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Evaluation and Differentiation Analysis of China's Construction of Ecological Civilization from the Perspective of Collaboration: Using China's Representative Region as an Example

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Abstract: The construction of ecological civilization is an important part of the cause of Chinese socialism, and the evaluation of the construction of ecological civilization and the differentiated analysis of its synergistic development will guide the coordinated development and coordinated ecological governance and protection in China. Synergistically, an evaluation index system was constructed based on the social–economic–natural multisystem, and the deviation coefficient coupling coordination model was used to evaluate the construction of the ecological civilization of 83 cities in the region from 2000 to 2020. The spatial and temporal development characteristics were explored using the spatial autocorrelation index and standard deviational ellipse, and the urban–rural differences were quantitatively analyzed by using the Thiel index. The results show that from 2000 to 2020, the degree of coordinated development of the social–economic–natural multisystem in different cities was low, and there are different reasons for cities with different urban–rural divisions. In this study region, the spatial distribution of the social–economic–natural coordinated development of cities is becoming increasingly discrete, and the center of urban distribution, which has a higher level of coordinated development, is gradually shifting to the southwest. In 2020, the level of coordinated social–economic–natural development in the study area was significantly different in urban and rural areas.

Keywords: construction of ecological civilization; regional coordinated development; coupling coordination degree model; spatial characteristics; urban–rural differences

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1. Introduction

1.1. Background

The Chinese government values the construction of ecological civilization and has issued a series of decisions and deployments, which have led to significant progress and positive results. Ecological priority and green development are the key themes of China's construction of ecological civilization. Unbalanced, uncoordinated and unsustainable development is the embodiment of the structural and institutional contradictions of China's economy today. The research area of this study mainly includes the middle and lower reaches of the Yellow River and the Beijing–Tianjin–Hebei urban agglomeration, and the coordinated development of the Beijing–Tianjin–Hebei region and the promotion of ecological protection and high-quality development of the Yellow River Basin appear in the Report to the 20th National Congress of the Communist Party of China [1] as important examples of regional coordinated development. Based on this research area, evaluating the coordinated development of the construction of ecological civilization and its regional differentiation is important for exploring the coordinated development path of the construction of ecological civilization in China. The successful practice of China's construction of ecological civilization will provide a valuable experience as a significant reference for the development of ecological civilization in an international community.

1.2. Literature Review

The sustainable development and construction of ecological civilization are hot research topics on a global scale. Human beings have become the main driving force of changes in the Earth system, threatening most ecosystems on Earth, and human beings themselves objectively require the creation of a new and more sustainable society or ecological civilization [2]. China's proposed ecological civilization is lacking in other major capitalist powers. Ecological civilization advances after industrial civilization. The study of the construction of ecological civilization can promote regional sustainable development [3]. This study analyzes the dependence of the construction of ecological civilization on society, economy and nature and the interactions between the three.

Sustainable development and the construction of ecological civilization require systematic analysis of the three sectors of society, economy and nature. A study identified three pillars of society, economy and environmental and sustainable development [4]. Anne et al. [5] regard the importance of a circular economy as equivalent to that of sustainability, arguing that sustainability needs to be assessed from a systems perspective, integrating a set of economic, social and environmental indicators. Among them, the social–economic–natural multisystem is an important tool for systems analysis. Wang et al. [6] elaborated its definition, arguing that the human-dominated landscape is a social–economic–natural system with complex ecological dynamics and cybernetics. The system is a tool for understanding the relationship between man and nature, and this systematic approach promotes the sustainability of socioeconomic development. The coordinated development of subsystems in the social, economic and environmental complex system is an important part of sustainable urban development and will directly affect the quality of urbanization. This method is not only in the theoretical stage in China [7]. Wang et al. [8] discuss the practical application of the social–economic–natural multisystem in China, among which Dafeng City has obtained significant ecological and economic benefits based on this system theory.

The coupling coordination model is an important method to analyze sustainable development, the construction of ecological civilization and coordinated development between systems. The coordination between the environment, resources and economy is very important for sustainable development, and the possible imbalance between the three needs to be coupled from the perspective of sustainability [9]. The coordinated development of society, economy and ecological environment is a necessary condition for the sustainable development of cities, which requires the construction of an evaluation indicator system and a coupled coordination model for analysis [10]. In an article on countries and regions outside China, Liu et al. [11] analyzed the coupling and coordination relationship between the ecological environment and tourism development in seven prefectures in the Kyushu region based on the Pressure–State–Response (PSR) model, entropy weight method and index system coupled coordination model. Liu et al. [12] explored the relationship between the sustainable development of the tourism economy and ecological environment and constructed a PSR model based on data from Nagasaki Prefecture in Japan to evaluate the coupling and coordination degree of the tourism economy and ecological environment.

The coupling coordination model is often combined with the social–economic–natural multisystem and entropy method and is often used in the analysis of the construction of ecological civilization or sustainable development in a region of China. Chen et al. [13] use a socioeconomic ecological composite system, entropy weight method and coupling coordination model to analyze the social, economic and ecological coupling coordination degree of forest parks in Heilongjiang Province. Dong et al. [14] believe that exploring the interaction and coupling effect of the economy–society–environment system is conducive to promoting high-quality sustainable development. In addition, they constructed the economic–social–environmental system based on systems theory and used the entropy method and coupling coordination model to evaluate the coupling coordination degree of the system. The combination of these methods is also often used in the analysis of urban development and regional coordinated development of the construction of ecological civilization. Chu et al. [15] used the coupled coordination model to analyze the population, economy, society, ecological environment urbanization level and their coupled coordinated development degree in Russia. Achieving the sustainable development of the system is very important, and the Greater Bay Area and its surrounding areas have regional development imbalance problems [16]. Zhao et al. [17] used the Yellow River Basin of China as a research object, constructed an index system of economic development and ecological status in the Yellow River Basin and analyzed the temporal and spatial evolution trend of the coupling degree and coordination degree of economic development and ecological state.

In addition to numerical analysis of the results obtained by using the coupling coordination degree model, further spatial analysis and regional difference analysis can be carried out. The coupling coordination degree of an ecosystem and economic system represents the quality of sustainable urban development. This paper estimates the coupling and coordination level of the economic system and ecological system in the Chengdu–Chongqing urban agglomeration area from 2005 to 2019 and uses a local indicator of spatial association analysis to illustrate its spatial distribution. This paper measures the coupling and coordination degree of new urbanization and ecological environments in various provinces in China and analyzes the spatial correlation between the coupling degree and the coordination degree [18]. The Thiel index is a tool for analyzing differences. Bianco et al. [19] used methods such as the Thiel index to analyze the inequality of energy targets in the Eurasian Economic Union in the Sustainable Development Goals, and the analysis of the Thiel index showed that the inequality between energy consumption and the economy is decreasing and that the inequality within the population is increasing. Li et al. [20] analyzed the socioeconomic vulnerability of countries along the Belt and Road, and the analysis using the Thiel index showed that the overall gap in the socioeconomic vulnerability of countries along the Belt and Road is large and that there is no convergence trend. The Thiel index can be used to analyze regional differences in the sustainable development and construction of ecological civilization. Yang et al. [21], based on the concept of strong sustainability, proposed evaluation indicators such as the ecological environment pollution index and ecological environment management index and used the Thiel index to explain the regional differences and contribution rates of China's ecological environment quality. Cui et al. [22] used the Thiel index to analyze regional differences in the carbon footprint and carbon footprint intensity and analyze the impact of socioeconomic indicators such as GDP per capita, population density and urbanization level on the carbon footprint and carbon footprint intensity. In China, urban–rural differences are an important regional difference in the construction and development of ecological civilization. China's weak urban–rural economic linkage, unbalanced social and cultural development and disconnect between urban and rural environmental protection are all serious sustainable development problems in China's urban development [23]. We believe that urban–rural income imbalance is a key factor restricting sustainable economic and social development, the use of the Thiel index can analyze the relative differences between regions, and analyzing their causes is of great significance for determining the coordinated development of regional urban and rural areas. The study concludes that the income gap between urban and rural areas is affected by socioeconomic factors as well as natural factors [24].

In summary, most of the current research in China uses the areas designated by provincial or national policies as the research areas for a coordinated analysis of the construction of ecological civilization, but ecological-related problems are often cross-regional and not limited by administrative divisions. Therefore, it is of great theoretical significance to use ecological regional division to determine the research area when analyzing ecological civilization-related issues. At present, Chinese academic circles have recognized the importance of urban–rural integration and the relationship between urban–rural differences and the construction of ecological civilization. However, there are few studies that use data for empirical analysis, and it is of great practical significance to divide the research area between urban and rural areas and establish an evaluation index system for the construction of ecological civilization to analyze urban–rural differences. In this study, the warm temperate zone of eastern China was used as the research area, the coupling coordination model was used to calculate the coordinated development coefficient of the social–economic–natural multisystem in this region, and then the spatial autocorrelation and standard deviational ellipse were used to analyze the spatial characteristics of the coordinated development level of the construction of ecological civilization. Finally, the Thiel index was calculated to quantitatively study the total difference in the coordinated development level between urban and rural areas in the region and the contribution degree of urban–rural areas and urban–rural differences.

1.3. Article Structure

The structure of this article is as follows. Section 2 explains the data source and introduces the methods and models used. Section 3 explains the results of the coordinated development coefficient of the construction of ecological civilization and then analyzes the spatial properties and urban–rural differences of the coefficient. Section 4 describes the conclusions and policy recommendations. Section 5 describes the outlook for future research.

2. Materials and Methods

2.1. Data Sources

In this study, for urban–rural type division, 30 m China Land Use Land Cover (CNLUCC) remote sensing monitoring data (2000~2020) are used [25]. The dataset and the map used in this study are provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC). The socioeconomic data are obtained from the "China Urban Statistical Yearbook" and the statistical yearbooks of various provinces and cities. Some missing data are supplemented by reference to the "China Statistical Yearbook for Regional Economy" and "China County Statistical Yearbook", and other missing data are filled in by interpolation. The data in the process of calculating ecosystem service value are obtained from the statistical yearbooks of various provinces and cities, namely the National Farm Product Cost-benefit Survey and China Rural Statistical Yearbook. The latitude and longitude data of each city's administrative center are obtained using the web API interface service provided by the Baidu Map Open Platform.

