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Analysis of Coupling Coordination Variance between Urbanization Quality and Eco-Environment Pressure: A Case Study of the West Taiwan Strait Urban Agglomeration, China

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Abstract: Rapid urbanization has affected the eco-environment in China. A clear understanding of the coupling relationship between urbanization quality and eco-environment pressure is needed for sustainable urban development. This study focused on the relationship between urbanization quality and eco-environment pressure in the West Taiwan Strait Urban Agglomeration (WTSUA) with panel data collected from 2003 to 2017. An index system was established to measure urbanization quality from four urbanization subsystems: demographic urbanization, spatial urbanization, economic urbanization, and social urbanization. An index of eco-environment pressure was developed from resource availability, energy consumption, pollution emissions, and pressure response. The level of urbanization quality and eco-environment pressure was assessed using analytic hierarchy process (AHP) and entropy method (EM). The coupling process was described using a coupling coordination degree model. Results showed the following: (1) Economic urbanization contributed the most to urbanization quality. The contribution of the four subsystems to eco-environment pressure was similar. (2) Eco-environment pressure decreased with improving urbanization quality. The coupling coordination degree between urbanization quality and eco-environment pressure increased. Spatially, the coupling coordination degree of eastern cities was higher than that of western cities. The findings of this paper will help government in planning and implementing sustainable urban development and eco-environment conservation.

Keywords: urbanization quality; eco-environment pressure; coupling coordination degree; West Taiwan Strait Urban Agglomeration; analytic hierarchy process; entropy method

1. Introduction

Urbanization is one of the most important human activities to affect the earth [1]. At present, more than 50% of the population lives in cities in the world, and this proportion is growing rapidly

[2]. Urbanization promotes global economic growth, affects regional resources, and changes the natural environment on several scales [3,4]. China has experienced high rates of economic prosperity and urban population growth, and the urbanization process has increased in speed significantly since 'reform and opening-up' of China in 1978 [5]. In 2018, the proportion of China's urban population was 56.1%, with an increase of 38.2 percentage points compared with 1978 [6]. However, severe challenges have emerged during the process of urbanization, including regional economic disparity, environmental pollution intensification, excessive resource consumption, and increasing traffic congestion [7–10]. The conflict between urban growth and eco-environment sustainability has become increasingly obvious. Therefore, understanding how to coordinate urbanization and eco-environmental protection is crucial for promoting coordinated, stable and sustainable development that balances the regional economy, society, and eco-environment.

Assessment and analysis of the relationship between urbanization and the eco-environment have attracted attention from researchers and policymakers. Many studies have been conducted using different methods and models—both equalization and quantitation [11–13]. Previous studies on urbanization have concentrated on population. For example, the relationship between the urban population and ecological footprint was analyzed in the Middle East and North African region, and urbanization was considered a significant factor leading to environmental degradation [14]. In developing countries, Martínez-Zarzoso [15] examined the relationship between urbanization and carbon emissions and found that the relationship between urbanization and CO₂ emissions followed an inverted-U shape. Urbanization reflects social and economic change closely, including extensive changes in land-use, demographic migration, lifestyle, and industrial structure [16]. Consequently, the phenomenon of urbanization should be treated with a more comprehensive view. Studying urbanization quality has become a focus, as this can reflect the essential characteristics of urbanization in relation to the economy, society, eco-environment, and other aspects. In recent years, a comprehensive index system has been introduced to measure urbanization quality [17,18]. In Guangdong province, an index system of urbanization quality was established that comprehensively considered the elements associated with urbanization quality in terms of population, economy, society, and space, and the coupling relationship between urbanization quality and energy-environment efficiency were quantified [2]. Zang and Su [19] proposed an indicator system of urbanization quality including economy, population, public services and ecology to analyze the spatiotemporal evolution of the internal coordination degree of urbanization in 283 prefecture-level cities in China. Existing research has focused on the effects of urbanization on eco-environment [20–23] and the relationship between urbanization and eco-environment [24–26], and the interaction mechanism between urbanization and the eco-environment has been explained. Zhao et al. used an improved environmental Kuznets curve (EKC) model to study the relationship between urbanization and the eco-environment in the Yangtze River Delta region, and the result showed that the coordination coupling relationship between urbanization and eco-environment conformed to the s-shaped curve [27]. In a study of the Beijing–Tianjin–Hebei region, the relationship between urbanization and eco-environment presented a double-exponential curve with an inverted u-shaped curve, which verified that there was an interactive coercing effect between them [16]. Additionally, studies on urbanization and eco-environment are mostly focused on developed areas in China, such as the Beijing–Tianjin–Hebei region [28,29], Shanghai [30] and Wuhan [31], with few studies on emerging urban agglomerations. There is an urgent need to analyze changes with respect to urbanization quality and eco-environment pressure in new and developing regions, and identify the interaction mechanism between the two. This will provide theoretical guidelines and suggestions for policymakers in the formulation of urban development and environmental conservation policy.

The West Taiwan Strait Urban Agglomeration (WTSUA) is one of the most dynamic growth areas in China. In recent years, the WTSUA has suffered from several eco-environment pressures. However, there is little research into the relationship between urbanization quality and eco-environment pressure. Therefore, the objectives of this study are to: (1) evaluate the urbanization quality and eco-environment pressure for the WTSUA from 2003 to 2017; (2) analyze the spatiotemporal dynamics of urbanization quality and eco-environment pressure; (3) reveal the

characteristics of the coupling coordination relationship between urbanization quality and eco-environment pressure; and (4) propose more feasible urban development policies and environment protection proposals. To fulfill these objectives, a comprehensive evaluation method based on the analytic hierarchy process (AHP) and entropy method (EM) was applied to assess urbanization quality and eco-environment pressure. The dynamic coupling process between urbanization quality and eco-environment pressure was described using a coupling coordination degree model.

2. Materials and Methods

2.1. Study Area

The WTSUA is located on the southeast coast of China (Figure 1). The latitude ranges from 113.86° to 121.23° E and the longitude ranges from 22.82° to 29.57° N. It covers 0.27 million km² and accounts for 2.8% of China's territory. The urban agglomeration covers 20 cities across Fujian, Zhejiang, Guangdong, and Jiangxi provinces and five cities (Fuzhou, Quanzhou, Xiamen, Wenzhou, and Shantou) were taken as the core cities. Table 1 shows the basic information for each city of the WTSUA [32].

