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Spatial-temporal Evolution Analysis on Land Use Multifunctionality in the China-Vietnam Border Area

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Abstract: Exploring the spatial and temporal evolution characteristics of the border land use multifunctionality (LUMF) provides insights for taking advantage of border land use and optimizing border land use policies. Based on the improved Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) mode, this study identifies and evaluates the LUMFs in the China-Vietnam border area between 2000 and 2018 from the perspectives of agricultural production, social security, ecological service, landscape recreation, and national security. The results show that: 1) The comprehensive land use functions in most counties and cities continued to be improved. 2) The comprehensive land use function exhibits remarkable spatial divergence and aggregation characteristics. The high-value area of the agricultural production function and social security function evolves from the east to the west. In addition, the spatial evolution of ecological service function is complicated, without an obvious spatial divergence and aggregation pattern. The landscape recreation function shows different spatial differentiation characteristics in the early and middle stage, and forms a large cluster in the later stage. Finally, the spatial evolution pattern of the national security function is significant. 3) Designing differentiated border land policies, improving border land use security, and establishing a long-term mechanism for ecological protection and ecological compensation can aid in optimizing the LUMF level in the border area.

Keywords: land use multifunctionality; spatial-temporal evolution characteristics; improved Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS); spatial analysis; China-Vietnam border area

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1 Introduction

In the late 1990s, the term multifunctionality originated from the theoretical framework of agricultural policy reforms carried out by the Organization for Economic Cooperation and Development (OECD) and European Union (EU), emphasizing the many services that agriculture involves (Wiggering et al., 2006). Since the establishment of the Global Land Project (GLP) in 2005, the concept of multifunctionality has been closely linked to land use. The idea of 'land use multifunctionality (LUMF)' has thus evolved, and the development, utilization, conservation, and management of land resources from the perspective of land use multifunctionality has

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gradually gained momentum in both academic and policy circles (Lovell and Taylor, 2013; Song et al., 2015; Baró et al., 2016).

Along with the rapidly changing human-land interrelations (Yan et al., 2018), over the past several decades the understanding of land use functions has undergone an evolutionary process from simple to complex. Compared with the traditional land use system, which focuses on a single function of land use (Gao et al., 2012), LUMF integrates a series of coordinated land use subsystems (Zhou et al., 2017), including economic growth, social welfare, and environmental protection (Wiggering et al., 2006; Paracchini et al., 2011; Zou et al., 2020), all of which contribute to people's welfare (Wang et al., 2017). Identifying and classifying land use function types is the key to LUMF evaluation (Verburg et al., 2009), and serves as the basis for implementing land use control policies. Therefore, scholars are paying close attention to the specification of LUMF from different aspects (Pérez-Soba et al., 2008; Song and Deng, 2017; Fan et al., 2018). Some studies have attempted to extend the existing system of land use functions, and have shown that land use functions can be further subdivided based on traditional functions into resource, landscape, and cultural functions, etc. For example, Pérez-Soba et al. (2008) developed an innovative conceptual framework of Land Use Functions (LUFs) based on European data, which integrates the changes observed in a large set of impact indicators into nine LUFs, such as provision of work, human health and recreation, cultural, and residential and land independent production. Fan et al. (2018) proposed a classification system with three primary functions and 12 sub-functions. Another strand of research focuses on specializing a certain type of land use function, including land production (Song et al., 2015), forest transition (Barbier et al., 2010), and ecosystem services (Jiang et al., 2018). Despite an ever-growing body of literature on the identification of land use function, a consensus on the classification system of LUMFs has not yet been reached. A widely accepted practice is to divide it into three subfunctions, i.e., economic, social, and ecological functions (Schindler et al., 2015; Verstegen et al., 2016; Zou et al., 2021).

At the same time, extensive studies have been conducted on the evaluation of LUMFs (Delgado-Matas et al., 2015; Shi and Yang, 2015; Liu et al., 2021a). Zhou et al. (2017) assessed the LUMFs in six cities in the urban agglomeration around Hangzhou Bay in eastern China's Zhejiang Province using 22 indicators, and found that urban development in the area focuses more on economic growth than on ecological protection. Xue et al. (2019) compared the LUMFs of three representative Asian cities, Godagari Upazila of Bangladesh, Guyuan of China, and Noto of Japan. Zhang et al. (2019) suggested that the indices of economic, social, and ecological functions in China ranged from 0.00 to more than 0.95, displaying obvious heterogeneity in spatial distribution. Combining land-use, geographic and socio-economic data to valuate LUMFs, Liu et al. (2021a) discovered that the LUMFs have spatially heterogeneous characteristics in northern Hebei Province, China. Above all, due to the differences in human-land relationship and land use characteristics in different regions (Brown and Castellazzi, 2014; Peng et al., 2016), the dominant land use functions are usually distinct, as are the evaluation indicators, thus it seems unrealistic to establish a 'one-size-fits-all' classification and evaluation system.

As the main target area of opening-up, the land use changes in border areas are dynamic, and the land use functions are complex, variable, and possess special characteristics. It is thus critical to evaluate the LUMFs at the border, so as to gain a profound understanding of the border land use demand, and to provide statistical reference for the formulation of territorial spatial planning and land use policies tailored to the economic and social development of the border. Moreover, with increasingly frequent interactions between countries, there is an urgent need to understand the evolution of LUMFs at the China-Vietnam border, so as to ensure border land use security, and thus promote the sustainable development of border economy and society. Given this, using land and socio-economic data in the China-Vietnam border area, this study investigates the spatial and temporal evolution characteristics of the border LUMFs based on the improved TOPSIS model and the spatial analysis method of ArcGIS, and proposes policy recommendations for optimizing the border LUMFs. The objectives of this study are as follows: 1) establish a framework to identify and quantify LUMFs in the China-Vietnam border area; 2) examine the spatial-temporal characters of LUMFs in the border area to improve our understanding of the processes of land use evolution;

and 3) put forward tailored policy suggestions for optimizing sustainable border land use.

The marginal contribution of our study is the innovation in the research contents. The existing literature has mainly investigated the LUMFs from the perspectives of economic, social, and ecological factors (Wiggering et al., 2006; Xue et al., 2019). Considering the flourishing tourist industry in the border area, the landscape recreation function is incorporated in our study. Aside from this, since issues such as border land use structure and efficiency affect border land use both directly or indirectly, this paper presents the national security function based on the characteristics of border land use and evaluates its evolutionary features. Therefore, the contents of our study reflect the special characteristics of border land use.

2 Materials and Methods

2.1 Study area

We select the China-Vietnam border area, the intersection of these two countries, as our study area (Fig. 1). It is located at the southern border of China, south of the Tropic of Cancer (23°26′N) and at the southeastern edge of the Yunnan-Guizhou Plateau. The borderline between China and Vietnam is 1450 km in length, spanning eight counties and cities in Guangxi Province, namely Napo County and Jingxi City in Baise City, Daxin County, Longzhou County, Ningming County and Pingxiang City in Chongzuo City, Fangcheng District and Dongxing City in Fangchenggang City; and seven counties in Yunnan Province, namely Funing County, Malipo County and Maguan County in Wenshan Zhuang and Miao Autonomous Prefecture, Hekou County, Jinping County and Lvchun County in Honghe Hani and Yi Autonomous Prefecture, and Jiangcheng County in Pu'er City.