2.2. Urban and Rural Type Division and Research Area Determination

2.2.1. OECD Urban–Rural Division

This study refers to a related study (we attached the website of the article in Appendix A) of the OECD-based urban–rural division method optimized according to the Chinese population. The method is mainly divided into three steps. In the first step, counties with a population density greater than 500 persons per square kilometer are identified as urban in county-level geographic units, and those below this threshold are deemed to be rural areas. Thus, the population in each county-level geographical unit is urban or rural. In the second step, the county-level population is merged into the municipal level at the municipal geographical unit, and then three areas are determined according to the ratio of the rural population to the total population classified in the first step: a predominantly urban area (the rural population accounts for less than 15% of the total population), an intermediate area (the rural population accounts for between 15% and 50% of the total population) and a predominantly rural area (the rural population accounts for more than 50% of the total population). The third step adjusts the results obtained in the second step according to the population size of the urban center of the municipal geographical unit, and if the second step determines that there is an urban center with a population size of more than 500,000 people in the predominantly urban area and the population of the center accounts for more than 25% of the total population of the region, the area is redefined as a transition area between urban and rural areas. If the second step determines that there is an urban center with a population of more than 1 million people in the intermediate area and the population of the center accounts for more than 25% of the total population of the area, the area is redefined as an urban area.

Combined with the 2020 administrative divisions, the data were processed using QGIS, and the urban and rural types were divided according to the population density and number of counties obtained by processing. Figure 1 shows the 2020 China OECD urban–rural classification map. The capital city circle, North China Plain, Yangtze River Delta, Pearl River Delta and Sichuan Basin are predominantly urban areas; the predominantly urban area is surrounded by an intermediate area; and the periphery is the predominantly rural area, forming a "point-axis" spatial structure. The area of intermediate areas in the Yangtze River Delta, Pearl River Delta region and Sichuan Basin has increased, indicating that the radiation effect of predominantly urban areas is more obvious, and the central cities drive the surrounding predominantly rural and intermediate areas to gradually progress to predominantly urban areas.

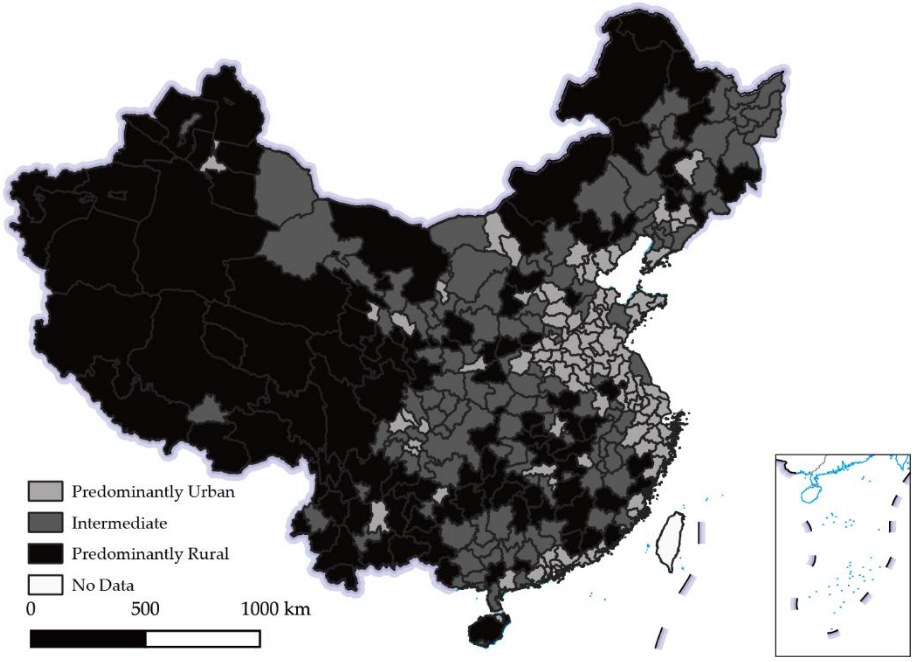

Figure 1. 2020 OECD urban–rural classification in China (Note: the map is made based on the GS (2019) 1823, available online: http://bzdt.ch.mnr.gov.cn, accessed on 15 August 2023).

2.2.2. Study Area Determination

At the regional scale, this study mainly determines the research area from three aspects, mainly based on the ecological division in the natural geographical division, combined with the ecological carrying capacity that plays a fundamental role in the construction of ecological civilization and the classification of urban and rural types. Functional zoning of the ecological environment has become an important tool for governments at all levels in China to establish a harmonious relationship between socioeconomic welfare and the ecological environment, and the ecological zoning used in this paper belongs to one of them [26]. Due to the differences in climate, hydrology and other aspects between different ecological regions, the ecological environment in the region and the difference between regions overlap. In addition, the division comprehensively considers the relationship between the human and ecological environment, and the regions divided by ecological differences are suitable for exploring the construction of ecological civilization.

The ecological carrying capacity determines the upper limit of regional construction of ecological civilization, which is the basis for building an ecological civilization, and it should be considered when selecting regions. This study refers to the zoning of China's ecological carrying capacity in related studies. Among them, the western region has a low ecological carrying capacity, but because it is located west of the Aihui–Tengchong line, the land is sparsely populated, and the eastern region is located east of the Yantai–Hechi line, which is densely populated but has a high ecological carrying capacity. The central region is located between the Aihui–Tengchong line and the Yantai–Hechi line, and the ecological carrying capacity of this region is between the east and west. The population density is similar to or even higher than in the eastern region, and the problem between people and the ecological environment is the most serious among the three regions. The construction of ecological civilization is people-oriented, and the more prominent the contradiction between people and the ecological environment is, the more important it is for the city to pay attention to the construction of ecological civilization. Therefore, this study divides regions according to the ecological carrying capacity and selects the research area in the central region. Since the 18th National Congress, the coordinated environmental governance of the Beijing–Tianjin–Hebei region and the high-quality development of the Yellow River Basin have reflected the country's determination to govern the ecological environment in the region. Hence, it is of great significance to explore whether the construction of ecological civilization of cities in the region is related to the coordinated development of the social economy.

To study the difference between the urban and rural construction of ecological civilization, the research area must contain three types of cities: predominantly urban areas, predominantly rural areas and intermediate areas. In addition, there needs to be a certain number of cities of each type. Referring to the results of the urban and rural type classifications, China's warm temperate cities meet the requirements and are suitable for the analysis of urban–rural differences in the construction of ecological civilization evaluation. Because the warm temperate zone spans the east and west and the western part of the warm temperate zone is not in the central region of the ecological carrying capacity with prominent ecological and environmental problems, this study selects the cities in the eastern warm temperate zone of China divided by municipal administrative regions as typical research areas. The area is based on municipal administrative divisions and does not completely overlap with the eastern part of the warm temperate zone.

2.2.3. Overview of the Study Area

The study area is between the middle temperate zone and the northern subtropics, covering parts of Beijing, Tianjin, Hebei, Shanxi, Liaoning, Jiangsu, Anhui, Shandong, Henan, Shaanxi, Gansu and Ningxia, and is located at 103°46′~123°51′ E, 32°27′~42°61′ N. The typical climate is a temperate monsoon climate, and the annual average rainfall is between 400 mm and 1000 mm.

This study outlines the eastern region of China's warm temperate zone based on ecological regionalization. The research area selected according to the municipal administrative division in this paper is shown in Figure 2. The study area includes 83 prefecture-level cities and municipalities directly under the central government, including 44 cities in the predominantly urban area, 27 cities in the intermediate area and 12 cities in the predominantly rural area.

2.3. Construction of the Evaluation Index System for Construction of Ecological Civilization

2.3.1. Multivariate System Action Relationship

From an economic perspective, the involvement of ecological environmental protection, investment and governance in the construction of ecological civilization can easily form positive externalities, while non-governance will form negative externalities and local governments are prone to form a "free rider" situation. The collaborative development mechanism of the construction of ecological civilization based on synergy can break the drawbacks of "administrative district administration" to a certain extent and promote the collaboration of local governments. Synergy has theoretical significance for the coordinated development of the construction of ecological civilization in the study area, which can improve the thinking mode of win–win cooperation formed by cities in the research area.

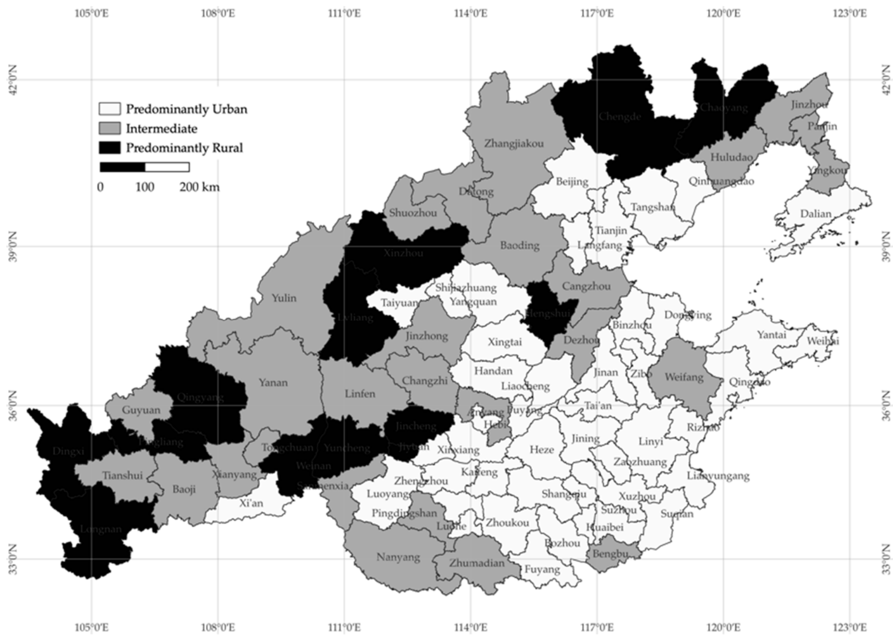

Figure 2. Map of urban and rural distribution in the study region (Source: made by the authors).

