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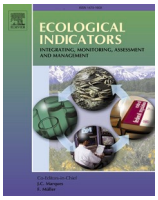

Analysis of the tourism-economy-ecology coupling coordination and high-quality development path in karst Guizhou Province, China

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ABSTRACT

Developing tourism is conducive to stimulating the vitality of regional economic development, improve economic backward areas of people's living standards. However, the development of tourism often brings great negative impact on regional sustainable development, especially in ecologically fragile areas. Therefore, the main purpose of this article is to identify the spatial changes of tourism-economy-ecological (TEE) system development in ecologically fragile areas of southwest China and promote the coordinated development of the system. Based on the entropy weight method, coupling coordination degree (CCD) model and obstacle degree model, this article focuses on the analysis of the development level, coupling coordination status and related obstacle factors of the TEE system in prefecture cities of Guizhou Province from 2009 to 2021. This result shows that: (1) Guizhou Province has made remarkable progress in environmental governance, however, the comprehensive development level of tourism system in most cities was relatively low, and obviously lagged behind the comprehensive development of economy and ecology. (2) The CCD level of each city had been continuously improved from 2009 to 2021. Cities with low coupling coordination in 2009 showed a relatively high rate of improvement in later period. (3) The obstacle factors affected harmonious development changed from the low number of domestic tourists and low tourism income in 2009 to insufficient number of travel agencies and star-rated hotels in 2019, and to the sharp decline of international tourists and tourism foreign exchange income in 2021. (4) The impact of COVID-19 on the harmonious development in TEE system, was relatively controllable. Nowadays, the ecological environment of most cities in Guizhou Province maintains a steady improvement trend, but the development of tourism lags behind and the lack of economic growth momentum is a serious problem. Based on the above analysis, tourism should be stimulated within the carrying capacity of ecological environment, and enterprises with development potential should be invited for investment and production in the future. Targeted policies should be formulated according to regional development differences, such as mountain tourism and ethnic culture tourism in the western mountainous area of Guizhou Province, while the eastern ecologically sound areas should pay more attention to the investment and management of ecological environment, attach importance to the construction of tourism infrastructure, improve the service level, and constantly enhance the quality of tourism development. These conclusions can also provide relevant experience and reference for realizing high quality economic development in other ecologically fragile areas.

1. Introduction

Nowadays, the polluted environment, climate change and depletion of natural resources pose a threat to people's living space (Hang, 2022). There is a strong coupling between ecological environment and poverty, and a vicious cycle between fragile ecological environment and underprivileged (Chen et al., 2021; Lawson et al., 2012). Fortunately, harmonization between promoting economic development, addressing poverty, and protecting the ecosystem can still be achieved and improve the well-being of the population (Gray and Moseley, 2005; Bilgen and Sarıkaya, 2015). Reasonable arrangement of production and life within the capacity of resources and the environment is a prerequisite for sustainable development. Tourism is one of the largest and most potential industries in the world (Smith, 1993; Adiguzel et al., 2022). The

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development of tourism, especially environmental tourism and ecotourism based on rational use of resources, is seen as an important step towards sustainable development (Cetin et al., 2018; Mehmet and Hakan, 2016). Additionally, the healthy development of tourism requires a comprehensive consideration of ecological environmental carrying capacity and the impact of human activities (Liu et al., 2017a). In summary, the virtuous cycle of the TEE system is key to the regional sustainable and healthy development (Xiong et al., 2007). Therefore, the systematic elaboration of the interaction between TEE systems and the identification of the key factors affect the coordinated development of the systems are of great importance to resolving regional development contradictions, especially in ecologically fragile and economically backward areas.

Regional tourism development, ecological protection and economic growth are an open system with complex coupling, and tourism industry is the key to promoting harmonious development of different systems (Fei et al., 2021). The interaction between tourism, ecology and economy has been studied extensively, such as the research the mutual influence between tourism and ecology (Day et al., 2012), economy and tourism (Milman and Pizam, 1988; Paramati et al., 2017), and the interaction between the three (Lacitignola et al., 2007). To be specific, good tourism resources and beautiful ecological environment are the prerequisite and guarantee for tourism industry rapid development, which can push the transformation and development of regional economy, while unreasonable development mode will also cause severe destruction of natural environment and serious consumption of resources (Adu-Ampong, 2018; Xiao et al., 2022; Liao et al., 2020). In particular, tourism has also added a great impetus to China's economic development, but what cannot be neglected is that the conflict between natural environment protection and tourism industry development is becoming continuously intensify (Wei, 2015). Unreasonable tourism development patterns or high-insensitive tourism economic activities can lead to environmental degradation (Andersen, 2007; Xu et al., 2022). For example, the expansion and development of tourism industry around the Yangtze River in China have intensified the ecological and environmental conflicts, leading to environmental degradation, resource waste and environmental pollution (Xiao et al., 2022).

In terms of the actual development situation, most tourism activities have brought serious great pressure to ecological protection (Day et al., 2012). It has become a consensus to correctly handle tourism industry and the relationship between the environment protection (Zhang et al., 2022). How to properly handle the relationship between tourism industry development and environmental protection, realize the harmonious development between human well-being and ecological environmental protection is one of the important challenges for ecologically fragile western regions of China (Ma and Tang, 2022). The karst-areas in south China are considered to be the most representative, sophisticated, and landscape-rich among the worldwide karst-areas regions (Sweeting, 1993). This region is mainly mountainous, with large topographic fluctuations, serious soil erosion, large bedrock area exposure, low carrying capacity of ecological environment, and small elasticity of disaster threshold (Yuan, et al., 2022; Pu et al., 2022), soil and water loss is manifested in the dual forms of surface and underground loss (Wu et al., 2020), result in difficult development, high cost of ecological restoration and serious problem of engineering water shortage. Therefore, rocky desertification has become the main ecological problem, which greatly restricts the development space and development capacity, aggravates the contradiction between human and land, and makes karst-areas become one of China's four poor natural conditions, as well as one of its most poverty-stricken areas (Wang et al., 2018; Liu et al., 2017a, 2017b). Furthermore, rocky desertification has increased the pressure on ecological protection and restoration, causes and exacerbates poverty in karst-areas (Fan et al., 2015; Zhou et al., 2008). Agriculture has been a weak point in the economic development of this region, seriously affecting the sustainable development (Yang et al., 2016). Irrationality in production method and lifestyle further aggravates ecological and environmental problems in karst-areas (Liu, 2018), making karst topography a key restricting factor in socio-economic harmonious development (Tan et al., 2021). Under the support and guidance of the government, tourism has become one of the important ways to realize economic development in China's western underdeveloped areas, and has turned into the leading industry of the local area (Xie et al., 2021; Li et al., 2021a). However, the adaptability of tourism and eco-economic development in karst areas is still unknown, and the key factors hindering the coordinated development of local areas are not clear.

It is undeniable that long-term development of tourism industry in ecologically fragile region faces great pressure (Yang et al., 2021). Under the guidance of high-quality development, the evolution of ecotourism in karst-area of China is facing new opportunities and challenges (Li et al., 2021b). The booming tourism industry also caused huge menace to ecological protection, making the potential adverse impact on ecological environment a tangible fact (Hall, 2006). There is mutual interaction between ecological security and social economy, and it is of crucial importance to identify the key influencing factors and achieve a balance between them (Sun et al., 2020). The CCD model is often seen as a tool to analyze the interaction between multiple subsystems, with the degree of coupling reflecting the interplay between subsystems and the degree of coordination reflecting the intensity of cooperative development (Lai et al., 2020; Yang et al., 2020).

Tourism plays an increasingly important role in the current economic and social development and plays an important supporting role for economic development (Adu-Ampong, 2018), and will also have an important impact on karst areas development of China. However, current research on coupled coordination has focused more on the economy, ecology and environment (Lee and Chang, 2008), with relatively little research on the role of tourism with other systems. Specifically, the existing scales of coupled coordination analysis on karst region are mainly developed from the perspectives of economy and ecology (Liu and Hu, 2020), or tourism and ecology (Sun et al., 2020; Chen et al., 2021), and the research on coupled coordination of TEE system is still blank. However, the economy, ecology and tourism system are closely linked and interact with each other, and the lack of multi-scale and multi-module systematic analysis, the conclusions drawn may deviate from the actual. Finally, significant differences in the factors affecting the degree of coordination of system coupling over time. However, most researches only focus on the classification of system coordination and coupling degree, with insufficient effort in the exploration of the obstacles to system harmonious development, thus providing little value as a guide to the realization of coordinated regional development. Therefore, in order to make up for the lack of existing research and to provide a useful reference for the coordinated development of ecological economy in ecologically fragile areas, this study (1) analyses the development of the TEE system in Guizhou Province; (2) explain the coupling and coordination status of the system with the CCD model; (3) identify the key factors affecting the coordinated development of the system with the obstacle degree model, (4) provide relevant targeted policy insights and suggestions. The possible innovations of this paper are as follows: (1) The coupling and coordination changes of TEE system were analyzed, which enriched the research on the role of tourism in economic and ecological development; (2) The role of tourism in economic development and ecological construction in ecologically fragile areas is explored, which can provide a useful reference for ecologically fragile areas to break through the development dilemma; (3) Introducing the obstacle degree model to identify the factors of coordinated development of the system enriches the research on coupled coordination degree, which can provide a useful reference for the subsequent related research.

2. Materials and methods

This article takes the nine prefecture-level cities under the jurisdiction of Guizhou Province from 2009 to 2021 as evaluation units. The data related to tourism industry, economic development and ecological environmental protection mainly come from Guizhou macroeconomic database, the statistical yearbook and the research platform of China's economic and social big data. In this study, entropy weight method is used to process the data, and then CCD model and obstacle degree model are used to analyze the coupling coordination level of TEE system and identify the main influencing factors. In order to clearly show the logical framework and research steps of this article, the analysis framework is shown in Fig. 1.