The WTSUA was first proposed in the “National Urban System Planning” in 2006 and became one of the eight major urban agglomerations supporting national development [33]. The WTSUA has undergone rapid urbanization by virtue of its geographical location and mild climate. The population increased from 85.14 million in 2003 to 96.06 million in 2018, with a growth rate of 12.8%. At the end of 2018, the urbanization rate of the urban agglomeration was 61.42%, which was higher than the average level of China. The GDP was 5.87 trillion Yuan, accounting for 6.5% of the national GDP. The ratio of the three industrial structures was 7:47:46, and light industry accounted for a larger proportion than heavy industry. About 80% of land is still covered by forests in the WTSUA, which carries a wealth of biodiversity resources and offers more ecological advantages than some other areas.

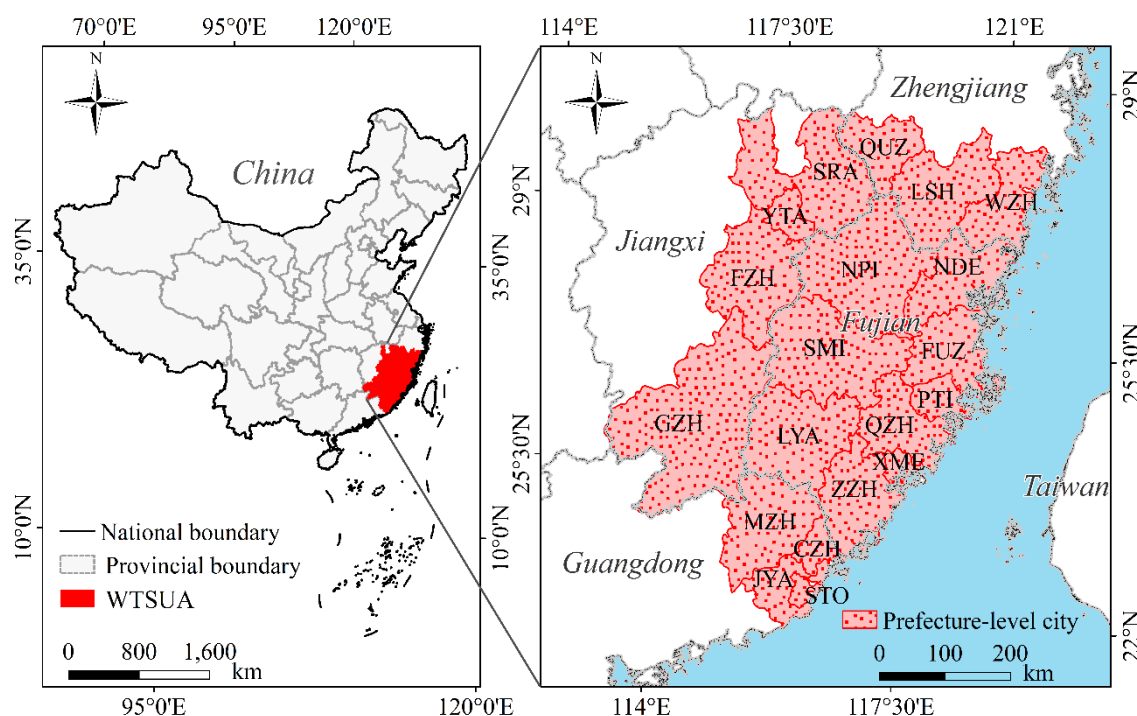


Figure 1. Location of the study area (WTSUA represents the West Taiwan Strait Urban Agglomeration, FUZ represents Fuzhou, XME represents Xiamen, PTI represents Putian, SMI represents Sanming, QZH represents Quanzhou, ZZH represents Zhangzhou, NPI represents Nanping, LYA represents Longyan, NDE represents Ningde, STO represents Shantou, JYA represents Jieyang, CZH represents Chaozhou, MZH represents Meizhou, WZH represents Wenzhou, LSH

represents Lishui, QUZ represents Quzhou, FZH represents Fuzhou, SRA represents Shangrao, YTA represents Yingtan, GZH represents Ganzhou).

Table 1. Basic information description for each city of the WTSUA.

Name	Municipality or Province	Area (Thousand km ²)	Population (Million Persons)	GDP (Trillion-Yuan)	Percentage of Urban Population (%)	Code
Fuzhou	Fujian	12.0	0.70	0.79	70.30	FUZ
Xiamen	Fujian	1.7	0.24	0.48	89.10	XME
Putian	Fujian	4.2	0.36	0.22	61.00	PTI
Sanming	Fujian	2.3	0.29	0.24	60.20	SMI
Quanzhou	Fujian	11.0	0.76	0.85	66.60	QZH
Zhangzhou	Fujian	12.6	0.52	0.39	59.00	ZZH
Nanping	Fujian	26.3	0.32	0.18	56.70	NPI
Longyan	Fujian	19.0	0.32	0.24	57.00	LYA
Ningde	Fujian	13.5	0.35	0.19	56.70	NDE
Shantou	Guangdong	2.2	0.57	0.25	70.41	STO
Jieyang	Guangdong	5.2	0.71	0.22	51.18	JYA
Chaozhou	Guangdong	3.7	0.28	0.11	65.30	CZH
Meizhou	Guangdong	15.9	0.55	0.11	50.49	MZH
Wenzhou	Zhejiang	11.6	0.83	0.60	70.00	WZH
Lishui	Zhejiang	17.3	0.27	0.14	61.50	LSH
Quzhou	Zhejiang	8.8	0.26	0.15	58.00	QUZ
Fuzhou	Jiangxi	18.8	0.42	0.14	49.81	FZH
Shangrao	Jiangxi	22.8	0.76	0.22	52.00	SRA
Yingtan	Jiangxi	3.6	0.13	0.08	60.68	YTA
Ganzhou	Jiangxi	39.4	0.98	0.28	51.70	GZH

Note: The data in the table denote the basic information of each city in 2018.

2.2. Evaluation Index System of Urbanization Quality and Eco-environment Pressure

To accurately evaluate the relationship between urbanization quality and eco-environment pressure for the WTSUA, comprehensive index systems of urbanization quality and eco-environment pressure were established based on objective scientific principles. The index system of urbanization quality was established from the four dimensions of population growth, spatial expansion, economic development and life improvement to evaluate the level of urbanization quality [34], which corresponded to the four subsystems of demographic urbanization, spatial urbanization, economic urbanization, and social urbanization, and 10 basic level indicators were selected (Table 2). A comprehensive index system of eco-environment pressure included four subsystems (resource availability, energy consumption, pollution emissions, and pressure response) and 12 basic level indicators [27,35] (Table 3).

