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Evaluation and Spatiotemporal Characteristics of the Ecological Civilization Construction Level of Prefecture-Level Cities in Guizhou Province Based on Multi-Source Data

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Abstract

A systematic assessment of the level of ecological civilization development across Guizhou's prefecture-level cities is a key pathway to advancing the construction of the National Ecological Civilization Pilot Zone and supporting high-quality regional development. Given the shortcomings of existing research indicator systems, this paper introduces public and government attention levels based on Baidu Index, incorporating them into the ecological culture dimension. By combining data from multiple sources—including statistical yearbooks and ecological environment bulletins—the paper constructs a comprehensive evaluation system comprising four dimensions—ecological economy, ecological environment, ecological livability, and ecological culture—as well as 37 secondary indicators. Based on panel data from nine prefecture-level cities in Guizhou from 2011 to 2025, an entropy-weighted TOPSIS model was used for evaluation, and the Dagum Gini coefficient method was employed to analyze regional disparities. The research findings show that, over time, the average proximity index for the nine prefecture-level cities has trended upward. In terms of spatial distribution, Guiyang performs best, followed by Zunyi, while Liupanshui ranks last and Qianxinan Prefecture has regressed. The Gini coefficient reflects a pattern of "the central region leading the way, with the eastern and western regions following", and the imbalance is becoming entrenched.

Keywords

Ecological Civilization Construction, Comprehensive Evaluation, Multi-Source Data, Entropy-Weighted TOPSIS Method, Spatiotemporal

Characteristic Analysis

1. Introduction

According to the report presented to the 20th National Congress of the Communist Party of China, Chinese-style modernization is defined as a distinct form of modernization that is characterized by the establishment of a harmonious relationship between humanity and nature. The 2023 "Opinions of the Central Committee of the Communist Party of China and the State Council on Comprehensively Advancing the Construction of a Beautiful China" delineated the objectives and strategies for achieving this goal. The centrality of propelling ecological civilization has become increasingly pronounced. Guizhou is located in the upper reaches of the Yangtze and Pearl Rivers. It serves as a key pilot region for the nation's ecological civilization efforts. In 2017, the State Council promulgated the "Implementation Plan for the National Ecological Civilization Pilot Zone (Guizhou)", which mandated Guizhou to undertake three major strategic initiatives: comprehensive poverty alleviation, big data, and ecological conservation. The objective of this plan was to establish a "Guizhou model" for a Beautiful China. The "Guizhou Provincial Regulations on Promoting Ecological Civilization" stipulate the development of an indicator system for ecological civilization. Since the establishment of the pilot zone, its achievements have been validated by the academic community: Xu, M. Q. *et al.*, (2024) found that policies in the pilot zone have significantly reduced agricultural carbon emission intensity, with the most pronounced effects observed in Guizhou [1]; Wei, Y. *et al.*, (2024) calculated that the total value of ecological products in Guizhou Province reached 2.08 to 2.54 times the GDP for the same period, indicating that a pathway for transforming "the two mountains" has begun to take shape [2]. Against this backdrop, as statistical data, internet big data, and government text data become increasingly abundant, multi-source data offers new opportunities for a detailed assessment of the level of ecological civilization construction.

A substantial corpus of academic research has emerged on the evaluation and measurement of ecological civilization development. At the national level, Fang, C. *et al.*, (2019) proposed the theoretical foundation and evaluation framework for building a "Beautiful China" [3]; Qin, C. B. *et al.*, (2022) designed an indicator database and system for evaluating the progress of "Beautiful China" construction [4]. At the provincial level, Zhang, C. *et al.*, (2023) evaluated the achievements of ecological civilization development in Shanxi Province [5]. At the regional and urban scales, Wang, H. *et al.*, (2021) assessed the level of ecological civilization development in the "2 + 26" cities from 2015 to 2017 and analyzed its dynamic changes [6]; Chai, Y. Y. *et al.*, (2025) revealed the spatiotemporal characteristics and coordinated development trends of ecological civilization construction performance in the Yangtze River Economic Belt [7]. With respect to the evaluation methodologies employed, the entropy-weighted TOPSIS method has been a subject of considerable attention due to its merits, which include the integration of objective weighting with the capacity to approximate an ideal solution. Fu, C. Y. *et al.*, (2020) employed the entropy-weighted TOPSIS model to evaluate the regional resource and environmental carrying capacity and identify constraining factors [8]. Guo, S. J. *et al.*, (2024) utilized the entropy-weighted TOPSIS model to assess the level of green agricultural development in Henan Province, revealing heterogeneous characteristics within prefectures [9]. Tang, J. X. *et al.*, (2023) found, based on data from 284 prefecture-level and higher cities, that the level of ecological civilization construction exhibits a decreasing pattern from east to central to west [10]. Tan, Y. M., & Wang, S. T., (2023) combined kernel density and Markov chains to examine regional differences and dynamic evolution in the construction of a "Beautiful China" [11]. With respect to the methodological origins of the integrated evaluation approach, it can be traced back to Zhang, M., & Zhou, Z. F., (2008) [12]; Zhang, M., & Zhou, Z. F., (2009) further developed a multi-objective planning model based on positive and negative ideal points in the TOPSIS method [13].

The integration of multi-source data provides methodological support for improving the foundation of evaluation information. Xiang, Y. *et al.*, (2021) integrated multi-source data to assess the urban health of Changsha [14]. Dong, X. *et al.*, (2022) evaluated the ecological livability of urban residential areas in Shenzhen using multi-source data [15]. Sang, X. *et al.*, (2020) studied the livability of Changzhi City in Shanxi Province using multi-source data [16]. These studies demonstrate that integrating multi-source data can significantly enhance the precision and comprehensiveness of evaluations. With respect to the realm of Internet big data, the Baidu Index draws upon internet user search volume as its foundational data element, thereby providing a quantitative representation of public attention directed towards specific issues. As demonstrated by Wu, L. B. *et al.*, (2022), who employed the Baidu Index to gauge public environmental concern in prefecture-level cities and to examine its impact on environmental governance [17]; by Zhou, K. *et al.*, (2024)and Xu, S. *et al.*, (2026), who further examined the effects of public environmental concern on corporate green governance and urban green development [18] [19]; and by Li, L. *et al.*, (2020), who used the Baidu Index to reveal the spatiotemporal differentiation characteristics of public interest in ecological civilization [20]; and by Mao, Z. *et al.*, (2023), who used the Baidu Index to characterize the spatiotemporal features of online interest in Wuyishan National Park. The frequency of words in government work reports has been identified as an authoritative tool for measuring government attention and characterizing the focus of government governance [21]. Shen, W. N. *et al.*, (2020) examined the relationship between attention to the ecological environment and environmental governance performance based on the "Government Work Reports" of the Beijing-Tianjin-Hebei region [22]. You, J. X. *et al.*, (2024) used text analysis of Government Work Reports to measure government environmental attention and examine its impact on corporate environmental governance [23]. In the context of Guizhou, Feng, X., & Zhang, M., (2020) pioneered the integration of Baidu Index into an evaluation system for ecological civilization construction [24]. Their study encompassed a period from 2013 to 2017, encompassing nine prefecture-level cities in Guizhou. This pioneering work established a direct methodological precedent for the present study.

Specialized evaluations and spatiotemporal analyses of ecological civilization construction in Guizhou are also being deepened. At the provincial level, Du, X. L., & Zhou, X., (2021) employed the entropy method to evaluate the performance of ecological civilization construction in Guizhou Province [25]; Zhao, P. Y. *et al*., (2024) used the entropy-weighted TOPSIS method to assess the development level of ecological civilization construction in Guizhou Province from 2006 to 2022 [26]; Li, X. L. *et al*., (2023) conducted a spatiotemporal evolution analysis of agricultural ecological efficiency using 78 counties in Guizhou as case studies, providing a precedent for decomposing intra-provincial disparities [27]. Regarding the spatiotemporal patterns of ecological civilization, Zhang, Q. *et al*., (2024) examined the spatiotemporal evolution of the coupling and coordination between the tourism industry and ecological civilization construction in ethnic minority regions [28]; Fu, Y. P., & Wang, Z., (2025) studied the spatiotemporal patterns and convergence of the coupling and coordination between science and technology finance and ecological civilization construction [29]. In the realm of spatiotemporal feature analysis, the Dagum Gini coefficient and its decomposition method have gained widespread adoption due to their ability to discern between intra-regional disparities, net inter-regional disparities, and hypervariability density. Li, H., & Dong, Y. L., (2021) examined the origins of regional disparities in China's high-quality economic development [30]. Sun, X. *et al*., (2023) revealed that high-quality development in the tourism economy is primarily driven by inter-regional disparities [31]. Lü, Y. Y. *et al*., (2025) combined the Dagum Gini coefficient decomposition with exploratory spatiotemporal data analysis to examine the spatiotemporal differentiation of nature reserve coverage in China [32]. Liu, T., & Zhou, H. R., (2022) employed Dagum decomposition and kernel density estimation to reveal regional differences and dynamic evolution in high-quality rural development, finding that inter-regional differences play a dominant role [33]. Li, X. H. *et al*., (2024) combined coupling and coordination with the Dagum decomposition to characterize the spatiotemporal features of the The coordinated development of digitalization and greening at the provincial level is underway, with the establishment of a "measurement-decomposition-attribution" spatiotemporal analysis framework [34].

