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SPATIO-TEMPORAL EVOLUTION AND DRIVING FACTORS OF LANDSCAPE PATTERN IN MINORITY VILLAGES: A CASE STUDY OF ZAHAN VILLAGE IN HAINAN PROVINCE

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Highlights:

- woodlands are the dominant landscape in Zahan Village;
- landscape fragmentation increases and agglomeration decreases, and the landscape tends to become fragmented and less connected;
- decrease in forest land, waters, and grassland, and increase in construction land and cropland;
- changes in landscape patterns are influenced by population, economy, and climate;
- it can provide ideas for the planning and development, ecological protection and management practice of minority villages in other regions of China.

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Abstract. Ethnic minority settlements, as an important medium for the transmission of ethnic cultures, are also a key resource for accelerating the development of ethnic minorities and the regions where they are located. Currently, research on landscape patterns focuses on traditional villages and ancient villages, whereas there is a relative lack of discussion on ethnic minority settlements. This study focuses on the multi-ethnic Zahan Village in Hainan Province, adopting the analysis methods of landscape pattern index and land-use transfer matrix, based on the theoretical framework of landscape ecology, to systematically analyze the spatial and temporal characteristics of the landscape pattern of the village and its patterns between 2007 and 2022, and to qualitatively analyze the influencing factors of its landscape changes from two dimensions, namely, humanities and nature. Research findings: (1) As the dominant landscape type, the proportion of woodland (although decreasing year by year) still exceeds 80%, whereas other land types, such as watersheds and grasslands, are gradually transformed into construction land and arable land, whose increment is significant. (2) During the study period, Throughout the study period, the landscape homogeneity of Zahan Village became better and better, the landscape types tended to be richer, and the spatial heterogeneity of the landscape also increased. (3) The area of woodland landscapes shows a decreasing trend from year to year, whereas construction land and arable land show an overall increasing trend, and the area of watersheds and meadows also decreases slightly. (4) The village landscape is mainly spatially "clustered," concentrated in the center and southern part of the village, with a few "dots" distributed in the east and northwest, and the overall trend is spreading from the center to the periphery. (5) The evolution of village landscapes is influenced by a combination of human factors, including demographic, economic, and policy factors, as well as natural geographic factors, such as topography, climate change, and precipitation. The study provides theoretical support and practical guidance for the sustainable development of Zahan Village, as well as valuable experience and inspiration for the optimal development of other minority villages.

Keywords: minority villages, landscape pattern, time-space evolution, Zahan Village.

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1. Introduction

A "minority village" is a type of settlement formed under certain historical conditions, with obvious territorial scope boundaries. It is a product of the long-term development of the economic and cultural phenomena of ethnic minorities in ethnic minority areas, as well as the result of the interaction between the two (Cui, 2016). The landscape pattern of minority villages precipitated over long-term historical development is not only a visual mapping of the life characteristics and cultural features of the minorities, but also a heritage carrier for passing down minority village culture (Wu et al., 2022). Hainan Province, with 48 ethnic minorities including Li, Miao and Hui, is a multi-ethnic province with a relatively well-preserved heritage of traditional ethnic villages, as well as a rich humanistic history and natural environmental landscape. Protecting, utilizing, and inheriting the landscape of Hainan's minority villages is not only the need of the times for the strategy of rural revitalization, but also the realistic need for scientific optimization of the rural landscape pattern (Dou et al., 2022). Focusing on the evolution of the landscape pattern of Hainan's minority villages can provide a comprehensive understanding of the evolution of the landscape pattern of minority villages in general, provide new ideas for the protection of the diversity and endemism of the landscape patterns of Hainan's minority villages, and be of great significance for the promotion of the sustainable development of minority villages.

The spatial structural feature of landscape is its landscape pattern, which refers to the arrangement and combination of landscapes of different shapes and sizes embedded in space (Han et al., 2005), and contains elements such as the type and number of landscape constituent units (Li et al., 2019), which can comprehensively reflect the heterogeneity of landscape (Forman, 2019). Landscape pattern change is the result of the interaction between natural and anthropogenic multifactors at different spatial and temporal scales (Fu, 2001), which is manifested in two main aspects: the change of time series and the change of spatial gradient. Time series research mainly employs remote sensing image data in different periods to analyze the characteristics and dynamic changes of regional landscape patterns in different periods. Since the 1980s, with the rapid development of geographic information system (GIS) and remote sensing (RS) technologies, the ability to detect and analyze landscape evolution has been significantly improved (Abou Samra & El-Barbary, 2018; Abou Samra & Ali, 2021; Abou Samra, 2022, 2023). In assessing the change of spatial gradient, urban centers, suburbs, and rural areas are generally used as particular gradients to analyze the differences in landscape pattern characteristics of regions under different levels of economic development (Sun & Guo, 2011). In recent years, research studies related to the evolution of landscape patterns of villages have tended to focus on the changes of natural and humanistic elements such as buildings, roads and farmland of the villages, as well as the changes of the influencing factors under different cultural backgrounds and different historical periods. In terms of research methodology, quantitative means are widely used to analyze landscape pattern changes (Xi et al., 2014; Wang et al., 2019) and to establish a "pattern-process" model based on ecological principles (Sun et al., 2002; Zou et al., 2018; Li & Zhang, 2022), supplemented by qualitative studies, to fully understand the cultural connotation of landscape (Ge et al., 2019; Chen et al., 2021), habitat relationship (Zhang et al., 2019; Jiang et al., 2019), landscape evolution (Liu & Tu, 2017), sustainable development and conservation (Zhang et al., 2018).

In summary, the study of the evolution of rural landscape patterns has received increasing attention within the academic community, and the content of the study has been continuously expanded and enriched, however, research have focused on traditional villages and ancient villages, while less attention has been paid to ethnic minority villages. Minority villages are villages dominated by ethnic minority residents and are a special form of villages, which carry a rich ethnic culture and traditional way of life. It has been shown that the spatial imaginations of multiple subjects are interlocked with one another in the spatial change and reconstruction of minority villages (Sun & Su, 2013), forming an intricate mechanism for the evolution of the landscape pattern; as a result, minority villages face the spatial and social dilemma of inheritance and transformation (Wang et al., 2020). Although Hainan's Zahan Village is a typical Li and Miao mixed village, along with the rapid development of rural construction, its landscape pattern has undergone drastic differentiation and reorganization, and the spatial pattern has also changed drastically. Thus, the study of the landscape pattern evolution characteristics and influencing factors of Zahan Village can help to explore the spatial evolution law of minority villages and provide scientific basis as well as strategy support for the sustainable development and cultural inheritance of minority areas. From the perspective of landscape ecology combined with the science of human habitat, the study reveals the characteristics of the landscape pattern evolution of Zahan Village and analyzes the influencing factors of the village landscape pattern evolution through the combination of quantitative analysis and qualitative research, which can better understand the evolution process of the rural landscape pattern and the driving mechanism behind it. This is of great significance for the formulation of rational land-use planning, the protection of the ecological environment, the maintenance of the cultural characteristics of ethnic minorities, and the promotion of the overall economic and social development of villages. At the same time, the study also provides valuable experience and reference for other minority areas, while promoting comprehensive knowledge and in-depth understanding of the evolution of landscape patterns in minority villages.