Table 2. Evaluation index system of urbanization quality.

System	Subsystem	Basic Level Indicators	Unit	Data Source
Urbanization Quality	Demographic urbanization	Urban population density (X ₁)	persons/km ²	China City Statistical Yearbook [32]
		Percentage of the secondary and tertiary industry employment (X ₂)	%	China City Statistical Yearbook [32]
	Spatial urbanization	Area of built districts in municipal district (X ₃)	km ²	China City Statistical Yearbook [32]
		Per capita city road area (X ₄)	m ² /capita	China City Statistical Yearbook [32]
		GDP per capita (X ₅)	Yuan	China City Statistical Yearbook [32]
	Economic urbanization	Proportion of the value of the secondary and tertiary industry to GDP (X ₆)	%	China City Statistical Yearbook [32]
		Total fixed asset investment (X ₇)	10 ⁴ Yuan	China City Statistical Yearbook [32]
	Social urbanization	Proportion of educational expenditure to financial expenditure (X ₈)	%	China City Statistical Yearbook [32]
		Number of beds of hospitals and health centers per 10,000 capita (X ₉)	bed	China City Statistical Yearbook [32]
		Disposable income of urban residents per capita (X ₁₀)	Yuan	China City Statistical Yearbook [32]

Table 3. Evaluation index system of eco-environment pressure.

System	Subsystem	Basic Level Indicators	Unit	Data Source
Eco-Environment Pressure.	Resource availability	Green areas (X ₁)	hm ²	China City Statistical Yearbook [32]
		Percentage of completed area with green covered area (X ₂)	%	China City Statistical Yearbook [32]
		Normalized Difference Vegetation Index (NDVI) (X ₃)	-	MODIS remote sensing data* [36]
	Energy consumption	Annual electricity consumption (X ₄)	10 ⁴ kW·h	China City Statistical Yearbook [32]
		Water consumption for residential use (X ₅)	10 ⁴ tons	China City Statistical Yearbook [32]
		Consumption of liquefied petroleum gas for residential use (X ₆)	tons	China City Statistical Yearbook [32]
	Pollution emissions	Discharged volume of industrial wastewater (X ₇)	10 ⁴ tons	China City Statistical Yearbook [32]
		Discharged volume of industrial SO ₂ (X ₈)	tons	China City Statistical Yearbook [32]
		Discharged volume of industrial dust (X ₉)	tons	China City Statistical Yearbook [32]
	Pressure response	Hazard-free treatment rate of domestic garbage (X ₁₀)	%	China City Statistical Yearbook [32]
		Urban domestic sewage treatment rate (X ₁₁)	%	China City Statistical Yearbook [32]
		Comprehensive utilization rate of industrial solid waste (X ₁₂)	%	China City Statistical Yearbook [32]

Note: *MODIS means moderate-resolution imaging spectroradiometer.

2.3. Comprehensive Assessment Combining EM and AHP

A combination of EM and AHP was used in this study to determine the weight of each indicator in the urbanization quality system and the eco-environment pressure system. EM is an objective weighting method that is not disproportionally influenced by experts' subjective opinion [37]. For the objective weighting method, the EM is far more widely used than any of the other techniques [38–40]. EM determines the indicator's weight based on the information size of each indicator by fully mining the information of the original data [41]. The greater the relative change in the indicator, the higher the weight [42]. Thus, the results have a strong theoretical and mathematical basis [43]. The AHP method, as a multi-objective decision analysis approach, quantifies expert empirical judgments to determine the index weights by combining quantitative and qualitative analysis, which has higher rationality [43–46]. Thus, combining the EM and AHP methods to determine the weight of each index can improve the accuracy of the weight and the credibility of the evaluation results. The flowchart of comprehensive evaluation combining EM and AHP was illustrated as Figure 2.

Step 1: Weight determination using EM

To eliminate differences in each indicator in dimension, magnitude, and sign, the maximum–minimum method was adopted to normalize the original data, so that the data were limited to a range of [0,1] [47]. The higher the value of indicator, the better the system efficiency. If a variable was a positive indicator, which showed that the indicator could contribute positively to the system, Equation (1) was selected to standardize the data. If the variable was a negative indicator, Equation (2) was chosen. After normalization of the original data, a matrix (H) of evaluation indicators (Equation (3)) was established. Then, the entropy value and weight of each indicator were calculated by Equations (4)–(6), in turn [48]:

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

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

$$H = (h_{ij})_{mn} \quad (3)$$

$$S_i = -\frac{1}{\ln m} \left(\sum_{j=1}^n X_{ij} \times \ln X_{ij} \right) \quad (4)$$

$$X_{ij} = h_{ij} / \sum_{j=1}^n h_{ij} \quad (5)$$

$$w_{ei} = (1 - S_i) / \sum_{i=1}^m (1 - S_i) \quad (6)$$

where x_{ij} is the original value of the i th ($i = 1, \dots, m$) indicator for the j th year ($j = 1, \dots, n$), h_{ij} is the normalized value of i th indicator, $\min x_i$ is the minimum of x_i , $\max x_i$ is the maximum of x_i , X_{ij} represents the proportion of the i th indicator in the j th year, S_i is the entropy value of the i th indicator, w_{ei} is the weight of the i th indicator.

Step 2: Weight determination using AHP

First, the established index systems of urbanization quality and the eco-environment pressure were regarded as an AHP structure. Second, the judgment matrix of the indicators for each hierarchy was established. Finally, the consistency index (CI), the corresponding average random consistency

index (RI), and the consistency ratio (CR) were calculated to test the judgement matrix's consistency and determine the weight of indicators at each level. When $CR < 0.01$, the ranking results based on AHP present a desirable consistency, that is, the allocation method of weight coefficient is feasible. Otherwise, the values of the matrix's element need to be adjusted and the weight coefficients reassigned [42]. The different order of each judgment matrix determines the corresponding average random consistency index of RI. CI and CR can be calculated by Equations (7) and (8):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (7)$$

$$CR = \frac{CI}{RI} \quad (8)$$

where $\lambda_{\max}$ is the highest real eigenvalue, n is the number of factors, CR represents the consistency coefficient, RI is the average random consistency indicator, and CI is the consistency indicator.