In summary, extant research in this area exhibits two notable shortcomings. First, the system for integrating and applying multi-source data—such as official statistics, internet big data, and government documents—to the evaluation of ecological civilization construction remains incomplete. Existing evaluations largely rely on a single statistical metric, and few studies have simultaneously incorporated public attention measured by the Baidu Index and government attention measured by word frequency in government work reports into the indicator system to enhance the ecological culture dimension. Furthermore, evaluations based on the integration of multi-source data for Guizhou are particularly lacking. Second, a paucity of systematic characterization of the spatiotemporal characteristics of prefecture-level cities over extended time periods persists. Studies on Guizhou have predominantly centered on province-wide evaluations [25] [26] or evaluations of prefecture-level cities encompassing relatively brief sample periods [24]. A paucity of systematic research exists on the spatiotemporal characteristics of prefecture-level cities over an extended period—spanning the 12th Five-Year Plan to the 14th Five-Year Plan—that integrates temporal evolution, spatial differentiation, and the decomposition of sources of variation.

In accordance with the preceding research, the innovations of this paper are as follows: First, an evaluation system was constructed, comprising 37 secondary indicators across four dimensions: ecological economy, ecological environment, ecological livability, and ecological culture. This system was built using multi-source data, including statistical yearbooks, statistical bulletins, Baidu Index, government work reports, and bulletins on the state of the ecological environment. The use of these data enhanced the information foundation for the ecological culture dimension.

Second, the sample period was extended to 2011-2025, covering the entire policy cycle from the 12th Five-Year Plan to the 14th Five-Year Plan. This extension enabled a long-term, systematic evaluation of the level of ecological civilization construction in Guizhou's nine prefecture-level cities at the prefecture-level city scale.

Third, a spatiotemporal characteristic analysis framework of "temporal evolution—sp" was established using the entropy-weighted TOPSIS method with the Dagum Gini coefficient decomposition. The objective of this study is to elucidate the mechanisms that underpin the spatiotemporal differentiation in the level of ecological civilization construction across Guizhou's prefecture-level cities. To this end, the paper will examine "spatial differentiation—sources of variation". The specific structure is as follows: The following three-step process was undertaken to assess the level of ecological civilization construction in Guizhou's prefecture-level cities. First, an evaluation indicator system was established. Second, an evaluation model was developed based on the entropy-weighted TOPSIS method. Third, an empirical evaluation of the nine prefecture-level cities in Guizhou from 2011 to 2025 was conducted, and regional disparities and their sources were decomposed. Finally, policy recommendations were proposed to address the relevant issues identified in each prefecture-level city.

2. Development of an Evaluation Indicator System for Ecological Civilization in Prefecture-Level Cities in Guizhou

The selection of indicators for measuring the level of ecological civilization construction exerts a direct influence on the results of such measurements. The paper's selection of 37 secondary indicators across four dimensions—ecological economy, ecological environment, ecological livability, and ecological culture—is grounded in the principles of comprehensiveness and representativeness, relevance and comparability, and guidance and foresight. These principles are further informed by data availability, scientific rigor, and practicality. The selection process is outlined in **Table 1**, and the resulting indicator system is designed to evaluate the level of ecological civilization construction in Guizhou's prefecture-level cities.

Table 1. Evaluation indicator system for the level of ecological civilization development in prefecture-level cities in Guizhou.

Objective Level	Primary Indicators	secondary Indicators (Unit/Symbol)	Indicator Attribute
Level of Ecological Civilization Development	Ecological Economy (A1)	Per capita GDP (average for permanent residents) (yuan/A1-1)	Efficiency-oriented
		Value added in the tertiary sector (100 million yuan/A1-2)	Efficiency-oriented
		Share of value added in the tertiary sector in GDP (per cent/A1-3)	Efficiency-oriented
		Rate of reduction in energy consumption per unit of GDP (per cent/A1-4)	Efficiency-oriented
		Comprehensive utilisation rate of industrial solid waste (%/A1-5)	Efficiency-oriented
		General public budget expenditure - energy conservation and environmental protection (100 million yuan / A1-6)	Efficiency-oriented
	Ecological Environment (A2)	Average temperature (˚C/A2-1)	Fixed-type
		Annual precipitation (mm/A2-2)	Fixed-type
		Average relative humidity (%) A2-3	Fixed-type
		Hours of sunshine (hours/A2-4)	Fixed-type
		Forest cover (%/A2-5)	Efficiency-oriented
		Percentage of days with good air quality (%/A2-6)	Efficiency-oriented
		Annual average PM2.5 concentration (micrograms per cubic metre/A2-7)	Cost-based
		Application rate of agricultural fertilisers (on a pure nutrient basis) (10,000 tonnes/A2-8)	Cost-based
		Total industrial wastewater discharge (10,000 tonnes/A2-9)	Cost-based
		Total sulphur dioxide emissions (10,000 tonnes/A2-10)	Cost-based
	Ecological and Liveable (A3)	Completed floor area of residential buildings (10,000 square metres/A3-1)	Efficiency-oriented
		Length of roads in the central urban area (kilometres/A3-2)	Efficiency-oriented
		Road area in the central urban area (10,000 square metres/A3-3)	Efficiency-oriented
		Total tap water production capacity (10,000 tonnes per day/A3-4)	Efficiency-oriented
		Length of tap water supply pipelines (kilometres/A3-5)	Efficiency-oriented
		Length of drainage pipelines (kilometres/A3-6)	Efficiency-oriented
		Total natural gas supply (10,000 cubic metres/A3-7)	Efficiency-oriented
		Urban domestic sewage treatment rate (per cent/A3-8)	Efficiency-oriented
		Urban domestic waste harmless treatment rate (%/A3-9)	Efficiency-oriented
		Green space coverage rate in built-up areas (%/A3-10)	Efficiency-oriented
		Per capita park green space area in built-up areas (square metres per person/A3-11)	Efficiency-oriented

Continued

Ecological Culture (A4)	Public interest in ecological Civilization (frequency/A4-1)	Efficiency-oriented
	Level of government attention to ecological Civilization development (frequency/A4-2)	Efficiency-oriented
	General Public Budget Expenditure - Education (100 million yuan/A4-3)	Efficiency-oriented
	General Public Budget Expenditure - Culture, Tourism, Sport and Media (100 million yuan/A4-4)	Efficiency-oriented
	Number of graduates from ordinary higher education institutions (persons/A4-5)	Efficiency-oriented
	Number of graduates from secondary vocational education (schools) (persons/A4-6)	Efficiency-oriented
	Number of general secondary school graduates (persons/A4-7)	Efficiency-oriented
	Radio coverage rate (per cent/A4-8)	Efficiency-oriented
	Television coverage rate (per cent/A4-9)	Efficiency-oriented
	Total holdings in public libraries (10,000 volumes/items/A4-10)	Efficiency-oriented

Note: Public interest in ecological Civilization construction is derived from the Baidu Index platform. The Baidu Index is based on the volume of searches conducted by internet users on Baidu; it uses keywords as the subject of analysis, scientifically analysing and calculating the weighted search frequency of each keyword in Baidu web searches. This reflects the scale of searches for a keyword and user interest over a given period, and serves as a valuable reference for analysing and assessing trends; Government attention to ecological Civilization construction is derived by collating annual government work reports from prefecture-level cities and counting the frequency of the term "ecological Civilization" within them, reflecting the government's level of emphasis on ecological Civilization construction and its policy orientation.

3. An Evaluation Model for the Level of Ecological Civilization Construction Based on the Entropy-Weighted TOPSIS Method

The TOPSIS method, also known as the Technique for Order Preference of Solutions, performs a multi-criteria evaluation by measuring the distance between the evaluation object and positive and negative ideal solutions. The entropy weighting method is an objective approach to determining weights, based on the information content of the indicator data itself. The amalgamation of these two methods effectively addresses the subjectivity inherent in weight assignment. The following steps are to be followed in order to create the model:

Step 1. Construct the original evaluation matrix. Let there be m evaluation objects and n evaluation indicators. If the value of evaluation object i for indicator *j* is x_{ij}, then the original evaluation matrix is $X = \left(x_{ij}\right)_{m\times n}$.

Step 2. Determine the indicator weights using the entropy weighting method.

1) Calculate the weight of the nth evaluation object under the th indicator:

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}, \left(1 \le i \le m, 1 \le j \le n\right) \tag{1}$$

2) Then calculate the entropy value for the nth indicator:

$$p_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}, (1 \le i \le m, 1 \le j \le n) \tag{2}$$

where, if $p_{ij} = 0$, then $p_{ij} \ln p_{ij} = 0$ is defined.

