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Conflict or Coordination? A Coupling Study of China's Population–Urbanization–Ecological Environment

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Abstract: Whether the new type of urbanization implemented in China in the past decade has been effective in regulating urbanization and balancing human development and environmental protection remains to be verified. Therefore, this study develops a framework for assessing population-urbanization–ecological environment interactions by combining the coupling coordination degree model and the decoupling index. Firstly, the proposed framework establishes an indicator system of population, economy, society, space, environmental pressure, ecological governance, ecological status, and ecological services based on two sets of national census data; secondly, this study combines the coupling coordination degree model and decoupling index to comprehensively understand the coupling coordination relationship and the decoupling relationship of the population–urbanization–ecological environment across time and space. Overall, this study contributes to a deepened understanding of coupled population–urbanization–ecological environment interactions and provides a scientific basis for effective guidance on urban–rural management and the balance between human development and environmental protection.

Keywords: conflict or coordination; new-type urbanization; coupling; environmental pressure; China

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1. Introduction

As the global economy grows, the urban population is increasing dramatically. By 2022, 55% of the world's population lived in urban areas [1]. Furthermore, the United Nations 2030 Agenda for Sustainable Development indicates that the number of people living in urban areas will rise to 60% by 2030. However, urbanization is coupled with a series of environmental problems, such as urban soil and water pollution, water and energy shortage, green space loss, natural habitat fragmentation, the heat island effect, the waterwash effect, the congestion effect, and habitat quality decline [2–5]. These ecological problems create huge challenges for human life and seriously hinder the sustainable development of cities. Since the reform and opening up of China, the urbanization level has increased from 17.9% in 1978 to 64.72% in 2021, and urban construction land has increased from 6720 km^2 to 58,355.3 km^2 [6]. By 2030, China's urbanization level will further increase to 70%, and such rapid urbanization will not only determine the future development of the country itself but also influence the global urbanization process [7,8]. China has recognized the pressure on various ecological functions and services in areas where human activities are concentrated during its new type of urbanization and has emphasized the importance of ensuring harmony between humans and nature, enhancing urban resilience, and mitigating and adapting to climate change during the urbanization process [9]. For example, measures such as Multiplan Integration, three-zone and three-line delineation, land quota control, ecological protection red lines, and permanent basic farmland control have balanced population, urban development, and ecosystems [10–12]. However, some scholars believe that the increase in urban population will create greater poverty, social inequality, and environmental unsustainability in cities [13]. Evidently, due to the complex relationship between urbanization and ecosystems, the effectiveness of urban management policies in China remains unclear, and the conflicts and coordination among the population, urbanization, and the ecological environment are also yet to be clarified. Therefore, it is necessary to explore the dynamic relationship between the population, urbanization, and ecological environment to provide a scientific basis for effectively regulating urbanization and the balance between human development and environmental protection.

China's new type of urbanization proposed in 2014 attempts to address three major policy challenges regarding land, people, and the environment [14]. Meanwhile, China conducted two national population censuses in 2010 and 2020, and these data provide a reliable database to reflect the real relationship between urbanization and environmental pressure and are a strong support to explore the effectiveness of the new type of urbanization. It validates whether China's development over the past 10 years has been on a trajectory of ecological conflict or a trajectory of harmony and whether this new wave of global urbanization will succeed in breaking the pattern. Studies have shown that China's urban built-up land area has increased by 80% over the past 40 years, while its urban population has increased by only 50% [15]. Pessimists argue that the growth of land urbanization has far outpaced the population growth in these areas and has led to serious "diseconomies", including the emergence of many empty or ghost cities [16]. This has apparently increased public spending by local governments, thus limiting the "absorption effect" of migrant workers. Optimists, on the other hand, argue that population growth can generate economic and technological benefits that have a strong positive impact on the region while also avoiding extensive land development in the countryside. Four times more rural land is used for various types of construction than urban land, as evidenced by its inefficient land use [14]. As a result of increased population and urbanization, cities face ecological challenges. However, due to the complexity of the relationship between man and land, the possible changes in the impact of population on urbanization and the ecological environment have not yet received enough attention. Therefore, in order to achieve sustainable management of ecosystems, it is necessary to determine the urbanization–population–ecological environment relationship.