Step 3: Calculation of the level of urbanization quality and eco-environment pressure

According to the normalized value and weight of each indicator, the level of urbanization quality and eco-environment pressure were calculated by weighted summation. The formula is as follows:

$$w_i = \frac{(w_{ei} + w_{ai})}{2} \quad (9)$$

$$F_j = \sum_{i=1}^m (w_i \times h_{ij}) \quad (10)$$

where w_{ei} is the weight of the i th indicator using EM, w_{ai} is the weight of the i th indicator using AHP, w_i is the average weight of the i th indicator combined with AHP and EM, F_j represents comprehensive level in the j th year, h_{ij} is the normalized value of the i th indicator.

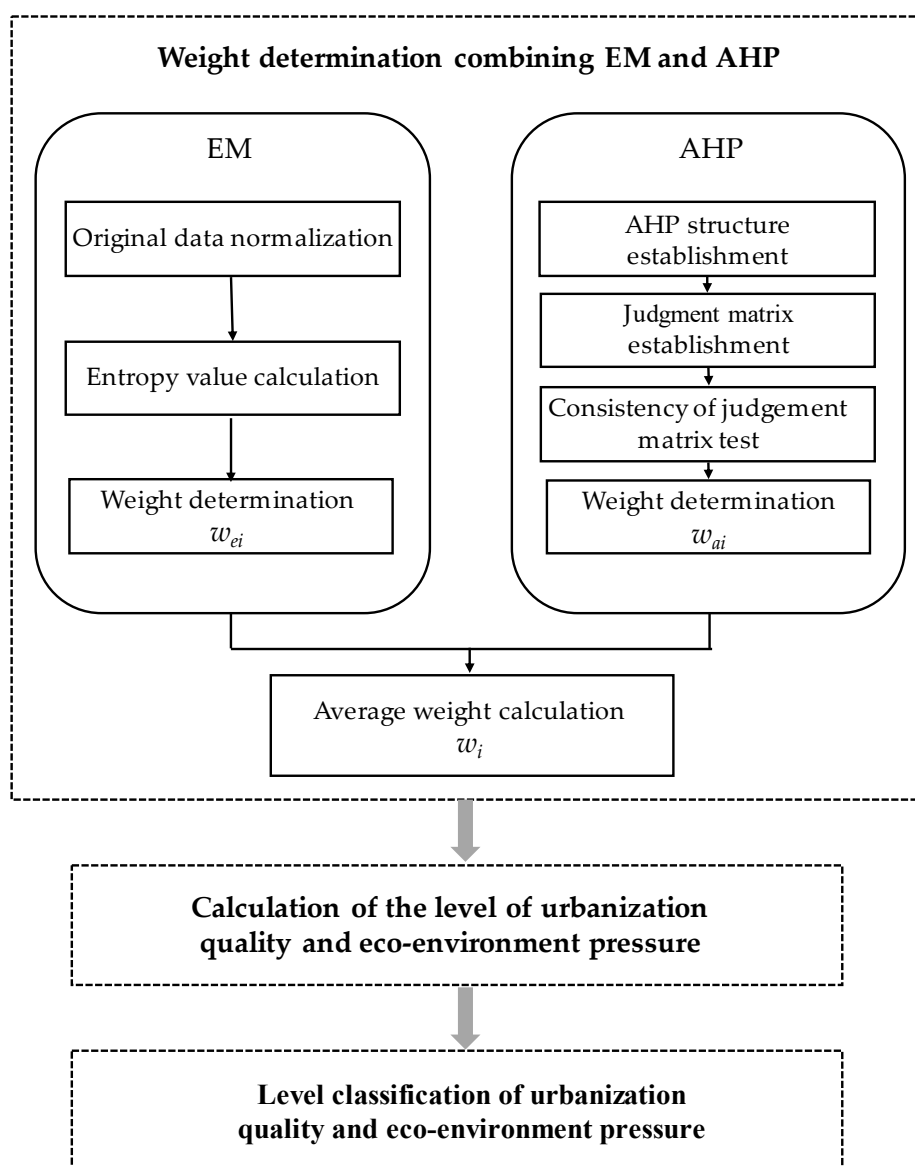


Figure 2. Flowchart of comprehensive evaluation combining the entropy method (EM) and analytic hierarchy process (AHP).

Step 4: Level classification of urbanization quality and eco-environment pressure

To clearly describe the spatial distribution characteristics of urbanization quality and eco-environment pressure within each dimension in the WTSUA, an equal interval method was adopted to analyze the level of urbanization quality and eco-environment pressure in 20 prefecture-level cities in this study. Specifically, the value of urbanization quality was divided into 0.118–0.280, 0.281–0.443, 0.444–0.606, and 0.607–0.770, which correspond to the level of very poor, poor, moderate, and good, respectively [49–51]. The value of eco-environment pressure was divided into 0.158–0.236, 0.237–0.315, 0.316–0.394, and 0.395–0.473, which correspond to the level of good, moderate, poor, and very poor, respectively.

2.4. Coupling Coordination Degree Model

A coupling coordination degree model was used in this study to accurately estimate the coordination level and relationship between the urbanization quality and eco-environment pressure. The coupling coordination degree model can be calculated by Equations (10)–(12):

$$C = 2\sqrt{f(UQ) \times g(EP)} / [f(UQ) + g(EP)] \quad (11)$$

$$D = \sqrt{C \times T} \quad (12)$$

$$T = \alpha f(UQ) + \beta g(EP) \quad (13)$$

where C defines the coupling degree of urbanization quality and eco-environment pressure, $f(UQ)$ and $g(EP)$ are the comprehensive level of urbanization quality and eco-environment pressure, respectively. D represents the coupling coordination degree, T shows the comprehensive coordination index of urbanization quality and eco-environment pressure, α and β stand for the contributions of urbanization quality and eco-environment pressure, respectively. The contributions of the two systems should be the same, thus the values of α and β are equal to 0.5 [52].