2. Study area

Zahan Village belongs to Hongmao Town, Qiongzhong Li and Miao Autonomous County, Hainan Province, and is located in the alpine basin between Lima Mountain and Parrot Ridge, situated on a high mountain (more than 800 meters) in Hongmao Town. It is one of the highest villages in Hainan Province, with geographic coordinates between latitude 18°14′–19°25′N and longitude 109°31′–110°09′E (Figure 1). The whole village consists of three Li villages, namely Chongsha, Zatuo and Yuanya, and two Miao villages, namely Laomiaozhai and Xinmiaozhai, with a total population of 108 households and 523 people; among them, 314 are Li and 209 are Miao. Zahan Village is densely forested; the east, west, and north sides of the village are all natural forest reserves, with a forest coverage rate of 80%; the streams are entangled and the climate is mild: Summers are long without scorching heat, while winters are short without severe cold. The average annual temperature is 22 °C and the rainfall is plentiful, with a normal yearly rainfall of 1500–2000 millimeters. Zahan Village is representative of the island tribal settlements in the tropical region, with the advantage of original ecological scenery: It bears the beautiful title of "heavenly Zahan," a title awarded to recognize it as featuring most beautiful countryside and minority villages in China (Figure 2). The upper-left photo shows the entrance to Zahan Village, where there is a sign that reads "Most Beautiful Chinese Countryside – Zahan Village"; the upper-right photo provides an overhead view of the entire village, showing the full extent of Zahan Village, with the cloudy landscape giving the impression of being in a fairyland; the bottom-left photo shows a residential house with the characteristics of the Li ethnic group (the Li motifs on the walls are important symbols of the culture of this ethnic group); and the bottom-right photo shows an ethnic Hmong residence with Miao motifs adorning the walls.

Zahan Village was once one of the poorest and most backward administrative villages in Qiongzhong County, with a per capita net income of only 946 yuan in 2009. In recent years, through poverty alleviation and development, as well as grass-roots party building and rural tourism in-depth integration of the scientific development of a new way, the means of production and living environment have improved significantly, the industrial structure has been gradually optimized, the village has a new look. Villager's net income grew from 2,720 yuan in 2012 to 10,003 yuan in 2015, receiving 58,000 tourists in 2015, with 70,039 overnight visitors, generating 1,651,400 yuan. From January to October 2016, the village received 81,656 tourists, with 78,669 overnight visitors, realizing 8,380,000 yuan of tourism revenue. However, the development of the tertiary industry, with tourism as the mainstay, has also inevitably brought about some problems, such as the proliferation of construction areas, the increase in environmental pollution, and the rough utilization of land resources, which have brought about potential ecological security threats for Zahan Village.

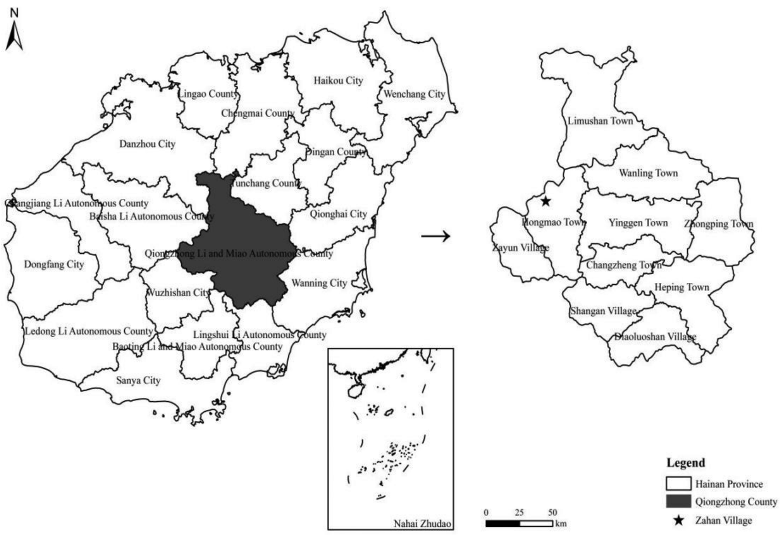
Figure 2. Zahan Village

3. Research methods and data sources

3.1. Research methods

3.1.1. Construction of a land-use classification system

Based on the Chinese national standard Classification of Land Use Status (GB/T21010-2017), the land-use types in Zahan Village are classified into five primary land classes–forest land, grassland, arable land, watersheds, and construction land– as well as 15 secondary land classes. This classification provides a structured and standardized framework for the study, which aids in conducting systematic land-use analysis and comparison. At the same time, this study refers to the CORINE (Coordination of the European Union Environment) land classification used by Burkhard et al. (2009); this comparison ensured the scientific validity and rigor of the land classification used. In addition, the land-use type classification system of Zahan Village was obtained by combining the actual land cover situation in the study area (Table 1).



Note: Produced based on the standard map with review number GS(2019)1822 on the Ministry of Natural Resources Standard Map Service website, with no modifications to the base map boundaries.

Figure 1. Geographic location of Zahan Village in Hainan Province

Table 1. Classification system of land-use types in Zahan Village

Primary land classes	Secondary land classes	Refer to CORINE land classes
Woodland	Forested, open, shrub and other woodlands	Coniferous forests, broadleaf forests, shrub forests, tree forests, etc.
Grassland	High-cover and low-cover grasslands	Natural grasslands, artificial grasslands, other grasslands, etc.
Arable land	Paddy land, dry land	Non-irrigated cropland, permanently irrigated cropland, vegetable land, etc.
Watershed	Reservoirs, rivers, lakes, ponds	Ditches, river water, breeding ponds, marshes, etc.
Const-ruction land	Residential land for villagers, land for transportation and storage, and other construction land	Land for public administration and services, agricultural land for facilities and land for logistics and warehousing, etc.