The construction of ecological civilization includes social, economic and natural aspects. Zhu et al. [27] combine the social–economic–natural multisystem with PSR models. The logic of the PSR model is "pressure P-state S-response R". Based on the social–economic–natural multisystem, this study combines the PSR model to establish an evaluation index system for the construction of ecological civilization. Under the three subsystems of society, economy and nature, there are natural pressure, natural state and other order parameters.

According to the research objectives, human beings are the subjective initiative of the multisystem, and the natural subsystem will reflect the pressure on the resource supply of human society. Therefore, the social and economic subsystem corresponds to the three aspects of pressure, state and response in the PSR model, and its sequence parameters include economic and social pressure, state and response. The ecological environment does not have subjective initiative, the natural subsystem corresponds to the pressure and state in the PSR model, and its sequence parameters are natural pressure and natural state. The connection between the composite systems is shown in Figure 3.

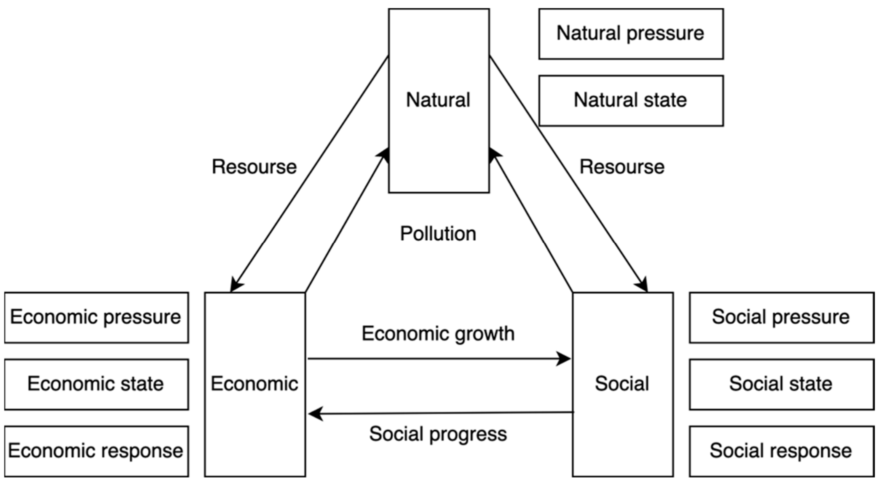

Figure 3. Multivariate system diagram (Source: made by the authors).

As shown in Figure 3, there is a circular promotion effect of economic growth and social progress between economic and social subsystems, and the continuous development of economic and social subsystems will inevitably produce pollution pressure on the natural environment, which is expressed as economic and social pressure. When faced with pressure from the economic and social subsystems, the state of the natural subsystem will change, such as unsustainable land use, resource depletion, and environmental degradation, and the deteriorated resource supply will affect the normal development of the economic and social subsystems. Natural pressures will cause economic and social subsystems to produce economic and social responses, respectively, and environmentally friendly responses will have a positive effect on natural subsystems and enhance ecological sustainability.

The above analysis can describe the effects of each subsystem and other subsystems in more detail through the sequence parameters of each subsystem. For social subsystems, social pressure is the source of pollution pressure on natural subsystems, mainly reflected by the resources consumed by people's own survival. Social state expresses the development of social subsystems themselves, mainly reflected in people's quality of life. Social response affects economic subsystems in the form of social progress and natural subsystems in ways that reduce pollution pressures caused by social pressures, mainly reflected in the actions taken by society to reduce pollution. For the economic subsystem, the impact of economic pressure is similar to that of the social subsystem, and the impact on the natural subsystem in the form of pollution pressure is mainly reflected by the destruction of the ecological environment brought about by the pursuit of economic development. The economic state describes the development of the economic subsystem itself, which needs to be reflected in people's economic income; the economic response affects social subsystems in the form of economic growth while reducing the pollution pressure of economic pressures on natural subsystems through investment in pollution control. For the natural subsystem, nature has no subjective initiative and cannot actively produce pressure on human society; that is, social and economic subsystems can only indirectly reflect pressure from the resource supply aspect through a natural response, and the natural state represents the status quo of the natural subsystem, mainly through land use status reflection.

2.3.2. Indicator Selection

According to the synergy theory and combined with the three-component model and PSR model commonly used in the framework of the construction of ecological civilization index system, this study establishes an evaluation index system for the construction of ecological civilization based on the social–economic–natural multisystem. Among them, society, economy and nature are the first-level indicators, and according to the previous theoretical framework, pressure, state and response sequence parameters are set up under the social and economic subsystems. Pressure and state sequence parameters are set under the natural subsystem. The degree of synergy development of the multivariate system as a whole depends on the interaction and cooperation between systems and system sequence parameters. The ordinal parameters are affected by the indicators, and the principles of representativeness within the system, comparability between regions and availability of indicators are considered when selecting indicators.

Geography can facilitate the analysis of the relationship between people and the environment and sustainability research, and geographic data should be added when exploring sustainable development [28]. Human activities have altered natural ecosystems and the services they provide, with significant changes in land use/land cover in China due to rapid population growth. Taking Guangzhou as an example, this paper finds that from 1987 to 2017, cultivated land and forest areas decreased significantly, and the ecosystem services value decreased. The authors advocated that promoting land use management in the future can effectively protect natural ecosystems [29]. Zhai et al. [30] used New England as the study area and argued that demographic and economic factors are important drivers of land use and cover change (LUCC) and that they have a complex nonlinear relationship. Liu et al. [31], using big data methods, argued that land use influences human activities at specific times and places. Dong et al. [32] pointed out the problem that the rapid socioeconomic development of port cities in Southeast Asia has led to intensive changes in LUCC. The study predicted the 2020–2050 situation under the current development model through the changes in LUCC in 1990–2020. This paper uses the fragmentation index to analyze the relationship between development level and fragmentation at the landscape level. In summary, there are studies that combine LUCC and territorial spatial indicators with the social–economic–natural multisystem, but they are not comprehensive enough and only reflect land use ratios or landscape indicators. There are precedents for combining PSR models with the social–economic–natural multisystem to construct an evaluation index system, but the natural subsystems do not have subjective initiative, and the author believes that the natural response should be removed.

In this study, the territorial spatial indicators obtained from CNLUCC data are added to the index evaluation system. We add the proportion of ecological–production–living spaces, ecosystem service value and landscape indicators to the natural subsystem. These indicators provide a comprehensive assessment of territorial space in terms of proportion, value and distribution. In the system, relevant indicators that can reflect agricultural development are selected to reflect the agricultural characteristics of the study area. The natural response is removed from the sequence parameter layer, and the corresponding indicators are decomposed into the social response and economic response sequence parameter layers. The Shannon's evenness index (SHEI) and contagion (CONTAG) of each municipality are batch processed in Fragstats 4.2, with each indicator calculated at the landscape level. The indicator units and their attributes are shown in Table 1.

Table 1. Indicator table of construction of ecological civilization evaluation system.

Target Layer	Order Parameter Layer	Indicators	Units	Index Direction
Social	Social pressure	Ratio of Living Space	%	+
		Growth of Population	%	-
		Electricity Consumption by Society	Million kW·h	-
	Social state	Higher Education Enrolment	Person	+
		Number of Beds in Health Institutions	Bed	+
		Collections of Public Libraries	1000 copies	+
	Social response	Number of Buses and Trolley Buses in Operation	Unit	+
		Centralized Treatment Rate of Sewage Treatment Plants	%	+
		Rate of Domestic Garbage Harmless Treatment	%	+
Economic	Economic pressure	Ratio of Production Space	%	-
		Number of Industrial Enterprises above Designated Size	Unit	-
		Gross Regional Product Growth Rate	%	+
	Economic state	Total Retail Sales of Consumer Goods	10,000 CNY	+
		Per Capita Disposable Income of Urban Households	CNY	+
		Per Capita Disposable Income of Rural Households	CNY	+
	Economic response	The Proportion of Tertiary Industry in GDP	%	+
		Expenditure for Science and Technology	10,000 CNY	+
		Total Power of Agricultural Machinery	10,000 kW	+
Natural	Natural pressure	Total Volume of Sulphur Dioxide Emission by Industry	Ton	-
		Total Volume of Industrial Waste Water Discharge	10,000 tons	-
		Consumption of Chemical Fertilizers	Ton	-
	Natural state	Ecosystem Service Value	CNY	+
		SHEI	-	+
		CONTAG	%	+

Source: made by the authors.

2.4. Calculation Methods and Results of Some Indicators

2.4.1. Proportion of Space Areas for Ecological–Production–Living Types Based on CNLUCC

The ecological–production–living spaces are the production space, living space and ecological space. The development goal of ecological–production–living spaces is of great significance to urban development. As shown in Table 2, this study refers to related studies, combining the ecological–production–living spatial classification with the CNLUCC classification and adding the number 62 Gobi in other ecological spatial parts.

Table 2. Ecological–production–living spatial classification system and CNLUCC classification articulation.

Ecological–Production–Living Spaces	CNLUCC Classification
Production space	11 Paddy Field, 12 Dry Land, 53 Other Built-up Land
Living space	51 Urban Built-up, 52 Rural Settlements
Ecological space	21 Forest, 22 Shrub, 23 Woods, 24 Other Woodland, 31 Dense Grass, 32 Moderate Grass, 33 Sparse Grass, 41 Stream and Rivers, 42 Lakes, 43 Reservoir and Ponds, 44 Permanent Ice and Snow, 45 Beach and Shore, 46 Bottomland, 61 Sandy Land, 62 Gobi, 63 Salina, 64 Swampland, 65 Bare Soil, 66 Bare Rock, 67 Others

Note: referring to the research of related studies in Appendix B.