3) Calculate the coefficient of variation:

$$G_j = 1 - E_j \tag{3}$$

The smaller the entropy value E_j, the larger the coefficient of variation G_j; this indicates that the data for that indicator is more dispersed and contains a greater amount of information.

4) Normalize the coefficient of variation to obtain the indicator weights:

$$W_j = \frac{G_j}{\sum_{j=1}^{n} G_j}, (j = 1, 2, \cdots, n) \tag{4}$$

Step 3. Normalise the indicators. To eliminate differences in the units of measurement between indicators and standardise their direction, the raw data is normalised using range normalization.

For efficiency-oriented indicators:

$$y_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}}, \quad i = 1, 2, \cdots, m, \ j = 1, 2, \cdots, n \tag{5}$$

For cost-based indicators:

$$y_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}}, \quad i = 1, 2, \cdots, m, \ j = 1, 2, \cdots, n \tag{6}$$

For fixed-type indicators:

$$y_{ij} = 1 - \frac{\left| x_{ij} - x_j^* \right|}{\max_i \left| x_{ij} - x_j^* \right|}, \quad i = 1, 2, \cdots, m, \ j = 1, 2, \cdots, n \tag{7}$$

x_j^* Represents the optimal stable value for the jth fixed-type indicator. The advancement of ecological civilization has driven a historic shift in China's ecological environment from "targeted remediation" to "systematic governance", resulting in significant improvements in ecological and environmental quality. Consequently, climate indicators such as temperature, precipitation, humidity, and sunshine duration indirectly reflect the performance of ecological civilization efforts. Climate indicators are fixed-value metrics; higher values are not necessarily better, nor are lower values necessarily worse. Since there are generally no universally recognized optimal values for these indicators, average values are used as an approximate substitute for optimal values. $\max_i \left| x_{ij} - x_j^* \right|$ represents the maximum deviation between the observed value of the indicator and the optimal stable value. After normalisation, the values of each indicator fall between 0 and 1, and the direction is uniformly defined such that higher values are better.

Step 4. Construct the weighted normalised decision matrix. By combining the normalised matrix $Y = \left(y_{ij} \right)_{m \times n}$ with the indicator weights, the weighted normalised decision matrix $Z=\left(Z_{ij}\right)_{m\times n}$ is obtained:

$$Z_{ij}=W_j\times y_{ij} \tag{8}$$

Step 5. Determine the positive and negative ideal solutions. The positive ideal solution S_j^+ corresponds to the maximum of the weighted normalised values for each indicator, whilst the negative ideal solution S_j^- corresponds to the minimum of the weighted normalised values for each indicator; since the range of the normalised indicators is 0, the negative ideal solution is the zero vector.

$$S_j^+=\max_{1\le i\le m}\left\{Z_{ij}\right\},\left(j=1,2,\cdots,n\right) \tag{9}$$

$$S_j^-=\min_{1\le i\le m}\left\{Z_{ij}\right\},\left(j=1,2,\cdots,n\right) \tag{10}$$

Step 6. Calculate the Euclidean distances between each evaluation object and the positive and negative ideal solutions:

$$D_i^+=\sqrt{\sum_{j=1}^{n}\left(S_j^+-Z_{ij}\right)^2},\left(i=1,2,\cdots,m\right) \tag{11}$$

$$D_i^-=\sqrt{\sum_{j=1}^{n}\left(S_j^--Z_{ij}\right)^2},\left(i=1,2,\cdots,m\right) \tag{12}$$

Step 7. Calculate the proximity score:

$$C_i=\frac{D_i^-}{D_i^++D_i^-},\left(i=1,2,\cdots,m\right) \tag{13}$$

$C_i\in\left[0,1\right]$; the higher the value, the closer the subject under evaluation is to the optimal solution, and the higher the level of ecological Civilization; conversely, the lower the value, the lower the level.

4. Empirical Evaluation of the Level of Ecological Civilization Development in Prefecture-Level Cities in Guizhou

4.1. Data Sources

Data Sources: The temporal scope of this study encompasses the period from 2011 to 2025, with a particular emphasis on the nine prefecture-level cities within Guizhou Province. The raw data for various ecological civilization indicators are primarily sourced from the 2011-2025 Statistical Yearbooks published by the statistical bureaus of the nine prefecture-level cities in Guizhou Province, the statistical bulletins on national economic and social development issued by each prefecture-level city, and the Guizhou Province Macroeconomic Database. In this study, a set of indicators was developed to assess the environmental performance of Guizhou Province and its prefecture-level cities. The indicators included environmental monitoring indicators, such as the annual average concentration of PM2.5, which were derived from the ecological and environmental status bulletins released by the relevant bureaus. Public interest is measured using “ecological civilization” as the sole search keyword. On the Baidu Index platform, the geographic filter is set to specific prefecture-level cities based on user location, and separate indices for desktop and mobile devices are extracted for each city. The annual index is calculated as the arithmetic mean of the daily indices from January 1 to December 31 of that year. The city's public interest for that year is then measured as the arithmetic mean of the annual desktop and mobile indices; For dates where search volume fell below the platform's statistical threshold and was displayed as 0, these values were included in the annual average as 0, without being excluded or smoothed. Government attention was measured by collecting the full texts of the annual government work reports for the nine prefecture-level cities from 2011 to 2025 and counting the total number of times the term "ecological civilization" appeared in the full reports using it as a search term. Given that the annual government work reports of each prefecture-level city are full-text reports delivered by the mayor to the People's Congress at the same level, their length and structural scope are essentially consistent, making word frequencies comparable across cities and years. This study comprises a total of 4,995 data points, of which 298 original observations were missing, accounting for 5.97% of the total. Linear interpolation and exponential smoothing methods were used to reasonably estimate and complete the missing data (see **Appendix 1**).

4.2. Descriptive Statistics

The descriptive statistics for the primary variables in this study are presented in Table 2. The sample consists of panel data from nine prefecture-level cities in Guizhou Province, covering the period from 2011 to 2025, with a total of 135 observations. The first-level indicators encompass four dimensions: ecological economy (A1), ecological environment (A2), ecological livability (A3), and ecological culture (A4), which collectively comprise 37 secondary indicators. These secondary indicators can be categorized into three types: benefit-based, cost-based, and fixed indicators.

Table 2. Descriptive statistics of key variables.

Secondary indicators (symbols)	N	Mean	Standard Deviation	Minimum	Maximum
A1-1	135	39,394.04	18,511.60	4,608.00	90,995.00
A1-2	135	855.01	710.54	128.59	4,035.72
A1-3	135	50.02	7.05	32.13	66.80
A1-4	135	5.43	3.26	0.28	20.39
A1-5	135	67.42	16.09	37.16	100.00
A1-6	135	11.85	5.75	3.12	36.03
A2-1	135	15.90	1.29	13.00	18.20
A2-2	135	1,206.86	217.70	747.90	1,723.90
A2-3	135	79.40	2.17	73.00	84.80
A2-4	135	1,258.76	229.61	800.60	2,138.00
A2-5	135	56.65	8.12	39.19	70.90

Continued

A2-6	135	97.20	3.88	72.90	100.00
A2-7	135	27.67	7.58	10.00	48.00
A2-8	135	9.94	5.74	4.42	28.46
A2-9	135	2,855.93	2,718.34	80.00	13014.51
A2-10	135	5.82	5.21	0.37	23.60
A3-1	135	359.94	495.36	13.94	2,459.72
A3-2	135	1,305.41	1,078.90	155.00	5,852.00
A3-3	135	2,266.81	1,568.98	385.00	7,939.00
A3-4	135	56.73	41.88	15.08	186.56
A3-5	135	2,419.72	1,634.37	473.45	8,293.50
A3-6	135	1,487.16	1,078.65	158.50	4,512.05
A3-7	135	11,962.43	20,448.05	0.00	112,263.48
A3-8	135	95.21	6.57	65.36	100.00
A3-9	135	95.71	5.98	62.63	100.00
A3-10	135	34.32	9.82	11.54	45.32
A3-11	135	12.24	6.18	1.30	34.40
A4-1	135	16.81	24.59	0.00	102.00
A4-2	135	4.32	4.53	0.00	23.00
A4-3	135	89.48	39.76	18.77	187.78
A4-4	135	5.21	2.39	1.01	12.93
A4-5	135	21,477.63	32,530.17	1,067.00	146,840.00
A4-6	135	14,125.05	10,094.18	1,462.00	43,965.00
A4-7	135	103,437.17	44,915.56	45,730.53	228,962.00
A4-8	135	95.02	4.80	81.40	100.00
A4-9	135	97.11	2.77	86.10	100.00
A4-10	135	135.26	156.33	2.00	759.92

In terms of the ecological economy, the average per capita GDP (A1-1) was 39,394.04 yuan, with a maximum of 90,995.00 yuan and a minimum of only 4,608.00 yuan. The standard deviation was as high as 18,511.60, and the data exhibited a clear right-skewed distribution, indicating that the economic output of more than half of the prefectures and cities was below the provincial average. This finding reflects imbalances in economic development across regions. The maximum value of value-added in the tertiary sector (A1-2) was approximately 31 times the minimum value, indicating a vast disparity in the scale of the service economy across prefectures. The average share of value-added in the tertiary sector in GDP (A1-3) was 50.02%, with a difference of 34.67 percentage points between the maximum and minimum values, reflecting uneven progress in industrial structure transformation and upgrading. The average rate of decline in energy consumption per unit of GDP (A1-4) was 5.43%, with the maximum at 20.39%. The minimum is set at 0.28%. Fiscal expenditure on energy conservation and environmental protection (A1-6) exhibited a 11.5-fold variation between its maximum and minimum, reflecting substantial disparities among prefectures and cities in terms of investment in green development.