2.1. Research area

Located in southwest China (Fig. 2), Guizhou Province (geographic coordinates: 24°37′ N – 29°13′ N, 103°36′ E ~ 109°35′ E), boasts a terrain which is high in the west and low in the east, and four landforms: plateaus, mountains, hills and basins. Mountains and hills account for 92.5% of the total area. Due to dense forest and rich biodiversity, this province plays a crucial part in maintaining the total ecological security of China (Sun et al., 2020). In addition, Guizhou Province is also a considerable ecological barrier in southeast China, playing a crucial role for the sustainable development of the Yangtze valley (Cui et al., 2019). However, it is also an ecologically fragile region in southwest China. Guizhou Province is particularly characterized by the most prominent poverty scope, depth and ecological fragility in southwest China (Chen et al., 2021). Affected by karst rocky desertification, the economic and social development of Guizhou Province has been under long-term constraints of the ecological environment struggling in a vicious circle (Jiang et al., 2014). The State Council of China enacted several advices on enhancing the development level of social and economic of Guizhou Province in 2012, aiming at the comprehensive implementation of the "Trinitarian (water conservancy, ecological construction and rock desertification control) development plan", and deepening poverty-relief development and institutional reform. Subsequently, China began to set up the first batch of national pilot zones for ecological civilization experiment in 2016, and Guizhou Province is the only province in Southwest China to be selected, which fully demonstrates its important position in the construction and development of China's ecological civilization.

At present, Guizhou Province insist sustainable development strategy and explores the road of coordinated development between economy and ecological protection (Pan et al, 2021). Since 2012, this province annual GDP growth rate has been in the forefront of China (Sun et al., 2020). The development strategy of "one hand for flow, the other for quality" for strengthening tourist industry has resulted in the growth spurt of tourism. The annual tourism income maintained a 30% growth rate from 2016 to 2019. However, the rapid economic growth also brought greater threat to the ecological environment carrying capacity in this province (Zhao et al., 2022; Liang et al., 2020). Problems such as stony desertification as constraints of economic development and the acute contradiction of man-land relationship remain prominent (Fu et al., 2019).

2.2. Data and pre-processing

Because the indicators are positive and negative, and the measurement units and orders of magnitude of each indicator are significantly different, it is necessary to conduct standardized data processing to enhance the comparability of different indicators, and standardized calculation is as follows:

Positive indicator:

$$d_{ij} = \frac{x_{ij} - min\ x_{ij}}{max\ x_{ij} - min\ x_{ij}} \quad (1)$$

Negative indicator

$$d_{ij} = \frac{max\ x_{ij} - x_{ij}}{max\ x_{ij} - min\ x_{ij}} \quad (2)$$

The positive indicator selection formula (1) and negative indicator selection formula (2) are shown as above, where x_{ij} on behalf of the initial value of second-level index j of subsystem i, while $x_{ij\ max}$ and $x_{ij\ min}$

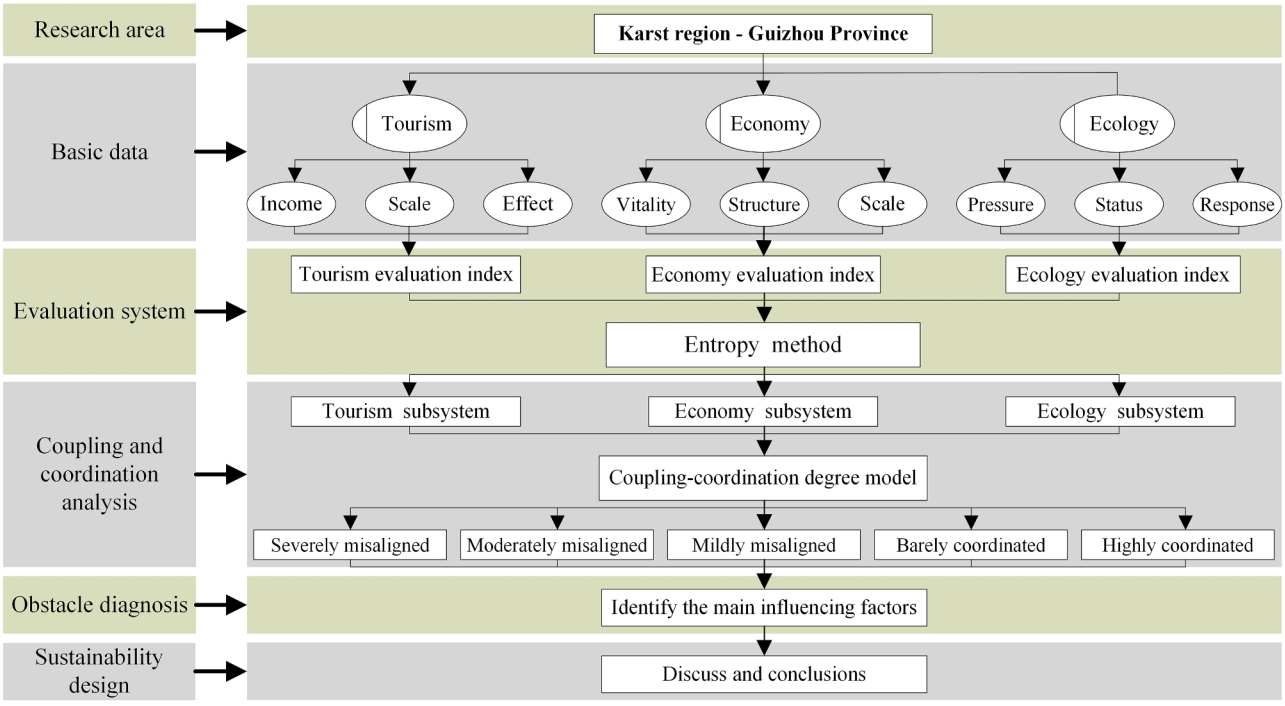

Fig. 1. Tructural framework proposed in this study.

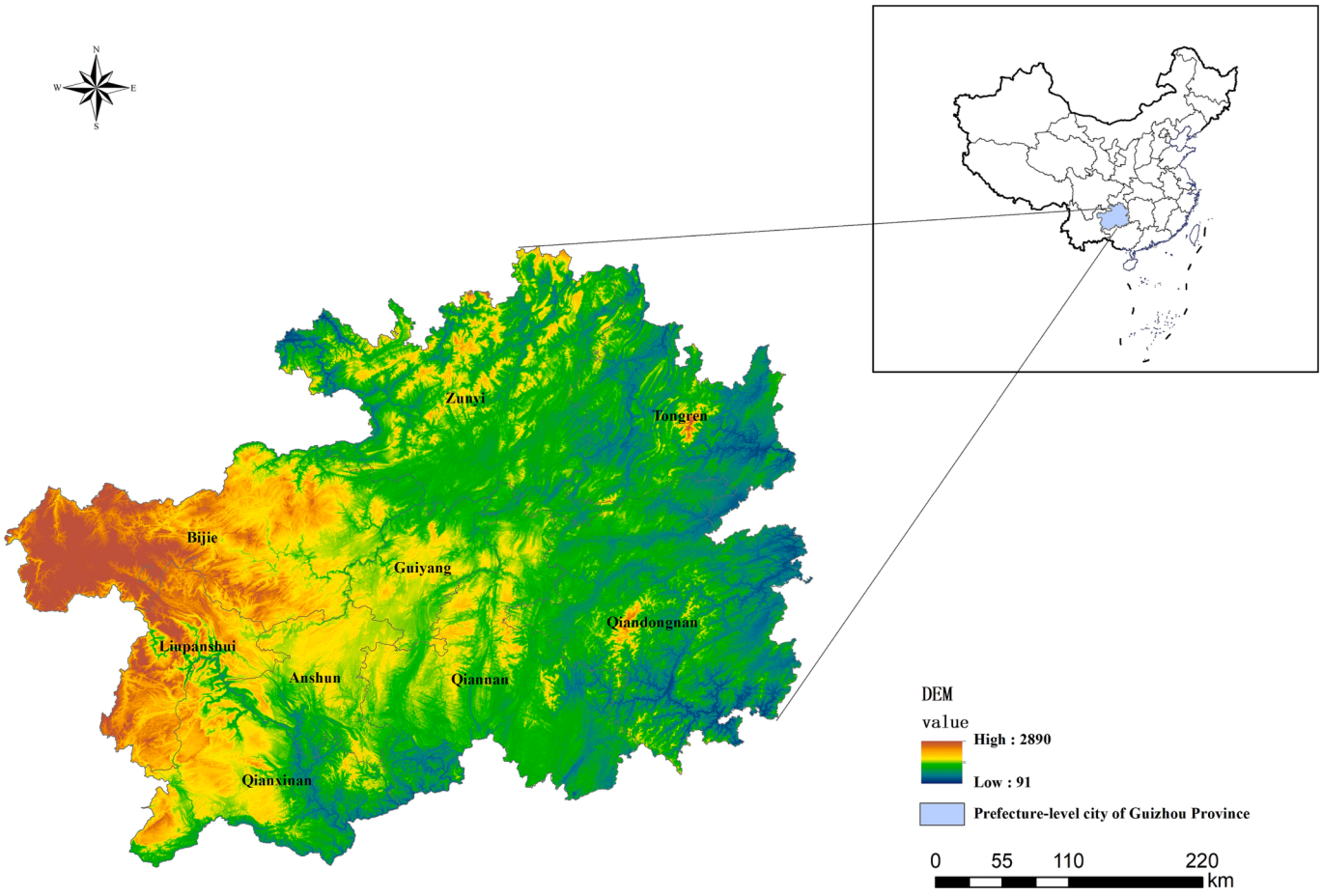

Fig. 2. Geographical location and topography of Guizhou Province.

represent the maximum and minimum value respectively of second-level index *j* in each subsystem, d_{ij} represents the standardized data of second-level index *j* in subsystem *i*, and $d_{ij} \in [0,1]$.