The land use dynamic degree can express the change in the area of a certain land use type in the study area over a time period. According to the study of Tang et al. [33], the equation is as follows:

$$S = (S_j - S_i)/S_i \times (1/T) \times 100\% \quad (1)$$

where S represents the dynamics of a certain land use type, S_j and S_i represent the area of a certain land use type at the beginning and end of the period, respectively, and T is the number of years in each research period. In this study, $T = 5$.

Table 3 shows the proportion and dynamic changes in the area of the ecological–production–living spaces in the study area from 2000 to 2020. Refer to Fan et al. [34] for the CNLUCC classification details. The study area includes the North China Plain, one of the four major granaries in China, and the large land coverage area represented by dry land and paddy fields is the main reason for the relatively large proportion of the production space in the study area. Recently, the Chinese government has valued the redline policy of cultivated land. If that trend continues, the proportion of production space in the research area will gradually increase and stabilize in the future. The proportion of living space is relatively small, and the single dynamic degree of living space between 2000 and 2020 is positive, which is expected due to the rapid development of urbanization. From the data in Table 3, the increase in living space is mainly due to the decrease in production space, which indicates that some construction land or settlement land may be converted from cultivated land. The forest and grass resources in the study area are mainly concentrated in the Taihang Mountains and the outer areas of Beijing, among which the Taihang Mountain greening project increased the area of woodland and grassland in some cities in Shanxi, Hebei and Henan, while the implementation of the greening project around Beijing and Tianjin in recent years increased the ecological space area of some Beijing peripheral cities.

2.4.2. Ecosystem Service Value

The method for estimating ecosystem service value was created by Costanza, but this method is not fully applicable to the Chinese environment, and the calculation method in this study refers to the research of Zhao et al. [35]. In this paper, CNLUCC is matched with the land use type of ecosystem service value. Therefore, the ecosystem service value coefficient table is revised based on the current situation of the study area, and the unit price, value coefficient and total value of ecosystem service for each land use type in the study area are obtained.

Table 3. Ratio of ecological–production–living spaces.

Year	Indicators	Production Space	Living Space	Living Space
2000	Area/10^4 km^2	54.82	7.09	42.55
	Ratio/%	52.08	6.78	40.73
2005	Area/10^4 km^2	54.29	7.48	42.69
	Ratio/%	51.97	7.16	40.87
2010	Area/10^4 km^2	53.4	9.1	42.05
	Ratio/%	51.08	8.7	40.22
2015	Area/10^4 km^2	53.1	9.47	42
	Ratio/%	50.78	9.05	40.16
2020	Area/10^4 km^2	52.35	9.7	42.56
	Ratio/%	50.05	9.27	40.68
2000–2005	Land Use Dynamic Degree/%	−0.19	1.12	0.07
	Land Use Dynamic Degree/%	−0.33	4.32	−0.3
2005–2010	Land Use dynamic Degree/%	−0.11	0.81	−0.03
	Land Use Dynamic Degree/%	−0.29	0.48	0.26
2010–2015	Area/10^4 km^2	54.82	7.09	42.55
	Ratio/%	52.08	6.78	40.73
2015–2020	Area/10^4 km^2	54.29	7.48	42.69
	Ratio/%	51.97	7.16	40.87

Source: made by the authors.

The economic value of the ecosystem service value equivalent factor per unit area of farmland under the national average yield is converted into the ecosystem service value coefficient table, and the economic value of one ecosystem service value equivalent factor is 1/7 of the national average grain yield market value of the year. The main food groups in the study area are rice, wheat and maize, which are calculated as follows:

$$E_a = \left(\sum P_i \times O_i/S\right) \times 1/7 \quad (2)$$

where E_a is the economic value of food produced per unit area of farmland ecosystem, i is the food crop species, P_i is the national average market price per 50 kg of the ith food crop in the current year, and O_i is the total yield of the ith food crop. Due to the large number of missing grain unit area yield data in the early years, this study replaces the product of grain yield and planting area in the original equation with the total yield O_i. Lastly, S is the total planting area of ith grain crops. Based on the total yield, sown area and national average selling price of 50 kg of main products in cities in the study area from 2000 to 2020, ecosystem service value in one equivalent in the study area is calculated to be 1365.4 CNY/hm^2. Table 4 shows the revised ecosystem service value coefficient for the study area, and the ecosystem service value of each city in the area can be calculated according to this table and the area of different land cover types in each city.

There is no land classification, such as farmland and forest land in the original equivalent factor table using the CNLUCC land classification standard, unless it is converted. In this study, farmland includes two secondary classifications of dry land and paddy fields. Forest land includes forest, shrub, woods and other woodland. The forest land in the study area is mainly warm temperate deciduous broad-leaved forest, corresponding to the secondary classification of four ecosystems: coniferous, coniferous mixed, broadleaf and shrub. Grassland includes dense, moderate and sparse grass. The grassland in the study area is mainly warm shrub grassland and a small number of meadows, so grassland corresponds to the secondary classification of shrubland and meadow. Wetlands include streams and rivers, lakes, reservoirs and ponds, permanent ice and snow, beaches and shores, bottomlands and swamplands. There is only a very small amount of permanent glacial snow in the study area, so wetlands correspond to the secondary classification of wetlands and aquatic ecosystems. Bare land includes sandy land, Gobi, salina, bare soil and bare rock, corresponding to the secondary classification of desert and bare land. The ecosystem service value of urban built-up, rural settlements and other built-up land was not calculated in this study.

Table 4. Ecosystem service value factor per unit area.

Ecosystem Classification	First Class	Farmland		Forest Land	Grassland	Wetland	Bare Land
	Second Class	Dry Land	Paddy Field				
Provisioning services	Food	1160.60	1856.96	344.77	409.62	894.35	6.83
	Materials	546.17	122.89	791.94	607.61	498.38	20.48
	Water	27.31	−3591.04	409.62	334.53	7427.86	13.65
Regulating services	Air quality regulation	914.83	1515.61	2604.53	2123.22	1822.83	88.75
	Climate regulation	491.55	778.29	7793.11	5618.68	4021.15	68.27
	Waste treatment	136.54	232.12	2283.66	1856.96	6246.77	279.91
	Regulation of water flows	368.66	3713.93	5099.82	4116.73	86,342.01	163.85
Support Services	Soil conservation	1406.38	13.65	3171.18		2587.46	2211.97
	Maintenance of soil fertility	163.85	259.43	242.36		197.99	170.68
	Maintain biodiversity	177.50	286.74	2887.85		2355.34	7113.81
Cultural services	Provide aesthetic landscape sum	81.92	122.89	1266.42		1037.72	4519.52

Source: calculated by the authors.

2.5. Research Methods

First, the improved panel entropy method is used to evaluate the development level of construction of ecological civilization in each subsystem in the multisystem, and then the spatial distribution is analyzed by using the spatial method. Finally, the research area is divided into three parts: predominantly urban area, intermediate area and predominantly rural area. The Thiel index is used to analyze the difference between urban and rural areas and the coordinated development of multiple systems of the construction of ecological civilization in urban and rural areas.

2.5.1. Improved Entropy Method

The comprehensive evaluation method of multiple systems can be divided into subjective and objective empowerment evaluation methods, as in the study of He et al. [36], using the improved entropy method with time variables. To prevent the normalization of the value as 0, the normalized value was translated in this study and was then used in the subsequent calculations. In addition, in defining the information entropy equation, the denominator uses the logarithm of the product of the study year and the number of cities. In this study, an improved panel entropy method was used, and the equation is as follows:

$$x'_{\theta ij} = (x_{\theta ij} - x_{\min})/(x_{\max} - x_{\min}) \tag{3}$$

$$x'_{\theta ij} = (x_{\max} - x_{\theta ij})/(x_{\max} - x_{\min}) \tag{4}$$

$$X_{\theta ij} = x'_{\theta ij} + A \tag{5}$$

$$p_{\theta ij} = X_{\theta ij} / \sum\sum X_{\theta ij} \tag{6}$$

$$e_j = -[1/\ln(rn)] \times \sum\sum p_{\theta ij} \times \ln(p_{\theta ij}) \tag{7}$$

$$g_j = 1 - e_j \tag{8}$$

$$w_j = g_j / \sum g_j \tag{9}$$

$$Y_{\theta is} = Y_{\theta ie} = Y_{\theta in} = \sum w_j \tag{10}$$

where θ represents the year, i represents the city and j represents the indicator. Equations (3) and (4) are standardized equations for positive and negative indicators, respectively, where $x_{\max}$ and $x_{\min}$ are the maximum and minimum values of the j index of all sample years, respectively, and $x'_{\theta ij}$ is the normalized value. In Equation (5), A is the magnitude of translation, A = 0.0001, and $X_{\theta ij}$ is the normalized value of the offset. In Equations (6)–(9), $p_{\theta ij}$, e_j, g_j and w_j are the index weights, the entropy value of the jth index, the information utility value of the jth index, and the jth index weights, respectively. In Equation (7), r represents the total number of years, r = 5, n is the number of cities, and n = 83. Because the number of natural subsystem indicators in the evaluation index system of the construction of ecological civilization established in this study is significantly smaller than that of social and economic subsystem indicators, the weight w_j in Equation (9) is calculated separately for each subsystem. In Equation (10), $Y_{\theta is}$, $Y_{\theta ie}$ and $Y_{\theta in}$ are the social, economic and natural subsystem development scores in the social–economic–natural multi-system of city i, respectively, which are used to evaluate the social, economic and natural development levels of cities in different years in the study area under the framework of the construction of ecological civilization.