The China-Vietnam border area not only serves as the hub and most convenient international corridor from China to the ASEAN (Association of Southeast Asian Nations) countries, it is also an essential part of the Greater Mekong Subregion. It is considered a critical land and sea access area in jointly building the Silk Road Economic Belt and 21st-Century Maritime Silk Road. In recent years, with the continued opening-up of China and the ASEAN countries, the economy in the China-Vietnam border area is becoming increasingly prosperous. Under the joint effect of special geographical location, as well as economic and social transformation, the land use function of the border has transformed from simple to diversified, with specific features.

2.2 Data sources

The land use data were collected from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (http://www.resdc.cn/), with a resolution of 30 m × 30 m. To facilitate the data analysis, the 26 secondary land classes in the original map are classified into six primary land classes using the reclassification function of ArcGIS software, namely arable land, forest land, grassland, water, construction land, and unused land, which are respectively coded from 1 to 6.

According to the field research, arable land will generally become grassland within a short period of time after abandonment. In addition, only land that has been abandoned for a long time (usually at least several decades) may convert naturally into forest land. Since the analyze interval in this study is at most 5 yr, and that there is little pastureland in the China-Vietnam border area, it is reasonable to measure the area of abandoned arable land by the area of arable land converted into grassland in each time period. Applying the map algebraic operation function of ArcGIS and the pivot func-

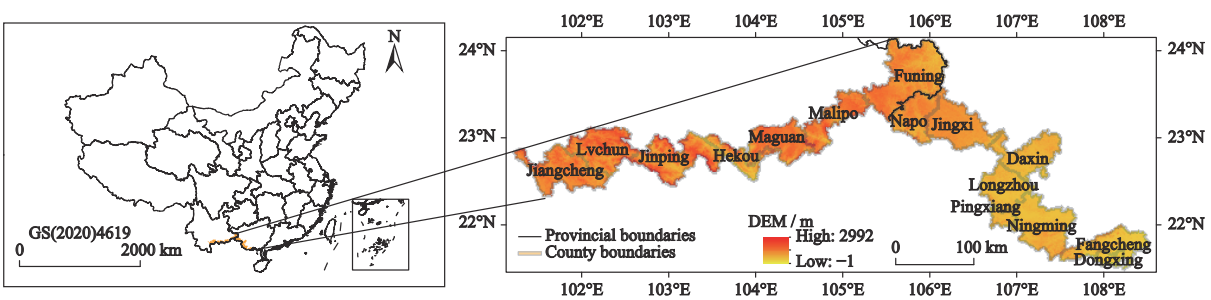

Fig. 1 Geographical location and DEM map of the China-Vietnam border area

tion of Microsoft Excel, we construct the land use transfer matrix for each time period, so as to obtain the preliminary area of abandoned arable land. This is then presented to local agricultural and rural bureaus and natural resource bureaus for data calibration advice. Following the approach described by Li et al. (2017), a sample survey on the abandoned arable land is conducted for further verification.

Economic and social statistics are collected from county statistical yearbooks of Guangxi Bureau of Statistics (http://tjj.gxzf.gov.cn/), and Yunnan Bureau of Statistics (http://stats.yn.gov.cn/). Tourism and other data are based on statistics published on the websites of Guangxi (http://wlt.gxzf.gov.cn/) and Yunnan Department of Culture and Tourism (http://dct.yn.gov.cn/). Minor missing data are supplemented by local chronicles of Guangxi Province (http://www.gxdfz.org.cn/) and Yunnan Province (http://dfz.yn.gov.cn/).

The year 2000 marked the opening of the China ASEAN Expo, which is characterized by the further opening-up of the China-Vietnam border area. Therefore, this study takes 2000 as the starting point. Considering data availability, the analyzing period in this study is from 2000 to 2018, with each five years as the interval. Relevant data are collected for 2000, 2005, 2010, 2015, and 2018. Price-relevant variables are converted to the constant 2000 price to mitigate the effects of changes in general price levels.

2.3 Methodology

2.3.1 Construction of land use multifunctionality index system

In view of the special land features in the border area, we propose the landscape recreation and national security function of land use in addition to the widely recognized 'ecological-production-living' function framework. Therefore, in this study, the LUMFs of the China-Vietnam border area consist of five dimensions, namely agricultural production, social security, ecological service, landscape recreation, and national security.

Agriculture is the pillar industry in the China-Vietnam border area, and agricultural products are the main products in China-Vietnam trade. Therefore, the agricultural production function is recognized as one of the important functions in the study area. In addition, for a long time, human beings have had a great dependence on the land and regarded it as the last guarantee of survival, the social security function is included in our study. The ecological service function is also incorporated, considering the importance of guaranteeing sustainable land use in the China-Vietnam border area. Due to the rich natural tourism resources in the China-Vietnam border area and the unique border ethnic minority features there, border tourism has gradually transformed into an important pillar industry strongly supported by the local governments. Therefore, the landscape recreation function is assessed in this study. The national security function is a special function carried by the border area. Efficient border land use facilitates border economic and social development, whereas unreasonable structure of border land use, border land abandonment and low population density at the border can adversely affect land security. Therefore, to encourage active participation in land security protection from the perspective of land use, this study incorporates the national security function in the framework. The research framework is shown below:

As revealed in Fig. 2, the agricultural production function serves as one of the basic functions, referring to the ability of land to provide agricultural products and services to people (Long et al., 2018). Following the work of Jiang et al. (2020) and Andersen et al. (2013), this study evaluates the agricultural production function in terms of three aspects, namely land settlement rate, grain yield, and contribution of primary industry.

The social security function generally refers to the most basic living space and security that land provides for human beings (Geoghegan, 2002), including livelihood security, employment security, and income security. For the key measurements for the social security function, we select the per capita food guarantee rate, which reflects the basic living standard of residents; proportion of rural employees, which suggests the capability of rural fields to attract labors and provide employment opportunities; and the income balance index of urban and rural residents, which characterizes the income gap between rural and urban areas.

The ecological service function reflects the capacity of the ecosystem and ecological processes to provide products and services for people (de Groot, 2006; Zou et al., 2020). It mainly involves the formation, status, regulation, and protection of the ecosystem. Among these, the ecosystem formation is measured by the habitat abundance index, the regional ecological status is evalu-

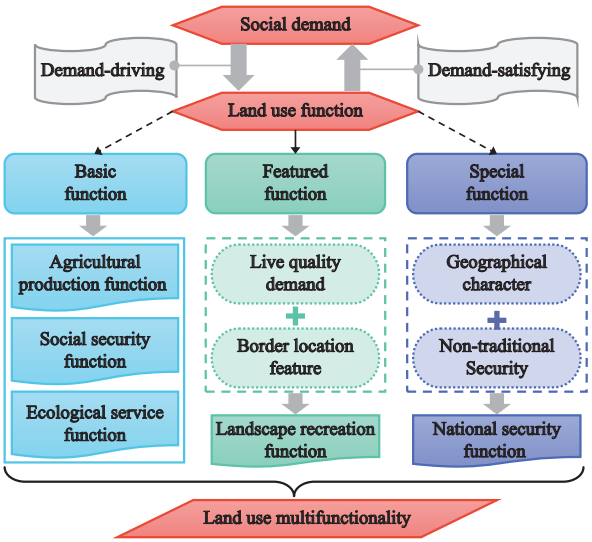

Fig. 2 Research framework of land use multifunctionality in the China-Vietnam border area

ated by the land-average ecological service value, the ecological regulation is valued by the forest cover rate, and the degree of ecological protection is reflected by the land degradation index.

