.)

Tunpu's ID	*Margalef*		*Shannon–Wiener*		*Pielou*	
	CPA	**CCA**	**CPA**	**CCA**	**CPA**	**CCA**
Vil1	0.7453	1.2103	0.7702	0.6720	0.5556	0.3232
Vil2	1.6908	1.8551	1.0496	0.9296	0.4558	0.3741
Vil3	0.9262	1.2325	0.7297	0.8073	0.4073	0.3674
Vil4	0.8654	1.1870	0.4609	0.8760	0.2573	0.4213
Vil5	1.0178	1.2046	0.8863	0.9053	0.4947	0.4353
Vil6	1.2463	1.4583	0.9204	1.0155	0.4426	0.4410
Vil7	0.8461	1.2852	0.8849	0.9320	0.5498	0.4482
Vil8	2.0544	1.9753	1.3299	1.2374	0.5546	0.5160
Vil9	1.9608	1.9039	1.3100	1.2152	0.5463	0.5068
Vil10	1.7113	1.6339	1.0969	1.0755	0.4574	0.4485

Table 7 The space *β*-diversity *among* the Tunpu settlements(MT is military Tunpu, CT is commercial Tunpu, RT is residential Tunpu)

SM	*Whittaker(βw)*		*Jaccard (Cj)*		*Bray–curtis(Cn)*	
	CPA	**CCA**	**CPA**	**CCA**	**CPA**	**CCA**
MT-MT	2.2105	2.1905	0.7500	0.9167	5.6190	6.6957
CT-CT	2.2000	2.2000	0.8333	0.8333	7.6364	9.5455
RT-RT	2.4205	2.2718	0.5112	0.7402	10.702	10.2810
MT-RT	2.2765	2.2230	0.5337	0.7059	6.8191	6.9161
CT-RT	2.2641	2.2314	0.4496	0.6824	9.6034	9.5327
MT-CT	2.2026	2.1911	0.8189	0.9183	4.0260	6.9908

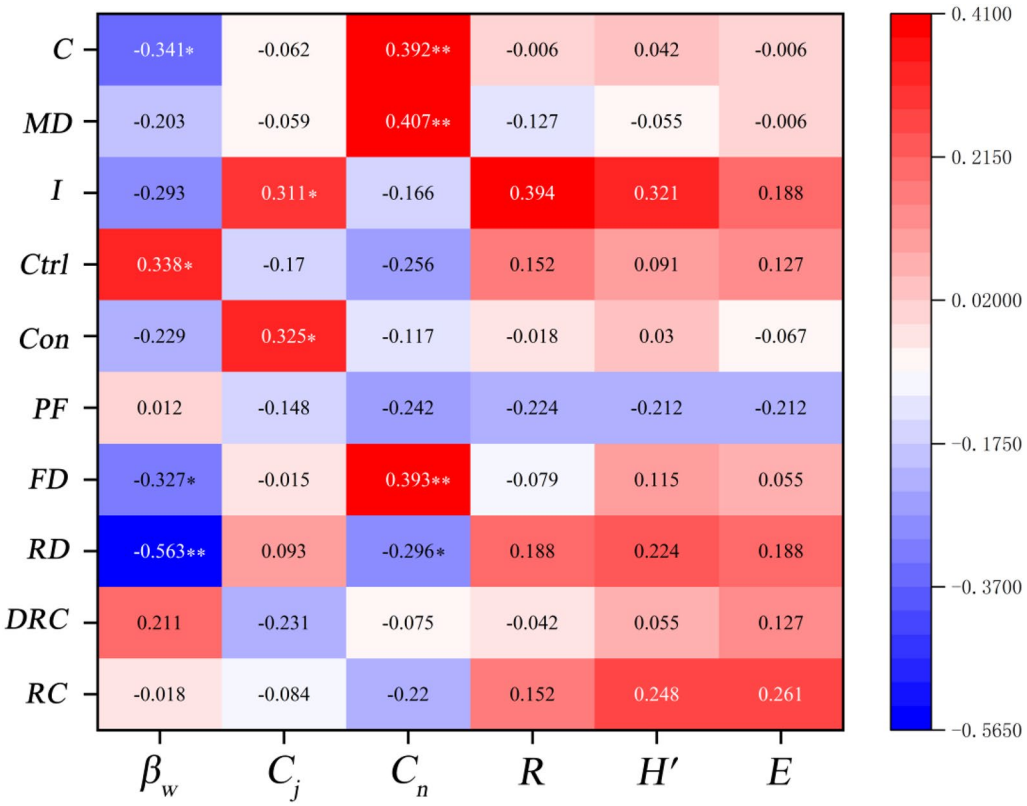

Fig. 6. Results of *spearman* correlation analysis between spatial characteristics indicators and space diversity indices of the Tunpu settlement(* $p < 0.05$; ** $p < 0.01$)