2.3. Index and method

2.3.1. Dimensions of the indexes

In order to carry out a profound analysis of the coupling coordination relationship of TEE system, in the first place, to construct an index system which reflects the characteristics of each system and make a comprehensive evaluation of each system. Firstly, although the indicator system of tourism system can be divided into tourism scale, tourism benefit and tourism service (Xiao et al., 2022), or tourism income, tourism scale and tourism effect (Ge et al., 2021), however, they can all be summarized into three categories: tourism economic income (Ruan et al., 2019), tourism tourist scale (Xiao et al., 2022) and tourism industry driving effect (Tang, 2015). Therefore, this paper selects the domestic and foreign income of tourism industry (C1-C2), the number of domestic and foreign tourists (C3-C4), the number of travel agency employees, travel agencies and star hotels (C5-C7) to reflect the development of tourism industry.

Secondly, economic development is reflected in the quantitative growth of the economy, as well as its qualitative improvement. The former is usually expressed in terms of economic scale, while the latter is reflected in terms of economic vitality and economic structure (Wang et al., 2021). Therefore, referring to existing studies, this paper chooses 'GDP growth rate' (Zhang et al., 2022), 'foreign trade dependence', 'consumption rate (Min et al., 2022) to reflect the economic vitality (C8-C10), and 'GDP per capital' (Zhang et al., 2022), 'the proportion of output value of the secondary industry' and 'proportion of tertiary industry output value' (Liu et al., 2022) to reflect the economic structure (C11-C13), and 'GDP' (Lirn et al., 2013), 'government revenue' and 'number of Internet broadband users' (Sheng et al., 2009) were selected to reflect the economic scale (C14-C16).

Finally, existing studies on the assessment and measurement of ecological environment, mainly quantitative analysis through the PSR model, constitute the basic answer to the three sustainable questions of "what happened and why, and future measures" (Zhang et al., 2014; Liu et al., 2020). Therefore, this paper chooses 'Total sulphur dioxide emissions' (Zhang et al., 2022), 'Total wastewater discharge', 'Amount of industrial solid waste generated' (Ruan et al., 2019) and 'Agricultural fertilizer application amount' (Sheng et al., 2009) to reflect the ecological pressure (C17-20), chooses 'forest park area', 'Greening rate of built-up areas', 'Park green space per capita'(Ruan et al., 2019), chooses 'Population affected' (Cheng and Li, 2021) to reflect the ecological status (C21-24), and 'Municipal sewage treatment capacity' (Ruan et al., 2019), 'Urban gas penetration rate' (Sheng et al., 2009) to reflect the ecological response (C25-26). At the same time, in order to reflect the ecological and environmental characteristics of karst-areas as much as possible, 'water-soil loss treatment area of specific years' (C27) and 'forest reservation area' (C28) are included in the analysis index (Cheng and Li, 2021). In this way, it not only includes the general characteristic index of ecological environment, but also highlights the ecological characteristics of karst area. With the principle of hierarchy, integrity, operability and data accessibility, the comprehensive judgement index system of TEE system is constructed. The specific indexes are shown in Table 1.

Table 1
Comprehensive evaluation index system and index weights of the TEE systems.

System	Factor	Index	Attribute	Weight	Reference
Tourism	B1 Tourism income	C1 Domestic tourism income	Positive	0.1569	Ruan et al., 2019
		C2 Travel foreign exchange income	Positive	0.1363	Ruan et al., 2019
	B2 Tourism scale	C3 Number of domestic tourists	Positive	0.1571	Xiao et al., 2022
		C4 Number of international tourists	Positive	0.1403	xiao et al., 2022
	B3 Tourism effect	C5 Number of travel agencies	Positive	0.1311	Tang, 2015
		C6 Number of star hotels	Positive	0.1621	Tang, 2015
		C7 Number of travel agency employees	Positive	0.1162	Xiao et al., 2022
Economy	B4 Economic vitality	C8 GDP growth rate	Positive	0.0831	Zhang et al., 2022
		C9 Foreign trade dependence	Positive	0.0610	Min et al., 2022
		C10 Consumption rate	Positive	0.0771	Min et al., 2022
	B5 Economic structure	C11 GDP per capital	Positive	0.0781	Zhang et al., 2022
		C12 The proportion of output value of the secondary industry	Positive	0.0843	Liu et al., 2022
		C13 Proportion of tertiary industry output value	Positive	0.2727	Liu et al., 2022
	B6 Economic scale	C14 GDP	Positive	0.1224	Lirn et al., 2013
		C15 Government revenue	Positive	0.0992	Sheng et al., 2009
		C16 Number of Internet broadband users	Positive	0.1220	Sheng et al., 2009
Ecology	B7 Ecological pressure	C17 Total sulphur dioxide emissions	Negative	0.2263	Zhang et al., 2022
		C18 Total wastewater discharge	Negative	0.2816	Ruan et al., 2019
		C19 Amount of industrial solid waste generated	Negative	0.0536	Ruan et al., 2019
		C20 Agricultural fertilizer application amount	Negative	0.0505	Sheng et al., 2009
	B8 Ecological status	C21 Forest park area	Positive	0.0471	Ruan et al., 2019
		C22 Greening rate of built-up areas	Positive	0.0519	Ruan et al., 2019
		C23 Park green space per capital	Positive	0.0505	Ruan et al., 2019
		C24 Population affected	Positive	0.0435	Cheng and Li, 2021
	B9 Ecological response	C25 Municipal sewage treatment capacity	Positive	0.0419	Ruan et al., 2019
		C26 Urban gas penetration rate	Positive	0.0520	Sheng et al., 2009
		C27 water-soil loss treatment area of specific years	Positive	0.0498	Cheng and Li, 2021
		C28 forest reservation area	Positive	0.0514	Cheng and Li, 2021

2.3.2. Method

(1) The entropy method

this method was applied to estimate the decline degree of the capability of the material system (ander and alfred, 1995). now it is often used to determine index weight by calculating the information entropy of the index item, which is more objective in weight determination. the formula of entropy weight method is as follows:

$$q_{ij} = x_{ij} \Big/ \sum_{i=1}^{m} x_{ij} \tag{3}$$

$$e_{ij} = -\frac{1}{\ln m} \sum_{i=1}^{m} \alpha_{ij} \ln \alpha_{ij} \tag{4}$$

$$w_{ij} = 1 - e_{ij} \Big/ \sum_{j=1}^{n} (1 - e_{ij}) \tag{5}$$

where q_{ij} and e_{ij} represent respectively the standardized index value and information entropy value of j index in i subsystem, and w_{ij} represents the above index weight based on information entropy; m and n represent respectively the corresponding years and the amount of the j index, and $\sum w_{ij} = 1$. Since q_{ij} contains 0 value after index standardization, in entropy calculation, the index translation method is adopted to add 0.0001 to this index, which is reflected in equation (4), $a_{ij} = q_{ij} + 0.0001$. According to the above calculation formula, the specific weights of each index of the subsystems are obtained as shown in Table 1.

(2) Subsystem comprehensive evaluation index

This index reflects the overall influence of all indexes in the system, and calculation formula is shown below:

$$f(x) \ or \ f(y) \ or \ f(z) = \Sigma w_{ij} * d_{ij} \tag{6}$$

where *f(x)*, *f(y)* and *f(z)* on behalf of the comprehensive evaluation index of tourism, economy and ecology subsystems respectively, and w_{ij} represents the weight of the above indexes ground on information entropy.

(3) The coupling coordination degree (CCD) model

1) Coupling degree model

Coupling degree is used to calculate the coupling effect degree, reflecting the coupling relationship among the TEE subsystems in Guizhou Province. The calculation formula of coupling degree is shown below.

$$C = \sqrt[3]{\frac{f(x)f(y)f(z)}{[(f(x)+f(y)+f(z))/3]^3}} = \frac{3\sqrt[3]{f(x)f(y)f(z)}}{f(x)+f(y)+f(z)} \tag{7}$$

where C is the system coupling degree. The smaller the C value, the lower the degree of connection of subsystems, and presenting a disordered state.

2) Comprehensive development index

This index can be used to show the comprehensive level of the subsystems. The formula for calculating the comprehensive development index T is shown below:

$$T = \alpha f(x) + \beta f(y) + \gamma f(z) \tag{8}$$

where α, β and γ represent respectively the weight of the comprehensive evaluation indexes of the subsystems. Most of the existing researches judge this weight according to experience or assign the same values based on the assumed equivalent importance of subsystems (Xiao et al., 2022). Considering the important role of tourism in Guizhou Province and the development direction of tourism industrialization, $\alpha = \beta = \gamma = 1/3$ is more in line with the actual economic development of the local area.

3) Coupling coordination degree model

The value of C can be used in quantitative analysis and determination of the level of interaction and development order among subsystems, while it cannot reveal effectively the systems comprehensive development level. High degree of coupling appears when each subsystem enjoys either high or low development levels. It is hard to predict the comprehensive effect of the research system based solely on the coupling degree. Hence, it is required to construct the CCD model of the TEE systems. The D represent CCD, and computation formula is shown below:

$$D = \sqrt{C^{*}T} \tag{9}$$

D ∈ [0,1], and the larger D is, the better coupling degree of the system is. When $D = 0$, it means the whole system is in an absolute dissonance state. Although the research topics are different, they are mainly divided into five types based on the D-value, and the coordination of each region in different years is judged (Chen et al., 2022; Wang et al., 2022; Zou et al., 2022). According to the existing results, the category standard of CCD of TEE system is determined, as shown in Table 2.

Where max *f(m)* and min *f(m)* on behalf of the maximum and minimum values of the comprehensive development index in the TEE subsystems, separately, and reveal the evolution standard of the subsystems on the basis of the relevant difference values. According to the D value, the coordination situation is divided into severely misaligned, moderately misaligned, mildly misaligned, barely coordinated, highly coordinated.