Differences in population, land, and ecological environment in different urbanization systems lead to different spatial structures, functions, and attributes [17]. Few studies have focused on the coupled urbanization–population–ecological environment relationship, which is not conducive to explicitly exploring the Territorial System of Human–Environment Interaction. In the long run, a better understanding of the coupling of urbanization–population–ecological environment interactions and assessing the coordination or conflict among them are the keys to balancing urbanization and ecosystem protection [13,18]. In this context, it is necessary to construct an indicator system for urbanization–population–ecological environment so as to monitor the development process of urbanization and the ecosystem and provide more scientific evidence for a sustainable human–Earth relationship. At the same time, a coupling analysis method is developed to deconstruct the relationship among urbanization, the population, and the ecological environment and to quantitatively measure the correlation degree, coordination degree, coupling degree, and decoupling degree across time and space. This will help us to take a global view of how the new type of urbanization leads to the conflict or coordination of the Territorial System of Human–Environment Interaction.

The previous literature has demonstrated that the negative effects tend to outweigh the positive effects, limited by the level of technology, economic development patterns, and ecological conservation awareness in the early stages of urbanization. As environmental investments increase and technology improves, the ecosystem gradually recovers, and the positive effects of urbanization on the ecosystem tend to outweigh the negative effects [19,20]. Whether China's new type of urbanization can break out of the old path of pollution first and treatment later remains to be verified by data. Regarding population transfer, urbanization has exerted great pressure on the environment and resources. Still, the gathering of talents can promote the development of green industries and improve the quality of the ecological environment. In terms of spatial urbanization, a large amount of ecological land is transferred to construction land, which reduces the resilience of the ecosystem and the expansion of road networks, makes landscape patches more fragmented [21], stops the disorderly development of the countryside, and improves the efficiency of land use. Ecological degradation can slow urbanization, but the excessive use of environmental funds can burden urbanization. With these challenges, China has a long way to go in achieving Sustainable Development Goals [22,23]. Therefore, clarifying the conflict and coordination relationship and internal mechanism of urbanization–population–ecological environment (Figure 1) is conducive to formulating effective policies to minimize the negative impact on the environment and maximize the benefits of urbanization. Figure 2 shows a photo of China's urbanization fragments.