3. Results

3.1. Contribution of Each Variable to Urbanization Quality and Eco-Environment Pressure

The weight of each indicator in the urbanization quality system and eco-environment pressure system calculated by the AHP and EM methods are shown in Table 4. For the urbanization quality subsystem, economic urbanization accounted for the highest proportion (32.1%), which indicates that it had the biggest influence on urbanization quality. This was followed by social urbanization, demographic urbanization, and spatial urbanization, with weights of 26.1%, 25.8%, and 16.0%, respectively. In terms of the basic level index, the three factors of urban population density (16.7%), GDP per capita (12.2%), and proportion of the value of the secondary and tertiary industry to GDP (10.9%) accounted for 39.8% of the total impact. This indicated that they were important influences on the urbanization quality in the WTSUA. For the eco-environment pressure subsystem, the contribution of the four subsystems to eco-environment pressure was similar, which indicated that the roles of all four subsystems were equally important. In terms of the basic level index, green areas occupied the highest proportion, and other indicators accounted for 8.1–8.5%, with little difference among them.

Table 4. The indicator weight of urbanization quality and eco-environment pressure.

System	Subsystem	Basic Level Index		
Name	Name	Weight	Name	Weight
Urbanization Quality	Demographic urbanization	25.8%	Urban population density	16.7%
			Percentage of the secondary and tertiary industry employment	9.1%
	Spatial urbanization	16.0%	Area of built districts in municipal district	8.1%
			Per capita city road area	7.9%
			GDP per capita	12.2%
	Economic urbanization	32.1%	Proportion of the value of the secondary and tertiary industry to GDP	10.9%
			Total fixed asset investment	9.0%
			Proportion of educational expenditure to financial expenditure	8.6%
	Social urbanization	26.1%	Number of beds of hospitals and health centers per 10,000 capita	8.6%
			Disposable income of urban residents per capita	8.9%
Eco-environment Pressure	Resource availability	25.9%	Green areas	9.0%
			Percentage of completed area with green covered area	8.5%
			Normalized Difference Vegetation Index (NDVI)	8.4%
			Annual electricity consumption	8.2%
	Energy consumption	24.6%	Water consumption for residential use	8.2%
			Consumption of liquefied petroleum gas for residential use	8.2%
			Discharged volume of industrial wastewater	8.1%
	Pollution emissions	24.6%	Discharged volume of industrial SO ₂	8.3%
			Discharged volume of industrial dust	8.2%
			Hazard-free treatment rate of domestic garbage	8.3%
	Pressure response	24.9%	Urban domestic sewage treatment rate	8.6%
			Comprehensive utilization rate of industrial solid waste	8.2%

3.2. Spatiotemporal Pattern of Urbanization Quality and Eco-Environment Pressure

Figure 3 illustrates the dynamic changes of urbanization quality and eco-environment pressure and the level of their subsystem from 2003 to 2017. The level of urbanization quality of the study area showed an increase, with a change rate of 100% from 2003 to 2017 (Figure 3a). The four subsystems of urbanization quality exhibited the same trend with varying rates of growth. Economic urbanization grew the fastest, increasing by 207.77% from 2003 to 2017. This was followed by a significant trend of social urbanization, which increased by 96.73% from 2003 to 2017. Demographic urbanization also grew steadily. The level of demographic urbanization was higher than the other three subsystems from 2003 to 2010. The level of spatial urbanization was the lowest and the development trend was slow. In general, the level of eco-environment pressure from urban agglomeration showed a downward trend (Figure 3b). However, the four subsystems of eco-environment pressure showed different trends. The resource availability curve and pressure response curve showed a downward trend, and the downward trend of the response control curve was significant. This suggested that the pressure on the background resources has been reduced during the study period and environmental protection has been strengthened. Conversely, the energy consumption showed an upward trend, which indicates that the use of energy was increasing. The pollution emission curve first increased and then decreased, indicating that pollution emissions in the study area had been controlled to a certain extent since 2015.

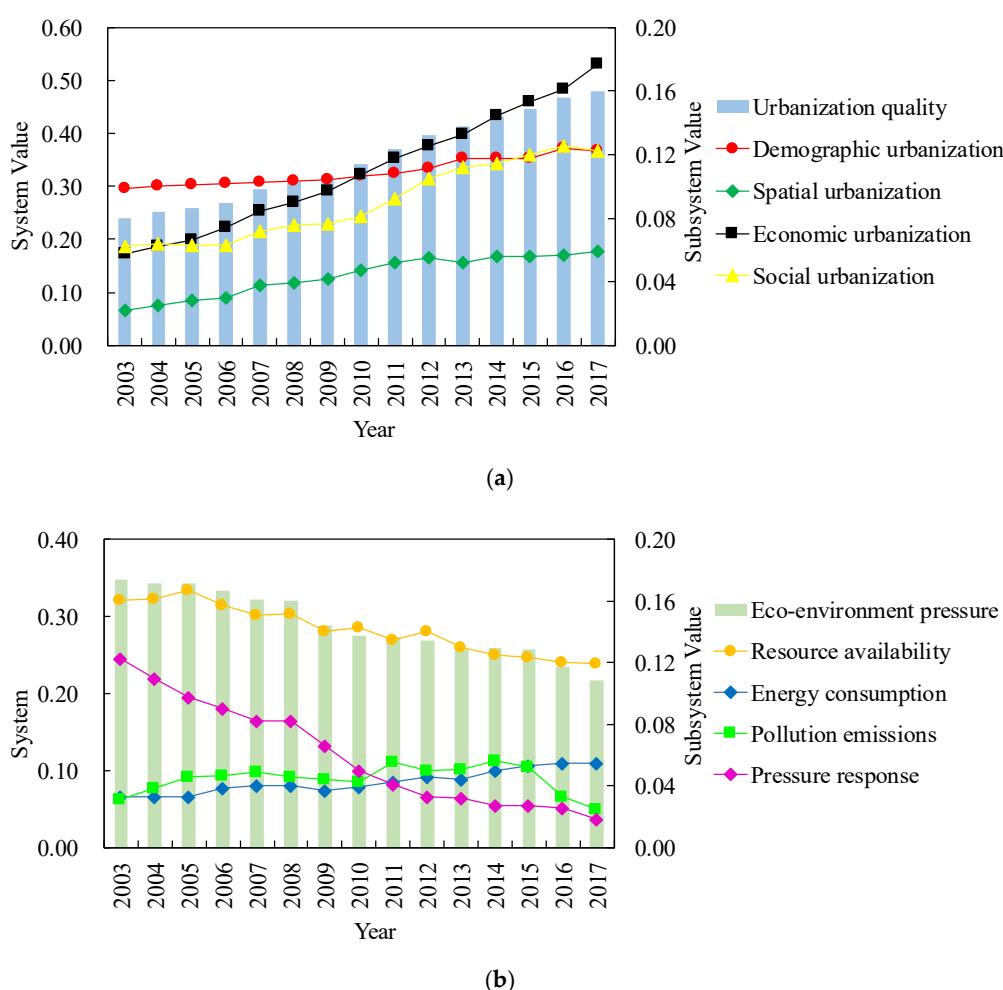


Figure 3. The dynamic changes of urbanization quality and eco-environment pressure and the levels of their subsystems from 2003 to 2017. (a) The dynamic changes of the level of urbanization quality and four subsystems from 2003 to 2017; (b) The dynamic changes of the level of eco-environment pressure and four subsystems from 2003 to 2017.