(4) Obstacle diagnosis model

This model is further adopted to analyze the key limitations influence the coordinated development in Guizhou Province.

$$M_{ij} = 1 - d_{ij}w_{ij} \Big/ \sum_{j=1}^{n} 1 - d_{ij}w_{ij} \tag{10}$$

M_{ij} represents the obstacle degree of the j index in i system to the CCD of the system: the larger the M_{ij} is, the greater the negative impact of this index on the CCD of the system is.

Table 2
Classification standard of coupling coordination degree of TEE system.

D range	*D classification*	*Max f(m) - Min f(m)*	*Type*
(0, 0.2]	*Severely misaligned*	*Max f(m) - Min f(m) > 0.5*	*Severely misaligned ; Existence subsystem lagging behind*
		Max f(m) - Min f(m) ≤ 0.5	*Severely misaligned ; With synchronous development*
(0.2, 0.4]	*Moderately misaligned*	*Max f(m) - Min f(m) > 0.5*	*Moderately misaligned ; Existence subsystem lagging behind*
		Max f(m) - Min f(m) ≤ 0.5	*Moderately misaligned ; With synchronous development*
(0.4, 0.6]	*Mildly misaligned*	*Max f(m) - Min f(m) > 0.5*	*Mildly misaligned ; Existence subsystem lagging behind*
		Max f(m) - Min f(m) ≤ 0.5	*Mildly misaligned ; With synchronous development*
(0.6, 0.8]	*Barely coordinated*	*Max f(m) - Min f(m) > 0.5*	*Barely coordinated ; Existence subsystem lagging behind*
		Max f(m) - Min f(m) ≤ 0.5	*Barely coordinated ; With synchronous development*
(0.8, 1.0]	*Highly coordinated*	*Max f(m) - Min f(m) > 0.5*	*Highly coordinated ; Existence subsystem lagging behind*
		Max f(m) - Min f(m) ≤ 0.5	*Highly coordinated ; With synchronous development*

3. Results and analysis

3.1. Analysis of each subsystem

In order to fully understand the coupling and coordination changes of the TEE system in Guizhou Province during the study period and its causes, it is necessary to deeply understand the development and changes of each subsystem. The changes of each subsystem during 2009–2021 are shown below.

3.1.1. Tourism subsystem

The trend of the comprehensive development level of tourism subsystem in each region of Guizhou Province from 2009 to 2021 is shown in Fig. 3. In 2012, with the support of the Chinese government, Guizhou Province set the goal of developing culture and tourism industries into pillar industries, emphasizing the construction of a number of cultural industry bases and regional cultural industry clusters by relying on the multi-ethnic cultural resources. Driven by relevant policies, funds, technologies, talents and other policies, the comprehensive development level of tourism subsystems in major cities of this province maintained a steady rising trend from 2012 to 2019. However, the comprehensive development level of the tourism subsystem in other cities except Liupanshui City showed varying degrees of decline in 2020, and recovered to some extent in 2021. The behind reason may be that the Covid-19 epidemic outbreak in early 2020 has restricted people's travel activities, resulting in a significant decrease in domestic and foreign tourists. With the deepening of people's understanding of the epidemic and the formulation of tourism development measures, the development of tourism industry in various regions of Guizhou Province has improve in 2021.

In terms of individual regions, it is worth noting that during the study period, the comprehensive level of tourism subsystem in most cities maintained a steady upward trend, but the comprehensive development level was relatively low, and the subsystem level of most cities was lower than 0.3. Compared with other cities, the comprehensive level of tourism subsystem in Guiyang, the capital city of Guizhou Province, maintained a far leading position from 2009 to 2021. In addition, although the comprehensive level of tourism industry in most cities maintained a steady upward trend during the study period, the comprehensive development level was relatively low, and the system comprehensive level was lower than 0.3 in most cases. Finally, the COVID-19 epidemic has resulted in relatively adverse impact on the tourism development of Guizhou Province, but the degree of impact varies greatly among different cities. Specifically, Guiyang City and Zunyi City, which enjoyed a high comprehensive development level of tourism subsystem from 2019 to 2020, suffered the greatest negative impact, and their system development levels decreased from 0.8371 and 0.3275 to 0.4284 (-48.82%) and 0.1197(-63.46%), respectively. Although China adopted normalized management measures for COVID-19 epidemic in 2021 and achieved remarkable control results, Guiyang witnessed an increase of only 0.57% in tourism subsystem development level, while Zunyi City, with a relatively low tourism subsystem level before, an increase of 68.86%. In particular, Liupanshui City maintained the lowest level of comprehensive tourism development from 2009 to 2019, but it is the only city in Guizhou Province that kept an improving momentum in comprehensive tourism level under the epidemic. In short, the impact of COVID-19 epidemic on different cities varies. Cities with higher development levels are more affected and have relatively weaker ability to recover. The reason behind this may be that developed cities have a higher level of economic and social development, a higher proportion of tertiary industry output, and a higher level of tourism

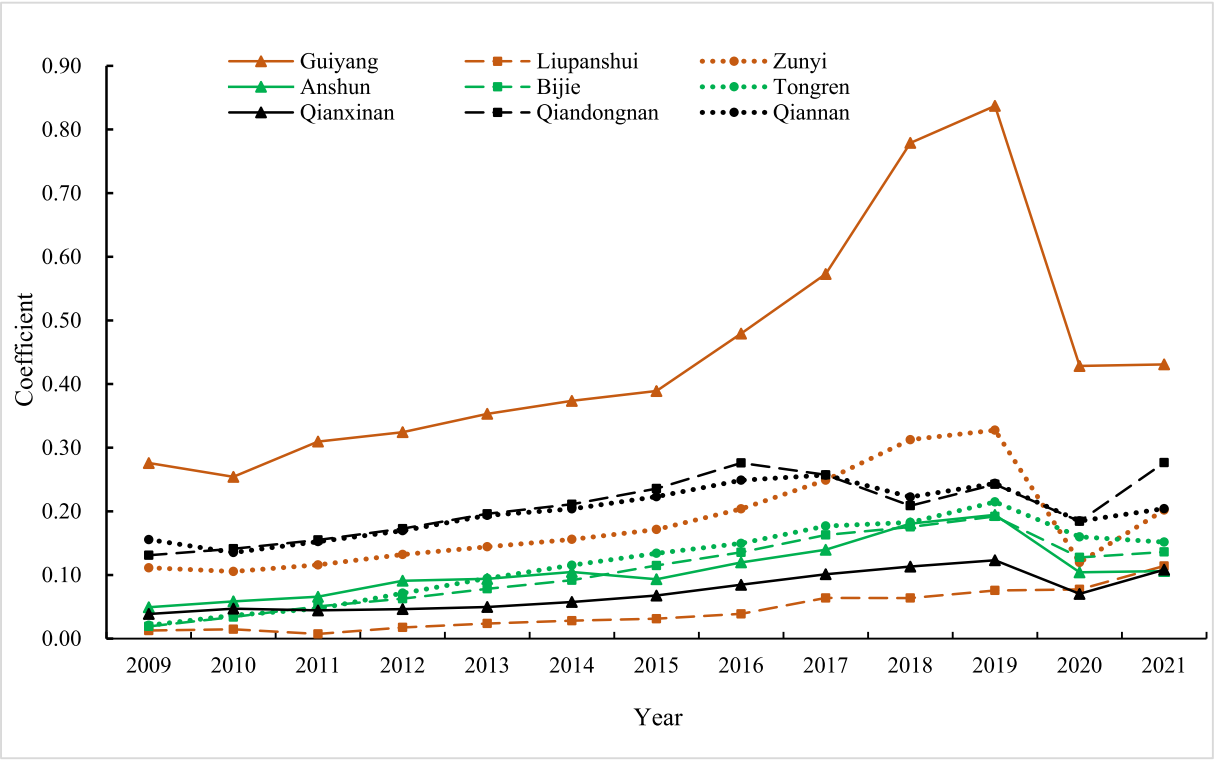

Fig. 3. Changes of tourism subsystems in each city of Guizhou Province.

development than smaller cities prior to the epidemic. At the same time, due to the high population density of large cities, they are more vulnerable to the impact of the new crown epidemic, and the greater control of the epidemic in China has led to a sudden decline in the incoming tourist population in these relatively developed cities for a longer period of time. Follow-up efforts should be made to address the reality of the low development level of the current tourism subsystem, constantly enhance cities' ability to resist external risks, and gradually