In terms of the ecological environment, the average forest coverage rate (A2-5), which reflects the ecological baseline, and the average rate of good air quality (A2-6) were 56.65% and 97.20%, respectively, indicating a generally high and relatively stable level. The coefficients of variation for fixed indicators such as average temperature, annual precipitation, and average relative humidity were all less than 0.20, suggesting limited differences in climatic background conditions across regions. However, the standard deviations for total industrial wastewater discharge (A2-9) and total sulfur dioxide emissions (A2-10) were as high as 2,718.34 and 5.21, respectively. The maximum value of the former was more than 160 times the minimum value, indicating that some industrial cities still face significant pressure to reduce emissions. The mean annual average concentration of PM2.5 (A2-7) was 27.67 micrograms per cubic meter, with a difference of 38 micrograms per cubic meter between the maximum and minimum values. This indicates that there is still room for improvement in air quality in some local areas.

In terms of ecological livability, the average urban domestic sewage treatment rate (A3-8) and urban domestic waste harmless treatment rate (A3-9) were 95.21% and 95.71%, respectively. These figures indicate that Guizhou's prefecture-level cities have achieved significant results in urban environmental governance in recent years and are generally at a high level. However, the total natural gas supply (A3-7) ranged from a maximum of 112,263.48 ten thousand cubic meters to a minimum of 0, with a standard deviation as high as 20,448.05. The distribution of data for this indicator exhibits a severe right-skew, indicative of the persistent under-supply of natural gas infrastructure, with the supply remaining at a low level in more than half of the regions. The coefficient of variation for the floor area of completed buildings (A3-1) was recorded at 1.38, and the standard deviations for municipal indicators such as comprehensive tap water production capacity and the length of drainage pipelines approached their respective means, suggesting significant disparities in the allocation of public services across regions.

In the terms of ecological culture, the mean values for public attention to ecological civilization construction (A4-1) and government attention (A4-2) were 16.81 and 4.32, respectively. Notably, the standard deviations for both were greater than the respective means. The data demonstrate a substantial right-skewed distribution, indicating that the overall social attention to ecological civilization in Guizhou remains minimal. Furthermore, the level of attention allocated to ecological civilization construction by the public and governments in select prefectures and cities is deemed to be inadequate and in urgent need of enhancement. The maximum number of graduates from conventional institutions of higher education (A4-5) was approximately 138 times the minimum, while the maximum total collection size of public libraries (A4-10) was 380 times the minimum. This underscores the pronounced regional concentration of educational and cultural resources. The mean population coverage rates for radio and television (A4-8, A4-9) were 95.02% and 97.11%, respectively, with coefficients of variation below 0.06. This indicates that fundamental cultural dissemination facilities have essentially achieved full coverage across the region.

4.3. Steps for Evaluating the Level of Ecological Civilization Development in Prefecture-Level Cities in Guizhou Province

Step 1: The original evaluation matrix constructed in this step is of order 135 × 37. This study comprises 135 evaluation subjects and 37 evaluation indicators.

Step 2: Calculation of indicator weights. In accordance with the model, entropy values, coefficients of variation and indicator weights were calculated using Equations (1) to (4); the results are shown in Table 3.

Table 3. Results of indicator weight calculations.

Secondary indicators	Entropy	Coefficient of Variation	Indicator Weights	Secondary indicators	Entropy	Coefficient of Variation	Indicator Weights
A1-1	0.97784	0.02216	0.01433	A3-4	0.95521	0.04479	0.02896
A1-2	0.94600	0.05400	0.03491	A3-5	0.96019	0.03981	0.02574
A1-3	0.99797	0.00203	0.00131	A3-6	0.95015	0.04985	0.03223
A1-4	0.96757	0.03243	0.02097	A3-7	0.81005	0.18995	0.12283
A1-5	0.99436	0.00564	0.00365	A3-8	0.99948	0.00052	0.00033
A1-6	0.97769	0.02231	0.01443	A3-9	0.99957	0.00043	0.00027
A2-1	0.99932	0.00068	0.00044	A3-10	0.99052	0.00948	0.00613
A2-2	0.99665	0.00335	0.00216	A3-11	0.97417	0.02583	0.01670
A2-3	0.99992	0.00008	0.00005	A4-1	0.84644	0.15356	0.09929
A2-4	0.99672	0.00328	0.00212	A4-2	0.89994	0.10006	0.06470
A2-5	0.99787	0.00213	0.00138	A4-3	0.98016	0.01984	0.01283
A2-6	0.99983	0.00017	0.00011	A4-4	0.97913	0.02087	0.01349
A2-7	0.99249	0.00751	0.00486	A4-5	0.85467	0.14533	0.09397
A2-8	0.97155	0.02845	0.01840	A4-6	0.95395	0.04605	0.02978
A2-9	0.91506	0.08494	0.05492	A4-7	0.98308	0.01692	0.01094
A2-10	0.92712	0.07288	0.04713	A4-8	0.99974	0.00026	0.00017
A3-1	0.86753	0.13247	0.08565	A4-9	0.99992	0.00008	0.00005
A3-2	0.94589	0.05411	0.03499	A4-10	0.88944	0.11056	0.07149
A3-3	0.95628	0.04372	0.02827				

Step 3: Normalisation of indicators. Efficiency-oriented and cost-type indicators are normalised by range according to Equations (5) and (6) respectively, whilst fixed-type indicators are processed according to Equation (7). Since fixed-

type metrics generally lack universally accepted optimal values, average values must be used as an approximation of the optimal values: mean temperature 15.90˚C, annual precipitation 1206.86 mm, mean relative humidity 79.40 per cent, and hours of sunshine 1258.76 hours.

Step 4: Normalise the matrix. Multiply the normalised matrix by the indicator weights according to Equation (8) to obtain the weighted normalised decision matrix.

Step 5: Determine the positive and negative ideal solutions. Determine the positive and negative ideal solutions using Equations (9) and (10). Since the minimum values of each indicator are 0 after range normalisation, the negative ideal solution is the zero vector; the positive ideal solution is the weight vector for each indicator, which is not shown separately here.

Step 6: Calculate the Euclidean distances D^+ and D^- between each observation and the positive and negative ideal solutions, respectively, using Equations (11) to (12); see Table 4 and Table 5. Then, calculate the proximity using Equation (13); the results are shown in Table 6. In this paper, the normalization of indicators, the calculation of entropy weights, and the determination of positive and negative ideal solutions are all performed uniformly based on the combined sample of all 135 "city-year" pairs. Consequently, the proximity index is a relative measure within the sample, reflecting the relative position of the evaluated entities within the sample rather than a measure of the absolute level of ecological civilization construction or the distance from an absolute ideal state.

Table 4. Distance D^+ between each city and the positive ideal solution, 2011-2025.

Year	Guiyang City	Liupanshui	Zunyi City	Anshun City	Bijie City	Tongren City	Southeatern Guizhou Prefecture	Southwet Guizhou Prefecture	Qiannan Prefecture
2011	0.1816	0.2419	0.2303	0.2400	0.2396	0.2393	0.2298	0.2314	0.2347
2012	0.1770	0.2403	0.2298	0.2395	0.2387	0.2384	0.2301	0.2315	0.2339
2013	0.1476	0.2364	0.2240	0.2368	0.2338	0.2348	0.2302	0.2275	0.2294
2014	0.1437	0.2305	0.2181	0.2357	0.2368	0.2294	0.2263	0.2278	0.2287
2015	0.1425	0.2302	0.2109	0.2359	0.2347	0.2283	0.2255	0.2275	0.2238
2016	0.1228	0.2307	0.1981	0.2302	0.2297	0.2265	0.2262	0.2257	0.2280
2017	0.1106	0.2268	0.1875	0.2303	0.2266	0.2227	0.2220	0.2262	0.2183
2018	0.1184	0.2260	0.1800	0.2306	0.2218	0.2193	0.2184	0.2246	0.2160
2019	0.0964	0.2281	0.1798	0.2305	0.2218	0.2192	0.2176	0.2273	0.2125
2020	0.0948	0.2255	0.1606	0.2307	0.2181	0.2171	0.2136	0.2229	0.2100
2021	0.0935	0.2242	0.1632	0.2203	0.2109	0.2119	0.2091	0.2176	0.1989
2022	0.0960	0.2192	0.1525	0.2115	0.2110	0.2122	0.2032	0.2193	0.1973
2023	0.0994	0.2214	0.1544	0.2195	0.2159	0.2168	0.2085	0.2249	0.1885
2024	0.1087	0.2235	0.1607	0.2249	0.2121	0.2156	0.2081	0.2273	0.1948
2025	0.1349	0.2232	0.1641	0.2267	0.2149	0.2182	0.2121	0.2312	0.1995

Table 5. Distance D^{-} between each city and the positive ideal solution, 2011-2025.