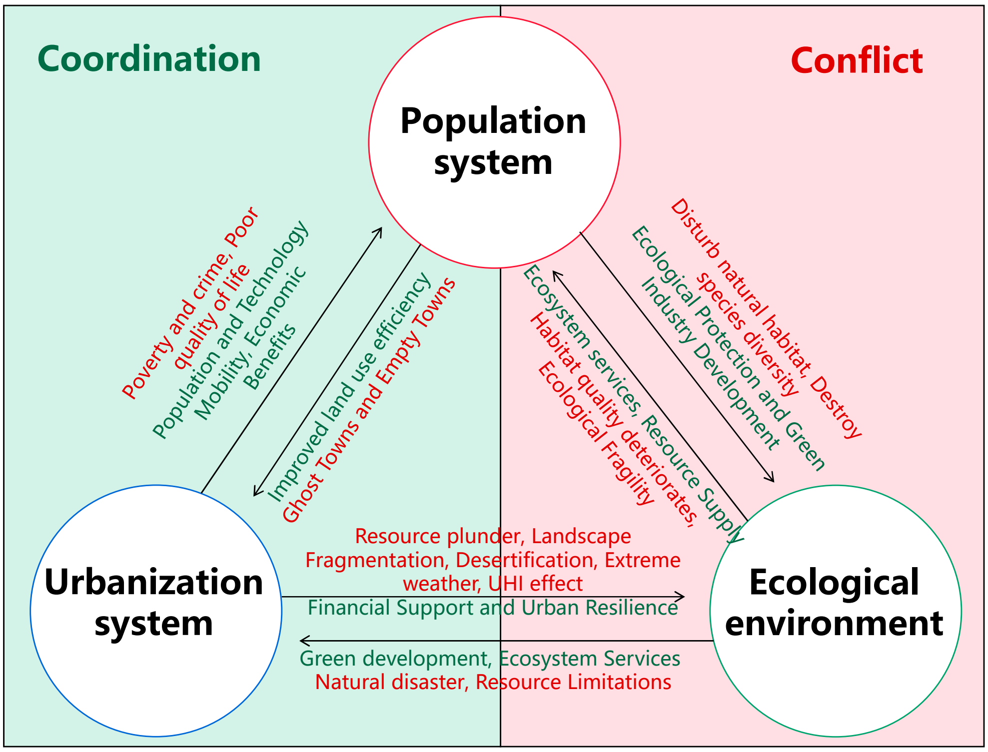

Figure 1. The conceptual framework of population–urbanization–ecological environment coupling.

Figure 2. Photos of China's urbanization fragments (Pictures from Baidu Gallery).

The study of the relationship of urbanization–population–ecological environment is an important topic in the study of humans and nature, and it is also the focus of implementing the international sustainable development strategy. This study attempts to construct an assessment framework of urbanization–population–ecological environment and tries to achieve the following objectives: (I) establish a systematic and scientific new assessment framework and coupling indicator system of urbanization–population–ecological environment; (II) reveal the coupling coordination degree relationship and the coupling indicator system of urbanization–population–ecological environment at the system and subsystem levels, so as to provide reference and support for the high-quality development of the new type of urbanization; (III) study the relationship between the ecological environment and urbanization using a population census in terms of the coupling coordination degree, spatial differences, and influencing factors so as to reveal the internal structure of Chinese provinces, provide a methodological reference for cities with the same regional characteristics in the future, and provide the basis for planning and policy making to effectively guide urban and rural management and balance human development and environmental protection.

2. Methodology

2.1. Data Sources

The remote sensing monitoring datasets of land use/land cover in China for 2010 and 2020 were obtained from the Institute of Geographical Sciences and Natural Resources Research of the Chinese Academy of Sciences, and the data were mainly used to calculate the relevant indicators of ecological environment. Data related to population indicators were obtained from the 2010 and 2022 population census data. The data on water resource indicators such as sewage discharge and sewage treatment were obtained from the provincial water resource bulletin and the provincial statistical yearbook. The data on ecological environment indicators such as forest coverage rate and park green area per capita were obtained from the China Ecological Environment Status Bulletin and Provincial Ecological Environment Status Bulletin. R&D expenditures were obtained from the China Science and Technology Statistical Yearbook, and fixed asset investment was obtained from the China Industrial Statistical Yearbook. The indicators related to urban and rural consumption were mainly obtained from the China Social Statistical Yearbook.

2.2. Research Framework

This study constructed a new assessment framework and coupled indicator system for the population–urbanization–ecological environment, which can be divided into two parts (Figure 3). In the first part, the main purpose is to construct and evaluate the indicator system of the population–urbanization–ecological environment. Firstly, this study uses China's two national censuses in 2010 and 2020 to establish a population indicator system. Secondly, the urbanization indicator system is divided into economic urbanization, spatial urbanization, and social urbanization using a structural approach. Further, this study establishes the framework of Pressure–State–Response–Ecosystem Services (PSRS) for the ecological environment. Finally, we use the entropy method and Analytic Hierarchy Process to comprehensively calculate various indicators.