The landscape recreation function refers to the ability of the land use system to provide leisure, health, sports, culture, entertainment, and medical rehabilitation products and services for people, and is closely related to the prosperity of local tourism industry. This can be measured by the number of scenic spots above grade AA, the number of star-rated hotels, the number of tourist arrivals, and tourism revenue.

The national security function reveals the capacity of the land use system to maintain land security. The structure and efficiency of land use at the border can directly affect national security. Moreover, insufficient investment in border construction, outdated infrastructure, and poor road transport facility may hinder economic development and population density at the border. This will further result in several chain reactions such as land abandonment at the border, thus further affecting land security. In addition, compared with the forest land in the inland cities, the medium-height forest cover at the border area plays an essential role in safety protection. For these reasons, we evaluate the national security function in terms of the proportion of land for construction, proportion of medium-height forest cover, proportion of abandoned arable land, population density, and road accessibility. Detailed information regarding the LUMF classification system is given in Table 1.

In terms of the indicator weights, this study applies both objective and subjective weighting methods. First, the weights of the indicator layer to the criterion layer and the target layers are calculated based on the entropy weight method (Kumar et al., 2021), which are then adjusted based on the Delphi method.

The indicators are classified as positive, negative, and moderate. In the process of weight calculation, the extreme value standardization method is applied to filter out the scale difference of different indicators:

Positive indicator:

$$x'_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}},\ 0 < i < m, 0 < j < n \tag{1}$$

Negative indicator:

$$x'_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}},\ 0 < i < m, 0 < j < n \tag{2}$$

Moderate indicator:

$$x'_{ij} = 1 - \frac{|x_{ij} - x_0|}{\max(|x_0 - x_{\min}|, |x_{\max} - x_0|)},\ 0 < i < m, 0 < j < n \tag{3}$$

where x'_{ij} and x_{ij} stand for the standardized and original values of indicator j in year i; $x_{\max}$ and $x_{\min}$ represent the maximum and minimum value; and x_0 is the threshold value of the moderate indicator. The standardized value of each indicator ranges from 0 to 1, which can be presented as the following matrix:

$$A = \begin{bmatrix} x'_{11} & x'_{12} & \cdots & x'_{1j} \\ x'_{21} & x'_{22} & \cdots & x'_{2j} \\ \cdots & \cdots & \cdots & \cdots \\ x'_{i1} & x'_{i2} & \cdots & x'_{ij} \end{bmatrix} \tag{4}$$

Determining the threshold value of the moderate indicators is a critical part in the evaluation of LUMF, suggesting the most reasonable state reached by the indicator value under sustainable use of land resources. The average values of the moderate indicators within the study period and corresponding threshold values are displayed in Table 2. The threshold value of the land settlement rate (x_1), which is 12.5%, is determined based on the share of arable land area that can guarantee national food security (1.8 billion mu[①], relative to the total national land area of 9.6 million km^2). This value, though

① Chinese unit of land measurement; 1 mu = 666.7 m^2

Table 1 Indicators for assessing the land use multifunctionality in the China-Vietnam border area

Target	Criterion	Indicator	Unit	Qualifications	Index type
Comprehensive function	Agricultural production function (X_1)	Land settlement rate (x_1)	%	Arable land area/total land area	Moderate
		Grain yield (x_2)	t/ha	Grain production / grain-sown area	Positive
		Contribution of primary industry (x_3)	%	Output value of primary industry / GDP	Moderate
	Social security function (X_2)	Per capita food guarantee rate (x_4)	%	Food production / (resident population × 400 kg/person)	Positive
		Proportion of rural employees (x_5)	%	Number of rural employees / total population	Moderate
		Income balance index of urban and rural residents (x_6)	–	Per capita net income of farmers / disposable income of urban residents	Positive
	Ecological service function (X_3)	Habitat abundance index (x_7)	–	(0.35 × forest land + 0.21 × grassland + 0.28 × water wetland + 0.11 × cultivated land + 0.04 × construction land + 0.01 × unutilized land) / total land area	Positive
		Land-average ecological service value (x_8)	RMB/ha	Total value of ecological services / total land area	Positive
		Forest cover rate (x_9)	%	Forestland area / total land area	Moderate
		Land degradation index (x_{10})	%	Degraded land area / total land area	Negative
	Landscape recreation (X_4)	Number of scenic spots above grade 2A (x_{11})	–	Obtain directly	Positive
		Number of star-rated hotels (x_{12})	–	Obtain directly	Positive
		Number of tourist arrivals (x_{13})	million people	Obtain directly	Positive
		Tourism revenue (x_{14})	100 million	Obtain directly	Positive
	National security (X_5)	Proportion of land for construction (x_{15})	%	Construction land area/total land area	Moderate
		Proportion of medium-height forest cover (x_{16})	%	Medium and high forest cover land area/total forest area	Moderate
		Proportion of abandoned arable land (x_{17})	%	Abandoned arable land area/total land area	Negative
		Population density (x_{18})	person/km^2	Number of people/total land area	Moderate
		Road accessibility (x_{19})	km/km^2	Road mileage/total land area	Positive

lower than that in the data for 2018, is in line with the current development trend in the China-Vietnam border area. This is because, under the strategies of 'Vitalizing Border Areas and Enriching the People' and 'Rural Revitalization' implemented in recent years, border construction will inevitably occupy arable land. Moreover, the topography of the study area is of a typical karst landscape type, suggesting that the average slope and fragmentation of arable land is high, which results in relatively serious arable land abandonment. Therefore, it is reasonable to take the national average of arable land as the future conservation target of arable land in the study area. In terms of the contribution of primary industry (x_3), cities in the border area will continue to strengthen the development of secondary and tertiary industries in the near future, particularly the development of border tourism and other tertiary industries, thus it is reasonable to assume that the contribution of the primary industry is declining year by year. Given this, referring to previous studies (Du et al., 2016), after comparing the percentage of agricultural land in the China-Vietnam border area with that of China as a whole, we set the threshold value of the contribution of primary industry as 20.00%, which is slightly lower than that of 2018. For the proportion of rural employees (x_5), with the adjustment of the industrial structure of border area toward secondary and tertiary industries and the improvement of the degree of mechanization of agricultural scale, it is reasonable to assume that the proportion of rural employees in the border area is on a de-

Table 2 Average values of the moderate indicators within study period and corresponding threshold

Moderate indicator	2000	2005	2010	2015	2018	Threshold value
Land settlement rate (x_1) / %	13.06	12.93	13.09	13.04	12.89	12.50
Contribution of primary industry (x_3) / %	41.61	35.02	25.71	23.09	20.26	20.00
Proportion of rural employees (x_5) / %	45.12	46.92	44.97	38.45	35.50	35.00
Forest coverage rate (x_9) / %	68.42	68.54	68.37	68.29	68	68.54
Proportion of land for construction (x_{15}) / %	1.05	1.09	1.13	1.26	1.62	2.83
Proportion of medium-height forest cover (x_{16}) / %	59.36	59.40	58.94	58.86	58.61	59.40
Population density (x_{18}) / (persons/km^2)	109	114	122	127	129	148

creasing trend. Therefore, the threshold value is set as 35.00%. The basis for determining the threshold value of this indicator is similar to that of the contribution of primary industries. We set the threshold values of the forest cover rate (x_9) and proportion of medium-height forest cover (x_{16}) as the maximum of the historical average values, which are 68.54% and 59.40%, respectively. The main reason for this is that our study area serves as an important ecological barrier and border area in southwestern China, and that part of the forest land serves the function of safety protection. The average value of the national construction land ratio and population density in 2018 are used as the threshold values for the proportion of land for construction (x_{15}) and population density (x_{18}), the goal being that the construction degree and population density of the study area will at least catch up with the national average.