Influencing factors of space diversity of the Tunpu settlements in central Guizhou

The correlation between the internal influencing factors and the space diversity of the Tunpu settlements

Figure 6 exhibited the correlation of the spatial network, spatial morphology and the space α, β diversity of the Tunpu settlement. It can be seen that the internal influencing factors had no obvious correlation with the space α-diversity indices of the Tunpu settlement, but had a significant correlation with β diversity indices. Specifically, *Whittaker* index (dissimilarity index) had a positive correlation with the control value, but a negative correlation with the road network density, fractal dimension and selectivity. The *Jaccard* index (similarity index) correlated positively with the degree of connection and integration. The *Bray–Curtis* index (dissimilarity index) had a significant positive correlation with fractal dimension, depth value and selectivity, while a significant negative correlation with road network density.

External influencing factors of space diversity of the Tunpu settlements in central Guizhou

Figure 7 demonstrated that the indices of space α-diversity and β-diversity were correlated with external factors to varying degrees. The *Margalef* index of space α-diversity was significantly positively correlated with altitude, Government protection time and the number of religious types, but negatively correlated with infrastructure investment and investment in traditional landscape maintenance. All space β-diversity indices were significantly correlated with external factors. Among them, the *Whittaker* index (dissimilarity index) was positively related to distance from urban areas, infrastructure investment, per capita cultivated land, investment in traditional landscape maintenance and number of educational facilities, but negatively related to altitude, hydrographic net, government protection time, number of religious types, and number of folk culture types; the *Jaccard* index (similarity index) was positively correlated with the number of folk culture types and altitude, but

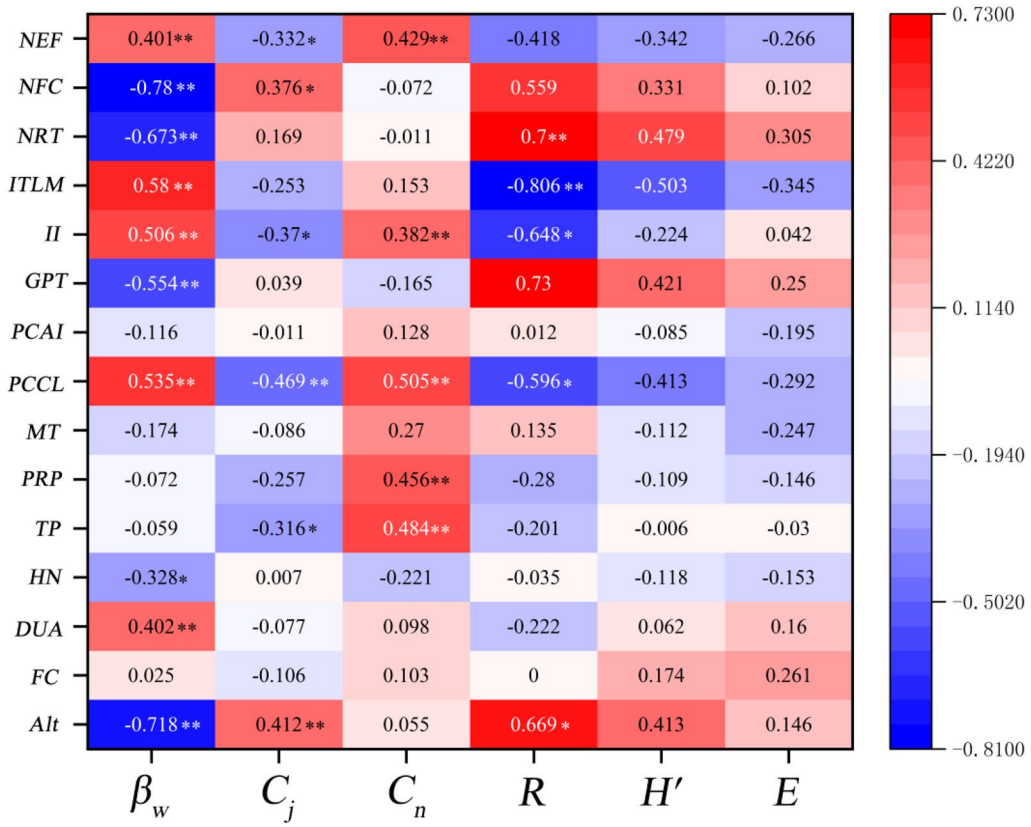

Fig. 7 Space diversity of the Tunpu settlement and correlation of influencing factors

negatively correlated with the total population, per capita cultivated land, infrastructure investment and number of educational facilities; As for *Bray–curtis* index (dissimilarity index) was significantly positive correlated with the number of educational facilities, infrastructure investment, per capita average, permanent resident population and total population.