3.1.2. Landscape index selection

The landscape pattern index refers to the deep aggregation of landscape pattern-related information, reflecting the characteristics of structural composition and spatial configuration (Wu, 2007), quantitatively describing and monitoring the changes of landscape structural characteristics over time. Landscape pattern indices comprise three types: patch scale (Patch), patch type scale (Class), and landscape scale (Landscape), which quantitatively capture landscape characteristics and trends of change (Qi et al., 2019). In the analysis of the landscape pattern of the whole region, because the contribution of the calculation and analysis of the landscape index of individual patches is relatively small, the exploration of the landscape pattern index in the empirical study mostly adopts the two larger scales, namely patch type and landscape level. The patch type index characterizes the structure and distribution of a particular landscape, and the landscape type index represents the overall characteristics of all the landscapes in the region, both of which can clearly express the characteristics of the regional landscape pattern. In this paper, according to the ecological significance of landscape pattern indices (classification criteria of FRAGSTATS) (McGarigal & Marks, 1995), with reference to the relevant studies on landscape pattern of scholars (Yang et al., 2020), and combining with the actual situation of Zahan Village, 6 landscape pattern indices were selected to analyze the changes of landscape pattern in Zahan Village (Table 2). Among them, Class Area (CA), Number of Patches (NP), Patch Density (PD), Largest Patch Index (LPI), Shannon's Evenness Index (SHEI), and Shannon's Diversity Index (SHDI) were selected for the landscape type index.

3.1.3. Correlation analysis method

Correlation analysis is a statistical method used to study the degree of closeness of the relationship between variables, and is often used to quantitatively describe the degree of correlation closeness of the linear relationship between two variables (Han et al., 2018). Fragstats 4.5 provides more than 50 landscape indices, and similarities exist between the landscape indices to characterize the landscape pattern. Therefore, Spearman correlation analysis of landscape pattern indices was performed with the help of SPSS statistical software to screen out the landscape pattern indices with weak correlations, thereby ensuring independence between the selected indices to reduce repetitive descriptions while improving the efficiency and accuracy of the analysis.

3.1.4. Land-use transfer matrix

Land-use changes can be realized through the land-use transfer matrix, which can reflect the composition of land-use types and the direction of transfer in different periods in the study area (Huang et al., 2020). The general formula for the transfer matrix is as follows:

$$D_{uv} = \begin{bmatrix} D_{11} & D_{12} & \cdots & D_{1n} \\ D_{21} & D_{22} & \cdots & D_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ D_{n1} & D_{n2} & \cdots & D_{nn} \end{bmatrix},$$

where n is the number of land-use types, u and v are the land-use types at the beginning and end of the study, and

Table 2. Landscape pattern index

Landscape index	Landscape meaning	Range of values
CA	Reflects the size of the patch; the larger the CA value, the larger the area of the patch type	CA ≥ 1
NP	Reflects the number of patches; the larger the NP value, the greater the landscape fragmentation and the greater the spatial heterogeneity	NP ≥ 1
PD	Reflects the overall heterogeneity and fragmentation of the landscape; the larger the PD value, the greater the degree of heterogeneity and fragmentation of the landscape	PD > 1
LPI	Reflects the type of dominance of the landscape, but also the degree of human disturbance; the higher the LPI value, the higher the degree of human disturbance	LPI > 0
SHEI	Reflects the uniformity of the landscape; the larger the SHEI value, the better the uniformity of the landscape	0 ≤ SHEI ≤ 1
SHDI	Reflects the heterogeneity and diversity of the landscape; the larger the SHDI value, the richer the landscape type and he greater the spatial heterogeneity	SHDI ≥ 0

D_{uv} represents the transfer of land from land u at the beginning to land v at the end of the study.

3.2. Data sources and processing

3.2.1. Data sources

The village of Zahan was chosen as the study area, and a series of rigorous data collection and processing measures were taken to ensure the accuracy and reliability of the data. Remote sensing data were obtained from the Geospatial Data Cloud website of the Computer Network Information Center of the Chinese Academy of Sciences (http://www.gscloud.cn) with a spatial resolution of 30 m. Image data with less than 5% cloud cover was selected because lower cloud cover can provide a clearer view, reduce the occlusion effect, and improve the accuracy of land-use type identification. At the same time, winter image data was selected because winter is usually a period with less vegetation cover; as such, images from this period permit easier identification of the real land use. In summary, potential sources of error were minimized and the accuracy and reliability of the land-use classification were improved by selecting winter image data with less than 5% cloudiness, as shown in Table 3 for an overview of the data. Other basic geographic information data (Hainan Province, municipal boundaries, etc.) are from the National Geographic Information Resources Catalog Service System (http://www.webmap.cn). Relevant statistical information comes from official websites and local statistical yearbooks. In addition, three field research trips were made to the study area in October 2022, May–June 2023 and October–November 2023, each lasting longer than six days, to collect data on the current status of land use in the study area and to provide supplementary information for some of the missing data.

Table 3. Summary of remote sensing image data

Source Satellite	Strip (row) number	Image date
Landsat 8-9 OLI/TRIS	124(47)	2013/10/26, 2018/10/12, 2022/12/22
Landsat 4-5 TM	124(47)	2007/11/1

3.2.2. Data processing

In this study, a series of precise remote sensing image processing steps and land-use classification methods were used to successfully analyze the land-use changes in Zahan Village from 2007 to 2022. The following are the main steps and methods of data processing:

Pre-processing. Pre-processing operations, such as radiometric calibration, image cropping and atmospheric correction, were carried out on remote sensing images for each period using ENVI 5.3 software to ensure the quality and availability of image data.

Wave combination analysis. By analyzing the color differences of different band combinations, and subsequently combining the results of historical images and field research in the study area, the correspondence between each band combination and land-use types was determined. For example, categorization is performed using a combination of bands 5, 4, and 3 to discriminate forest land and a combination of bands 6, 5, and 2 to discriminate cropland.

Supervised classification. The atmospherically corrected remote sensing images were used as the training set, and no fewer than 50 training samples were selected for each land-use type using the visual interpretation method. Then, the maximum likelihood method in supervised classification was utilized to classify the land-use types, and the land-use classification results were obtained for 2007, 2013, 2018, and 2022.

Accuracy assessment. The accuracy of the classification results was assessed by calculating the Kappa coefficients, all of which exceeded 0.8, indicating that the classification results have high accuracy and reliability.

Results validation. The classification results were verified using high-definition Google Earth images, and the data classification accuracy reached more than 90%, thus meeting the research requirements.