After standardizing the indicators, we employ the entropy weight method to calculate the corresponding weight of each indicator, given as follows:

2.3.2 Evaluation of land use multifunctionality based on TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a multi-indicator decision analysis method, which is used to identify and calculate the positive and negative ideal solutions of the problem (Hwang and Yoon, 1981). A solution which is close to the positive ideal solution and far from the negative ideal solution is considered desirable. TOPSIS exerts no strict limitation on data distribution, number of indicator or sample size, which is suitable for both the evaluation of small sample data and complex systems with multiple objectives and indicators, and is feasible for both horizontal comparison and vertical analysis. To date, TOPSIS has been widely employed in land use research (He et al., 2017; Wójcik-Leń et al., 2019; Zhang et al., 2020). In this study, we apply the improved TOPSIS proposed by Qiu et al. (2005) to evaluate the LUMFs. Compared with the traditional TOPSIS, the improved TOPSIS modifies the formula for calculating the distance from the evaluation object to the positive and negative ideal solutions, which can overcome the problem of inverse order. The improved TOPSIS can be described as follows:

(1) Constructing the weighted standardized decision matrix:

$$V = A \times W_{ij} = \begin{bmatrix} V_{11} & V_{12} & \ldots & V_{1j} \\ V_{21} & V_{22} & \ldots & V_{2j} \\ \ldots & \ldots & \ldots & \ldots \\ V_{i1} & V_{i2} & \ldots & V_{ij} \end{bmatrix} \tag{5}$$

where V is the weighted standardized decision matrix, A represents the standardized indicator matrix, and W_{ij} is the indicator weight.

(2) Calculating the positive (V_i^+) and negative ideal solutions (V_i^-):

$$V_i^+ = \{[\max V_{ij} | j \in J] \text{ or } [\min V_{ij} | j \in J'], \\ i = 1,2,\ldots,m; j = 1,2,\ldots,n\} = \{V_1^+, V_2^+, \ldots, V_n^+\} \tag{6}$$

$$V_i^- = \{[\min V_{ij} | j \in J] \text{ or } [\max V_{ij} | j \in J'], \\ i = 1,2,\ldots,m; j = 1,2,\ldots,n\} = \{V_1^-, V_2^-, \ldots, V_n^-\} \tag{7}$$

where J and J' are the sets of positive and negative indicators, respectively. There is only one ideal solution for the moderate indicator, i.e., the positive ideal solution is equal to the negative one, which is the average value of V for each year.

(3) Measuring the distance from each indicator value to the positive and negative solution:

$$L_i^+ = \sqrt{\sum_{i=1}^{m} (V_{ij} - V_i^+)^2}, \ (i = 1,2,\ldots,m; j = 1,2,\ldots,n) \tag{8}$$

$$L_i^- = \sqrt{\sum_{i=1}^{m}(V_{ij} - V_i^-)^2},\ (i = 1,2,...,m;\ j = 1,2,...,n) \quad (9)$$

(4) Calculating the closeness of each evaluation object to the ideal solution (C_i):

$$C_i = \sqrt{[L_i^+ - \min(L_i^+)]^2 + [L_i^- - \max(L_i^-)]^2},\ (i = 1,2,...,m) \quad (10)$$

(5) Calculating the score for each sub-function of land use (r_i):

$$r_i = 1 - C_i \quad (11)$$

Where $r_i \in [0,1]$, in which the closer the value of r_i to 1, the more prominent the sub-function is. $r_i = 1$ indicates that the sub-function reaches its optimal state. Meanwhile, if r_i is close to 0, it suggests that the sub-function is weak.

(6) Calculating the complex score of land use (R_i):

$$R_i = \sum_{j=1}^{n}(r_i \times W'_{ij}) \quad (12)$$

where W'_{ij} represents the weight of the target layer, and $R_i \in [0,1]$. A value of R_i closer to 1 suggests that the comprehensive function is improving, while $R_i = 1$ signifies that the comprehensive function is desirable. On the other hand, if R_i is close to 0, this indicates that the comprehensive function is inefficient, and that there is an urgent need to adjust the land use structure. The weight of each indicator can be found in Table 3.

3 Results and analysis

3.1 Evolutionary characteristics of land use multifunctionality in the China-Vietnam border area

3.1.1 Evolutionary trend of the comprehensive function

The comprehensive land use functions in most counties and cities continue improving over the analysis period (Fig. 3a). A possible reason for this is that national and local governments have launched several policies to enhance the LUMFs. The comprehensive land use functions in most counties and cities in 2018 are all above 0.90, suggesting that the land use efficiency in the study area is generally at a high level.

The comprehensive land use function of Jingxi City decreased in 2005 and 2010 compared with that in 2000. A possible explanation for this is that in 2000, Jingxi City began to carry out large-scale bauxite mining and processing, attracting young and strong laborers to the secondary industry, which resulted in a significant decline in the primary industry output, and in turn a sharp decline in the agricultural production function. Since it was difficult to improve the other subfunctions within such a short period, the comprehensive land use function was hampered. After 2010, with the gradual improvement of social security function, landscape recreation function and national security function, the comprehensive function in Jingxi City resumed its growing trend.

The comprehensive land use function in Ningming County remained at a relatively low level from 2000 to 2015, with a large increase by 2018, due to the fact that Ningming County capitalized on its comparative advantage in the tourism industry. In 2015, the local government carried out a world-class tourism brand project on its cultural heritage site, Huashan Rock Art Cultural Landscape, which led to the development of a series of tourist attractions and thus remarkable improvement in the landscape recreation function, thereby promoting the comprehensive land use function.

The comprehensive land use function in Fangcheng District in 2018 was significantly lower than that of other places, as well as its own value in 2015, thus indicating inefficient land use in Fangcheng District. This is mainly due to the significant decrease in the ecological service function and national security function in 2018, suggesting that the impact of urban development on ecological environment should be regarded seriously.

3.1.2 Evolutionary trend of the sub-functions

In terms of the agricultural production function, as seen in Table 4 and Fig. 3b, it improved stably from 2000 to 2018. The agricultural production function in the Guangxi section was generally higher than that in the Yunnan section from 2000 to 2015, but was overtaken in 2018. One possible explanation for this is that agriculture has been an important pillar industry in Yunnan, while in the Guangxi section, cities with desirable conditions for agricultural development, such as Fangcheng District, Pingxiang City and Dongxing City, are motivated by governments' preferential policies, and have gradually shifted toward high-end industries, which inhibits agricultural development.