Stepwise regression analysis between space diversity and influencing factors of the Tunpu settlements

It can be seen from Figs. 6 and 7 that the space α-diversity and β-diversity indicators of the Tunpu settlement were correlated with internal and external influencing factors to varying degrees. Through stepwise linear regression, the variables with no significant influence on space α-diversity and β-diversity were eliminated, and the stepwise regression equation of space diversity and influencing factors of the Tunpu settlement was obtained as follows.

$Y_R = 0.107 + 0.81GPT (R^2 = 0.674)$.

$Y_w = 1.148 - 0.759NFC - 0.593GPT - 0.492DUA + 0.257PCCL + 0.148Ctrl (R^2 = 0.929)$.

$Y_j = 0.557 - 0.444PCCL + 0.286Alt (R^2 = 0.311)$.

$Y_n = 0.150 + 0.491PCCL (R^2 = 0.371)$.

Where, Y_R *is the Margalef* index, Y_w *is the whittaker* index, Y_j *is the Jaccard* index, Y_n *is the Bray–curtis* index, *GPT* is the government protection time, *NFC* is the type of folk culture, *DUA* is the distance from the urban area, *PCCL* is the per capita cultivated land, and *Ctrl* is Control value, *Alt* is altitude.

The results of regression analysis showed that the fitting degree of Y_j and Y_n equations were and was low ($R^2 < 0.5$), but they all passed the significance test ($p < 0.01$) and the T test, indicating that altitude and per capita cultivated land had certain explanatory power on the space similarity between different Tunpu settlements. The fitting degree of Y_R and Y_w equations were high ($R^2 > 0.5$), showing that government protection time, folk culture types, distance from the urban area, altitude, per capita cultivated land and control values had strong explanatory power for the space diversity of the Tunpu settlements. The government protection time and the types of folk culture had a larger contribution rate in the space diversity index of the Tunpu settlements, meaning that policy factors and cultural factors were the main

influencing factors to explain the space diversity of the Tunpu settlements.

Discussion

Space diversity of the Tunpu settlements in different scales and types

The formation of the Tunpu settlements was affected by their defense functions and unique cultural characteristics. Compared with the residential Tunpu settlements, the military Tunpu settlements and the commercial Tunpu settlements had stricter defense requirements and construction scale levels [28, 36], and their spatial functions were more abundant, so it showed a higher space diversity. In addition, the space similarity between the commercial Tunpu settlements and the MT was significantly higher than that among the residential Tunpu settlements, indicating that the settlements with higher defense level were more similar in space composition. Through on-the-spot investigation, it was found that the traditional public landscapes such as streets, alleys, and watchtowers in the military Tunpu settlements and the commercial Tunpu settlements had very obvious defensive functions; and their historical features and cultural elements were relatively well preserved. On the other hand, the Residential Tunpu settlements had a low sense of cultural identity and a weak cultural binding force on the villagers. With the development of the social economy and the innovation of production methods and technologies, the transformation of material space of the residential Tunpu settlements was more random and diverse. This reflected that the space diversity of the Tunpu settlements had obvious cultural dependence, and further confirmed that the defense system played an important role in the spatial pattern of the Tunpu settlements [37, 38].

Urban space diversity varies significantly by the distance from the central urban area to expansion area [8, 39], representing a decreasing pattern of physical decay from the inside to the outside [40], and the internal space diversity of traditional settlements in suburbs shows an increasing trend with time [23]. Our results showed that the space diversity of the military Tunpu settlements and the commercial Tunpu settlements was consistent with the change of urban space diversity, showing a decrease from the inside to the outside. But the space diversity of the residential Tunpu settlements showed an opposite trend which increases from the core protected area to the coordinated control area. This result also confirms that the expansion of the Tunpu settlement has various spatial evolution mechanisms [27].