The grading results and spatial differentiation of urbanization quality and eco-environment pressure in different periods in the WTSUA are displayed in Figure 4. The urbanization quality increased from east to west across the urban agglomeration (Figure 4a). Cities with high urbanization quality were concentrated in the eastern coastal region, while the urbanization quality was lower in the central and western inland cities. The urbanization quality in core cities was significantly higher. In 2017, for example, the four core cities except STO were all at the “good” level. Additionally, the number of cities with an eco-environment pressure at the “good” level increased from 0 to 15, accounting for 75% of all cities in 2017 (Figure 4b). The number of cities with an eco-environment pressure below the “moderate” level decreased from 14 to 1. The eco-environment pressure in the study area showed significant differences between 2003 and 2008. The cities with the highest eco-environment pressure were mostly distributed in the southwest of the urban agglomeration, that is, the cities of Jiangxi and Guangdong provinces. The core cities of WZH and STO also showed high pressure. In 2013, the eco-environment pressure of each city in the study area had gradually decreased. In 2017, there was a narrowing of the differences in eco-environment pressure among the cities. The eco-environment pressure of most cities in the study area was at the “good” level, while the eco-environment pressure of core cities was still relatively high.

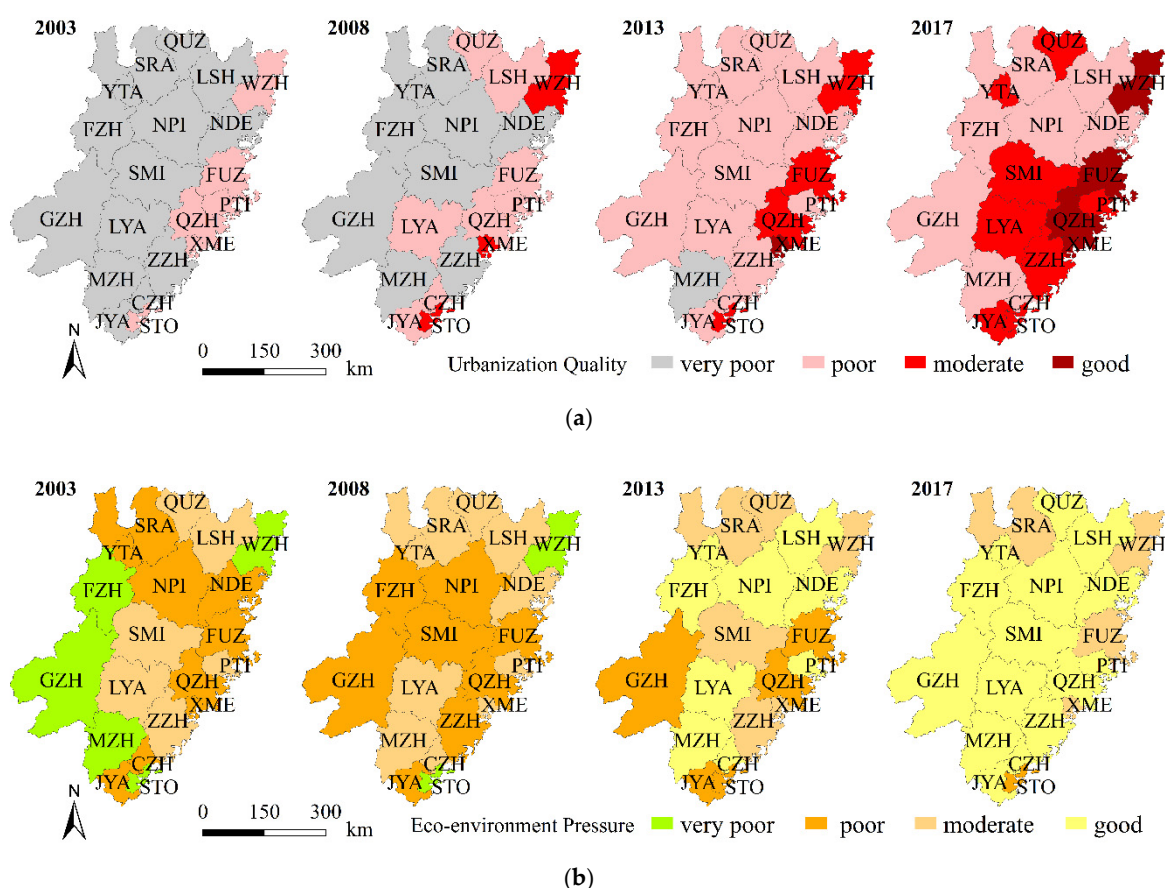


Figure 4. Spatial distribution characteristics of urbanization quality and eco-environment pressure in different periods in the WTSUA. (a) Spatial distribution characteristics of urbanization quality in 2003, 2008, 2013, and 2017; (b) Spatial distribution characteristics of eco-environment pressure in 2003, 2008, 2013, and 2017.

3.3. Coupling Coordination Relationship between Urbanization Quality and Eco-Environment Pressure

Figure 5 illustrates the coupling coordination degree between urbanization quality and eco-environment pressure in spatial and temporal dimensions. It was found that the coupling coordination degree between urbanization quality and eco-environment pressure presented a

general increase during the study period, which indicated that eco-environment pressure was decreasing with the continuous improvement urbanization quality.

Despite some spatial disparities, as for each city, the coupling coordination degree between urbanization quality and eco-environment pressure mostly presented an increase between 2003 and 2017. The coupling coordination degree of the eastern cities was higher than that of the western cities, which was consistent with the distribution pattern of urbanization quality. Compared with non-core cities, the core cities had a higher coupling coordination degree.