Year	Guiyang City	Liupanshui	Zunyi City	Anshun City	Bijie City	Tongren City	Southeast ern Guizhou Prefecture	Southwest Guizhou Prefecture	Qiannan Prefecture
2011	0.0996	0.0391	0.0530	0.0607	0.0414	0.0640	0.0653	0.0610	0.0641
2012	0.1070	0.0389	0.0525	0.0590	0.0363	0.0638	0.0643	0.0637	0.0639
2013	0.1481	0.0443	0.0590	0.0599	0.0408	0.0638	0.0637	0.0666	0.0663
2014	0.1456	0.0506	0.0617	0.0685	0.0293	0.0689	0.0670	0.0645	0.0560
2015	0.1399	0.0538	0.0763	0.0669	0.0354	0.0670	0.0683	0.0721	0.0616
2016	0.1617	0.0522	0.0959	0.0730	0.0561	0.0692	0.0724	0.0767	0.0669
2017	0.1710	0.0511	0.0899	0.0733	0.0550	0.0732	0.0769	0.0745	0.0792
2018	0.1752	0.0501	0.0892	0.0738	0.0611	0.0752	0.0744	0.0708	0.0754
2019	0.1803	0.0564	0.0903	0.0749	0.0680	0.0762	0.0779	0.0592	0.0798
2020	0.1833	0.0588	0.1102	0.0753	0.0722	0.0780	0.0818	0.0663	0.0822
2021	0.1927	0.0617	0.1128	0.0799	0.0776	0.0822	0.0832	0.0705	0.0839
2022	0.1876	0.0630	0.1290	0.0854	0.0773	0.0815	0.0873	0.0628	0.0892
2023	0.1837	0.0637	0.1355	0.0825	0.0732	0.0798	0.0859	0.0586	0.0920
2024	0.1655	0.0629	0.1426	0.0786	0.0815	0.0813	0.0862	0.0587	0.0894
2025	0.1612	0.0668	0.1556	0.0791	0.0829	0.0821	0.0885	0.0584	0.0939

Table 6. Proximity to the level of ecological civilization construction and rankings of prefecture-level cities in Guizhou, 2011-2025.

Year	Guiyang City	Liupanshui	Zunyi City	Anshun City	Bijie City	Tongren City	Southeast ern Guizhou Prefecture	Southwest Guizhou Prefecture	Qiannan Prefecture	Provinial average
2011	0.3542	0.1391	0.1871	0.2018	0.1473	0.2111	0.2213	0.2085	0.2146	0.2094
2012	0.3766	0.1392	0.1859	0.1977	0.1321	0.2111	0.2183	0.2157	0.2146	0.2101
2013	0.5009	0.1578	0.2086	0.2019	0.1484	0.2138	0.2168	0.2264	0.2243	0.2332
2014	0.5033	0.1801	0.2205	0.2252	0.1101	0.2311	0.2285	0.2206	0.1966	0.2351
2015	0.4954	0.1895	0.2658	0.2210	0.1312	0.2269	0.2324	0.2405	0.2157	0.2465
2016	0.5685	0.1845	0.3262	0.2408	0.1962	0.2341	0.2423	0.2536	0.2270	0.2748
2017	0.6073	0.1839	0.3242	0.2415	0.1952	0.2473	0.2573	0.2476	0.2663	0.2856
2018	0.5966	0.1815	0.3312	0.2424	0.2158	0.2554	0.2542	0.2398	0.2588	0.2862
2019	0.6516	0.1983	0.3342	0.2452	0.2346	0.2579	0.2637	0.2067	0.2730	0.2961
2020	0.6592	0.2068	0.4068	0.2461	0.2488	0.2644	0.2769	0.2293	0.2813	0.3133
2021	0.6733	0.2157	0.4087	0.2660	0.2691	0.2795	0.2847	0.2446	0.2966	0.3265
2022	0.6614	0.2231	0.4582	0.2875	0.2683	0.2775	0.3006	0.2226	0.3112	0.3345
2023	0.6489	0.2234	0.4674	0.2733	0.2531	0.2691	0.2919	0.2068	0.3281	0.3291
2024	0.6036	0.2197	0.4701	0.2589	0.2776	0.2737	0.2928	0.2052	0.3146	0.3240
2025	0.5444	0.2303	0.4867	0.2588	0.2783	0.2734	0.2943	0.2015	0.3201	0.3209
Average	**0.5630**	**0.1915**	**0.3388**	**0.2406**	**0.2071**	**0.2484**	**0.2584**	**0.2246**	**0.2629**	**0.2817**
Rank	**1**	**9**	**2**	**6**	**8**	**5**	**4**	**7**	**3**	**——**

4.4. Evaluation Results

4.4.1. Analysis of Indicator Weights

As demonstrated in Table 3, the entropy-weighted distribution of the 37 secondary indicators manifests distinct imbalances. The weights for the six indicators—total natural gas supply (A3-7), public interest in ecological civilization construction (A4-1), number of graduates from regular institutions of higher education (A4-5), completed floor area of residential buildings (A3-1), total book holdings in public libraries (A4-10), and government attention to ecological civilization construction (A4-2)—account for a combined weight of 0.5379. The six indicators in question are responsible for the transmission of more than half of the information present within the indicator system. They are the primary drivers of the variation in the level of ecological civilization construction among Guizhou's prefecture-level cities. These indicators are the group with the highest degree of dispersion in the descriptive statistics, indicating that the existing disparities among prefecture-level cities in terms of municipal infrastructure, public attention, and science, education, and cultural resources are the key factors driving the variation in the level of ecological civilization construction. From a dimensional summary perspective, the combined weights for ecological culture, ecological livability, ecological environment, and ecological economy are 0.3967, 0.3821, 0.1316, and 0.0896, respectively. The ecological culture and ecological livability dimensions together account for nearly 80 percent. Within the ecological environment dimension, the weights for total industrial wastewater discharge (A2-9) and total sulfur dioxide emissions (A2-10) are significantly higher than those of other environmental indicators. Pollution reduction is the core factor distinguishing the development levels of various cities and prefectures within this dimension. It is important to acknowledge that the entropy-weighted method is an objective weighting approach. The magnitude of the weights reflects the information content and discriminative power of the indicators within the sample, rather than their importance in a policy context. The weights for indicators such as average temperature (A2-1), average relative humidity (A2-3), the rate of good air quality (A2-6), radio (A4-8), and television population coverage (A4-9) are all less than 0.001 because the variations within the sample are extremely small, not because the indicators themselves are insignificant.

4.4.2. Analysis of Changes in Distance from the Ideal Solution

As demonstrated in Table 5 and Table 6, the alterations in the distance between each prefecture-level city and the positive and negative ideal solutions during the study period manifest two distinctive trajectories. One type of trajectory that can be identified is a trajectory of continuous improvement. For Guiyang City, the distance D^+ from the positive ideal solution decreased from 0.1816 in 2011 to 0.1349 in 2025, showing a 25.72% decline. Concurrently, the distance D^- from the negative ideal solution increased from 0.0996 to 0.1612, indicating an increase of 61.85%. The relative distance to the exact solution continues to decrease. Zunyi City demonstrated an even more significant improvement. The D^+ index exhibited a decline from 0.2303 to 0.1641, while the D^- index demonstrated an increase from 0.0530 to 0.1556, marking a 193.58% rise. This development signifies that the region in question possesses the most pronounced propensity to make up for lost ground among the nine prefecture-level cities. Another category exhibits a stagnant improvement trajectory: Liupanshui City's D^+ registered a slight decline, from 0.2419 to 0.2232. Conversely, D^- exhibited an increase from 0.0391 to 0.0668, though its absolute level remains the lowest in the province. Anshun City's D^+ registered a 5.54% decrease, while Qianxinan Prefecture's D^+ remained virtually unchanged during the observation period. However, its D^- dropped from 0.0610 to 0.0584, indicating a decline rather than an increase. This suggests that the relative gap between these cities and prefectures and the ideal state has not effectively narrowed, and their development momentum remains insufficient.