4. Results and analysis

4.1. Correlation analysis between landscape pattern indices

As shown in Table 4, the correlation coefficients of PD and NP, LPI and CA were all 0.6, with weakly significant positive correlations ($P < 0.1$). The correlation coefficient between SHDI and SHEI is 0.8, and there is a significant positive correlation between the two indices ($P < 0.1$).

The correlation analysis of the landscape pattern indices reveals a small correlation between the landscape pattern indices: Changes in some of the landscape pattern indices cause changes in the related indices, and the correlation between the landscape pattern indices is in line with the ecological significance of the indices. This is essentially consistent with the results of the landscape index analysis of the Linzhi section of the Yarlung Tsangpo River Basin conducted by Li et al. (2020), which further supports that the selection of the LPI mentioned above is reasonable.

Table 4. Results of correlation analysis

Index	CA	NP	PD	LPI	SHDI	SHEI
CA	1					
NP	0.4	1				
PD	0.4	0.6*	1			
LPI	0.6*	0.4	0.4	1		
SHDI	–0.2	0.8	0.8	–0.2	1	
SHEI	–0.2	0.8	0.8	–0.2	0.8*	1

Note: * represent 10% significance levels, respectively.

4.2. Analysis of landscape pattern evolution

4.2.1. Analysis of the patch type index

Based on the data in Table 5 and Figure 3, we can analyze the change of patches of different land-use types in Zahan Village during the period of 2007–2022.

Table 5. Changes in the patch type index

Type	Year	CA	NP	PD	LPI
Arable land	2007	51.57	80	9.50	1.97
	2013	36.81	94	11.17	0.56
	2018	19.62	55	6.53	0.50
	2022	55.53	109	12.95	2.11
Construction land	2007	19.44	30	3.56	1.14
	2013	45.72	114	13.54	1.25
	2018	95.85	71	8.44	8.95
	2022	73.08	133	15.80	3.97
Woodland	2007	723.87	7	0.83	85.14
	2013	723.15	9	1.07	85.41
	2018	719.91	8	0.95	85.04
	2022	691.38	14	1.66	81.29
Watershed	2007	7.83	39	4.63	0.13
	2013	5.49	40	4.75	0.05
	2018	1.89	12	1.43	0.05
	2022	5.94	30	3.56	0.18
Grassland	2007	38.97	68	8.08	1.07
	2013	30.51	65	7.72	0.59
	2018	4.41	28	3.33	0.05
	2022	15.75	88	10.46	0.36

The area of woodland patches decreased year by year, but the number of patches and the density of patches increased slightly; the maximum patch index remained at a high level; which indicated that although the overall area of woodland in Zahan Village is decreasing, the distribution of woodland patches has become more decentralized, which means that the woodland has been divided into smaller patches and the number of small patches is higher, but there are still some larger woodland patches. This may be due to a certain amount of woodland destruction by new rural construction and beautifying countryside building projects, which affect ecological stability and biodiversity.

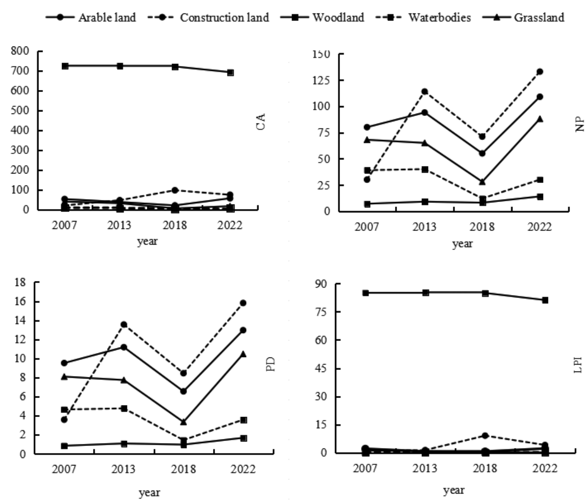


Figure 3. Changes in the patch type index

The patch area and maximum patch index of the construction land showed a trend of increasing and then decreasing, but overall it was increasing, indicating that the development of rural tourism promoted the increase of construction land area in Zahan Village. Meanwhile, the number of patches and patch density increased significantly, indicating that the degree of fragmentation and complexity of construction land increased, and that spatial distribution tended to be decentralized.

The patch area and maximum patch index of cropland decreased and then increased; the number of patches and patch density increased, and then decreased, and then increased again. These changes indicate that the degree of fragmentation of cropland has increased, but the shape of cropland patches tends to be regular and simpler, with increased aggregation and increasingly concentrated spatial distribution.

The patch area, number of patches, patch density and maximum patch index of the grassland showed a trend of decreasing and then increasing–but as a whole, the patch area and maximum patch index of the grassland decreased, whereas the number of patches and the density of patches increased, which indicated a decrease in the area of the grassland and an increase in the degree of fragmentation.

The patch area and maximum patch index of the watershed decreased and then increased; the number of patches and patch density increased and then decreased; and the maximum patch index tended to be zero. This indicates that waters are affected by anthropogenic disturbances, with a gradual decrease in watershed area and a reduction in fragmentation, albeit with a relatively dispersed distribution of large watersheds.

4.2.2. Analysis of landscape type index

The trends in the landscape pattern of Zahan Village revealed in Figure 4 reflect the dynamic changes in the land use and landscape structure of the village over time.

The trends of SHEI and SHDI reveal a more even distribution of landscape types and a diversification of landscape patterns in Zahan Village during the periods 2007–2013 and 2018–2022, which may be related to the implementation of ecological protection and restoration measures. In contrast, during the period 2013–2018, landscape types were unevenly distributed and the landscape pattern tended to be homogenized, which may be attributable to the overexpansion of certain landscape types (e.g., construction land), which led to a reduction in the area of other landscape types (e.g., woodland, watershed, and grassland).