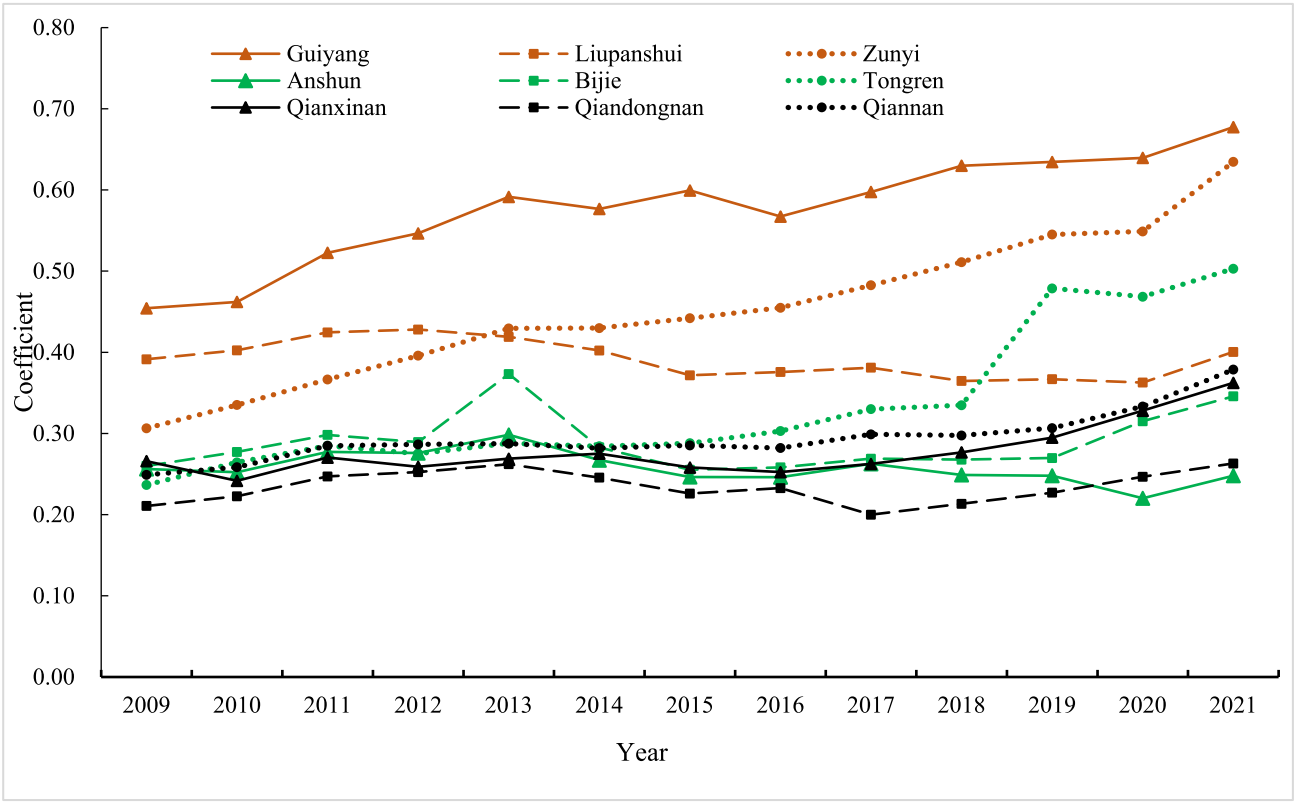

Fig. 4. Changes of economic subsystem in each city of Guizhou Province.

narrow the regional development gap.

3.1.2. Economic subsystem

The changing trend of the comprehensive development level of the economic subsystem in each region of Guizhou Province from 2009 to 2021 are shown in Fig. 4. During the study period, the comprehensive development level of economic subsystem in most cities was lower than 0.5, indicating the relatively low comprehensive development level of economic subsystem in these cities. In addition, the comprehensive development level of economic development in different regions is quite different from 2009 to 2019. The provincial capital city of Guiyang boasted the highest comprehensive development level of economic subsystem. However, Qiandongnan Prefecture, located in the southeast of Guizhou Province, has long lagged behind in its comprehensive economic development due to weak infrastructure and insufficient investment.

From the perspective of changes in the coefficient of economic subsystems of various regions from 2019 to 2021, the COVID-19 epidemic has not resulted in particularly obvious negative impact on the economic subsystem of Guizhou Province. On the contrary, with the exception of Tongren and Anshun which showed a significant decline in the comprehensive development level of the economic subsystem in 2020, all other cities showed a good rising trend year by year. In particular, the comprehensive development level of economic subsystem in Zunyi has been significantly improved in 2021 (15.61%). Therefore, based on the actual situation of the development level of the economic subsystems in various regions after 2019, it can be believed that the negative impact of COVID-19 on the economic growth of this province is controllable and limited, and shows relatively good ability in economic recovery and development. Future attention should be paid to the economic development of Qiandongnan, Anshun, Bijie and Qianxinan, so as to continuously improve the comprehensive level of regional economic development.

3.1.3. Ecological subsystem

The changing trend of the comprehensive development level of ecological subsystem in each region of this Province from 2009 to 2021 are shown in Fig. 5. The development difference of ecological environment in different regions is relatively small. During the study period, compared with the tourism and economic subsystems of Guizhou Province, the comprehensive development level of the ecological subsystem was relatively high, with the index generally higher than 0.4, an indication of the remarkable results achieved in the restoration and construction of the ecological environment.

The comprehensive coefficient of ecological subsystems in each region experienced a process of first decreasing and then steadily increasing. From 2009 to 2012, the comprehensive development level of ecological subsystem in most cities showed a downward trend to some extent, except Guiyang. The main reason was that during this period of one-sided attention to the promotion of economic scale, while ignoring the protection of the ecological environment. Then, from 2013 to 2021, the comprehensive development level of ecological subsystems in most cities showed different degrees of improvement, and Liupanshui City boasted the most remarkable growth, with its value rising from 0.3903 in 2009 to 0.6383 in 2021, an increase of 63.56%. The main reason is that Liupanshui, a city formerly developed by mining industry, has intensified its efforts in ecological and environmental governance and protection since 2012, which highlighted the ecological construction results. In addition, the COVID-19 epidemic has had little impact on ecological restoration and construction in Guizhou Province. In the future, we should focus on the ecological protection and construction of Guiyang City, and strengthen the ecological environment governance.

3.2. Analysis of the CCD

3.2.1. Temporal evolution features

The changes of CCD in different regions of Guizhou Province from 2009 to 2021 are shown in Fig. 6. In general, all regions maintain a

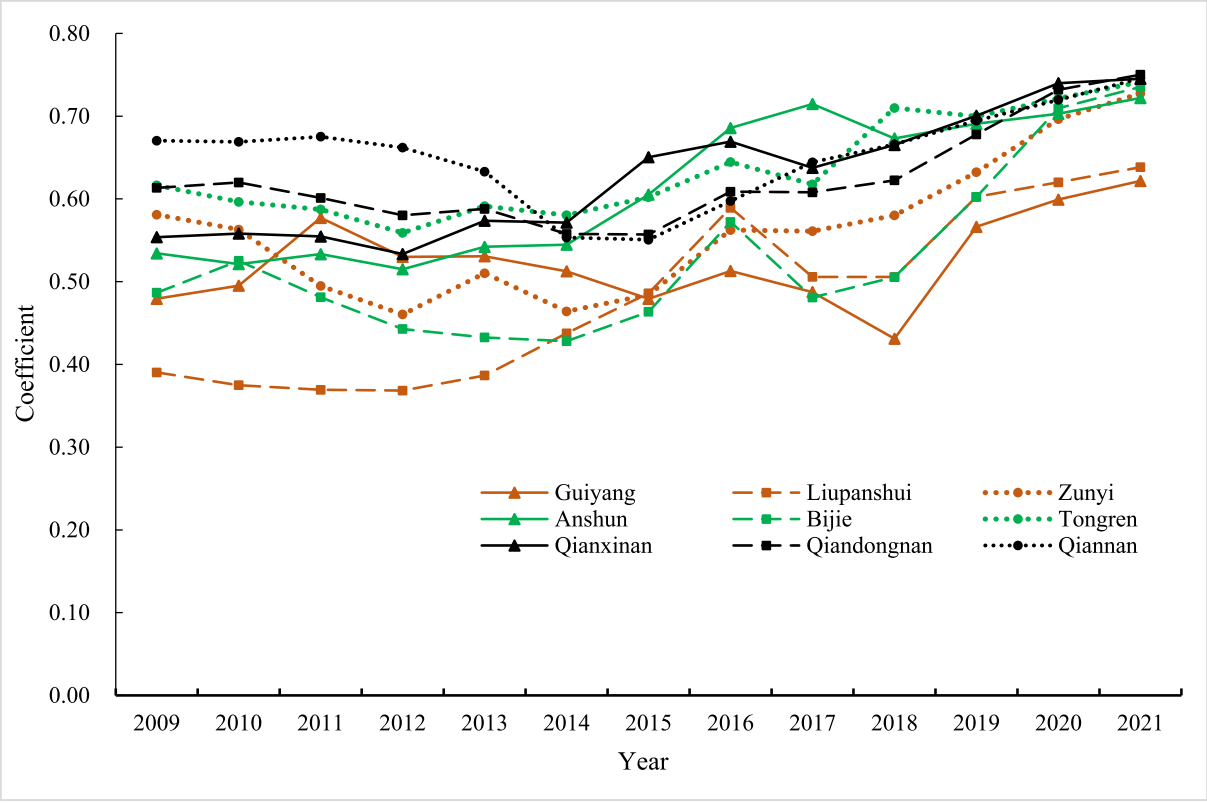

Fig. 5. Changes of ecological subsystem in each city of Guizhou Province.

steady growth trend. Only Liupanshui City showed slight improvement in the degree of coupling coordination in 2020, the rest of the cities showed a certain degree of decline. The main reason is that the COVID-19 epidemic has made the comprehensive coefficient of tourism subsystems in all regions of Guizhou Province decrease significantly in 2020, except Liupanshui City. According to the classification of CCD, Guiyang has been the highest ranked city for a long time, reaching highly coordinated level in 2019 and barely coordinated level in the other years, while other cities remained in the mildly misaligned level.

In terms of the improvement range of coupling coordination in each region, Tongren City ranked number one, with coupling coordination rising from 0.3809 (moderately misaligned) in 2009 to 0.6196 (barely coordinated) in 2021, an increase of 62.67%. The second was Liupanshui City, with the figure rising from 0.3533 (moderately misaligned) in 2009 to 0.5549 (mildly misaligned) in 2021, h an increase of 57.06%. Bijie City ranked third, with the figure rising from 0.3666 (moderately misaligned) in 2009 to 0.5709 (mildly misaligned) in 2021, an increase of 55.72%. The smaller increase rates happened in Qiannan (14.21%), Anshun (18.83%) and Guiyang (20.22%). Meanwhile, Qiannan Autonomous Prefecture had developed from mildly misaligned in 2009 to barely coordinated in 2021. Anshun City remained mildly misaligned. Therefore, it can be considered that cities that maintained a low level of CCD at the beginning showed a higher rate of improvement during the study period.