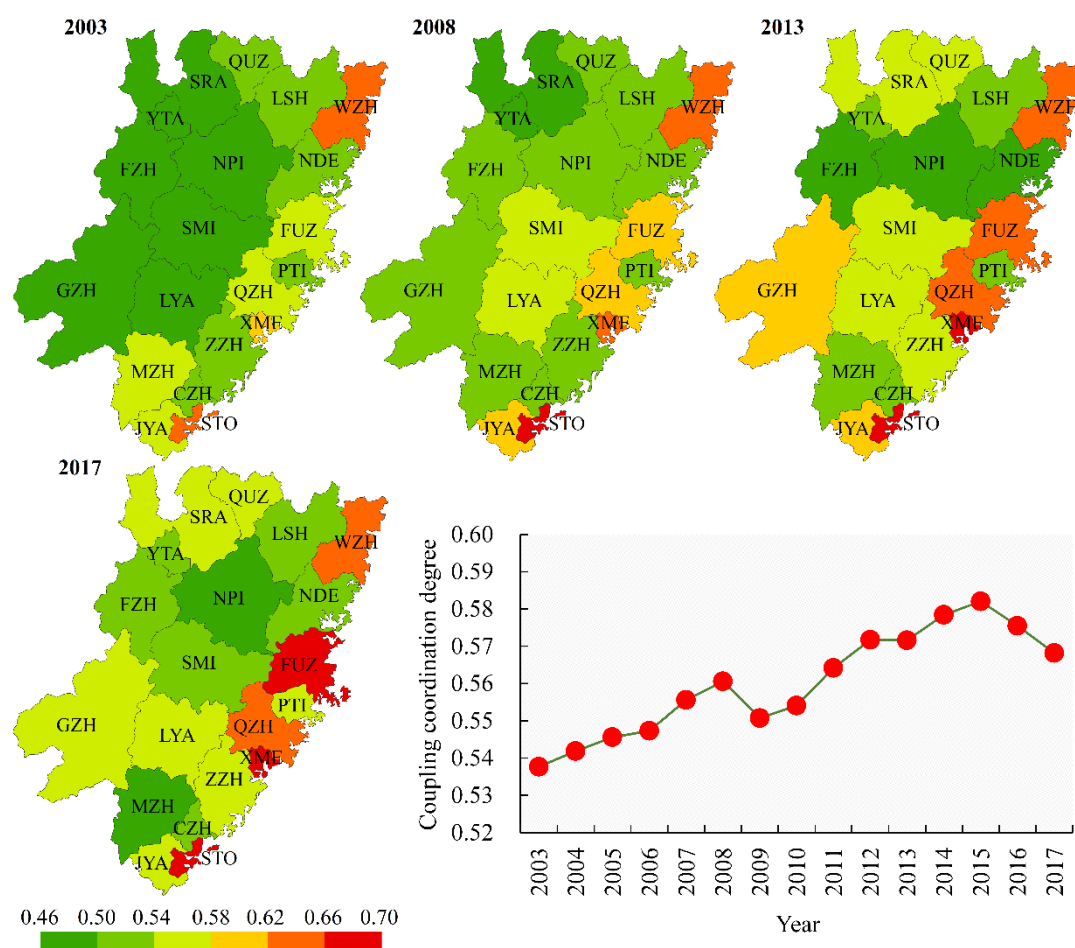


Figure 5. Spatiotemporal dynamics of coupling coordination degree between urbanization quality and eco-environment pressure in the WTSUA from 2003 to 2017.

4. Discussion

4.1. Interaction Coupling Mechanism between Urbanization Quality and Eco-Environment Pressure

The internal development law of urbanization quality is consistent with the conditions of synergetics [53]. Urbanization quality involves multidimensional meanings, including population growth, economic development, spatial expansion, and public services [41,54]. They are interrelated and interact, and ultimately affect the overall effect. Population is an underlying factor to promote the interaction of elements in the urbanization quality system [19]. Our results showed that the level of demographic urbanization was higher than the other three subsystems before 2010. The continuous influx of population from rural areas into urban areas greatly stimulated investment and consumption, as well as promoting economic development. At the same time, urban space was expanding and the spatial structure was changing to meet the space requirements brought about by population agglomeration. With the gradual development of the economy and the improvement of the people's economic level, people had higher demand for the city's development. Urban public services and infrastructure were gradually improved, which provided a good foundation for urban

economic development, and thus drove more rural people to migrate to the cities. Because of the interactions between the urbanization quality subsystems, a benign development situation has formed, in general. In the WTSUA, our results suggested that the overall level of urbanization quality showed an increase tendency, with a change rate of 100% from 2003 to 2017 (Figure 3a).

In the early days of urban development, a series of associated issues arose by the weak awareness of eco-environment protection [55–57], which had a destructive effect on the eco-environment. Facing severe challenges brought about by eco-environmental problems from urban development, several national plans and policies have been promulgated to reduce the eco-environment pressure. Figure 6 illustrates China's pivotal environment conservation plans and policies in different periods. The "Decision of the State Council on Several Issues Concerning Environmental Protection" was proposed in 1996, requiring "the control of total pollutant emissions to be implemented" [58]. The National "10th Five-Year Plan," "11th Five-Year Plan," and "12th Five-Year Plan" were subsequently implemented, which focused on adjusting the economic structure to reduce pollutant emissions [59]. Furthermore, the increase of investment in environmental protection is conducive to the construction of environmental infrastructure. Data show that, during the "11th Five-Year Plan" period, the national urban sewage treatment rate increased from 52% to 72%, and the hazard-free treatment rate of domestic garbage increased from 52% to 78% [58]. Driven by these policies, environmental protection has been continuously strengthened in the WTSUA. In 2012, the construction of ecological civilization was written into the "Party Constitution" and this accelerated environmental policy reform further [60]. An environmental protection tax levy has helped enterprises to focus on environmental governance issues, energy conservation, and emissions reduction during the process of production, which has reduced pollution emissions to some extent [61,62]. The progress of technology is another force to reduce eco-environment pressure [63,64]. On the one hand, technological progress is conducive to the governance of environmental pollution. As referenced by Grossman [65], the reform of production technology will reduce the intensity of pollution emissions. During the "11th Five-Year Plan" period, China's technological progress contributed about 60% to the reduction of chemical oxygen demand (COD), and about 45% to the reduction of SO₂ [66]. On the other hand, technological progress has promoted the upgrading of the industrial structure. The adjustment of industrial structure is conducive to improvements in energy efficiency [67]. Specifically, the structure of the energy industry has been changed. For example, the development of solar power, wind power, and hydropower technology could promote the efficient use of clean energy. Additionally, the improvement of industrial technologies for energy-saving, resource recycling, and environmental protection could promote the rapid development of the environmental protection industry [68]. As observed from our findings, the overall level of eco-environment pressure from the urban agglomeration has shown a downward trend from 2003 to 2017 (Figure 3b). Therefore, it can be inferred that the reduction of eco-environment pressure is driven to some degree by the implementation of protection policies and technological progress.