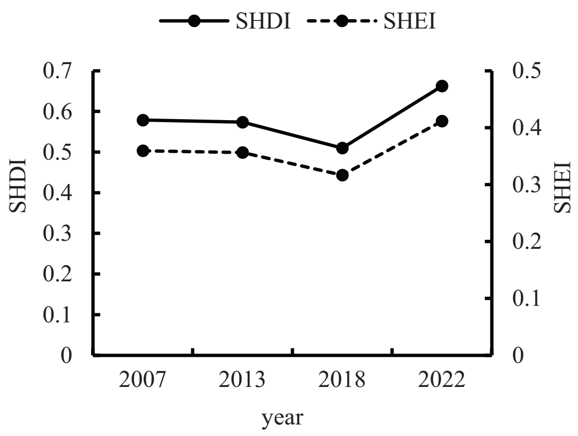


Figure 4. Changes in landscape type index

4.3. Analysis of land-use transfer

4.3.1. Analysis of land-use structure and quantitative changes

It is evident from Figure 5 and Table 6 that the land-use types in Zahan Village have undergone significant changes during these 16 years. Woodland, the dominant land-use type in the village, occupies approximately 85% of the total village area, a proportion that reflects the dominance of woodland in the landscape pattern of Zahan Village. During the study period, the area of forest land continued to decrease, with a cumulative decrease of 0.3249 km^2; changes in the area of waters, cultivated land and grassland showed a trend of decreasing and then increasing, which may be due to earlier patterns of land development and utilization. In particular, during the period 2007–2013, the area of water and grassland shrank significantly, whereas the area of built-up land grew significantly; this trend is closely related to the policy of poverty alleviation through the development of rural tourism established by the village in 2009. In the beginning stage of tourism development, a large amount of construction land is needed to build infrastructure and services, and the implementation of this policy has led to the transformation of the original natural landscape to accommodate the construction of tourism facilities and services.

4.3.2. Time-shift analysis of land-use types

Zahan Village experienced significant landscape type changes over the 2007–2022 study period, which reflect the impact of new urbanization on land-use patterns. As can be seen from the data in Tables 7–10, the transformation of the various land-use types has exhibited different characteristics and trends over time.

In the period 2007–2013, the most significant expansion of the area of construction land was realized mainly through the conversion of cultivated land and grassland. At the same time, the reduction in the area of woodland was not only converted into construction land, but also shifted to grassland and waters, possibly due to the needs of tourism development and infrastructure construction. The conversion of watershed area to cropland is the most frequent land-use type change, which may be related to agricultural demand and land development policies.

During the period 2013–2018, construction land remained the land-use type with the most significant change in area, and the conversion of cropland and grassland to construction land continued to dominate. During this period, most of the reduction in the area of watersheds was transformed into construction land, whereas the reduction

Table 6. Land use area (km^2), proportion (%) in Zahan Village

Year	Woodland		Watershed		Construction land		Arable land		Grassland	
	Area	Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area	Ratio
2007	7.2387	86	0.0783	0.93	0.1944	2.31	0.5157	6.13	0.3897	4.63
2013	7.2315	85.92	0.0549	0.65	0.4572	5.43	0.3681	4.37	0.3051	3.62
2018	7.1991	85.53	0.0189	0.22	0.9585	11.39	0.1962	2.33	0.0441	0.52
2022	6.9138	82.14	0.0594	0.71	0.7308	8.68	0.5553	6.6	0.1575	1.87

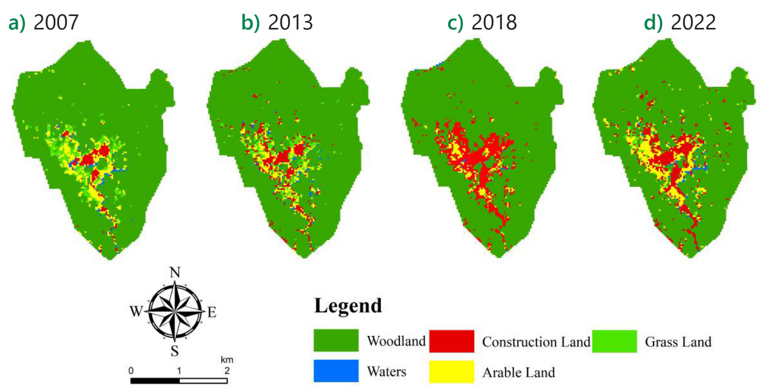


Figure 5. Land use types in Zahan Village

in the area of forest land was shifted mainly to construction land, watersheds and cropland, which further illustrates the transformation of land-use types in the process of tourism development and urbanization.

During the period 2018–2022, the most significant increase in the area of cultivated land is transferred mainly from construction land, which may be due to the implementation of the policies of land remediation and returning farmland to woodland and grassland. The area of woodland decreases the most, mainly transferred out of construction land, which indicates that woodland is still the main casualty of urbanization and tourism development. The increase in the area of watersheds and grasslands is mainly transferred from woodland and construction land, which may be due to measures taken for ecological restoration and environmental protection.

Overall, there is a clear trend of increase in construction land during the study period, with a cumulative increase of 0.5364 km^2, mainly at the expense of woodland, waters, and grassland. The shrinkage of grassland area was the most conspicuous, while woodland and water area also decreased. These changes indicate that Zahan Village faces challenges between ecological environmental protection and economic development in the process of new urbanization.

4.3.3. Spatial-shift analysis of land-use types

From Figure 6, it can be seen that during the 16 years from 2007 to 2022, the spatial pattern of land use in Zahan Village has changed significantly, exhibiting certain patterns and characteristics.

Table 7. Landscape type transfer matrix from 2007 to 2013

	Woodland	Watershed	Construction land	Arable land	Grassland	Total
Woodland	7.1604	0.0117	0.0333	0.009	0.0243	7.2387
Watershed	0.0099	0.0198	0.0162	0.0324	0.0000	0.0783
Construction land	0.0000	0.0000	0.1728	0.0216	0.0000	0.1944
Arable land	0.0000	0.0171	0.1017	0.2448	0.1521	0.5157
Grassland	0.0612	0.0063	0.1332	0.0603	0.1287	0.3897
Total	7.2315	0.0549	0.4572	0.3681	0.3051	8.4168

Table 8. Landscape type transfer matrix from 2013 to 2018

	Woodland	Watershed	Construction land	Arable land	Grassland	Total
Woodland	7.1775	0.0108	0.0396	0.0036	0.0000	7.2315
Watershed	0.0027	0.0036	0.0450	0.0000	0.0036	0.0549
Construction land	0.0027	0.0036	0.4329	0.0162	0.0018	0.4572
Arable land	0.0045	0.0009	0.2070	0.1404	0.0153	0.3681
Grassland	0.0117	0.0000	0.2340	0.0360	0.0234	0.3051
Total	7.1991	0.0189	0.9585	0.1962	0.0441	8.4168