3.2.2. *Spatial distribution characteristics of the CCD*

In order to show clearly the spatio-temporal variation trend of CCD of each city in Guizhou Province during the study period, ArcGIS was used to map the CCD of TEE system of cities in 2009, 2012, 2019, 2020 and 2021, as shown in Fig. 7.

There are obvious regional differences in the CCD of Guizhou Province. Guiyang City has always maintained a relatively high CCD. In 2009, Zunyi and cities in southern Guizhou Province boasted higher CCD than that of Bijie and Liupanshui City in the west. In 2012, except the leading Guiyang and the lagging Liupanshui, other cities showed similar coupling and coordination degrees. In 2019, Guiyang, together with Zunyi and Tongren to its north and Qiannan to its south, maintained a high CCD, while Qiandongnan in the east and most cities in the west were marked by a relatively lower development level. The epidemic in 2020 resulted in dramatic reduction in the CCD of Guiyang, Zunyi and Qiannan City, while the other cities were relatively stable. In 2021, the eastern cities enjoyed higher CCD while the overall coupling coordination level of western cities was significantly lower.

3.2.3. *Subsystem development in different periods*

The differences in tourism, economy and ecology among cities in Guizhou Province in 2009, 2012, 2016, 2019, 2020 and 2021 were compared and sorted out according to the calculation formulas in Table 2 and the specific results are shown in Table 3. According to this table, in addition to Guiyang and Liupanshui City, the development coefficient of ecological subsystem of other cities maintained a leading position during the study period, which reflects the good effect of ecological environment construction in Guizhou Province.

In terms of the development gap of TEE subsystem during the study period, in addition to the relatively consistent development of subsystems in Guiyang, other cities showed leading ecology subsystem but lagging tourism subsystem development. Furthermore, the gap between the development level of tourism subsystem and ecological subsystem in Qiandongnan Autonomous Prefecture was somehow reduced in 2021. Except for the two cities above, the development of the tourism subsystem in other cities was lagging behind and leading ecology subsystem, which was a reflection of the ever-increasing effort of the local government on ecological environment protection, but relatively insufficient incentives and strength on tourism and economic development, and the result was the less improvement of the latter two compared with that of ecological environment.

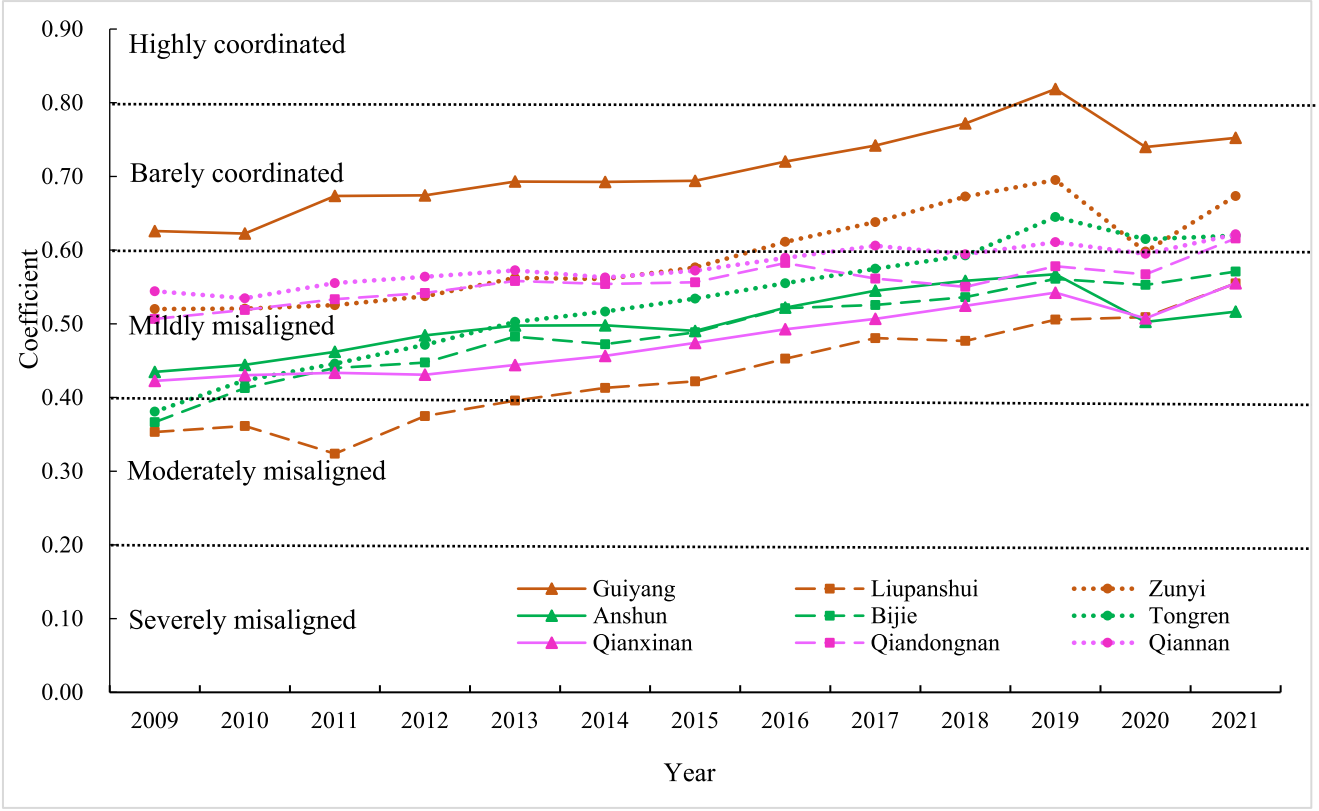

Fig. 6. Variation of coupling coordination degree in each city of Guizhou Province.

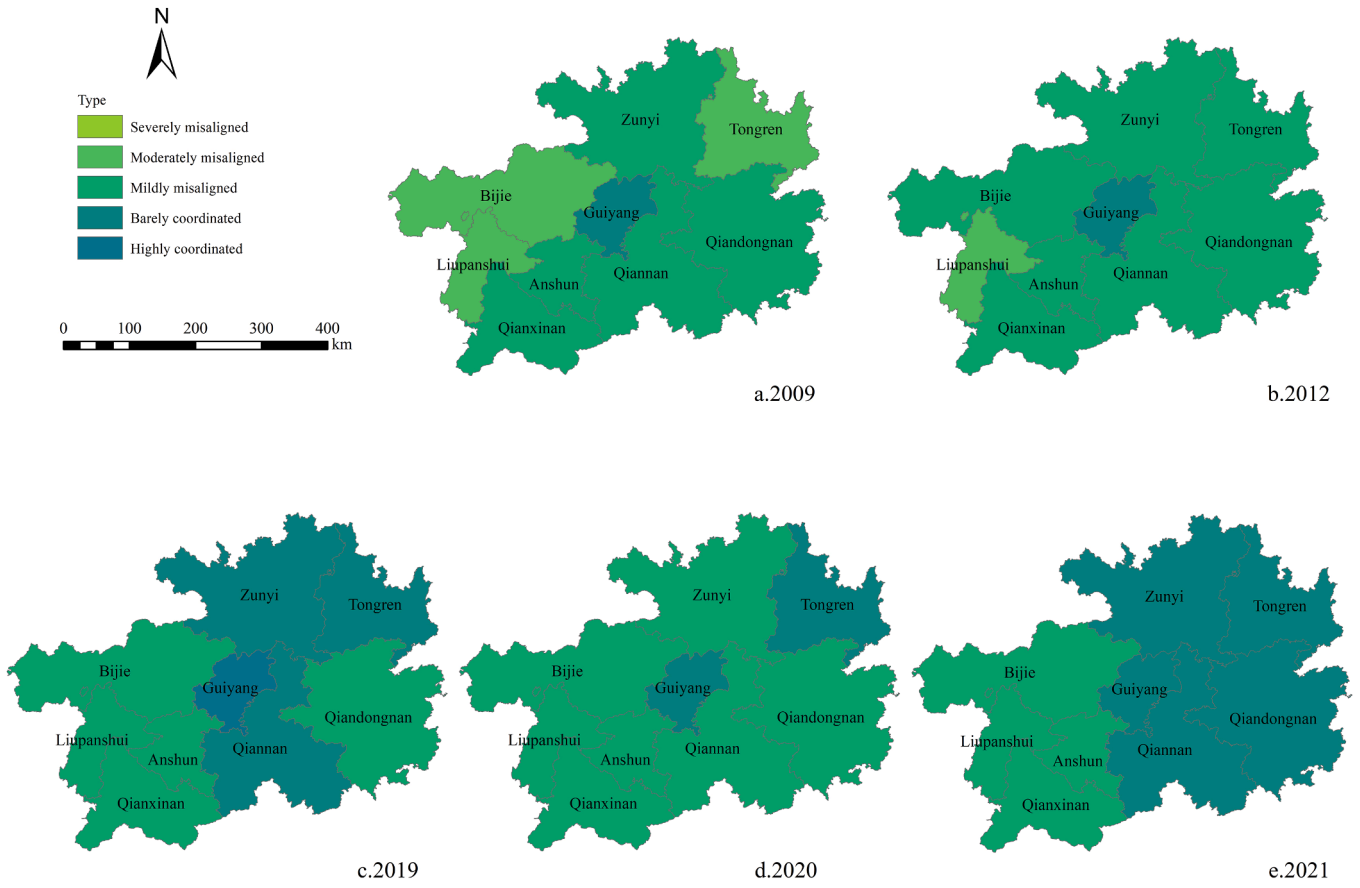

Fig. 7. Spatial variation of coupling coordination degree in each city of Guizhou Province.

Table 3
Comparison of TEE subsystem development level among cities in Guizhou Province.