Although policies and technologies have been improved and developed continuously, pollutant emissions have been effectively controlled, and environment pressure has also declined, air pollution is still a serious situation in China [69–71]. Nevertheless, due to the good resource endowment in the WTSUA, about 80% of the land is covered by forests and rich in biodiversity resources, there are more ecological advantages than some other areas [72]. Especially, Fujian province as the main component of the WTSUA, its number of days that the air met the standards accounted for 98.2%, which was 19.4% higher than the national average level in 2016. The annual average concentration of PM_{2.5} was 42.6% lower than the national average level. Moreover, the forest coverage rate of Fujian province reached 65.95%, ranking the first in the country [73]. This probably explains the reasons for the decreasing eco-environment pressure of WTSUA to some extent.

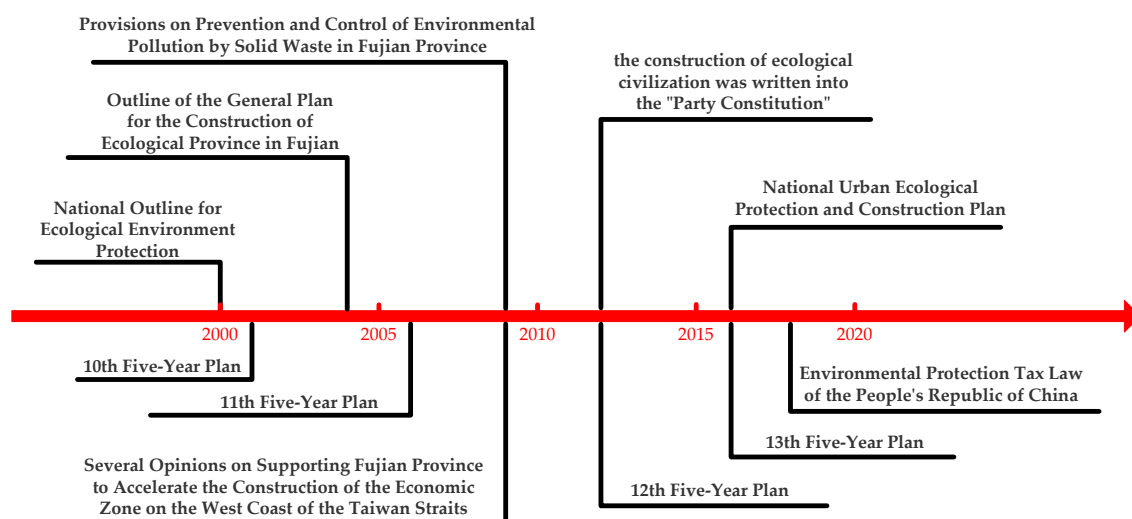


Figure 6. The Plans and policies of government affecting eco-environment pressure in different periods.

As referenced by Huang and Fang, Fang and Wang, and Liu et al. [74–76], a favorable eco-environment promotes and stimulates the sustainable and healthy urban development. The reduction of eco-environment pressure promotes the creation of a suitable living environment, attracting population agglomeration to the city. The concentration of the population is conducive to the improvement of socioeconomic efficiency and resource utilization efficiency, and thus urbanization quality is further improved. Furthermore, economic urbanization provides more investment for environmental protection. Policy interventions and up-to-date technology have allowed the pollution emissions to be controlled, and this also reduces eco-environment pressure. The mechanism of urbanization quality and eco-environment pressure is the interaction of two opposing forces, and once these are understood, coordinated development between urbanization quality and eco-environment pressure can be realized. Our results also suggested that the coupling coordination of urbanization quality and eco-environment pressures constantly increased (Figure 5).

4.2. Suggestions for Improving Sustainable Development between Urbanization Quality and Eco-Environment Pressure

Although the coupling relationship between urbanization quality and eco-environment pressure of the WTSUA has become more coordinated during the study period, there are still some issues that need to be addressed. Based on the above analysis, three suggestions are proposed that could be used as guidelines for achieving the coordinated development of urbanization quality and eco-environment pressure.

First, it is necessary to determine the development direction of each city. On the one hand, in order to give priority to the development of eco-environment protection, the eco-environment protection development model should be taken in coastal cities such as WZH and STO. Up-to-date technology should be introduced and investment increased to strengthen pollution control as well as improve resource utilization efficiency for the substantial development of a green economy in the future. On the other hand, a comprehensive development model should be adopted in inland cities such as GZH and SRA to jointly improve the urbanization quality and the eco-environment level. It is essential to take feasible measures to promote the development of a circular economy at the macro level, build ecological industrial chains at the meso level, and strengthen the use of cleaner production technologies at the micro level [77,78]. Second, it is advisable for urban planners and government policymakers to pay more attention to economic development and social security issues when formulating policies related to urban development. Third, the concept of eco-civilization should be cultivated and promoted. Eco-civilization education should be widely conducted, and eco-civilization concepts should be established across the whole of society. In order to provide more

practical guidance to other regions, the optimal coupling coordination degree in the coupling process of urbanization quality and eco-environment pressure would be explored in further studies.

5. Conclusions

In this study, we assessed the level of urbanization quality, the trend of eco-environment pressure, and the coupling coordination relationship between urbanization quality and eco-environment pressure in the WTSUA, by combining AHP, EM, and a coupling coordination degree model. Our results showed that eco-environment pressure decreased with improving urbanization quality from 2003 to 2017. The coupling coordination level between urbanization quality and eco-environment pressure achieved stable and continuous improvement. Spatially, the coupling coordination level in the eastern region was generally higher than that in the western region. This study provides a scientific basis and effective measures for sustainable urban development.

Although a clear assessment of the spatiotemporal distribution and evolution of coupling coordination between urbanization quality and eco-environment pressure was examined in this paper, there was a lack of in-depth exploration of the interaction mechanism between the two systems. The next stage of this study will analyze the detailed relationships between the systems by using quantitative methods, such as material flows and information flows among various systems, as well as focus on the coupling process mechanism, to provide more practical guidance.

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