2.5.2. Coupling Coordination Degree Model

The development of construction of ecological civilization does not depend solely on any subsystem in the social–economic–natural multisystem, and the coordinated development of all subsystems is the fundamental driving force for the construction of ecological civilization. From the perspective of synergy, ordinary linear models cannot comprehensively evaluate the degree of coordinated development between multiple systems, and the coupled coordination model is one of the commonly used models for the quantitative evaluation of multivariate systems in academia. In this study, the deviation coefficient model is used to evaluate the correlation and coordination degree between subsystems of the social–economic–natural multisystem because the degree of coordination cannot fully reflect the comprehensive benefit of the system as a whole, and further analysis of the coordinated development coefficient is needed. This study uses a two-system model in the deviation coefficient model, which can be used to evaluate and compare the coordinated development of the environment and economy in different periods between cities. The model used in this study refers to that used in the study by Tu et al. [37]. In this study, the social–economic–natural multisystem is decomposed into three dual systems for analysis, namely social–economic, social–natural and economic–natural dual systems. The two-system deviation coefficient coordination model equation is

$$C_{\theta i} = \{(Y_{\theta iu} \times Y_{\theta iv}) / [(Y_{\theta iu} + Y_{\theta iv})/2]^2\}^2, u, v \in \{s, e, n\}, u \neq v \tag{11}$$

where $C_{\theta i}$ represents the degree of coordination of dual systems, and $Y_{\theta iu}$ and $Y_{\theta iv}$ are the development scores of two different subsystems in any of the three subsystems of the social–economic–natural multisystem.

The three-system deviation coefficient coordination model and the deviation coefficient coordinated development model are as follows. According to relevant research, let the adjustment coefficient $k = 3$.

$$C_{\theta i} = [3 \times (Y_{\theta is} \times Y_{\theta ie} + Y_{\theta is} \times Y_{\theta in} + Y_{\theta ie} \times Y_{\theta in})/(Y_{\theta is} + Y_{\theta ie} + Y_{\theta in})^2]^k \tag{12}$$

$$T_{\theta i} = \alpha \times Y_{\theta is} + \beta \times Y_{\theta ie} + \chi \times Y_{\theta in} \tag{13}$$

$$D_{\theta i} = (C_{\theta i} \times T_{\theta i})^{1/2} \tag{14}$$

where $C_{\theta i}$ represents the degree of coordination of multivariate systems; in Equation (13), $T_{\theta i}$ is a comprehensive evaluation index of society, economy and nature, reflecting the overall synergistic benefits of multiple systems. α, β and χ are the weight coefficients, and we believe that the three subsystems in the multisystem have the same importance, so all of the weights are taken as $1/3$. In Equation (14), $D_{\theta i}$ represents the coordinated development coefficient of social–economic–natural multisystem. In this study, a coefficient greater than 0.5 indicates that the construction of ecological civilization has entered the stage of coordinated development, a coefficient between 0.3 and 0.5 indicates the low-level coordination of the construction of ecological civilization and development, and a coefficient less than 0.3 indicates that the development of the construction of ecological civilization is not coordinated.

The coupling coordination model can reflect the intrinsic correlation strength of the system but cannot reflect the gap between systems. The relative development degree can be used to measure the degree of relative advance or lag development between systems [38]. Therefore, this study introduces a relative development degree to measure the advanced or lagging development subsystems in the multisystem of the construction of ecological civilization. The equation is as follows:

$$P = Y_{\theta ise}/Y_{\theta in} \tag{15}$$

where P represents the relative development degree, $Y_{\theta ise}$ represents the average social and economic subsystem development score of each city, and $Y_{\theta in}$ represents the natural subsystem development score of each city. The relative development degree of ternary systems usually defines the subsystem with the minimum score as a lagging development system, but such an analysis may have two systems with almost the same score and a small value, and the third system has a large value, in which case only one system is judged to be a lagging development system. In this study, the social subsystem and the economic subsystem are regarded as a system in which the natural subsystem is used for comparison, and the average value of the social and economic subsystem score is compared with that of the natural subsystem when judged. The determination method of the ratio threshold is referred to by Xie et al. [38]. The division criteria are shown as follows: the coordinated development features are a natural lag when the relative development degree is less than 2, the coordinated development features are balanced when the relative development degree is between 2 and 4, the coordinated development features are social and economic lag when the relative development degree is more than 4.

2.5.3. Spatial Analysis Tools

It is necessary to calculate the spatial autocorrelation and standard deviational ellipse to further analyze the spatial characteristics and comprehensively analyze the coordinated development level of the construction of ecological civilization in the study area.

Global Moran's I [39] can be used to measure the overall spatial autocorrelation in the area, and the average coordinated development degree of a city and neighboring cities is compared with the overall average coordinated development degree of the study area. The global Moran's I reflects the average of the spatial correlation degree of each city.

When the global Moran's I is greater than 0, it means that the values of the city and its neighboring cities are similar, and there is a positive correlation with the space representing agglomeration. When the global Moran's I is less than 0, it means that the values difference between the city and its neighboring cities is high, and there is a negative correlation representing discrete space.

Local Moran's I, also known as the Local Indicators of Spatial Association (Lisa), was proposed by Anselin [40]. The local Moran's I can accurately determine the spatial autocorrelation of local samples, and in the agglomeration category output, high–high agglomeration indicates that the attribute values of the current provinces and cities and related areas are higher than those of the whole region. High–low agglomeration indicates that the attribute value for that region is higher than the average attribute value for its related region. In this study, the local Moran's I was used to analyze the agglomeration of the coordinated development coefficient of cities in the study area.

The standard deviational ellipse is one of the important tools in point data analysis, which can analyze the distribution characteristics of point objects and the temporal and spatial variation process by analyzing the position of the center of the circle, the length of the two axes of the ellipse and the rotation angle [41]. The coordinated development coefficient is city-level polygon data. When converting it to point data, the geographic center of gravity or administrative center can usually be chosen as a representative point because there is a point in the study area where the geographic center of gravity of the city is outside the urban area. At this time, the point obviously cannot represent the city, so this study selects the administrative center as the city representative point to convert the city-level polygon data into city-level point data. The latitude and longitude data of each city's administrative center are obtained using the web API interface service provided by the Baidu Map Open Platform, and the initial geographic coordinate system is BD09, which is converted to WGS84 and the vector map coordinate system.

2.5.4. Thiel Index

This study uses the Thiel index to quantitatively calculate the urban–rural gap between the level of coordinated development of the construction of ecological civilization in the study area. The Thiel index was first used to analyze income disparities and was later widely used in the analysis of overall regional differences and interregional differences. To analyze the total difference in the coupling and coordination degree of social–economic–natural multisystem coupling in the study area, decompose the total difference between urban and rural and within urban–rural differences and calculate the contribution of the two to the total difference, we calculated the social and economic coordinated Thiel index weighted by ecosystem service value and total volume of industrial waste water discharge and the unweighted Thiel index of social, economic and natural coordination based on the data of each city in the study area in 2020. To consider the impact of land use on the degree of difference in coordinated socioeconomic development, ecosystem service value was selected as the weight value. To consider the impact of environmental pollution on the degree of difference in coordinated social and economic development, the total volume of industrial waste water discharge was selected as the weight value. The proportion of the social–economic coordinated development coefficient in the study area under each urban–rural division type is closer to the proportion of ecosystem service value or total volume of industrial waste water discharge in the total study area, and the smaller the Thiel index, the smaller the impact of the difference in land use or environmental pollution on the difference in coordinated socioeconomic development.

Equations (16)–(19) are Thiel index equations weighted by ecosystem service value, and Equation (20) is for the contribution of the Thiel index under this weight, in addition to a similar equation weighted by the total volume of industrial waste water discharge.

$$T_1 = D_U/D \times \ln\,[(D_U/D)/(E_U/E)] + D_I/D \times \ln\,[(D_I/D)/(E_I/E)] + D_R/D \times \ln\,[(D_R/D)/(E_R/E)] \tag{16}$$

$$T_U = \sum (D_i/D_U) \times \ln [(D_i/D_U)/(E_i/E_U)],$$
$$T_I = \sum (D_i/D_I) \times \ln [(D_i/D_I)/(E_i/E_I)], \quad (17)$$
$$T_R = \sum (D_i/D_R) \times \ln [(D_i/D_R)/(E_i/E_R)]$$

$$T_2 = D_U/D \times T_U + D_I/D \times T_I + D_R/D \times T_R \quad (18)$$

$$T = T_1 + T_2 \quad (19)$$

$$1 = T_1/T + (D_U/D) \times (T_U/T) + (D_I/D) \times (T_I/T) + (D_R/D) \times (T_R/T) \quad (20)$$

where D_U, D_I, D_R, E_U, E_I and E_R represent the sum of the coordinated development coefficients of all urban construction of ecological civilization in predominantly urban areas, intermediate areas and predominantly rural areas and the sum of ecosystem service values of these areas, respectively; T_U, T_I and T_R represent the regional Thiel index under these three types of urban–rural type division; and T_1 and T_2 represent the Thiel index of the difference in the coordinated development coefficient of the construction of ecological civilization between regions and within the region, respectively. T represents the Thiel index of the difference in the coordinated development coefficient of the overall construction of ecological civilization in the study area. In Equation (17), D_i and E_i indicate the coordinated development coefficient of the construction of ecological civilization and ecosystem service value in the ith city, respectively. The weightless Thiel index equation is as follows:

$$T_1 = D_U/D \times \ln [(D_U/D)/(U/N)] + D_I/D \times \ln [(D_I/D)/(\mathrm{I}/\mathrm{N})] + D_R/D \times \ln [(D_R/D)/(\mathrm{R}/N)] \quad (21)$$

$$T_U = \sum (D_i/D_U) \times \ln [(D_i/D_U)/(1/U)],$$
$$T_I = \sum (D_i/D_I) \times \ln [(D_i/D_I)/(1/I)], \quad (22)$$
$$T_R = \sum (D_i/D_R) \times \ln [(D_i/D_R)/(1/R)]$$

$$T = T_1 + (D_U/D) \times T_U + (D_I/D) \times T_I + (D_R/D) \times T_R \quad (23)$$

The same symbols in Equations (21)–(23) and Equations (16)–(20) have the same meaning, and U, I, R and N represent the number of cities in the predominantly urban area, intermediate area, predominantly rural area, and overall city in the study area, respectively. Urban development is a process of change, and the urban–rural nature of cities differs every year. Because this study only uses the 2020 Chinese data to divide the urban and rural types of eastern warm temperate cities, to ensure rigor, the 2020 data are used to calculate the Thiel index for differentiation analysis.