City	Max *f(m)* − Min *f(m)*						
	Type	2009	2012	2016	2019	2020	2021
Guiyang	*f(z) - f(x)*	0.2035					
	f(y) - f(x)		0.2222	0.0880	0.2707	0.2111	0.2465
Liupanshui	*f(y) - f(x)*	0.3787	0.4105				
	f(z) - f(x)			**0.5503**	**0.5268**	**0.5427**	**0.5241**
Zunyi	*f(z) - f(x)*	0.4696	0.3282	0.3586	0.3048	**0.5767**	**0.5254**
Anshun	*f(z) - f(x)*	0.4849	0.4240	**0.5659**	0.4963	**0.5987**	**0.6159**
Bijie	*f(z) - f(x)*	0.4675	0.3801	0.4365	0.4104	**0.5818**	**0.5992**
Tongren	*f(z) - f(x)*	**0.5955**	0.4876	0.4949	0.4849	**0.5614**	**0.5896**
Qianxinan	*f(z) - f(x)*	**0.5151**	0.4870	**0.5845**	**0.5774**	**0.6696**	**0.6368**
Qiandongnan	*f(z) - f(x)*	0.4824	0.4075	0.3760	0.4508	**0.5475**	0.4870
Qiannanzhou	*f(z) - f(x)*	0.5148	0.4925	0.3486	0.4507	**0.5348**	**0.5415**

Note: The bold part indicates that a subsystem has a serious lag; and f(x), f(y) and f(z) on behalf of the comprehensive evaluation index of tourism, economy and ecology subsystems respectively.

3.3. Diagnosis of obstacle factors for TEE system coupling coordination

In order to further identify the influencing factors in the above determination of the comprehensive development level of the TEE systems and CCD in various cities of Guizhou Province from 2009 to 2012, formula (10) is used to calculate major obstacle factors of each city in different years. Limited by length, Table 4 lists the top 5 obstacle factors for each city in 2009, 2019 and 2021. The dark to light colors respectively indicates the high to low influence degrees, and the proportion of different obstacle factors is also calculated. According to Table 4, obstacles affecting the coordinated development of TEE vary greatly in different periods from the provincial level. To be specific, the number of domestic tourists (C3) and domestic tourism income (C1) were the most important factors in the coordinated development in 2009. In 2019, the number of travel agencies (C5) and star hotels (C6) became the most influential factors for coordinated development. In 2021, the number of international tourists (C4) and travel foreign exchange income (C2) became the main factors, followed by the number of travel agencies (C5) and star hotels (C6).

Specifically, the main obstacle factors of the coupling and coordinated development of TEE system of each city in different periods vary a lot, so the governance measures should be targeted. To be specific, total sulfur dioxide emission (C17) and total wastewater discharge (C18) were the biggest obstacle factors in the coordinated development of Guiyang City in 2009 and 2019, respectively. In 2021, under the impact of COVID-19, the proportion of output value of the secondary industry

Table 4
The main obstacle factors and the order of obstacle degree from 2009, 2019 and 2021 in Guizhou Province.

Cites	Year	Obstacle factors and the order of obstacle degree (%)										
		C1	C2	C3	C4	C5	C6	C7	C8	C12	C17	C18
Guiyang	2009	7.96	6.75	7.98	7.09						10.58	
	2019					7.54	8.88		6.74	16.59		17.67
	2021		10.22		10.66	6.03				12.54		11.39
Liupanshui	2009	7.11		7.12	6.36		6.95				9.10	
	2019	7.00	6.93		7.10	6.50	7.73					
	2021	7.64	7.37		7.58	6.08	7.83					
Zunyi	2009	7.58	6.76	7.36	6.94	6.23						
	2019		8.67		8.77	8.08	7.03	7.07				
	2021		9.47		9.71	8.19	7.49	7.55				
Anshun	2009	6.96	6.30	7.03			6.39			6.24		
	2019		6.68			6.87	7.86	5.84		10.68		
	2021	6.96	6.79		7.27		7.63			10.87		
Bijie	2009	6.87	6.08	6.78			7.06				7.07	
	2019				7.14	6.64	7.02	5.92		12.04		
	2021		6.77		7.86	6.96	8.11			13.11		
Tongren	2009	7.29	6.31	7.22	6.29		7.52					
	2019	7.09	6.91		7.94	7.87		6.87				
	2021	8.18	7.78		8.70	7.91	7.65					
Qianxinan	2009	7.30	6.19	7.22	6.23		6.44					
	2019	6.44			6.87	6.73	8.38			9.34		
	2021		7.63		7.84	7.11	8.35			9.91		
Qiandongnan	2009	7.45	6.28	7.34		6.11				10.27		
	2019		6.92		7.07		5.79	5.59		14.54		
	2021	6.38	7.91		8.13	6.60				15.95		
Qiannan	2009	7.90	6.98	7.80	6.66					7.63		
	2019		6.73		7.71	7.15		6.40		9.29		
	2021	6.97	7.61		8.35	7.28				10.08		

(C12) became the biggest obstacle factor, and was followed by the total wastewater discharge (C18) which was counted as an important obstacle factor for the improvement of ecological environment quality and sustainable development of Guiyang City. Liupanshui City was faced serious sulfur dioxide emission (C17) problem in 2009 due to its early unitary economic development mode. In 2019 and 2021, the number of star hotels (C6) became the biggest obstacle to the coordinated development, and the number of travel agencies (C5) also restricted the development of tourism. Therefore, it is necessary to strengthen the construction of infrastructure to serve the needs of tourism development and promote the coordinated development of TEE system in Liupanshui City. Although Zunyi City boasts the largest number of tourist attractions in Guizhou Province, but the attraction is not well known, and this is the reason for its insufficient appeal for domestic and international tourists (C3, C4), and low tourism income (C1, C2), which has become the biggest bottleneck for the coordinated development of the city. The main problem faced by Anshun City in 2009 was insufficient number of domestic tourists (C3).

By 2019 and 2021, the economic development structure (C12) and the number of star hotels (C6) had become the biggest obstacles. As to Bijie City, in 2009, the Sulphur dioxide emission problem (C17) was an important obstacle to the coordinated development of TEE system; in 2019 and 2021 the relatively lagging development of the secondary industry (C12) became an important factor hindering the coordinated development, an indicator of the remarkable results achieved by Bijie City in environmental improvement; and the current focus is to strengthen productive investment and proper development of industry, and to facilitate high-quality development. From 2009 to 2019 and in 2021, the most important obstacle in the coordinated development of the TEE system in Tongren City changed from insufficient tourism hardware facilities represented by the number of star hotels (C6) to the reduction of international tourists (C4); the number of travel agencies (C5) and star hotels (C6) also acted as factors for the coordinated development of Tongren City. In 2009, Qianxinan and Qiannan Autonomous Prefecture were faced, in their effort to realize TEE system coordinated development, with the biggest obstacles of insufficient

domestic tourism income (C1) and domestic tourists (C3). The internal reasons may lie in the lack of tourism facilities and the low development level of tourist attractions in these two cities, which led to insufficient appeal for domestic tourists. At present, the relatively backward development of the secondary industry (C12) has become an important factor hindering the coordinated development, among which, the improvement of service facilities and appropriate increase in the number of star hotels (C6) are the key issues that call for special attention in Qianxinan Autonomous Prefecture. The relatively backward development of the secondary industry (C12) is a long-term obstacle to the sustainable development of Qiandongnan. Besides, domestic tourism income (C1) and the number of domestic tourists (C3) were the other obstacles faced by Qiandongnan Autonomous Prefecture in 2009, while inbound tourists (C4) and foreign exchange income (C2) were the main problems in 2019 and 2021.

In conclusion, great differences exist in the obstacles for achieving coordinated development of TEE system in various cities of Guizhou Province in different periods, and the major obstacle factors to be addressed in different cities also vary. The lack of tourism facilities and incomplete service functions were the direct and important reasons for inadequate domestic tourists and domestic tourism income in 2009. In 2019, with the improvement of the tourism environment in this province, domestic tourists increased significantly, and this obstacle to the coordinated development of various regions no longer existed. During this period, shortage of travel agencies and star hotels was the biggest issue. In 2021, due to the impact of COVID-19, the reduction of inbound tourists and foreign exchange income became the biggest obstacle for achieving coordinated regional development. In addition, the problem of insufficient urban production capacity, represented by the reduction of the proportion of secondary industry output value, was also prominent.

In addition, we found that among the many factors, the indicators of economic scale (B6), ecological status (B8), and ecological response (B9) have less influence on the coupling and coordinated development of TEE systems in Guizhou Province. It also reflects that the current status of ecological protection and construction in Guizhou Province is good, while the province has achieved better development in terms of economic scale. Among them, the number of Internet broadband subscribers (C16), as a commonly used proxy indicator for digital economy research (Ying et al., 2023), has also countered the development of the digital economy to promote the coupled and coordinated development of the TEE system.

4. Discussion

4.1. The applicability of the method

There are many theories and methods that can be used to guide or measure the degree of sustainable development of human society. Relevant guiding theories include pastoral city theory (Howard and Osborne, 1968), coordinated development theory (Norgaard, 1990), environmental kuznets curve (Grossman and Krueger, 1995), pressure-state-response model (Berger and Hodge, 1998) and decoupling theory (Oecd, 2002). A common method for identifying the interaction between two or more systems is CCD model (Xiao et al., 2022). This model has been applied in the analysis of the relationship between regional tourism and ecological environment (Zhang et al., 2020), coupling diagnostic analysis between eco-economy and society in Jiangsu Province (Wang et al., 2022), coordinated development level of urbanization and ecological along Silk Road Economic Belt (Ariken et al., 2021), and problems existing in the harmonious development of environment-resources-economy system (Xing et al., 2019). However, most of the previous studies were on the relationship between ecology and economy (Liu et al., 2022), and there are relatively few studies on the relationship between tourism industry, ecological environment and economic development, especially in areas with fragile ecological environment and backward economic development. Therefore, this method is chosen to analyze the evolution of TEE system in karst Guizhou Province. In addition, although most studies have only analyzed the coupling coordination between multiple systems (Wang et al., 2022; Yang et al., 2020; Chen et al., 2022), but it is not enough to guide local development. The main methods to identify the influence of system coupling level include geographical weighted regression (Li et al., 2021c), grey correlation degree (Tang et al., 2018) and obstacle degree model (Sun et al., 2022). At the same time, the obstacle degree model is relatively widely used, and has good cohesion with the CCD model in content. Hence, this study further selected the obstacle degree model to identify the key factors affecting the coordinated development of tee system in Guizhou Province in different periods. The research in this study shows that the coupling coordination level of TEE system and the obstacle factors that affect the development of TEE system coordination can be effectively judged by using the CCD model and the obstacle degree model.