Table 9. Landscape type transfer matrix from 2018 to 2022

	Woodland	Watershed	Construction land	Arable land	Grassland	Total
Woodland	6.9075	0.0171	0.1314	0.0603	0.0828	7.1991
Watershed	0.0063	0.0081	0.0045	0.0000	0.0000	0.0189
Construction land	0.0000	0.0288	0.5697	0.2907	0.0693	0.9585
Arable land	0.0000	0.0000	0.0216	0.1692	0.0054	0.1962
Grassland	0.0000	0.0054	0.0036	0.0351	0.0000	0.0441
Total	6.9138	0.0594	0.7308	0.5553	0.1575	8.4168

Table 10. Landscape type transfer matrix from 2007 to 2022

	Woodland	Watershed	Construction land	Arable land	Grassland	Total
Woodland	6.9102	0.0153	0.1836	0.072	0.0576	7.2387
Watershed	0.0018	0.0387	0.027	0.0108	0.0000	0.0783
Construction land	0.0000	0.0000	0.1935	0.0009	0.0000	0.1944
Arable land	0.0000	0.0054	0.1827	0.3213	0.0063	0.5157
Grassland	0.0018	0.0000	0.144	0.1503	0.0936	0.3897
Total	6.9138	0.0594	0.7308	0.5553	0.1575	8.4168

First, from 2007 to 2013, the spatial shift of land use was mainly concentrated in the central and southern parts of the village, indicating that development in Zahan Village was also concentrated in these areas during that period. The conversion of cropland and grassland to construction land may reflect the advancement of population growth, economic development, and urbanization. This conversion may have been in response to residential housing needs as well as commercial and infrastructure development.

Second, between 2013 and 2018, land-use conversion continued to be dominated by the conversion of cropland and grassland to construction land, but the center of gravity of the conversion shifted to focus mainly on the vicinity of residents' homesteads, expanding in all directions. This may mean that residents' demand for improved living conditions increased during this period, or that they preferred construction activities near their original homesteads due to policy guidance and economic incentives.

Once again, the spatial shift in land use from 2018 to 2022 is concentrated in the central part of the village, which may indicate that the development potential of the central part of the village has been further tapped or that more construction and investment has been attracted to the central part due to its better infrastructure and public services.

Finally, as a whole, the spatial conversion of land use in Zahan Village shows a trend of spreading from the center of the village to the surrounding area. This is related to the geographic environment of Zahan Village, which is surrounded by mountains on three sides and has a large area of forest land. Because most of the forest land is distributed around the village, the expansion of residential and infrastructure land can only spread in all directions; this geographical restriction affects the land-use conversion pattern to a certain extent.

4.4. Analysis of factors influencing the evolution of landscape patterns

The formation of the landscape pattern of minority villages is a dynamic and historically evolving process. It is not only the result of the interaction between the natural geographic environment and human activities, but also a comprehensive embodiment of cultural dimensions. In this process, ethnic minorities-as the main body-have continuously transformed and reshaped the environment they live in through their cognitive and practical activities, forming a unique cultural landscape (Xiao, 2014). Fu et al. (2002) divided the factors affecting the evolution of landscape pattern into natural and human factors: Natural factors include temperature, precipitation and geological features, which have a fundamental impact on ecosystems and land cover; human factors include socio-demographic, economic and cultural aspects, which have a direct impact on human activities and land-use patterns. Following that model, this paper also summarizes the factors influencing the landscape pattern of Zahan Village as natural factors and human factors, which are particularly prominent in the process of landscape pattern evolution of Zahan Village.

4.4.1. Human factors analysis

Socio-demographic. Population size and distribution have a direct impact on land-use patterns. Population growth increases the pressure on land resources, which in turn causes changes in land-use patterns. As can be seen in Figure 7, the year-end population of Zahan Village remained relatively stable over the period 2007–2022, and the field study found that the micro-changes in population were caused mainly by weddings and funerals. Changes in the population size of Zahan Village are driven mainly by changes in the number of tourists received.

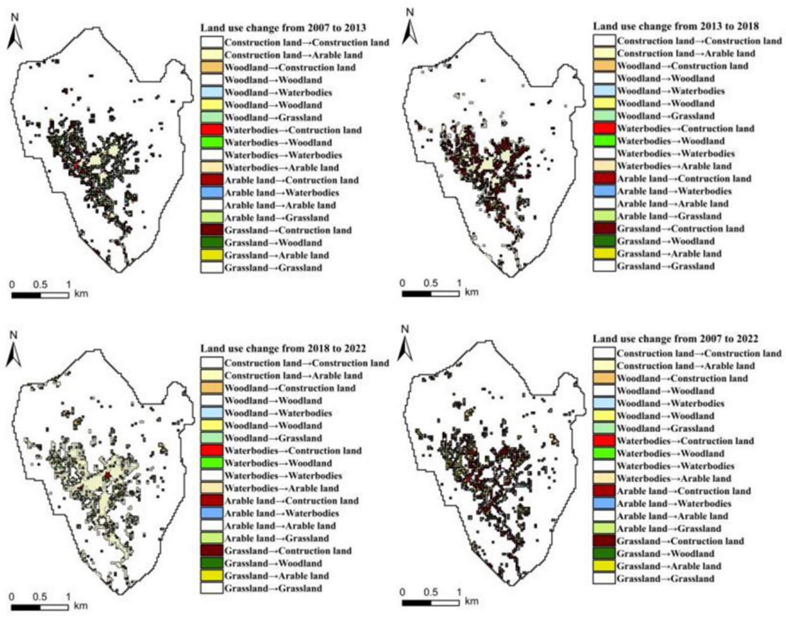


Figure 6. Spatial shift of landscape types

In 2009, Zahan Village established the strategy of vigorously developing rural tourism to achieve rural revitalization (Xi et al., 2014; Lu et al., 2019), and the industrial transformation further promoted the transformation of land use. Zahan Village saw a year-on-year rise in tourist reception until 2018, and in order to provide better tourism services to tourists, villagers under the leadership of the village collective constructed infrastructure represented by countryside lodges and farmhouses; as a result, land use was dominated by the conversion of arable land and grassland to construction land during this period. The outbreak of the COVID-19 pandemic had a significant impact on the tourism industry, resulting in a precipitous drop in visitor reception; however, the village collectively undertook the construction of tourism support facilities during the outbreak, including measures to improve infrastructure and increase service facilities, in order to further improve visitor reception. These construction activities have changed the landscape type of the village, resulting in the conversion of woodland and grassland to construction land. This change in land use, on the one hand, helps to improve the village's reception capacity for tourists and tourism experience–but on the other hand, it also inevitably brings about ecological and environmental problems. Reduction of woodlands and grasslands may affect local biodiversity and alter soil and water conservation and water-holding functions, as well as exacerbate land degradation and landscape fragmentation.