4.4.3. Comprehensive Evaluation of Proximity

As demonstrated in Table 7, from a province-wide perspective, the average proximity index of the nine prefecture-level cities increased from 0.2094 in 2011 to 0.3209 in 2025, indicating a cumulative increase of 53.25% and an average annual growth rate of 3.09%. Following a surge to 0.3345 in 2022, the figure underwent a modest decline. A general upward trend in the level of ecological civilization construction in Guizhou has been observed. However, the mean values are only at a moderate level within the sample, and the relative distance from the ideal solution remains significant. At the prefecture-level city level, the average proximity scores exhibited a discernible tiered differentiation during the study period. Guiyang City maintained its leading position with an average of 0.5630, being the sole region with an average exceeding 0.50. The proximity score of Zunyi City peaked at 0.6733 in 2021 before experiencing a slight decline, this may be due to a slight decline in some of Guiyang's own indicators, while other prefecture-level cities have been steadily improving, gradually narrowing the gap between Guiyang and other cities. From 2021 to 2025, public attention toward ecological civilization construction in Guiyang City fell from 102 instances to 17, government attention dropped from 10 instances to 1, the floor area of completed residential buildings decreased from 20,075,400 square meters to 11,586,300 square meters, and the total number of books in public libraries declined from 7,599,200 to 4,260,700. The contribution rates of these four indicators to the widening gap between the city's performance and the ideal solution were 72.4%, 26.4%, 19.3%, and 10.5%, respectively; The average proximity score of Zunyi City was 0.3388, marking an upward trend from seventh place in 2011 to second place in 2025. Its annual average growth rate in proximity reached 7.06%, the highest in the province, and together with Guiyang City, it forms the Central Guizhou growth pole. Qiannan Prefecture, Southeast Guizhou Prefecture, Tongren City, Anshun City, Bijie City, and Southwest Guizhou Prefecture all had average values ranging from 0.20 to 0.27, forming the middle tier. Among them, Bijie City ascended from eighth to fifth place, manifesting clear characteristics of a latecomer rapidly gaining ground. Conversely, Qianxinan Prefecture experienced a decline, dropping from fifth to ninth place. Its 2025 proximity index was lower than that of 2011, suggesting a regression rather than a progression. Liupanshui City exhibited an average of 0.1915, placing it at the bottom of the rankings. However, its proximity index exhibited a steady upward trend, increasing from 0.1391 to 0.2303, with no interruption in this positive progression. In summary, during the review period, the level of ecological civilization construction in Guizhou's prefecture-level cities exhibited an overall enhancement, accompanied by a discernible differentiation among tiers. The provincial capital demonstrated a prominent leading role; however, the alignment index for most prefecture-level cities and prefectures remained below 0.30, and the relative distance from the ideal solution within the sample is still quite large, Moreover, cities and prefectures at the lower end of the spectrum exhibit inadequate momentum for enhancement. In the future, targeted measures should be implemented for the middle tier and lagging regions, with a focus on addressing shortcomings in municipal infrastructure and ecological culture.

4.5. Analysis of Spatio-Temporal Characteristics

The proximity scores and their rankings depict the static distribution of the evaluation results, but they do not adequately reveal the dynamic evolution and spatial differentiation patterns of ecological civilization development. Drawing on the spatiotemporal analysis framework developed by Li, X. H. *et al.* (2024) [34], this section conducts a further analysis of the evaluation results from the dual perspectives of temporal evolution and spatial differentiation.

4.5.1. Temporal Analysis

Figure 1 shows the results of the measurement of the degree of alignment with ecological civilization construction in Guizhou's nine prefecture-level cities. From a province-wide perspective, the average degree of alignment across all prefecture-level cities generally followed a fluctuating upward trend, rising from 0.2094 in 2011 to 0.3209 in 2025, with an average annual growth rate of 3.09%. In terms of the evolution over time, the average proximity index rose steadily from 2011 to 2022, reaching a peak of 0.3345 in 2022 during the study period, before declining slightly to 0.3209 in 2025. This indicates that the construction of ecological civilization in Guizhou has progressed steadily overall and has entered a phase of consolidation at a high level in recent years. At the beginning of the study period, the proximity indices of all cities were generally low, with only Guiyang City reaching 0.3542—significantly higher than the other prefecture-level cities; the proximity indices of Bijie, Liupanshui, and Zunyi were below 0.2000, revealing marked disparities in the foundational conditions for development across the region. By the middle of the study period, Guiyang City's proximity index had risen to 0.5966, further widening its lead. As the provincial capital, Guiyang possesses strong economic agglomeration and the ability to attract production factors. Investments in ecological governance, infrastructure improvements, and the provision of public services have advanced in tandem, providing robust support for its ecological civilization development. During the same period, Zunyi's proximity index rose to 0.3312, while Liupanshui's stood at only 0.1815, ranking last among the nine cities.By the conclusion of the study period, the proximity indices of each city had undergone changes to varying degrees compared to the beginning of the period. As a relative measure, Guiyang's proximity index reached its apex at 0.6733 in 2021, subsequently exhibiting a modest decline to 0.5444 in 2025. This does not represent an absolute decline in development levels, but rather reflects accelerated growth in areas such as Zunyi City and Qiannan Prefecture, leading to a gradual narrowing of regional disparities. During the study period, Zunyi City's annual average growth rate in convergence reached 7.06%, ranking first in the province; Bijie City and Liupanshui City recorded annual average growth rates of 4.65% and 3.67%, respectively; Qianxinan Prefecture's annual average growth rate declined by 0.24%, with its convergence index falling slightly from 0.2085 in 2011 to 0.2015 in 2025, indicating relatively lagging progress. In summary, during the study period, the level of ecological civilization construction in Guizhou's prefecture-level cities exhibited an overall enhancement. However, the proximity index for the majority of cities and prefectures remained below 0.30, indicating that the level of ecological civilization construction still requires further enhancement.

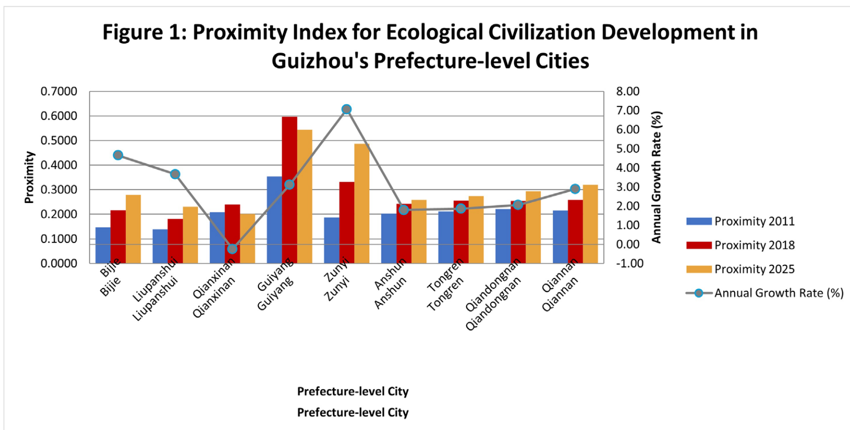

Figure 1. Proximity index for ecological civilization development in Guizhou's Prefecture-level Cities.

4.5.2. Spatial Analysis

The proximity index is a continuous evaluation value ranging from 0 to 1. To characterize the relative levels of ecological civilization development across cities, drawing on the approach used by Peng, K. J. *et al.* (2025) and Li, W. *et al.* (2026)—who employed heatmaps to visualize spatiotemporal changes in regional evaluation levels—the proximity index is categorized into the four levels shown in Table 7 [35] [36]. However, a universally accepted classification standard for the proximity index is currently lacking. The values for the 135 "city-year" observations range from 0.1101 to 0.6733. The application of the breakpoints of 0.3, 0.5, and 0.7, which are commonly used in the literature on coupling coordination, would result in no observations falling into the highest category. Consequently, the classification would become meaningless. This paper determines the cutoff points based on the actual distribution of the sample. The sample is comprised of 20, 85, 18, and 12 observations, respectively, in each level. The classification results are used solely to characterize structural differences in relative levels and do not alter the conclusions regarding the ranking of proximity.

Table 7. Classification criteria for the level of ecological civilization development in prefecture-level cities in Guizhou.