Some studies have reported that due to the changes in social conditions, the buildings of traditional settlements have tended to be modernized in order to meet the needs of current residents, and the core functional spaces with cultural characteristics have been transformed into resident daily activity spaces, resulting in a decrease in the number of traditional spaces [23, 41] In this study, the differences in space types among different settlements showed a decreasing trend with the change of scale, which explains to a certain extent that the modernization and expansion of the Tunpu settlements had reduced the diversity of space functions among traditional settlements, which is consistent with the development trend of the homogenization of the space functions of traditional Chinese settlements. Through investigation, it is found that in the coordinated control areas of the Tunpu settlements, the space functions are mostly the daily living space of the villagers, and the original space functions of military defense and cultural characteristics are weak. Therefore, the settlement space with relatively complete cultural attributes has a strong self-organized space system, which can maintain a relatively stable spatial development model, while the modern settlement development will lead to the homogenization of the settlement space. Compared with the urban space diversity, although the overall space diversity of the Tunpu settlement was relatively low, its diversity indices still showed certain regularities. It showed that it was scientific and feasible to analyze the space diversity of traditional settlements by referring to the theory and method of species diversity of plant communities. This also requires a lot of empirical research to further verify and improve.

The relationship between space diversity and the spatial characteristics of the Tunpu settlements

The changes of spatial network and spatial morphological characteristics are usually caused by social and political influences that directly or indirectly affect the endogenous logic of traditional settlements [42]. Although some studies have shown that spatial morphology and spatial network have an important impact on the traditional settlement space system [15, 43], and have strong correlations with urban space diversity [10, 32], in this study, there was no correlation between the spatial network and spatial form of the Tunpu settlement and its space α-diversity, indicating that the spatial network, spatial morphology and space diversity might be the results of social, economic and cultural activities on settlement space in the process of settlement development. However, the spatial network and spatial form of the Tunpu settlements presented a significant correlation with the space β-diversity, and the control value had the most obvious effect on the space difference among the Tunpu settlements. The Tunpu settlement is an overall defense system constructed by local control of the internal space, which profoundly affects the spatial representation of the

settlement [44]. The composition and layout of the interior space of different types of the Tunpu settlements are different due to the difference of their main functions. For example, in the settlement site selection and construction of the military Tunpu settlements, the walls and gate of the village were often taken as the boundary to form a group layout, and this spatial form has also been maintained in the later expansion [27]; due to the diversity of production, life and commercial activities, the spatial composition and layout of the same type of the commercial Tunpu settlements or the residential Tunpu settlements also showed certain differences. Comparing the relationships between the spatial network and spatial morphological characteristics and the space β-diversity among the sample Tunpu settlements, it was found that the settlements with higher spatial accessibility had relatively high spatial similarity, and relatively stable spatial morphological change. This result could explain the important role of spatial organization in shaping the space diversity of the Tunpu settlement.

Analysis of external influencing factors of space diversity in the Tunpu settlements

Settlement space is a system constructed by the interaction of different elements [45]. The specific social-culture and natural environment make the physical space of traditional settlements appear in various forms [46]. China has a vast territory, and the geographical environment of the north and the south is quite different, so that the traditional settlements in different geographical locations have obvious differences in spatial characteristics [41, 47], the driving mechanism also has corresponding complexity. In general, the space diversities of the Tunpu settlements in central Guizhou were a comprehensive response under the synergistic effect of multiple driving factors such as natural environment, social economy, policy factors, and cultural factors, which confirmed that external factors are inevitable driving force on the evolution of traditional settlement space system [22, 28, 48–50].

Stepwise regression analysis proved that the natural environment and social economy have a certain explanatory power for the space diversity of the Tunpu settlement. The Tunpu settlements were mostly built in the valleys among mountains, forming a defense system combined with mountains layout [38]. To a certain extent, it reflected that the Tunpu settlement was a manifestation of the spatial pattern of settlements adapted to nature and humanities [28, 51]. However, policy factors and cultural factors were the main factors influencing the space diversity of the Tunpu settlements. This is significantly different from the driving factors of the space diversity of traditional settlements in Guangzhou suburbs [23]. This might be due to the relatively rapid urbanization in the plain area, which has great damage to the complete rural traditional cultural landscape [52]. Guangzhou occupies a coastal economic area, and the rapid economic development stimulates the transformation of traditional suburban settlements from agriculture to urban spatial functions, and promotes the replacement of regional physical and spatial functions [23]. The Tunpu settlements in central Guizhou are special settlements formed by the migration of the Han nationality with advanced culture and technology from Jiangnan region, China to the central area of Guizhou where the local ethnic minorities lived with relatively backward culture and technology. Tunpu culture had played an important role in uniting the hearts and minds of the Tunpu people and jointly resisting harassment, therefore, the Tunpu settlement has a very strong cultural dependence. At present, under the background of modernization development, homogeneous culture has a serious impact on the traditional Tunpu culture, the contradiction between social development and traditional cultural elements is increasingly prominent, and a large number of traditional cultural elements and facilities have been destroyed. This contradiction has been effectively alleviated since the Chinese government has protected the traditional settlements. Through the field investigation, it was found that due to the inclination of the protection policy, the material space and the non-material space of the Tunpu settlements selected into the Chinese traditional list have been effectively protected, while the construction of the settlement space with weaker policy protection is more casual, and the damage to the traditional cultural landscape is more serious. It shows that the government's protection intervention can make the Tunpu settlement better and more effective, and proves that the organic combination of cultural and policy factors plays an important role in the sustainable development of Tunpu settlements [53].