Economic culture. The influence of economic activities and cultural traditions on landscape patterns cannot be ignored. The development of tourism, the promotion of specialty agriculture, and the preservation and inheritance of the Li and Miao cultures in Zahan Village have all had a significant impact on the landscape of the village. In order to eliminate the poverty and backwardness, in 2009, the local government decided to pursue tourism as an important strategy to promote regional development. In recent years, tourism has gradually become the pillar industry of Zahan Village. In August 2013, Zahan Village officially opened its doors to the public, and annual tourism revenue has steadily increased to the point where the total tourism revenue in 2016 was close to 10 million yuan, accounting for about 50 percent of the gross regional product (Figure 8).

The rise of rural tourism has brought about a series of profound changes in the socio-economic structure, land use, and production methods of ethnic minority villages,

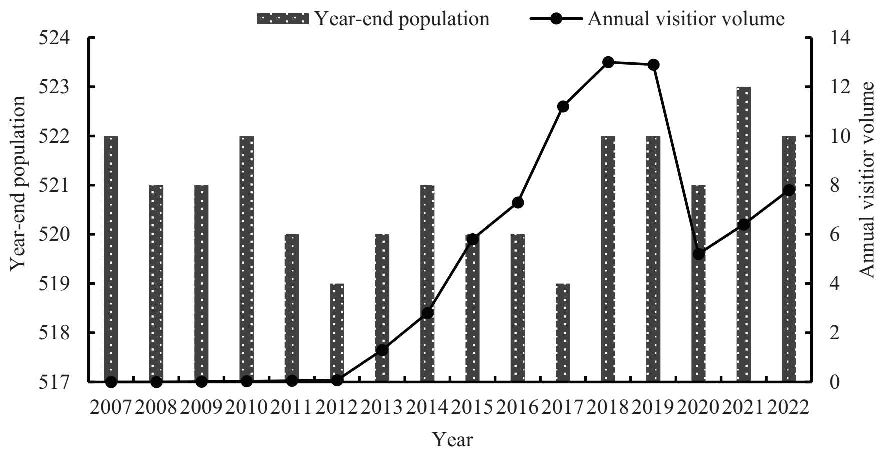


Figure 7. Trend chart of year-end population and annual tourist reception in Zahan Village from 2007 to 2022

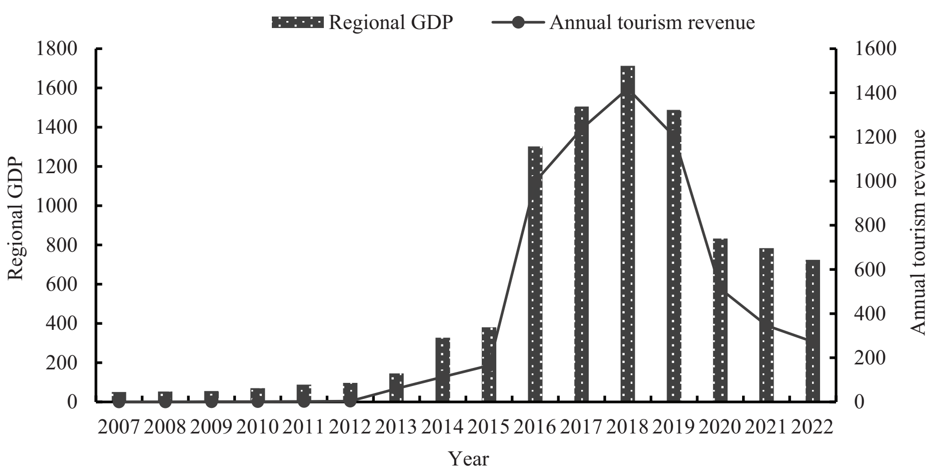


Figure 8. Trend chart of regional GDP and annual tourism income in Zahan Village from 2007 to 2022

significantly improving production and living conditions and giving the countryside a new look. However, as the number of tourists continues to increase, so does the demand for tourism facilities and services, which has prompted the villages to continuously increase the amount of land for construction to meet the need for the construction of hotels, lodges, restaurants and recreational facilities. The continuous increase in the built-up land area, from 2.31% to 8.68%, indicates a significant change in the spatial structure of the village, and the increase in the number of man-made patches implies a shift from natural to man-made landscapes. In this process, the traditional worship of nature and the concept of harmonious coexistence in the Li-Miao culture have prompted villages to pay more attention to living in harmony with the natural environment when developing tourism and carrying out construction. The practice of this concept has helped to protect the natural landscape of the villages, reduce human damage, and promote the concept of sustainable development to take root in the local community.

Policy orientation. Policy orientation is another important factor influencing land-use change (Xie et al., 2021). Since the late 1980s and early 1990s, the policy of closing the mountains to forests has had a positive impact on Zahan Village's ecological environment, with forest coverage exceeding 85% and the ecological environment being significantly improved. The implementation of this policy not only protected local natural resources, but also laid a solid foundation for subsequent sustainable development. The land-use structure of Zahan Village began to change in 2009 when the Qiongzhong County government decided to use rural tourism as the leading approach to eliminate the village's poverty and backwardness. This government decision led to a significant increase in the area of land used for construction in the village, which was necessary to accommodate the development of tourism. In order to enhance the attractiveness and service capacity of tourism, a series of subsequent investment and construction projects have been implemented in Zahan Village. In 2011, Qiongzhong County Government raised 2.87 million yuan of poverty alleviation funds from all levels and departments to renovate the unsafe houses of 71 farmers in Zahan Village; in 2012, the government invested another 460,000 yuan of funds in the environmental renovation of Zahan Village, and at the same time, 10 million yuan was allocated to construct the cultural plaza, the road around the village, facade renovation, solar streetlights, public toilets, and basketball courts and other infrastructure; in 2013, the government allocated another 2.92 million yuan for the construction of tourist facilities such as inns, thatched-roof houses, crossbow shooting ranges, camping bases, lodgings, farmhouses, and landscape terraces. The government's support and promotion of rural tourism, as well as its policy on ecological and environmental protection, will influence the direction of land-use development in Zahan Village.

4.4.2. Natural factors analysis

The natural environment plays a decisive role in the formation and evolution of ethnic minority villages. It not only provides the basic resources necessary for survival, such as water, land and food, but also profoundly influences local production methods, living habits and cultural traditions. Natural factors such as climate, topography, soil and biodiversity all determine, to a large, extent the landscape pattern of villages and the pattern of human activities. At larger spatial and temporal scales, changes in landscape patterns due to natural factors are more pronounced (Han et al., 2009); climate change may lead to diversion of rivers, drying up of lakes, or disappearance of wetlands; and changes in topography, such as earthquakes and landslides, may alter the land-use patterns, which usually take longer to become apparent.