Regarding the social security function, from Table 4

Table 3 Weight of the indicator

Target	Criterion	Weight of the criterion layer	Indicator	Indicator weight for the target layer	Indicator weight for the criterion layer
Comprehensive function	X_1	0.1287	x_1	0.0301	0.1704
			x_2	0.0565	0.3753
			x_3	0.0619	0.4543
	X_2	0.1441	x_4	0.0404	0.3606
			x_5	0.0373	0.2537
			x_6	0.0673	0.3857
	X_3	0.2046	x_7	0.0455	0.2224
			x_8	0.0585	0.2693
			x_9	0.0368	0.2064
			x_{10}	0.0663	0.3019
	X_4	0.2448	x_{11}	0.0749	0.2778
			x_{12}	0.0621	0.2055
			x_{13}	0.0698	0.2375
			x_{14}	0.0768	0.2792
	X_5	0.2778	x_{15}	0.0303	0.1710
			x_{16}	0.0357	0.2028
			x_{17}	0.0623	0.2331
			x_{18}	0.0329	0.1726
			x_{19}	0.0547	0.2205

and Fig. 3c, it can be seen to have generally undergone a fluctuating trend from 2000 to 2018. A possible explanation for this is industrial transformation. More specifically, for Jingxi City, Pingxiang City, Ningming County and Dongxing City, their dominant industry gradually changed from agriculture to secondary and tertiary industries in 2005 and 2010, thus attracting a large number of laborers to secondary and tertiary industries, in turn decreasing the food guarantee rate. This decrease has drawn the attention of local governments, which in turn has implemented policies to enhance the income of rural residents through measures such as improving grain yields. After that, the social security functions in the above counties and cities have gradually been restored to growing trends. Malipo County is the only county where the social security function has improved continuously. It has a relatively high altitude, with poor natural conditions and weak economic and social development. With the implementation of a series of national strategies, such as Rural Vitalization and Poverty Alleviation, Malipo County has gradually developed with agriculture as its leading industry, and the social security function of land use continue to rise. With the rapid development of urbanization, the population scale of Fangcheng District continues to expand, and the limited arable land area is barely sufficient to meet the food demand created by its rapid population growth.

For the ecological service function, as revealed in Table 4 and Fig. 3d, it is the only type of subfunction within the study area that is declining. The situation in each county is intricate and complex, reflecting the adverse effects of human activities on ecological environment, as well as the complexity of the impact process. Since the China-Vietnam border area is considered an important ecological barrier, the local governments should pursue green and ecological development by promoting green agriculture, ecological tourism and other advantageous special industries based on local ecological advantages. Moreover, high pollution-creating enterprises should be resisted. As can be seen from Table 4, the ecological service function of the Yunnan section is fluctuating, and that of the Guangxi section continues to decline. This suggests that economic development in the border area is achieved at the expense of the environment, which is largely due to the leading industry in some regions.

As revealed in Table 4 and Fig. 3e, the landscape recreation function in each county has increased gradually. It is expected that the border tourism industry will gradually thrive in the counties and cities along the China-Vietnam border.

It is shown in Table 4 and Fig. 3f that the pattern of national security function in the China-Vietnam border area has changed considerably. From 2000 to 2015, areas with better national security function mainly lie in the Guangxi section where the economic development level is relatively high, whereas in 2018, areas with superior national security function are mainly concentrated in the Yunnan section. In short, the national security function in the China-Vietnam border area has increased in volatility.

3.2 Spatial distribution of land use multifunctionality in the China-Vietnam border area

3.2.1 Spatial distribution of the comprehensive function

Comprehensive function of land use in the China-Vietnam border area is characterized by significant spatial differentiation and spatial aggregation (Fig. 4a). In 2000 and 2005, the comprehensive functions of land use in the Guangxi and Yunnan areas exhibit a significant spatial divergence, being high in the east and low in the west, and bounded by the administrative boundary between the two provinces. The main reason for this is that the economic and social development in the Guangxi area is generally better than that in the Yunnan area during this period. The area with high comprehensive land use function in the Guangxi section is mainly distributed in several key counties and cities, such as Jingxi City, Longzhou County, Pingxiang City, Fangcheng District and Dongxing City. The highly-developed comprehensive function areas in the Yunnan section exhibit obvious spatial aggregation characteristics, showing a spatial distribution pattern of high in the middle and low at both ends, with the relative high value area mainly concentrating in Lvchun and Jinping Counties in the central part.

Since 2010, the high-value area has gradually shifted from the east to the center and west, mainly in Funing County, Malipo County, Maguan County and Lvchun County in the mid-western part and Pingxiang City and Dongxing City in the eastern part. The distribution of high value areas in 2015 is similar to those in 2000 and 2005. In short, the evolution of the comprehensive land

Table 4 Evaluation statistics of land use functions in the China-Vietnam border area

Land use function	Study area	2000	2005	2010	2015	2018	Evolutionary type
Comprehensive function	Entire area	0.7634	0.7722	0.8035	0.8565	0.9506	Stable improvement
	Yunnan section	0.7333	0.7376	0.7974	0.8481	0.9683	Stable improvement
	Guangxi section	0.7898	0.8025	0.8089	0.8638	0.9351	Stable improvement
Agricultural production	Entire area	0.7848	0.8293	0.8651	0.9292	0.9455	Stable improvement
	Yunnan section	0.7544	0.7586	0.8380	0.9281	0.9667	Stable improvement
	Guangxi section	0.8115	0.8912	0.8888	0.9301	0.9270	Volatile improvement
Social security	Entire area	0.7431	0.6979	0.6679	0.8801	0.9603	Volatile improvement
	Yunnan section	0.6772	0.6193	0.7291	0.9883	0.9697	Volatile improvement
	Guangxi section	0.8008	0.7667	0.6143	0.7854	0.9520	Volatile improvement
Ecological services	Entire area	0.9183	0.9331	0.8812	0.8547	0.8640	Volatile decrease
	Yunnan section	0.9283	0.9238	0.8341	0.8047	0.9043	V-shaped
	Guangxi section	0.9095	0.9412	0.9225	0.8984	0.8288	Volatile decrease
Landscape recreation	Entire area	0.5844	0.6030	0.6482	0.7688	1.0000	Stable improvement
	Yunnan section	0.5955	0.6236	0.6601	0.7525	1.0000	Stable improvement
	Guangxi section	0.5747	0.5850	0.6378	0.7831	1.0000	Stable improvement
National security	Entire area	0.8077	0.8150	0.9250	0.8892	0.9682	Volatile improvement
	Yunnan section	0.7304	0.7526	0.9079	0.8546	0.9877	Volatile improvement
	Guangxi section	0.8753	0.8695	0.9399	0.9195	0.9511	Volatile improvement