3. Results

3.1. Evaluation of the Coordinated Development of Construction of Ecological Civilization in Social–Economic–Natural Multisystem

3.1.1. Analysis of the Coordinated Development of Construction of Ecological Civilization in the Dual System

From Figure 4, it can be seen that the social–economic, social–natural and economic–natural dual systems in the study area do not reach the stage of coordinated development from 2000 to 2020, but the coordinated development coefficients of the three systems maintain an upward trend, and the coordinated development coefficients of social–natural and economic–natural dual systems increase by a large margin in 20 years; in 2020, they are 2 to 3 times those of 2000. The degree of coordinated development of the social–economic dual system is higher than that of the other two dual systems, which indicates that the level of social–economic coordination of cities in the study area is much higher than that of society–nature and economy–nature, and the contradiction between development and environment is more prominent.

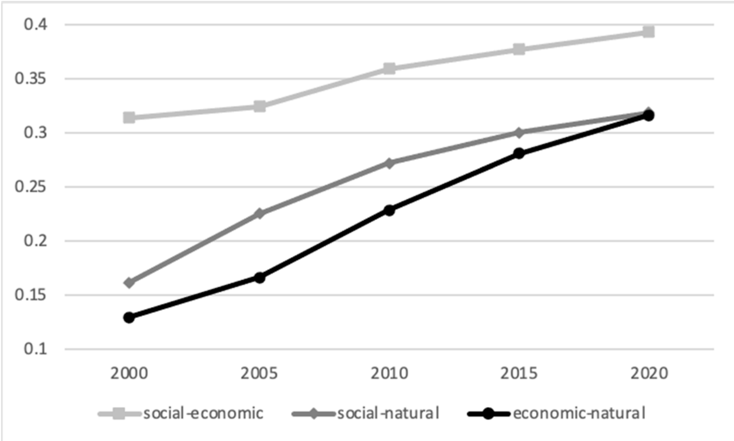

Figure 4. Dual system coordinated development coefficient (Source: made by the authors).

3.1.2. Analysis of the Coordinated Development Coefficient of Construction of Ecological Civilization in Social–Economic–Natural Multisystem Construction

Figure 5 shows the median coordinated development coefficient of social–economic–natural multisystem coordination in all cities in the study area from 2000 to 2020. Figure 6 shows the number of cities with a coordinated development coefficient greater than 0.3 for each urban–rural division type in the study area in 2020 and its proportion to the total number of cities belonging to the urban–rural division type. It can be seen from Figure 5 that although the coordination level of the overall construction of ecological civilization in the study area has not reached the stage of coordinated development, it has exceeded the dividing line of the uncoordinated development stage, the level has maintained a trend of increasing year by year, and the coordinated development coefficient in 2020 is more than twice that in 2000. In 2020, the median coordinated development coefficients of cities in the predominantly urban area, intermediate area and predominantly rural area in the study area are 0.36, 0.29 and 0.24, respectively; the coefficient for the predominantly urban area is 50% higher than that for the predominantly rural area; and the gap between the coordinated development level of urban and rural pluralistic systems is obvious. As shown in Figure 6, the distribution of urban and rural areas in the coordinated development level of the construction of ecological civilization in the study area in 2020 is very uneven, with more than 90% of cities with a coordinated development coefficient greater than 0.3 in predominantly urban areas and less than 10% in predominantly rural areas. The intermediate area and the predominantly rural area are mainly located in the middle reaches of the Yellow River in the western part of the study area. These cities have made more efforts to protect the ecology of the Yellow River Basin in recent years and are currently in the throes of development transformation, which is an important reason for the low level of coordinated development of most urban pluralistic systems in these two urban–rural classification areas.

Figures 7 and 8 are made using QGIS, and the figures show the distribution of coordinated development coefficients in all cities in the study area in 2000 and 2020. Because the maximum value of the coordinated development coefficient in the study year is 0.67, the minimum value is 0.05, and the only city above 0.6 is Beijing. This study classifies the coefficient values into three ranges: 0–0.3, 0.3–0.5 and 0.5–0.7. As seen in Figures 7 and 8, in 2000, only Beijing and Tianjin in the study area had a coordinated development coefficient greater than 0.3 during a stage of mild dysfunction and decline. At this time, China was still in the stage of extensive development, the rapid development of most urban economies largely depended on the high input and consumption of energy resources, and some areas even sacrificed the environment. Compared with that in 2000, the coordinated development level of multiple systems in cities in 2020 has improved greatly, and more than half of the cities in the study area are in the stage of mild or near decline of 0.3–0.5. These cities are mainly concentrated in the eastern and southern provinces of Hebei, Shandong and Henan, and most of the western and northern parts of the region are in a stage of serious imbalance. For 2020, there are three cities with a coordinated development coefficient of multiple systems that are not in the decline stage, namely Beijing, Tianjin and Zhengzhou, and there is more room for the coordinated development level of cities in the study region.

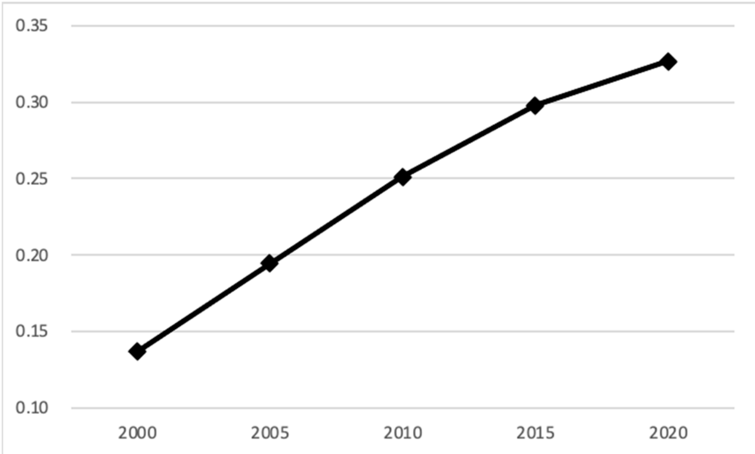

Figure 5. Multisystem coordinated development coefficient (Source: made by the authors).

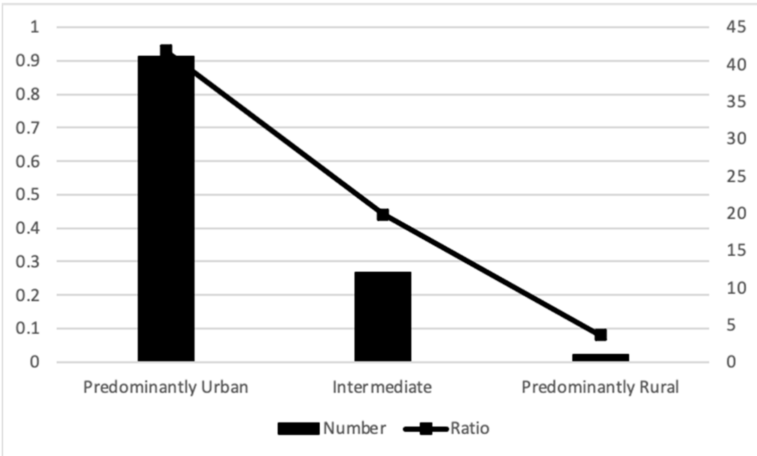

Figure 6. The number and proportion of cities with a high degree of coordinated development (Source: made by the authors).

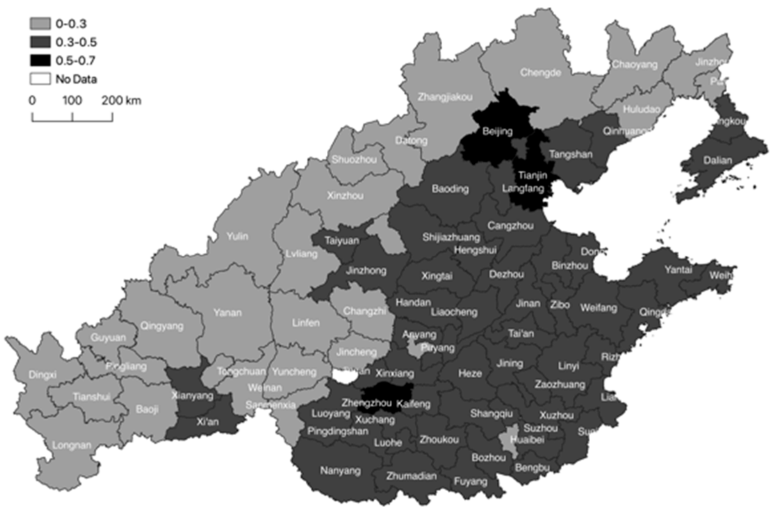

Figure 7. Coordinated development coefficient for 2020 (Source: made by the authors).

Figure 8. Coordinated development coefficient for 2000 (Source: made by the authors).

3.1.3. Analysis of the Characteristics of the Coordinated Development of Multiple Systems in the Construction of Ecological Civilization

Figure 9 shows the coordinated development characteristics of the overall multisystem in the study area from 2000 to 2020. Figure 10 shows the number of cities with ecological lag, balance and social and economic lag among the three urban and rural types under the urban–rural type division in 2020. According to Figure 9, in 2000, most cities were in a lagging stage of socioeconomic development, and fewer cities were lagging behind in social and economic development. The socioeconomic development of cities in the region as a whole is relatively fast, but the number of cities with lagging ecological types has increased yearly from 2000 to 2020, and some cities have neglected the protection of the ecological environment while developing. Compared with that in 2015, the number of cities with a poor social economy decreased in 2020, while the number of cities with a poor ecological lag remained almost unchanged and the number of balanced cities increased slightly, indicating that since 2015, cities in the study area have paid attention to the protection of the ecological environment while developing the social economy and achieved good results. According to Figure 10, the main problem of the coordinated development of the construction of ecological civilization in unbalanced cities in predominantly urban areas is that ecological protection lags behind social and economic development in 2020. Most cities in the intermediate area coordinate with each other in socioeconomic development and ecological environmental protection. The problem with the coordinated development of the construction of ecological civilization in cities in predominantly rural areas is that they are more concentrated on lagging social and economic development, which may be because, in recent years, the Chinese government's emphasis on wetland protection and ecological governance in the middle reaches of the Yellow River has enabled coastal cities to invest more resources in ecological protection than in social and economic development and pay attention to social and economic development while protecting them, which can more effectively promote the coordinated symbiosis.