Compared to human factors, natural factors are more stable and have a weaker impact on shorter time scales (Yin et al., 2009). However, this does not mean that natural factors are unimportant in the short term. In fact, short-term changes in the natural environment, such as extreme weather events and seasonal climate variability, may also have a significant impact on the production and life of the village.

Over the 2007–2022 period, multiple natural triggers caused a decrease in the area of woodlands, watersheds, and grasslands in the Village of Zahan, whereas the area of construction land increased. In recent years, climate change in Qiongzhong County has been characterized by a weak decrease in precipitation and a weak increase in average temperature. This climate change may have an impact on the ecological environment of grasslands and watersheds, reducing the ecological service function of these areas and thus creating conditions for their succession to construction land. Reduced precipitation may lead to a reduction in the size of watersheds, and increased temperatures may render some grasslands no longer suitable for their original vegetation; such changes may make these areas more susceptible to conversion to construction land.

5. Discussion

The development and change of Zahan Village provides us with a valuable case study. By analyzing the formation and evolution of its landscape pattern, we can gain a deeper understanding of the development paths of ethnic minority villages in the context of the combined effects of natural and human factors. The study of Zahan Village shows that the formation and evolution of village landscapes are the result of the interaction between both natural and human factors, a finding that emphasizes the need to take into account the combined effects of these two aspects when undertaking landscape planning and management. The study also reveals the importance of finding way of ethnic minority villages to protect their unique cultural and natural environments while simultaneously pursuing economic development. This requires us to find a balance in development to ensure that the cultural heritage and ecological environment of the villages are protected and passed on while improving the residents' quality of life (Ma et al., 2019; Zhang & Liao, 2018). In the future, when developing tourism in Zahan Village, the government should strictly control the expansion of construction land, avoid encroachment on farmland and forest land, and reduce the fragmentation of natural landscape. At the same time, scientific land use will be realized by fully exploring the potential of the stock of non-agricultural construction land, rationally planning tourism transportation routes, and controlling land use in an orderly manner. In addition, tourism enterprises recommend exploring and promoting new modes of land-use, such as eco-agriculture and leisure agriculture, to develop interactively with village tourism and form a virtuous cycle (Qiao et al., 2021). However, due to the limitation of data acquisition and the short research time, the study failed to quantitatively screen the magnitude of the force of various influencing factors and the reciprocal transmission mechanism between different factors. Future research must analyze and screen the specific force of different influencing factors on the evolution of landscape pattern and the transmission mechanism between them over a longer time series of data and with a more accurate quantitative method, so as to further explore the optimization and development model for China's minority villages.

This in-depth study of Zahan Village, shows that the future protection of ethnic minority villages requires in-depth case studies on the basis of theoretical discussions to understand the evolution of the landscape of ethnic minority villages in different regions in time and space, to understand the commonality and individuality of ethnic minority villages in different regions, and to probe into the laws of formation of their landscape patterns. Also on this basis, this study further explores how the new development can strengthen the spatial characteristics of ethnic minority villages and realize the sustainable development of ecology, economy, and society. This is not only of great significance for the future development of Zahan Village, but also provides valuable experience and inspiration for the sustainable development of other minority villages.

6. Conclusions

Based on the land-use data, this study combines quantitative analysis and qualitative research to study the characteristics of landscape pattern evolution and its influencing factors in Zahan Village from 2007 to 2022, and the main research conclusions are as follows:

The landscape of Zahan Village consists mainly of woodland, built-up land, cultivated land, water, and grassland. Among these landscape types, woodland occupies a significant dominant position; its area always maintains a proportion of more than 80% in the study area. This significant proportion reflects not only the dominant position of woodland in the village landscape, but also its important role in maintaining ecological balance, protecting biodiversity, and regulating climate and hydrological cycle, etc. Woodland in Zahan Village plays a crucial role in the ecological environment and overall landscape pattern of the village, which is essentially in line with the study results reported by Wang and Xu (2023).

Between 2007 and 2022, the landscape homogeneity of Zahan Village is getting better and better, which indicates that the ecological environment of Zahan Village is recovering, the vegetation cover is more uniform, and the stability and health of the ecosystem is improved. The increasing spatial heterogeneity of the landscape means that the biodiversity of Zahan Village is improving, and species of different ecological niches and habitats can coexist better.

Analyzing the time dimension, the area of woodland landscape in Zahan Village shows a decreasing trend year by year, whereas the construction land and cultivated land show an overall increasing trend, which is related to the growth of the number of tourists in the village, economic development and land-use policies. In addition, the decrease in the area of water and grassland may be related to climate change and land use transformation, which may lead to the decrease and uneven distribution of water resources, while the transformation of land-use from traditional agriculture to tourism may also have an impact on the area of water and grassland.

Analyzing the spatial dimension, the spatial distribution of the landscape of Zahan Village shows the characteristic of "mass," concentrated mainly in the center and south of the village; at the same time, in the east and northwest of the village, it shows the characteristic of "point-like" distribution. This spatial distribution reflects the tendency of the landscape of Zahan Village to spread from the center to the surroundings, which is directly related to the village development plan and the construction of tourism facilities.

The evolution of the landscape pattern of Zahan Village is a complex process influenced by a combination of factors. Among them, human factors such as social demography, economy and culture, and policy orientation have a more significant impact on the landscape pattern over a shorter period of time; by contrast, natural factors such as topography, climate change, and precipitation have a stronger impact on the landscape pattern over a longer period of time.

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Author contributions

Shan Zhang: Lead role in topic conceptualization, contributed to original idea generation.

JiaMing Xie: Contributed to original idea generation, statistical analysis, wrote a draft of the paper, secondary research.

Weifang Liu: Assisted with drafting first manuscript, and identifying secondary sources.

Yupeng Zhu: Contributed to literature review and gather data.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Date transparency

The RS data and 30 m digital elevation data used in this study were obtained from the geospatial data cloud website of the Computer Network Information Center of the Chinese Academy of Sciences (http://www.gscloud.cn).

Other basic GIS data, such as Hainan Province and municipal boundaries, were obtained from the National Geographic Information Resources Catalogue Service System (http://www.webmap.cn).

Relevant statistical information was obtained from official websites and local statistical yearbooks. In addition, field research was conducted in the study area and information on the current status of land use and other information was collected and organized.

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