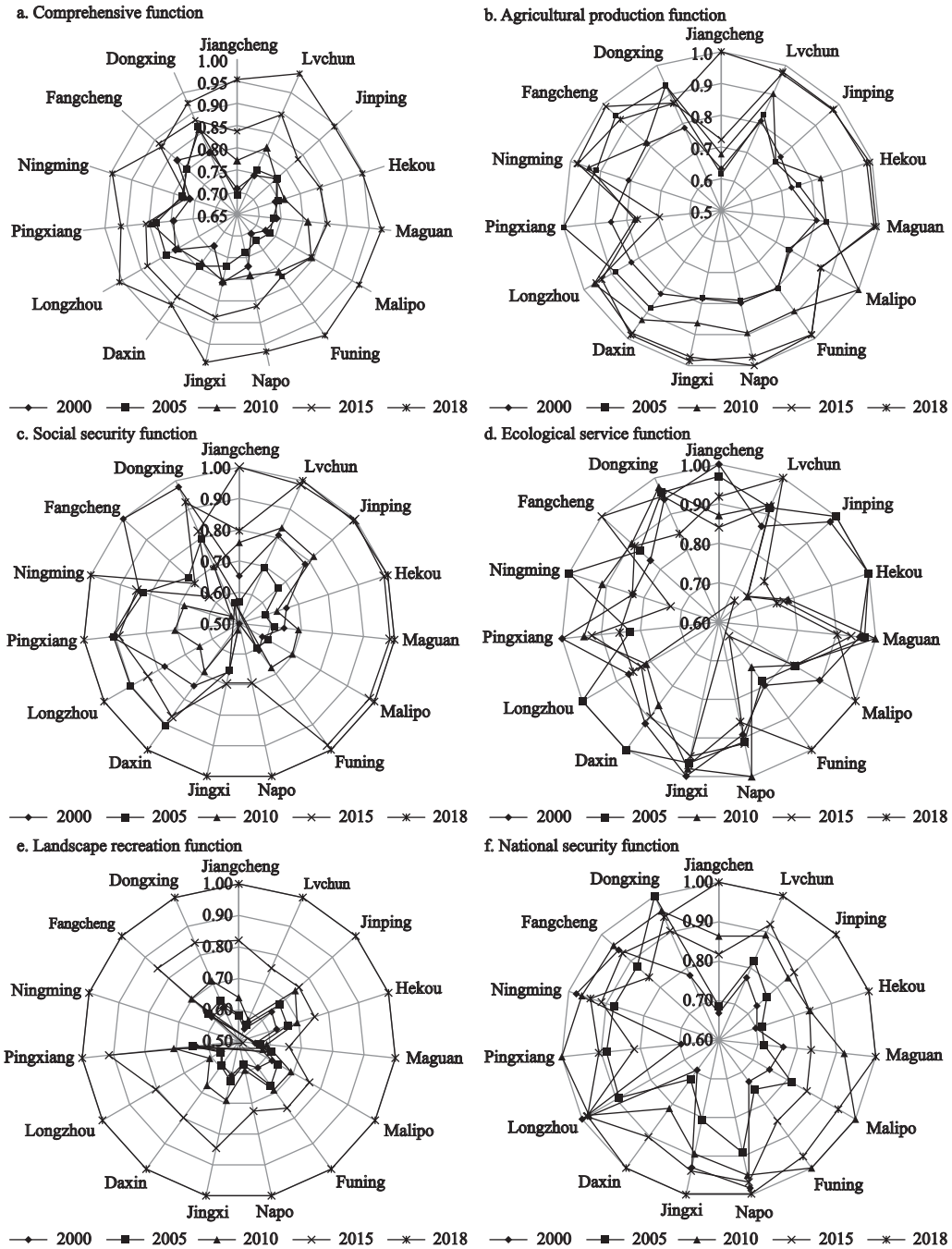

Fig. 3 Evolution trends of land use functions in different counties in the China-Vietnam border area (Fangcheng District is an urban area, Dongxing County and Jingxi County are county-level cities, and the remaining 12 research areas are counties)

use function has not yet stabilized, and the efficiency of comprehensive land use are in dynamic development depending on the local development goals set at each stage. In 2018, the comprehensive land use in the study area exhibits a distribution pattern of being high in the middle and low at the ends, with the high value areas concentrating in Jingxi City, Napo County, Funing County, Malipo County and Maguan County in the central region, and the relatively low value areas in Daxin County and Fangcheng District.

3.2.2 Spatial distribution of the sub-functions

For the agricultural production function, as can be seen from Fig. 4b, the areas with high agricultural production function are mainly concentrated in the eastern part during the early period, then they gradually shift to the central part, indicating that the eastern part, which ori-

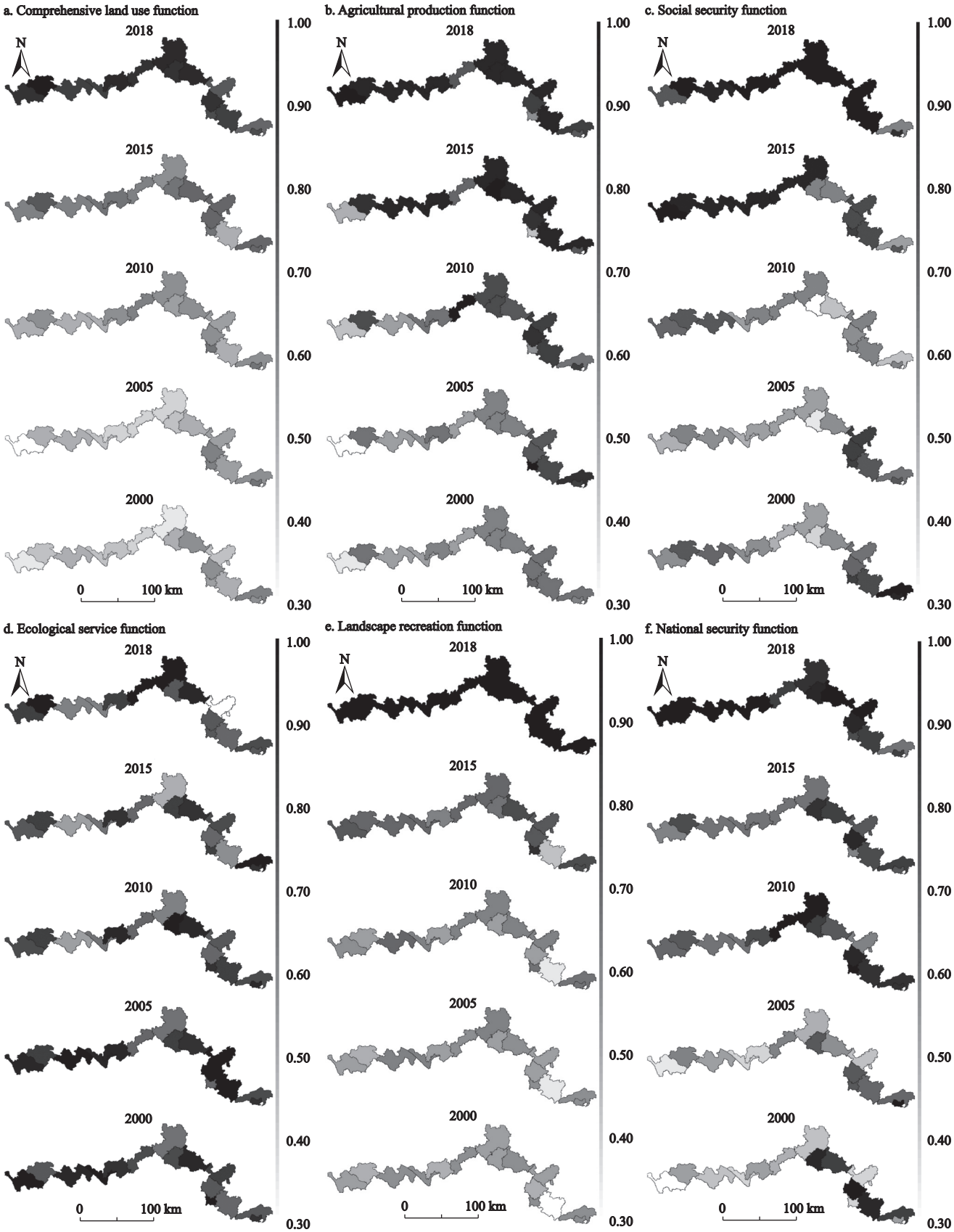

Fig. 4 Spatial distribution characteristics of land use multifunctionality in the China-Vietnam border area

ginally has advantageous conditions for agricultural production, gradually becomes a relatively weak area for agricultural production. This trend corresponds with the 'shift of the main grain producing area from the southeast coastal region to the northeast region' in China.