3.2. Analysis of Spatial Properties of Multiple Systems Coupled and Coordinated in the Construction of Ecological Civilization

3.2.1. Global Spatial Autocorrelation

In this study, the coordinated development coefficients of cities were aggregated on the map using QGIS, and Table 5 shows the global Moran's *I* calculated using Geoda. The adjacency spatial weight is selected as the queen adjacency, and the p-value is replaced by 999 Monte Carlo. From 2000 to 2020, the global Moran's *I* of the study area is positive, and the result is significant at 0.1%, indicating that there is a significant positive spatial correlation between the levels of social–economic–natural multisystem coordination in the study area. Regarding time series, the global Moran's *I* first increases and then decreases, with the maximum value in 2005, and the spatial positive agglomeration of the coordinated development level gradually weakens. Overall, the spatial distribution of the coordinated development level of the construction of ecological civilization in the study area tends to be random.

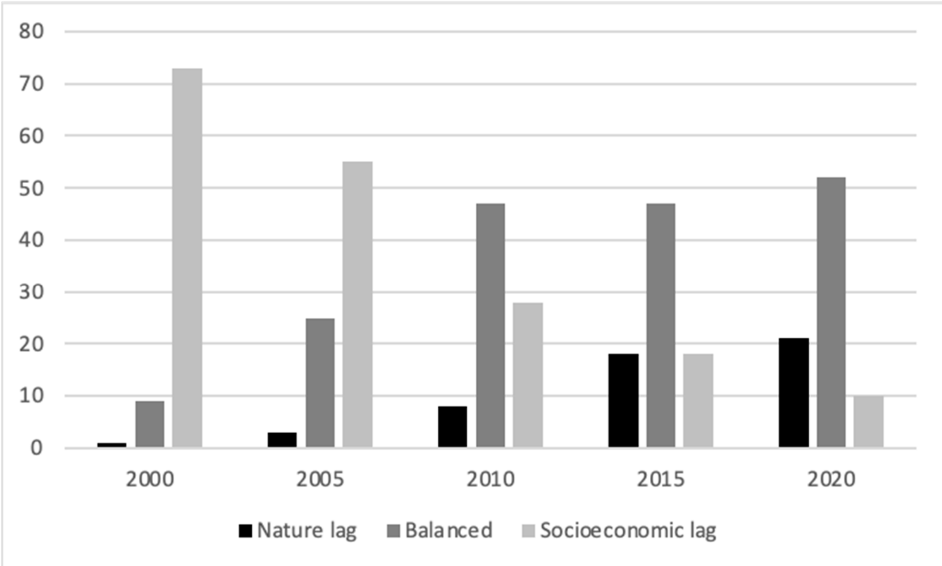

Figure 9. Coordinated development features (Source: made by the authors).

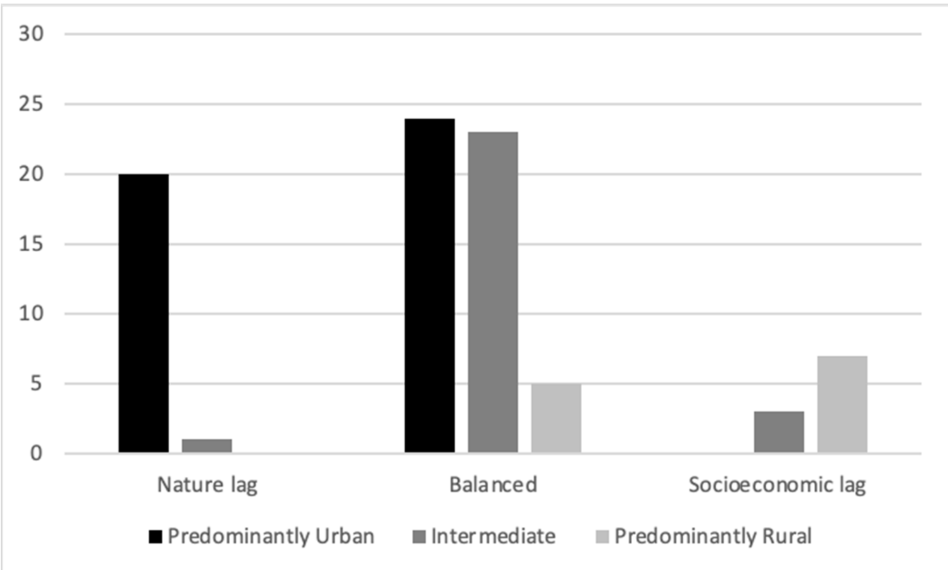

Figure 10. Coordinated development features under urban–rural division (Source: made by the authors).

Table 5. Global spatial autocorrelation results of coordinated development coefficient of regional multivariate systems.

	2000	2005	2010	2015	2020
Moran's *I*	0.263	0.337	0.327	0.291	0.255
p-value	0.001	0.001	0.001	0.001	0.001

Source: made by the authors.

3.2.2. Local Spatial Autocorrelation

To further analyze and study the spatial autocorrelation between regions in the study region, Geoda was used to calculate the local Moran's I, the results of which from 2000 and 2020 are shown in Table 6, and the p-values of the cities listed in the table are significant. Table 7 shows that the local spatial autocorrelation of most cities does not change in 2000 and 2020, and the high–high agglomeration mainly occurs in some cities in Hebei and Shandong, which may have driven the rapid improvement of the coordinated development level of the construction of ecological civilization in these cities and surrounding cities. Low–low agglomeration is mainly concentrated in Shanxi, Shaanxi and Gansu in the western part of the study area, mainly due to the relatively low level of socioeconomic development in these regions. The low–high agglomeration areas are Chengde, Binzhou and Rizhao, and the coordinated level of ecological civilization and social economy in these cities has developed more slowly than that of surrounding cities. From 2000 to 2020, the cities around Taiyuan gradually changed from a lagging socioeconomic development type to a balanced type, but Taiyuan's construction of ecological civilization developed at a faster pace.

Table 6. Local spatial autocorrelation results of coordinated development coefficient of multivariate system in the study area.

Categories	2000	2020
High–high	Tianjin, Cangzhou, Langfang, Yantai, Weifang, Tai'an, Linyi	Tianjin, Langfang, Yantai, Weifang
Low–low	Jincheng, Yuncheng, Linfen, Xianyang, Yan'an, Yulin, Tianshui, Pingliang, Qingyang, Dingxi, Longnan, Guyuan	Jincheng, Yuncheng, Linfen, Yan'an, Yulin, Tianshui, Pingliang, Qingyang, Dingxi, Longnan, Guyuan
Low–high	Chengde, Binzhou	Chengde, Rizhao
High–low	Taiyuan	Taiyuan

Source: made by the authors.

Table 7. Coordinated development coefficient standard deviation ellipse parameter.

Years	Mean x and Mean y	Majorsd/km	Minorsd/km	Area/km^2	Eccentricity/°
2010	116.8751° E, 36.9766° N	516.87	317.35	515,311.01	71.9
2015	116.2814° E, 36.3381° N	498.22	315.06	493,134.205	53.41
2020	116.1703° E, 36.1110° N	524.36	328.82	541,682.736	52.44

Source: made by the authors.

3.2.3. Spatial Distribution

In this study, the standard deviational ellipse of cities with a coordinated development coefficient greater than 0.3 from 2010 to 2020 is calculated to analyze the spatial distribution characteristics of these cities above the low level of coordination. In addition, the standard deviational ellipse is calculated using the Standard Deviational Ellipse plug-in [42] in QGIS, which can output the center point, major and semiaxis distance and direction angle of the standard deviational ellipse. The accurate values of these indicators need to be obtained based on the projected coordinate system, using the map as the EPSG:3857 Mercator projection. The values of each index are shown in Table 7, and the center point position is converted to the WGS84 coordinate system latitude and longitude using the QGIS Add Geometry Properties tool. The standard deviational ellipse and center point position are shown in Figure 11.

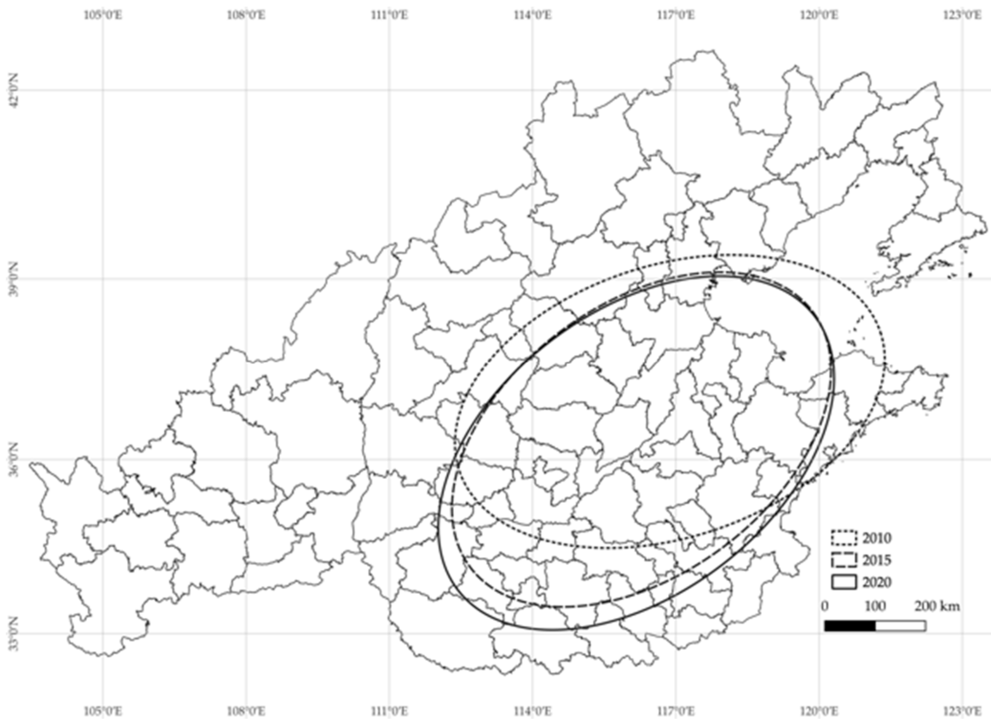

Figure 11. Coordinated development coefficient standard deviation ellipse (Source: made by the authors).