Grade	Proximity Value Range	Definition
Low Level	[0, 0.20)	Ranked toward the bottom of the sample, the construction task is daunting
Low level	[0.20, 0.30)	While there is a certain foundation in place, the relative level within the sample remains relatively low
Medium level	[0.30, 0.50)	Initial results of development efforts are becoming apparent, with considerable scope for improvement
High level	[0.50, 1.00]	It ranks relatively high within the sample and has a high level of development

Figure 2 illustrates the spatial distribution of ecological civilization development levels in Guizhou's prefecture-level cities at the beginning and end of the study period. The division of the three major regions—Eastern, Central, and Western—in this paper is based on geographic location and follows the commonly used classification method for Guizhou Province's regional economic development pattern. The Western region includes Qianxinan Prefecture, Liupanshui City, and Bijie City. The Central region includes Anshun City, Guiyang City, and Zunyi City. The Eastern region includes Qiannan Prefecture, Qiandongnan Prefecture, and Tongren City. As demonstrated in Figure 2, the degree of ecological civilization construction in Guizhou during the specified study period manifested a distribution pattern that can be characterized as "the central region leading, with the eastern and western regions following". In terms of typological distribution, in 2011, prefectures and cities with higher proximity scores were scattered around the central region. Guiyang City stood out among the nine cities with a proximity score of 0.3542, while Bijie City and Liupanshui City in the western region both had scores below 0.1500. By 2025, the level of ecological civilization construction had improved across all prefectures and cities. However, the gradient pattern of "medium-to-high in the center, average in the east, and low in the west" remained pronounced. The range between Guiyang City, which exhibited the highest proximity index, and Qianxinan Prefecture, which exhibited the lowest, widened from 0.2152 to 0.3429. An analysis of the growth rates across the three primary regions reveals that the average increase in the Central Region's alignment index was 73.56 percent, which is 1.98 times that of the Eastern Region. Meanwhile, the Western Region experienced a 43.50 percent increase, indicating a widening gap between the Central Region and both the Eastern and Western Regions. This phenomenon can be attributed to the presence of two major growth poles—Guiyang and Zunyi—in the central region. These cities possess a robust economic foundation and significant advantages in factor aggregation. Furthermore, investments in ecological governance and the development of green industries have progressed concurrently. Conversely, the western and eastern regions exhibit comparatively weaker economic foundations and constrained capacity for factor aggregation, leading to a comparatively languid pace of development.

Figure 2: Heatmap of the Grade Advancement in Ecological Civilization Construction Levels Across Prefecture-level Cities in Guizhou

Region	City	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
	Qianxinan	0.209	0.216	0.226	0.221	0.241	0.254	0.248	0.240	0.207	0.229	0.245	0.223	0.207	0.205	0.202
Western	Liupanshui	0.139	0.139	0.158	0.180	0.189	0.184	0.184	0.182	0.198	0.207	0.216	0.223	0.223	0.220	0.230
	Bijie	0.147	0.132	0.148	0.110	0.131	0.196	0.195	0.216	0.235	0.249	0.269	0.268	0.253	0.278	0.278
	Anshun	0.202	0.198	0.202	0.225	0.221	0.241	0.242	0.242	0.245	0.246	0.266	0.288	0.273	0.259	0.259
Central	Guiyang	0.354	0.377	0.501	0.503	0.495	0.568	0.607	0.597	0.652	0.659	0.673	0.661	0.649	0.604	0.544
	Zunyi	0.187	0.186	0.209	0.220	0.266	0.326	0.324	0.331	0.334	0.407	0.409	0.458	0.467	0.470	0.487
	Qiannan	0.215	0.215	0.224	0.197	0.216	0.227	0.266	0.259	0.273	0.281	0.297	0.311	0.328	0.315	0.320
Eastern	Qiandongnan	0.221	0.218	0.217	0.229	0.232	0.242	0.257	0.254	0.264	0.277	0.285	0.301	0.292	0.293	0.294
	Tongren	0.211	0.211	0.214	0.231	0.227	0.234	0.247	0.255	0.258	0.264	0.280	0.277	0.269	0.274	0.273

Grade: Low [0, 0.20) | Relatively Low [0.20, 0.30) | Medium [0.30, 0.50) | Relatively High [0.50, 1.00]

Figure 2. Heatmap of the grade advancement in ecological civilization construction levels across prefecture-level cities in Guizhou.

To more objectively characterize the evolutionary patterns of regional coordination in Guizhou's ecological civilization development and to analyze the underlying mechanisms behind regional disparities, this paper further introduces the Dagum Gini coefficient and its decomposition method to conduct a quantitative analysis of regional disparities [30] [34], as shown in **Table 8**. The province's overall Gini coefficient has shown a fluctuating upward trend, rising from 0.1352 in 2011 to 0.1758 in 2025, representing a total increase of 30.01%. Regional disparities in Guizhou's ecological civilization development are widening, and regional coordination needs to be strengthened; During this period, the overall Gini coefficient peaked at 0.2005 in 2023 before declining slightly, and regional disparities have shown signs of convergence in recent years. Analysis of the sources of variation reveals that regional imbalances in Guizhou's ecological civilization development primarily stem from disparities among the three major regions, which account for an average annual contribution of 74.44% to the overall disparity. Intra-regional disparities and hyper-variability density contribute 20.44% and 5.12% on average, respectively. The key to addressing the uneven development of Guizhou's ecological civilization lies in the reasonable and effective implementation of policies to promote coordinated improvement across regions.

At the regional level, it can be observed that the disparities in the level of ecological civilization development among regions primarily stem from the differences between the Central Region and the other two regions. The average proximity differences between the Central Region and the Western Region, and between the Central Region and the Eastern Region, were 0.2948 and 0.2135, respectively—both higher than the average inter-regional difference of 0.2066. From a developmental perspective, during the study period, the Gini coefficients for the Central Region relative to the Western Region and the Eastern Region both showed a fluctuating upward trend, rising from 0.2157 and 0.1302 in 2011 to 0.2964 and 0.2187 in 2025, representing increases of 37.40% and 68.06%, respectively; the Gini coefficient between the western and eastern regions, however, showed a fluctuating downward trend, falling from 0.1332 to 0.1132, a decrease of 14.98%. The level of ecological civilization development in Guizhou exhibits a distribution pattern characterized by "the central region leading, with the eastern and western regions following", and regional disparities have widened. The central region holds an absolute lead, and the pattern of "a strong central region and weak eastern and western regions" has become somewhat entrenched. Narrowing the gap between the central region and the other two major regions is key to addressing the imbalance in the development of ecological civilization in Guizhou.

Table 8. Gini coefficients for the proximity of ecological civilization development in Guizhou's Prefecture-Level Cities.

Year	Overall	G_w Contribution Rate (%)	G_{nb} Contribution Rate (%)	G_t Contribution Rate (%)	Central-Western	Central-East	West-East
2011	0.1352	21.51	64.96	13.53	0.2157	0.1302	0.1332
2012	0.1518	21.79	63.46	14.75	0.2447	0.1479	0.1422
2013	0.1767	23.22	68.08	8.69	0.2818	0.1971	0.1166
2014	0.1884	23.84	73.26	2.90	0.3002	0.1940	0.1383
2015	0.1750	22.92	72.31	4.77	0.2812	0.1923	0.1172
2016	0.1786	20.74	75.66	3.61	0.2880	0.2355	0.0803
2017	0.1850	20.95	76.58	2.46	0.3058	0.2227	0.1033
2018	0.1775	20.27	77.73	2.00	0.2950	0.2215	0.0934
2019	0.1910	19.98	77.45	2.57	0.3162	0.2349	0.1080
2020	0.1924	19.34	77.09	3.57	0.3150	0.2557	0.0913
2021	0.1815	19.91	77.35	2.74	0.2988	0.2395	0.0827
2022	0.1897	17.64	80.93	1.43	0.3268	0.2362	0.1093
2023	0.2005	17.99	79.27	2.75	0.3407	0.2411	0.1309
2024	0.1886	18.50	76.37	5.13	0.3157	0.2354	0.1144
2025	0.1758	17.91	76.14	5.95	0.2964	0.2187	0.1132

Note: The nine prefecture-level cities are divided into three major regions based on geographical location: the West (Southwest Guizhou Prefecture, Liupanshui City, Bijie City), the Centre (Anshun City, Guiyang City, Zunyi City) and the East (South Guizhou Prefecture, Southeast Guizhou Prefecture, Tongren City); G_w, G_{nb} and G_t represent intra-regional disparities, inter-regional net value disparities and hyper-variation density, respectively.

5. Conclusions and Recommendations

In response to the shortcomings of existing evaluation systems for the level of ecological civilization construction, this paper innovatively incorporates public attention—measured by Baidu Index—and government attention—measured by word frequency in government work reports—into the ecological culture dimension. By integrating multi-source data from statistical yearbooks, statistical bulletins, Baidu Index, government work report texts, and ecological environment status bulletins, this study constructs an evaluation indicator system for the level of ecological civilization construction in Guizhou's prefecture-level cities across four dimensions: ecological economy, ecological environment, ecological livability, and ecological culture; Using raw data from nine prefecture-level cities in Guizhou from 2011 to 2025, this study employs the entropy-weighted TOPSIS method to conduct an empirical evaluation of their ecological civilization development levels. Furthermore, the Dagum Gini coefficient decomposition method is utilized to analyze regional disparities and their sources, leading to the following research conclusions:

1) From a temporal perspective, Guizhou's nine prefecture-level cities demonstrated an overall steady upward trend in terms of ecological civilization development during the study period. Following an extended period of growth, the province's average proximity index attained its zenith in recent years and subsequently experienced a modest decline, entering a phase of adjustment at an elevated level. However, given the nature of the "proximity index" as a relative measure, the indices for the majority of prefecture-level cities and prefectures have persistently remained below the intermediate level. The discrepancy between their present state and the optimal state remains substantial; The relative distance from the optimal solution within the sample remains significant, and the overall level of construction remains relatively low, and there is still considerable room for improvement in the advancement of ecological civilization.