The second part mainly discusses the coupling relationship between the conflict and coordination of the population–urbanization–ecological environment. First, this study uses the coupling coordination model to explore the conflict and coordination relationship between the population, urbanization, and ecological environment from within the system. Secondly, we use the decoupling index to analyze the degree of decoupling between population, urbanization, and ecological environment and between various subsystems. Finally, the coupling coordination degree is combined with the decoupling index to explore the human–land configuration impact of population change, urbanization level, and ecological environment change through time and space. This discovery can provide strong evidence for whether this wave of China's new type of urbanization can successfully break the old road of "pollution first and then treatment".

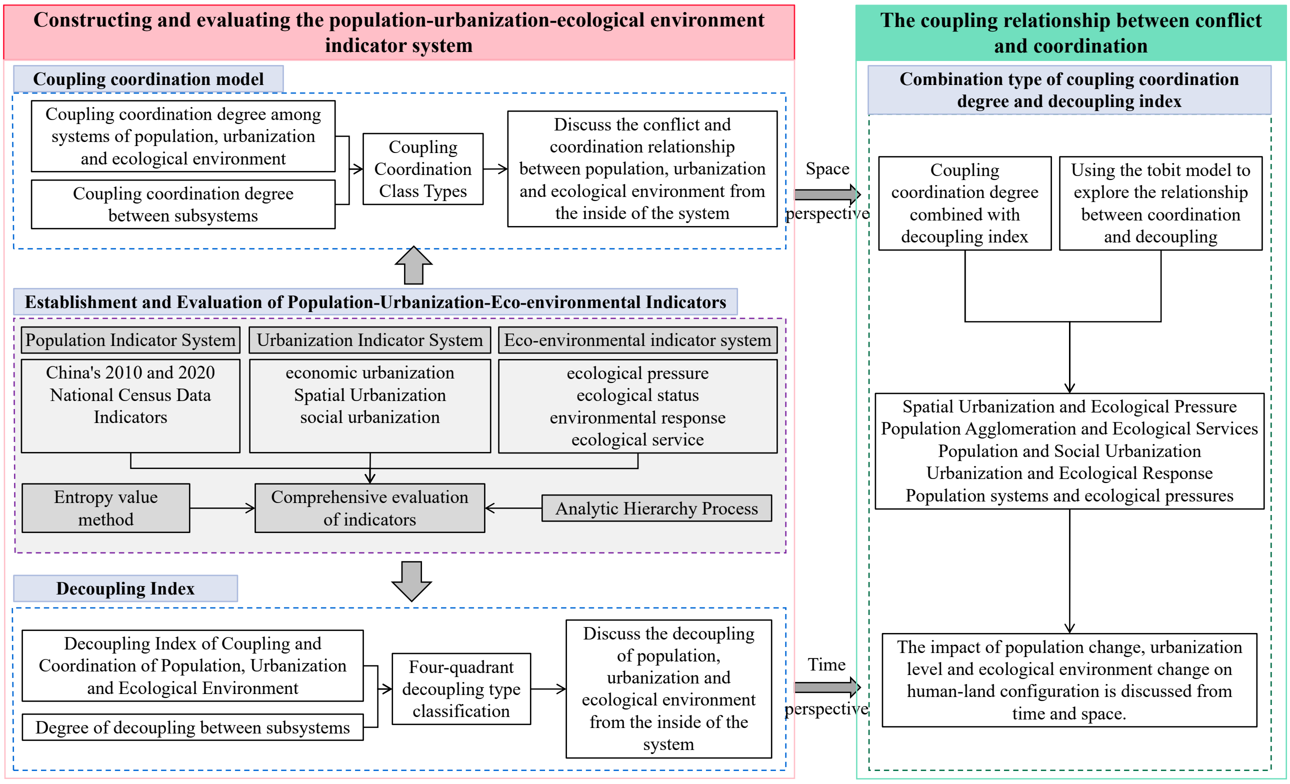

Figure 3. Research framework for population–urbanization–ecological environment coupling.