The protection and development strategy of the Tunpu settlements in Central Guizhou Province

Based on the results of this study, it is suggested that the maintenance and orderly development of space diversity should be paid attention to when planning for the protection, development and utilization of the Tunpu settlements. It is necessary to strengthen the government's guidance on the Tunpu settlement development, and coordinate the relationship between the protection of local cultural elements and settlement development. The traditional culture of the settlement core area should be strictly protected, and a buffer zone should be appropriately set up in the periphery of the core area to transition and connect with the cultural

convergence of modern economic and social development. It should not only meet the needs of the modern life of the villagers in the settlement, but also be conducive to the protection of the spatial pattern of the core area, to form a stable spatial structure of functional coordination between the internal space and the external space of the settlement. In addition, the government should actively cooperate with village committees to establish space diversity archives, delimit the space rich areas and space diversity maintenance ranges, and implement hierarchical management and maintenance according to space diversity archives and space richness level. For the Tunpu settlements with declining space diversity in the process of settlement expansion, orderly maintenance should be carried out in the core protected areas, and traditional landscape elements and space types should be appropriately increased in the coordinated control areas.

Conclusion

Quantitative research on space diversity of traditional settlements and its influencing factors could provide scientific basis for the protection of traditional settlements. Based on the theories and methods of community species diversity, this study analyzed the space diversity characteristics of the Tunpu settlement and its internal and external influencing factors, and the following preliminary conclusions were obtained: (1) On the whole, the military Tunpu settlements and commercial Tunpu settlements have relatively high space diversities, and have strong spatial similarity with each other; while the space diversities of the residential Tunpu settlements are low and significantly different each other. The space diversity of different types of the Tunpu settlements presents a variety of changes in the expansion from the inside to the outside. (2) The spatial network and spatial morphology indicators of the Tunpu settlements had no significant correlation with its space α-diversity, but were significantly correlated with space β-diversity, which could explain the change degree of spatial composition among the Tunpu settlements, and the spatial form has a strong explanatory power for the spatial differences of different settlements. (3) The space diversities of the Tunpu settlements were affected by the multiple synergies of the natural environment, policy factors, social-economic and cultural factors, among which policy factors and cultural factors are the dominant factors in the space diversity characteristics of the Tunpu settlements. In this study, the theory and method of plant community species diversity were applied to analyze the traditional settlement space system and its internal and external driving factors. It is shown that the theory and methods of plant community species diversity can be applied to traditional settlement space system research, which can enrich the traditional settlement space theory research methods. The results could provide theoretical reference for scientific guidance of the planning and development of the Tunpu settlements.

Abbreviations

RC: Road connectivity; DRC: Degree of road circulation; FD: Fractal dimension; PF: Patch fragmentation; C: Choice; Con: Connectivity; I: Integration; Ctrl: Control; MD: Mean depth; Alt: Altitude; FC: Forest Coverage; DUA: Distance from urban areas; HN: Hydrographic NET; TP: Total population; PRP: Permanent resident population; MT: Main traffic; PCCL: Per capita cultivated land; PCAI: Per capita average income; GPT: Government protect time; II: Infrastructure Investment; ITLM: Investment in traditional landscape maintenance; NRT: Number of religious types; NFC: Number of folk culture; NEF: Number of educational facilities; CCA: Coordinated control area; CPA: Core protected area.

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Author contributions

HG: writing—original draft, investigation, data curation, formal analysis, resources, visualization. ZW: conceptualization, writing—review and editing, supervision, funding acquisition. YB: project administration, resources. ZH: methodology. XC: writing—review and editing. BW: investigation. YQ: investigation. All authors read and approved the final manuscript.

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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].

Declarations

Competing interests

The authors declare there is no competing interests.

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