For the social security function, from Fig. 4c, it can be seen that the area with high social security function moves from the east to the west during 2000 and 2015, and by 2018, all counties and cities reached a more desirable state, except for Fangcheng District and Jiangcheng County, which are respectively located in the east and west ends. During the early stage, the social security function was relatively weak in the western part, suggesting low food production. This was likely due to the natural constraints and labor outflow. In the later stage, owing to the improvement in production and living services and increase in labor supply, the social security function gradually increased.

For the ecological service function, as revealed from Fig. 4d, the spatial evolution of the ecological service function in the study area is complex. The high-value area in 2000 mainly lie in Jiangcheng County, Jinping County, Hekou County, Maguan County and Malipo County in the Yunnan area, along with Jingxi City, Pingxiang City and Dongxing City in the Guangxi section. In 2005, the spatial distribution pattern of the high value area formed two clusters: one is Jinping County, Hekou County and Maguan County in the central part of the Yunnan section, and the other is Daxin County, Longzhou County and Ningming County in the central part of the Guangxi section. In 2010 and 2015, the spatial distribution of the ecological service function exhibit a pattern where the high- and low-value areas interweave, while in 2018, the distribution pattern is characterized by obvious spatial aggregation, with Maguan County, Malipo County, Funing County, and Jingxi City in the central part of the study area serving as a large cluster of high value counties and cities, and Jiangcheng County and Lvchun County in the westernmost part of the study area as a small cluster of high value counties.

For the landscape recreation function, in Fig. 4e, it can be seen that the landscape recreation function of each county underwent a continuous improvement trend, while each stage shows different spatial differentiation characteristics. At the beginning of the study period, the high value area mainly lied in Pingxiang City, Dongxing City and Fangcheng District in Guangxi, and Jinping County, Hekou County and Malipo County in Yunnan, among which Pingxiang City, Dongxing City and Fangcheng District are well-known tourist destinations that attract large numbers of domestic and foreign tourists. The high value area of landscape recreation function gradually shifted to the Guangxi section from 2005 to 2015, and the tourism industry in the China-Vietnam border area was booming by 2018. As of 2018, there have been 38 scenic spots of grade AA or above in the Guangxi section, while there are only three in the Yunnan section. It is thus foreseeable that, in the future, China-Vietnam border tourism will be dominated by counties in the Guangxi section, thus the Yunnan border should create border tourism scenic spots with regional ethnic characteristics if it aims to develop its tourism industry under such fierce competition.

For the national security function, in view of Fig. 4f, the national security function has undergone obvious geographical differentiation characteristics and spatial evolution pattern. In 2000, the high value areas were mainly distributed in Dongxing City, Fangcheng District, Ningming County, Longzhou County, Jingxi City and Napo County in the Guangxi section, and the national security function in the Yunnan section is generally lower than that in the Guangxi section. The high value area gradually shifted to the central and western regions in 2010 and 2015, but counties and cities in the Guangxi section still dominated. By 2018, the high value areas were mainly concentrated in Jiangcheng County, Lvchun County, Jinping County, Hekou County and Maguan County in the Yunnan section, as well as Napo County, Jingxi City, Daxin County and Longzhou County in the central and western regions of the Guangxi section. Pingxiang City, Ningming County, Fangcheng District and Dongxing City in the eastern part of the Guangxi section, which had previously belonged to the high-value area, gradually became the low-value area. A possible reason for this is that in recent years, Yunnan Province has made full use of the national strategies to expand its road network. Therefore, further improvement in the road accessibility and route options to the border area is critical to enhancing the national security function.

3.3 Discussion on the improvement of land use multifunctionality

3.3.1 Consolidating the agricultural production function in the border area

As a pillar industry in the border area, agriculture has undergone a vast growth trend in recent years. Food security has long been an important foundation for national security (Li et al., 2021), as well as a vision shared by people all over the world. Given this, cities in the China-Vietnam border area should continue to consolidate the agricultural production function of land use. In addition, the local governments should set up an intermediary organization for agricultural land transfer (Fei et al., 2021) that is responsible for service such as information collection, publication, consultation, commissioning agent leasing, contract drafting, and boundary confirmation, so as to provide farmers with a convenient and guaranteed land transfer mechanism. Also, measures should be taken to mitigate the separation of rural land ownership, contract rights and land management rights, so as to guide the orderly transfer of rural land management rights and lay a solid foundation for modern agricultural development. Governments should guide the reform of agricultural business pattern, and provide the necessary support for family farms, agricultural cooperatives, agricultural enterprises, and other new agricultural business entities to promote land transfer through leasing, valued shares, cooperative management, and production trust. Government support should also be given to market players and individuals who invest in agricultural scale operations, rural tourism, and ecological agriculture, such as direct financial incentives, seeds, pesticides, fertilizers, and other in-kind incentives. Local authorities should continue to promote land improvement and enhance the conditions of agricultural operation in the mountainous border areas to increase direct agricultural income.

3.3.2 Optimizing the social security function in the border area

In terms of optimizing the social security function in the border area, it is important to increase food yields through strengthening agricultural inputs (Niu et al., 2021). Furthermore, the relationship between food production and population growth should be reconciled to ensure that food production meets the food needs of the local population (Geng et al., 2019). In order to mobilize the enthusiasm and creativity of farmers, deepen the economic potential of the 'three rural areas', and narrow the income gap between urban and rural residents, the government should support the development of rural industries, encourage entrepreneurship and innovation in the rural area, and establish agricultural cooperatives with local characteristics. It is important to ensure the social security function of land use, yet without being overly dependent on it. That is to say, a portion of the rural population should be gradually released from agricultural labor to work in secondary and tertiary industry.