2) From the perspective of spatial patterns, the average convergence levels of various cities and prefectures during the study period exhibited distinct tiered differentiation and shifts in rankings. Guiyang City maintained its leading position in the province, showcasing its role as the provincial capital. Zunyi City ranked second, having rapidly ascended from a mid-to-lower position at the study's inception to its current leading position. Together with Guiyang City, Zunyi City constituted the Central Guizhou growth pole. Qiannan Prefecture, Southeast Guizhou Prefecture, Tongren City, Anshun City, Bijie City, and Southwest Guizhou Prefecture formed the middle tier. Among them, Bijie City exhibited distinct characteristics of a latecomer catching up, while Southwest Guizhou Prefecture lagged behind, exhibiting a relative regression rather than progress; Liupanshui City ranked last, but the trend of gradual improvement in its development level has not yet been interrupted.

3) From the perspective of regional disparities, the province's overall Gini coefficient fluctuated upward during the study period, and regional disparities tended to widen. A decomposition of the sources of these disparities showed that interregional disparities accounted for over 70 percent of the total, making them the dominant source of regional imbalances, while intraregional disparities and the contribution of hyper-dense areas were relatively limited. Disparities between the central and western regions, as well as between the central and eastern regions, have both widened significantly. The province displays a distribution pattern characterized by "the central region leading, with the eastern and western regions following", and the trend of "relative strength in the center and relative weakness

in the east and west" has become somewhat entrenched. Despite the initial indications of convergence in regional disparities in recent years, the necessity of enhanced regional coordination remains paramount.

In light of the aforementioned conclusions, the following policy recommendations are hereby proposed: Initially, it is imperative to consolidate the Guiyang and Zunyi growth poles in Central Guizhou, thereby fortifying their radiating and driving effects. The existing advantages of these two cities in ecological economy, municipal infrastructure, and science, education, and cultural resources should be leveraged to drive the coordinated development of surrounding prefectures and cities. This can be achieved through industrial collaboration, the flow of production factors, and the sharing of public services. Secondly, both eastern and western regions should prioritize the rectification of deficiencies in municipal infrastructure, as well as the advancement of ecological and cultural development. Efforts should prioritize increased investment in municipal facilities, such as natural gas supply and wastewater treatment, while expanding the supply of educational and cultural resources and upgrading public cultural dissemination facilities. Thirdly, resource-based cities such as Liupanshui should accelerate their transition toward a green and low-carbon economy, reduce pollutant emission intensity, and shift their industrial structure from reliance on energy extraction to a green industrial system. Fourthly, public and government awareness should be heightened by strengthening publicity and education on ecological civilization. This can be achieved by consistently incorporating ecological civilization construction into government work plans and forming a synergistic effort driven by government guidance and public participation. The fifth imperative is to establish and improve mechanisms for intra-provincial regional coordination and ecological compensation. Addressing the long-standing structural imbalances that have dominated interregional disparities is imperative. Horizontal ecological compensation and paired assistance between the central, eastern, and western regions must be promoted to effectively narrow regional gaps and reverse the entrenched trend of "a strong center and weak east and west".

"Data Availability" Statements

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Availability of Data and Material

Most of the data generated or analyzed during this study are included in the manuscript, and the rest data are promptly available to readers without undue qualifications.

Author Contributions

Conceptualization, Mu Zhang; methodology, Mu Zhang; validation, Mu Zhang and Xiaoyun Tian; formal analysis, Mu Zhang and Xiaoyun Tian; investigation, Xiaoyun Tian; resources, Mu Zhang; data curation, Mu Zhang and Xiaoyun Tian; writing—original draft preparation, Mu Zhang and Xiaoyun Tian; writing—review and editing, Mu Zhang and Xiaoyun Tian; supervision, Mu Zhang; project administration, Mu Zhang; funding acquisition, Mu Zhang. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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Appendix 1

Table S1. Missing data table.

City	Year	Indicator	Number of Imputed Values (Percentage)	Imputation Method
Guiyang City	2024	A1-4, A1-5, A3-4, A3-5	4 (10.8%)	Linear Interpolation, Exponential Smoothing
	2025	A1-4, A1-5, A2-8, A2-9, A2-10, A3-1, A3-4, A3-5, A3-6, A3-7, A3-8, A3-10, A3-11, A4-4	14 (37.8%)	
Liupanshui City	2011	A4-10	1 (2.7%)	
	2012	A4-10	1 (2.7%)	
	2024	A1-5, A3-4	2 (5.4%)	
	2025	A1-4, A1-5, A2-5, A2-6, A2-7, A2-8, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-8, A3-10, A3-11, A4-4	19 (51.4%)	
Zunyi City	2011	A4-10	1 (2.7%)	
	2012	A4-10	1 (2.7%)	
	2024	A1-4, A1-5, A3-4, A3-5, A3-11	5 (13.5%)	
	2025	A1-4, A1-5, A2-7, A2-8, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-8, A3-10, A3-11, A4-5, A4-6, A4-7, A4-10	20 (54.1%)	
Anshun City	2011	A3-1, A4-5, A4-6, A4-7, A4-10	5 (13.5%)	
	2012	A3-1, A4-5, A4-6, A4-7, A4-10	5 (13.5%)	
	2024	A2-5, A3-4, A3-5, A3-10	4 (10.8%)	
	2025	A1-4, A1-5, A2-5, A2-7, A2-8, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-8, A3-10, A3-11, A4-4, A4-5, A4-6, A4-7, A4-10	22 (59.5%)	
Bijie City	2011	A3-1, A4-10	2 (5.4%)	
	2012	A3-1, A4-10	2 (5.4%)	
	2017	A4-5	1 (2.7%)	
	2018	A4-5	1 (2.7%)	
	2019	A2-9, A4-5	2 (5.4%)	
	2024	A1-4, A3-4, A3-6	3 (8.1%)	
	2025	A1-4, A1-5, A2-5, A2-7, A2-8, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-8, A3-10, A3-11, A4-4, A4-10	19 (51.4%)	
Tongren City	2011	A3-9, A4-10	2 (5.4%)	
	2012	A4-10	1 (2.7%)	
	2019	A2-9	1 (2.7%)	
	2021	A3-1, A4-5	2 (5.4%)	
	2022	A2-9, A3-1, A4-5	3 (8.1%)	

Continued

	2023	A2-9, A4-5	2 (5.4%)
	2024	A1-4, A2-9, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-10, A3-11, A4-5	11 (29.7%)
	2025	A1-4, A1-5, A2-7, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-8, A3-10, A3-11, A4-4, A4-5, A4-6, A4-7, A4-10	20 (54.1%)
Qianxinan Prefecture	2011	A3-1, A3-9, A4-5, A4-6, A4-7, A4-8, A4-9, A4-10	8 (21.6%)
	2012	A3-1, A4-5, A4-6, A4-7, A4-8, A4-9, A4-10	7 (18.9%)
	2013	A3-1, A4-5, A4-6, A4-7, A4-8, A4-9	6 (16.2%)
	2014	A3-1, A4-5, A4-6, A4-7, A4-8, A4-9	6 (16.2%)
	2015	A3-1, A4-5, A4-6, A4-7	4 (10.8%)
	2016	A3-1, A4-5, A4-6, A4-7	4 (10.8%)
	2017	A3-1, A4-5, A4-6, A4-7	4 (10.8%)
	2024	A3-6	1 (2.7%)
	2025	A1-4, A1-5, A2-8, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-6, A3-7, A3-8, A3-10, A3-11, A4-5, A4-6, A4-7, A4-10	18 (48.6%)
Southeastern Guizhou Prefecture	2011	A2-10, A3-1, A3-9, A4-10	4 (10.8%)
	2012	A3-1, A4-10	2 (5.4%)
	2013	A3-1	1 (2.7%)
	2014	A3-1	1 (2.7%)
	2024	A1-4, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-10, A3-11	9 (24.3%)
	2025	A1-4, A1-5, A2-5, A2-7, A2-8, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-8, A3-10, A3-11, A4-7, A4-10	19 (51.4%)
Qiannan Prefecture	2011	A3-9, A4-10	2 (5.4%)
	2012	A4-10	1 (2.7%)
	2023	A2-9	1 (2.7%)
	2024	A1-4, A2-9, A3-2, A3-3, A3-4, A3-7, A3-11	7 (18.9%)
	2025	A1-4, A1-5, A2-5, A2-8, A2-9, A2-10, A3-1, A3-2, A3-3, A3-4, A3-5, A3-6, A3-7, A3-10, A3-11, A4-4, A4-10	17 (45.9%)
Total	—	—	**5.97%**

Note: ① This table uses "City-Year" as the row, listing all 298 cities with missing observations, along with their respective years and indicators (indicators are represented by symbols; see Table S1 for symbol definitions and units), covering a total of 49 city-year combinations; ② "Number (Proportion) of Imputed Values" refers to the number of imputed data points for that city-year combination and its proportion of the 37 secondary indicators; the proportion in the total row is calculated based on all 4,995 data points.