As shown in Figure 12, the three points in the direction of the arrow are the standard deviation elliptical center points in 2010, 2015 and 2020; the center moves from Dezhou to the southwest to Liaocheng between 2010 and 2015 and from Liaocheng to the southwest to Tai'an from 2015 to 2020, but it is always in Shandong Province. The shift direction of the center indicates that the coordinated level of development of cities in the western and southern parts of the study area is increasing faster than that of other cities. According to Table 8, from 2010 to 2020, the gap between the long and short half axes and the length of the short and short axes decreased first and then increased; overall, the distribution direction of the coordinated development level of the construction of ecological civilization in cities at the primary level and above becomes more obvious. The increase in the length of the semiaxis indicates that the deviation degree of the distribution of cities at the primary and above coordinated development levels in the region has become larger, and the main reason for the increase is the number of cities in the middle of the study area located in the intermediate area. In addition, the coordinated development coefficient is greater than 0.3 in 2020, which is nearly double that in 2015 and more discrete than the spatial distribution mainly concentrated in the eastern part of the study area.

Table 8. Thiel index and regional difference decomposition of two weights of the regional social-economic dual system in 2020.

Weight	Total	Between Urban and Rural	Within Urban and Rural	Predominantly Urban	Intermediate	Predominantly Rural
Ecosystem Service Value	0.19	0.01 (0.07)	0.17 (0.93)	0.2 (0.52)	0.17 (0.29)	0.17 (0.13)
Total Volume of Industrial Waste Water Discharge	0.57	0.26 (0.45)	0.31 (0.55)	0.36 (0.31)	0.26 (0.14)	0.38 (0.09)

Source: made by the authors.

Figure 12. Coordinated development coefficient central point (Source: made by the authors).

3.3. Analysis of Urban–Rural Differences in the Coordinated Development Coefficient of Construction of Ecological Civilization

3.3.1. Analysis of Urban–Rural Differences in Social–Economic Dual System

The 2020 Thiel index of the study region's social–economic system weighted by ecosystem service value and total volume of industrial waste water discharge is shown in Table 8, and the values in parentheses show the contribution rate to the total difference. The Thiel index between urban and rural areas of both weights is smaller than that of the Thiel index within urban–rural areas, which indicates that the difference between the social and economic dual system of cities in the study area mainly comes from within urban and rural areas, which is related to China's in-depth promotion of new urbanization.

According to the Thiel index under each urban–rural division type, the values weighted by ecosystem service value are greater than the values weighted by the total volume of industrial waste water discharge, indicating that although these two weighted indicators belong to the same natural subsystem, the impact of land use on urban–rural differences in the social–economic dual system is less than the impact of environmental pollution differences. The proportion of a region in the study area with an average social–economic coordination development coefficient and the proportion of the region in ecosystem service value or total volume of industrial waste water discharge in the study area are compared according to the definition of the size of the Thiel index; the larger the gap, the larger the Thiel index. For 2020, the proportion of the total volume of industrial waste water discharge in the predominantly urban areas of the study area is close to 70%, while ecosystem service value accounts for only 34%, and the gap between 49% of the social–economic subsystem coordinated development coefficient and the land use ratio is smaller, so the Thiel index value of the total volume of industrial waste water discharge in the region is larger. Due to the uneven proportion of predominantly urban areas in the total number of study areas in terms of environmental pollution, the Thiel index weighted by the total volume of industrial waste water discharge in intermediate and predominantly urban areas is also greater than the Thiel index weighted by ecosystem service value.

3.3.2. Analysis of Urban–Rural Differences in Social–Economic–Natural Construction of Ecological Civilization in Multisystem

The Thiel index of the regional social–economic–natural multisystem studied in 2020 is shown in Table 9, and the values in parentheses are the contribution rates to the overall index. The difference between urban and rural areas of coordinated social–economic–natural development in the study area is greater than that between urban and rural areas, and the contribution rate is close to 1:3, which is similar to the previous analysis results, indicating that the gap between urban and rural coordinated development level is an important part of the overall gap. In terms of the contribution of each urban–rural type, the gap between the predominantly urban area and the intermediate area is small, almost twice that of the predominantly rural area. At present, China is still in the process of rapid urbanization, and some cities have developed from predominantly rural or intermediate to predominantly urban areas in a short time; the level of coordinated development is relatively less compared with that of cities in long-term predominantly urban areas, which is an important reason why the difference between urban and rural areas is greater than that between predominantly urban and intermediate areas.

Table 9. The social–economic–natural multisystem Thiel index and regional difference decomposition in 2020.

Weight	Total	Between Urban and Rural	Within Urban and Rural	Predominantly Urban	Intermediate	Predominantly Rural
Social–economic–natural	0.05	0.01 (0.23)	0.04 (0.77)	0.02 (0.35)	0.01 (0.26)	0.01 (0.17)

Source: made by the authors.

Combined with the qualitative analysis results obtained from the previous local spatial autocorrelation study, the coordinated development coefficient of the social–economic–natural multisystem in most cities in the predominantly urban area in the western part of the study area is in a low–low agglomeration spatial autocorrelation state, and the contribution rate of the predominantly rural area in urban and rural differences is only 17%.

4. Conclusions and Policy Recommendations

4.1. Conclusions

The degree of the coordinated development of the construction of ecological civilization in the social–economic–natural multisystem in cities in the study region is low, and the reasons for the lagging development of cities with different urban–rural division types are different. The coordinated development level of society, economy and nature in the study region from 2000 to 2020 has not yet reached the stage of coordinated development, but it has maintained an increasing trend year by year. For 2020, the main factor hindering the coordinated development of cities in predominantly urban areas is the ecological environment, while the main reason for the incoordination of cities in predominantly rural areas is that socioeconomic development is lagging behind, and the social, economic and ecological development of cities in intermediate areas is more coordinated.

The spatial distribution of social–economic–natural coordinated development levels in cities in the study area is becoming increasingly discrete, and the spatial distribution center of cities with higher levels of coordinated development in the region has gradually shifted to the southwest. From 2000 to 2020, the spatial positive agglomeration of the coordinated development level has gradually weakened, and the coordinated development coefficient of the predominantly urban cities in the eastern part has significant high–high agglomeration areas.

For 2020, the level of coordinated social–economic–natural development in the study area differs significantly in urban and rural areas than between urban and rural areas. For 2020, the social–economic Thiel index between urban and rural areas of the study region weighted by ecosystem service value and total volume of industrial waste water discharge is smaller than that of the Thiel index within urban and rural areas. For 2020, the difference in the level of coordinated development between urban and rural areas in the regional social–economic–natural multisystem is an important part of the overall difference.

4.2. Policy Recommendations

Based on the conclusions drawn above, this study makes the following recommendations.

When implementing the construction of ecological civilization, we should pay attention to the simultaneous development of society, economy and nature. The predominantly urban area focuses on ecological protection. On the one hand, urban pollution prevention and control is a breakthrough, and the construction of more infrastructure supports pollution prevention and control. On the other hand, with the optimal utilization of land resources as a breakthrough, cities need to limit the unlimited expansion of construction land. Cities in intermediate areas and predominantly rural areas should focus on social and economic development. They are still in the stage of developing into cities, and the progress of ecological environmental protection should be consistent with that of social and economic development.

The Chinese government should formulate regional policies considering the various spatial properties of the coordinated development coefficient of the construction of ecological civilization. Predominantly urban areas should appropriately shift the distribution of resources to ecological protection, expand the positive driving role of the eastern cities of the research region and deepen cooperation with the predominantly rural areas to gradually promote the intermediate areas and the improvement of the socioeconomic level of cities in predominantly rural areas.

The Chinese government should pay attention to the gap in the level of coordinated urban development of ecological civilization in the same urban–rural classification, especially the internal gap in predominantly urban areas. Cities in intermediate areas can realize the new requirements of new urbanization by complementing urban and rural areas. Predominantly rural areas should promote the economical and intensive use of land and carry long-term economic growth with limited land. Predominantly urban areas should focus on continuously promoting green production, living and consumption patterns; integrating urban construction into the ecosystem; and narrowing the time gap in the construction of ecological civilization.

5. Discussion

China has paid more and more attention to the regional coordination of ecological and environmental problems, urban–rural integration and new-type urbanization. This paper also follows this trend and makes the following prospects according to the research conclusions.

First, the study areas selected by the Chinese academic circle to examine the level of coordinated development of ecological civilization construction are mainly concentrated in administrative divisions, urban agglomerations, or eastern, central and western regions. It is hoped that future research on the construction of ecological civilization will take a more natural geographical division as the basis for the selection of the study area.

Second, panel data for towns and villages cannot be obtained due to the dynamic changes in urban–rural relations over time, which makes the statistical methods used in most economic research unusable. It is for this reason that this study uses one year to analyze the urban–rural differences in the coordinated development of ecological civilization construction. It is hoped that there will be better urban–rural divisions that will provide coherent urban and rural data on a timeline for analysis.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

We refer in part to Wang in Section 2.2.1, available online: https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7i0-kJR0HYBJ80QN9L51zrP6J05xQjCrsjUh0ZodYfJsCX-8thKMraA0MAbbRQ_QXe&uniplatform=NZKPT (accessed on 15 August 2023).

Appendix B

We refer in part to Shi et al. in Table 2, available online: https://kns.cnki.net/kcms2/article/abstract?v=3uoqIhG8C44YLTlOAiTRKibYlV5Vjs7i0-kJR0HYBJ80QN9L51zrP2_aI-C7vaYreTTJdWrnGnyv58T_NM2pEtdyFxe3bKX1&uniplatform=NZKPT (accessed on 4 August 2023).

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