3.3.3 Enhancing the ecological service function in the border area

In recent years, due to increasing human activities, many ecosystems have been substantially disturbed, and their service functions have been greatly compromised (Ning and Liu, 2015). The China-Vietnam border area is considered an important ecological barrier in southwestern China. The ecological performance in the China-Vietnam border area not only changes the value of its own ecological service function, it also affects the ecological service function of the entire region (Shang et al., 2022). To promote the sustainable development of the border, it is important to establish a long-term mechanism for ecological protection and compensation in the border area. Based on the above analysis, the ecological service function in the China-Vietnam border area is currently in a state of decline, implying that the conflict between environmental protection and economic development is becoming increasingly prominent. At present, aside from the ecological compensation for returning farmland to forest and grass, which can directly benefit farmers (herders), the direct beneficiaries of other ecological compensation funds are governments at all levels and forest rangers. This signifies that, when forest land is classified into the ecological protection zone, forest right owners who make direct contributions to ecological protection do not receive the corresponding financial compensation. Therefore, it is important that government further clarify the beneficiaries of ecological compensation and formulate a market-oriented ecological compensation pattern in the China-Vietnam border area. It is also critical to establish a sound trading system for water rights, sewage rights, and carbon emission rights, etc., and to form an incentive mechanism for the protection of natural resources such as arable land, forests and waters, and the development of ecological agriculture.

In addition, local governments should explore various compensation measures, such as in-kind compensation, service compensation and facility compensation, so as to promote green and low-carbon development in the ecological reserves. Moreover, governments may carry out pilot projects on comprehensive ecological compensation in impoverished border areas, and encourage local poverty-stricken people with working ability to become ecological maintainers.

3.3.4 Strengthening the landscape recreation function in the border area

Under the joint influence of various factors, such as special geographical location and economic and social transformation and development, border land use not only involves the traditional production, living and ecological functions, but other special functions as well. For instance, with the rise of border tourism, the landscape recreation function of border areas has been increasingly enhanced. The tourism industry in the China-Vietnam border area has undergone rapid development, and has become an advantageous characteristic industry and an important pillar industry at the border. Meanwhile, tourism land is currently set under the category of construction land, which limits the available area for tourism construction (Xia et al., 2020; Liu et al., 2021b). Therefore, it is recommended that natural landscape land and non-permanent accessory facility land in the tourism projects be identified and managed according to its original land type, otherwise it may occupy permanent basic agricultural land, damage the ecological environment, or affect geological safety and agricultural production. Moreover, border rural collective economic organizations are encouraged to utilize collective agricultural land and unused land for tourism development through business cooperation and leasing. Governments should support these organizations to make use of the collective construction land that was originally planned for tourism.

3.3.5 Enhancing the national security function in the border area

As an active area of international interaction, border areas are gradually becoming a main concern for national affairs, thus the national security function carried by border land use is becoming increasingly prominent (Huang, 2022). Therefore, local governments should continuously focus on the dynamic monitoring of border land use and control, and be aware residents of the importance of doing so. For instance, arable land abandonment at the border is not conducive to maintaining clear boundaries of arable land, while unused rural house bases can become hiding places for law-breakers. Such issues pose potential threats to land security, and should be taken seriously in the future. In view of the current problems, such as land abandonment, low population size, and low density of road networks in the China-Vietnam border area, differentiated land use policies should be implemented. First, a single land use quota should be implemented regarding transportation infrastructure, and border tourism projects to maintain as much land area as possible. In addition, the construction land quota is encouraged to tilt toward border tourism, border trade ports, border trade logistics, border transportation and other special projects. In particular, for Guangxi, where road construction has been lagging in recent years, closer attention should be paid to road construction and its spatial layout, along with the construction of village roads within the 0–20 km range in the border area. At the same time, if the education, health and other important livelihood projects and industrial land projects occupy permanent basic farmland, then they should be compensated for according to the same amount and quality of basic farmland within the administrative region. For areas located within 0 to 3 km from the border line, the right to select housing sites for residents should be relaxed, and residents are encouraged to gather at the border line. Furthermore, reasonable arrangement of industrial and mining land in border towns is important to accelerating the agglomeration effect and market competition effect in border counties and cities. Second, improve the security of land use at the border. For arable land, the land utilization rate can be improved through land transfer, while for abandoned rural settlements, factories and other construction land, land reclamation or transformation should be carried out in a timely manner, so as to curb border land abandonment. For arable land with no transformation value, transform it into forest land to increase the coverage of medium-height forest and optimize border land use structure. Third, greater emphasis should be placed on promoting border household registration system reform and in-situ urbanization. The government can actively promote the reform of the household registration ('*hukou*') system that is conducive to the gathering of border population, to ensure that mobile popula-

tion can enjoy the same rights, public services, and other benefits as local households. A moderate level of population density and corresponding productive activities in the border areas are a natural and solid border wall. At the same time, population loss in border towns will lead to the "hollowing out" of border villages and the abandonment of farmland, which will in turn inhibit the long-term stability of border areas. Therefore, in order to develop a long-term mechanism to maintain population at the border, it is necessary to promote government-led in-situ urbanization with multi-party participation and a cost-sharing mechanism. During this process, supporting the construction of the border people's market points, avoiding merging border villages, and strengthening border specialty industries are all critical in improving the level of border development.

In summary, we still lack land use policies tailored to border areas. As the research on border land continues to deepen, governments at all levels should fully understand the special needs of the border areas, and, as soon as possible, implement an operational differentiated land policy that can support the economic and social development of these border areas.

4 Conclusions

Applying the improved TOPSIS model and spatial analysis method of ArcGIS, this study investigates the spatial and temporal evolution characteristics of LUMFs in the China-Vietnam border area. Based on the above analysis, we draw the following conclusions.

First, the comprehensive functions of land use in most counties and cities have undergone an increasing trend, indicating that a series of national and local policies have effectively enhanced border LUMFs in recent years. The agricultural production function rises continuously, where the level in the Guangxi section is gradually surpassed by that in the Yunnan section. Similarly, the landscape recreation function has continued to improve, and tourism has gradually become one of the important pillar industries in the China-Vietnam border area. Meanwhile, both the social security function and national security function in the study area have undergone a fluctuating trend and improved in volatility. The social security function exhibits distinct characteristics at different stages of economy and society development. The national security function in developing counties and cities has improved continuously, while the national security function in relatively mature counties and cities is sensitive to economic development conditions. The ecological service function is the only declining land use function in the study area, and the evolutionary trend in each county is intricate and complex, thus reflecting the adverse effects of human activities on the ecological environment and the complexity of its impact process.

Second, the comprehensive function of land use in the China-Vietnam border area exhibits significant spatial differentiation and spatial aggregation characteristics. The early period showed significant spatial divergence characteristics of being high in the east and low in the west, and the high value area is mainly distributed in the central-eastern counties and cities of Guangxi. In the middle period, the high value area gradually shifted from the east to the central-west. Finally, in the later period, the spatial distribution pattern was characterized by being high in the middle and low at both ends. The high-value area of agricultural production function was mainly concentrated in the eastern region in the early stage, then gradually shifted to the central region, while the high-value area was located in the central and western regions in the later stage. The high-value areas of the social security function and national security function also underwent a shift from the east to the west. The spatial evolution of the ecological service function and landscape recreation function is complex, with different spatial differentiation characteristics at each stage.

Third, in view of the spatial and temporal evolution characteristics of LUMFs in the China-Vietnam border area, it is necessary to formulate a series of differentiated land use policies for the border area. It is also vital to propose border land use security policies in terms of curbing land abandonment, optimizing the structure of land use, reforming the border household registration system, and promoting in-situ urbanization at the border. Finally, through establishing a long-term mechanism for ecological protection and ecological compensation, more residents at the border are encouraged to participate in ecological protection, which helps to maintain the role of the China-Vietnam border area as an important ecological barrier of China.

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