4.2. Enrich the study of tourism theme

Tourism industry plays an increasingly important role in promoting economic and social development. There are many studies closely related to the theme of tourism, and at the same time, there are also a lot of studies on the coupling and coordination between tourism industry and other systems, such as tourism urbanization and eco-environment (Ma et al., 2022), tourism industry ecologization (Xu et al., 2022), tourism development and resource environment carrying capacity (Xiao et al., 2022). However, the researches mainly focus on the coordination analysis between tourism and ecological environment or tourism industry and economic development, and there is little research on the relationship between tourism and the other two systems. There are abundant studies on the relationship between tourism, urbanization and ecological environment (Muyibul et al., 2023; Zhang and Li, 2021). The existing researches on TEE system still stay in the identification of coupling coordination degree, and lack of in-depth research on influencing factors (Xie, 2022), or take islands as research objects to analyze the changes of TEE system (Fei et al., 2021). The fragile ecological environment of karst mountainous areas in south China, represented by Guizhou Province, used to be a negative influence on local economic and social development. With the support of the Chinese government, this province has intensified efforts on rocky desertification treatment, and reversed the deterioration of the local ecological environment. In recent years, Guizhou Province has determined the development principle of “an ecological province strengthened by tourism”, and proposed in 2021 to double the added value of tourism and related industries on the basis of 2019, with “new industrialization, new urbanization, agricultural modernization and tourism industrialization” as the current development goal. The related obstacles were sorted out in order to provide useful reference for the coordinated development of ecological economy in ecologically fragile areas.

4.3. The change of coupling coordination degree and the main effect analysis

There have been many studies on the system CCD. No matter what the field, the final conclusion is that the system is constantly developing in the direction of coordination (Li et al., 2021c; Yang et al., 2020; Chen et al., 2022), and this paper is no exception. However, due to the differences of research areas, the development and change of subsystems are quite different, and the factors affecting the coordinated development of the system are also different. For island cities, the economy maintains a relatively fast development speed, and the ecological subsystem is the main obstacle factor affecting the coupled and coordinated development (Fei et al., 2021). Compared with the ecological subsystem, the development level of tourism and economic subsystem of most cities in Guizhou Province has remained at a low level for a long time, especially the tourism subsystem. The reason behind this is that

economic development puts pressure on the ecological environment. On the contrary, in economically backward areas, tourism development is slow, and economic activities under the ecological environmental carrying capacity have less damage to the ecological environment.

In addition, although existing studies have pointed out that the ecological environment in southwest China is gradually improved and the economic development speed is relatively lagging behind (Lai et al., 2020), and the coupling coordination degree of tourism and resource carrying capacity in Guizhou Province remains at a low level (Xiao et al., 2022; Fan et al., 2019). However, these studies lack the analysis of the factors affecting the comprehensive coefficient of subsystems, which is important to promote the coordinated development of regional economy. Outdated tourism infrastructure and low level of tourism service guarantee have reduced the tourism attractiveness of Guizhou Province. At present, most cities in Guizhou Province have a long-term lack of economic development power, insufficient ability to attract investment, and backward development of the secondary and tertiary industries, which affects the improvement of the comprehensive level of the economic subsystem and restricts the improvement of the coupling and coordination level of the TEE system. Finally, due to the time span, this article further explores the impact of COVID-19 pandemic on TEE systems and draws interesting conclusions. For example, the pandemic has a greater impact on the tourism subsystem and a relatively small impact on the ecological and economic subsystems. However, the development of tourism in Guizhou Province has lagged behind for a long time, so the pandemic has a smaller impact on the coupling and coordinated development of the TEE system.

4.4. Provides reference for the development of ecologically fragile and economically underdeveloped areas

During the study period, the coupling coordination level of TEE system in various regions of Guizhou Province showed a steady upward trend, indicating that tourism can be transformed into the driving force of regional economic development, and its rapid development can support and facilitate regional economic growth. It also proves that the blossom of tourism largely depends on the quality of ecotype, and the fragile natural environment will restrict the development of tourism to some extent (Tang, 2015). The quality of natural environment restoration affects the tourists' travel experience, and also plays a certain role, either positive or negative, in the development of tourism (Meethan, 1997). Ecological factors such as land use, environmental protection and biodiversity must be taken into account for the prosperity of tourism (Pang and Zhang, 2020; Lee and Brahmasrene, 2013). If human activities exceed the threshold of ecological environmental carrying capacity, the cost for sustainable economic and ecological development will show dramatic increase (Asongu et al., 2020). In view of the fact that tourism development of most cities in Guizhou Province is relatively backward, it is necessary to protect the local ecological environment, formulate relevant policies to stimulate the development of tourism industry, and promote the development of local economy through tourism, so as to realize a fully coordinated development of TEE system. Considering the main constraints facing the coordinated development of Guizhou TEE system, while protecting the ecological environment, it is necessary to increase the construction of tourism infrastructure, pay attention to the improvement of service level, promote high-quality tourism routes, enhance the external image and enhance the carrying capacity of tourism services, and realize the transformation of tourism development from "quantity" to "quality".

This paper has several limitations. In terms of measuring the comprehensive development level of ecological subsystems, although some relevant indicators that can reflect the actual situation of karst areas are selected, for example, "water-soil loss treatment area of specific years" and "forest reservation area", but due to the availability of data, such as "the potential for erosion in karstic soil", "Karst area change" and other indicators that can better reflect the actual situation of karst are not included in the measurement. In the future research, satellite remote sensing data can be considered to improve the accuracy of measuring and studying the changes of ecological environment system in karst areas. In addition, this paper analyzed the impact of COVID-19 epidemic mainly from the actual development of tourism, economy and ecology in various cities of Guizhou Province before and after the epidemic, and made an exploratory comparative analysis, without adopting more accurate measurement methods to assess the impact mechanism of COVID-19 on TEE system. Future studies may consider in-depth analysis of the impact of exogenous risks such as COVID-19 on TEE systems to enhance the ability of vulnerable areas to cope with the risks.

5. Conclusion and suggestion

5.1. Conclusion

Based on the above analysis, the paper draws the following interesting conclusions. (1) From the perspective of tourism subsystem, the comprehensive level of tourism of Guiyang, had been far ahead from 2009 to 2021, while most cities maintained a steady upward trend, but in a relatively low level. (2) From the perspective of economic subsystem: except Guiyang City, the comprehensive development level of economic system of most cities was lower than 0.5, reflecting the low level of overall economic development of Guizhou Province. (3) From the perspective of ecological subsystem: the comprehensive development level of almost all urban ecological subsystem had improved to varying degrees during the study period, and the city with the highest improvement rate was Liupanshui City. (4) In recent years, Guizhou Province has kept intensifying ecological environmental protection, but has adopted inadequate incentive measures and effort in tourism and economic development, resulting in lagging development of most urban tourism systems compared with ecological environment improvement. (5) From 2009 to 2021, the CCD of various cities had been continuously improved. The cities with low CCD in 2009 showed a higher improvement rate in the later period, but still in a relatively low level. (6) In different periods, great differences existed in the obstacle factors of cities in Guizhou Province for achieving the coordinated development of TEE system, and the obstacle factors to be addressed in different cities were not the same.

The impact of COVID-19 on the development of TEE system in Guizhou Province includes: first of all, COVID-19 epidemic exerted a relatively adverse impact on tourism development, and the degree of impact on different cities also varied. Guiyang, a city with a higher tourism development level, suffered the greatest impact, mainly reflected in the significant reduction in the number of international tourists and foreign exchange income, while Liupanshui, a city with a lower development level, received the least impact. Second, the economic system of cities in Guizhou Province was free of severe COVID-19 impact. On the contrary, except Tongren and Anshun whose comprehensive development level of economic system showed a significant decline in 2020, the other cities boasted a good trend of annual increase. In addition, the impact of COVID-19 on ecological restoration and construction in various regions was minimal, and various ecological restoration works were carried out as scheduled. Finally, the COVID-19 epidemic resulted in significant decrease in the CCD of most cities in 2020, but great improvement in 2021, although lower than the maximum value in 2019. In summary, the negative influence of COVID-19 epidemic was especially remarkable on tourism development of Guizhou Province, it was quite limited on economic and ecological development. In the case of coordinated development of TEE system, the negative impact remained under control.

5.2. Suggestion

In general, given the fragility of the ecological environment, efforts

in ecological protection and construction should be continued. At the same time, it should seize the current opportunity period for the development of the digital economy, increase the development of the digital industry, and tap the development potential of the digital industry. Furthermore, targeted policies and measures should be implemented according to regional differences. For example, given the low level of coordinated development in the western region and the geographical location of the plateau, mountain tourism and tourism with national cultural characteristics should be encouraged. In addition, industrial production is the unavoidable path to achieve rapid economic development in less developed areas. At present, the negative impact of economic development momentum in Guizhou Province has become more and more obvious after the epidemic. So, the current priority is to improve the operation and production environment of enterprises within the scope of ecological environmental carrying capacity, and attract enterprises with development potential to invest and produce.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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