2.3. Indicator System Construction

2.3.1. Population Indicator System

The migration of the population from rural to urban areas is the most significant feature and result of the urbanization process. The two national censuses conducted in China in 2010 and 2020 provided detailed demographic indicators for each province, and these indicators are the most powerful demographic data for analyzing the conflict and coordination between the new type of urbanization and ecological construction in China over the past decade. Economic theory suggests that population agglomeration creates a "labor pool effect" [24] and that an increase in urban population generates a "cost effect". Therefore, we used the two indicators of the urban population ratio and urban population density in this present study. Meanwhile, the new type of urbanization not only focuses on economic efficiency but also on the quality of the population and improvement in living standards. Hence, we selected the educational level and employment structure from the census indicators to reflect the improvement in population quality under urbanization. In addition, urban population mobility itself promotes the exchange of technology and the flow of capital, which in turn increases the attractiveness of the city and is more likely to attract more people to the city. Given this, we chose the ratio of the population of other provinces to express it [25]. Furthermore, marital status and the size of the family are also two important indicators of population characteristics, as the marital status reflects the change in the residential area, and the size of the family indirectly reflects the state of plundering ecological resources. Finally, the aging population, illiterate population, and population growth rate are also important demographic indicators of the new type of urbanization. The ratio of the aging population and illiterate population can reflect inefficient land use, while the population growth rate indirectly reflects the pressure on future ecological resources [26]. In summary, the specific indicators of the population are shown in Table 1.

Table 1. Population indicator system and its weights.

Indicator	Indicator Description	Unit	Objective Weight	Subjective Weight	Comprehensive Weight	Source
Population agglomeration	The proportion of the urban population to the total population	%	0.116	0.297	0.207	China census
Employment structure	The proportion of employees in secondary and tertiary industries per 10,000 people	%	0.113	0.212	0.163	China census
Educational level	The number of people with a college degree or above per 10,000 people	%	0.109	0.113	0.111	China census
Population of other provinces	The number of people from outside the province in the registered population	%	0.108	0.101	0.105	China census
Population density by province	The ratio of the total population to the total area of each province	People/km	0.106	0.145	0.126	China census China Statistical Yearbook
Aging population (-)	The population over 65 as a percentage of the total population	%	0.116	0.050	0.083	China census
Size of family	The population per household	People	0.114	0.039	0.077	China census
Illiterate population (-)	People who do not read as a percentage of the total population	%	0.108	0.024	0.066	China census
Population growth rate	The number of births per 10,000 people	People	0.112	0.020	0.066	China Statistical Yearbook

Note: "-" indicates that the impact is negative. In this paper, the linear transformation method converts it into a normal output—that is, multiply the number by "−1" to become a negative number and construct a translation vector to make it a positive output.

2.3.2. Urbanization Indicator System

Urbanization has multidimensional impacts, including urban landscape expansion and socioeconomic performance enhancement, and therefore, we considered the classification of urbanization systems to be more structural in nature. Referring to the existing literature [26–29], a preliminary indicator system for the new type of urbanization was established based on the principles of scientificity, objectivity, comprehensiveness, and data availability. In order to eliminate the subjectivity of indicator selection, we referred to three databases, China CNKI, Web of Science, and ScienceDirect, to select the indicators with a high frequency in recent years. The selected indicators were further screened by consultants and government staff in the fields of land use assessment, ecosystem management, and urban–rural development. They were divided into three major economic, spatial, and social urbanization dimensions.

Economic Urbanization

Economic development is the main basis for the construction of the new type of urbanization, and the development of economic urbanization leads to economic expansion. The new type of urbanization needs to advocate intensive and efficient economic development and move toward a more low-carbon and green energy direction. According to Petty–Clark's law and Chenary's industrial structure stage theory, the leading industries will change in the order of primary, secondary, and tertiary industries in economic development [24]. Therefore, we used the share of secondary industry in GDP and the share of tertiary industry in GDP to reflect the process of economic development mode transformation and industrial structure upgrading in the new type of urbanization. The share of R&D

expenditure in GDP reflects the potential of economic innovation, low carbon, and green energy in the new type of urbanization. Meanwhile, the per capita local fiscal revenue and per capita disposable income of urban residents reflect the economic development level in the new type of urbanization. Fiscal revenue and per capita income can promote the transformation and upgrading of consumption and are the basic conditions for developing new economic sectors. Finally, we used the fixed asset investment per unit of GDP to reflect the efficiency of resource utilization. Less input and more output reflect the intensive application of resources and a reduction in pollution emissions, which is an effective measure of the urbanization of a new economy. The specific indicators are shown in Table 2.

Table 2. The urbanization indicator system and its weights.

System	Indicator	Indicator Description	Unit	Objective Weight	Subjective Weight	Comprehensive Weight	Source
Economic urbanization	Local revenue per capita	Provincial revenue divided by the total population	CNY/person	0.160	0.174	0.167	China Statistical Yearbook
	Per capita disposable income	The per capita disposable income of urban and rural residents	CNY/person	0.164	0.401	0.283	
	The added value of the secondary industry	The added value of the secondary industry accounting for the proportion of the total GDP	%	0.173	0.132	0.153	
	The added value of the tertiary industry	The added value of the tertiary industry accounting for the proportion of the total GDP	%	0.163	0.203	0.183	
	Fixed asset investment per unit of GDP	The ratio of the total assets of industrial enterprises above the designated size to GDP	CNY	0.170	0.055	0.112	
	R&D spending	R&D expenditure as a percentage of fiscal expenditure	%	0.170	0.035	0.102	China Science and Technology Statistical Yearbook
Spatial urbanization	Land use	The proportion of urban villages and industrial and mining land to the total area	%	0.164	0.362	0.263	China Statistical Yearbook
	Infrastructure	The urban transport land area divided by the total population	Sqm/person	0.164	0.185	0.174	
	Per capita green area of parks	The urban green space divided by the total population	Sqm/person	0.165	0.094	0.130	China Environmental Statistical Yearbook
	Per capita living area	The total floor area divided by the total population	Sqm/person	0.167	0.054	0.111	China census
	Traffic line density	The ratio of the total length of railways and roads to the total area	Km/km^2	0.169	0.199	0.184	China Statistical Yearbook
	Public facilities	The total number of schools of each type divided by the total population	Number of schools/10,000 people	0.170	0.106	0.138	
Social urbanization	Number of sanitation facilities per 10,000 people	Expressed in the number of medical staff per thousand people	People	0.115	0.072	0.094	China Statistical Yearbook
	Public finance spending	Expressed in terms of public expenditure per capita	CNY/person	0.111	0.135	0.123	
	Urban registered unemployment rate (-)	Unemployed people as a percentage of the total population	%	0.117	0.035	0.076	China Population and Employment Statistical Yearbook
	Total retail sales of consumer goods per capita	The total retail sales divided by the total population	CNY/person	0.114	0.309	0.212	China Statistical Yearbook
	Social security and employment spending	The proportion of social security and employment expenditure in the total fiscal expenditure	%	0.077	0.106	0.092	
	Public transport	The number of public transport vehicles per 10,000 people	Vehicle	0.117	0.149	0.133	
	The number of people insured by urban basic medical insurance	The proportion of urban basic medical insurance participants in the total population	%	0.114	0.083	0.099	China Urban Statistical Yearbook
	Engel's coefficient ratio of urban and rural households (-)	The total food expenditure as a share of the total personal consumption expenditure	%	0.118	0.047	0.083	China Social Statistical Yearbook
	Proportion of consumption expenditure of urban and rural residents (-)	The total retail sales of consumer goods per capita divided by the per capita income	%	0.117	0.064	0.091	

Spatial Urbanization

Cities enhance sustainable development through the structural optimization of space and the rational allocation of land resources [30]. The new type of urbanization aims to beautify the ecological space and make the human living environment more livable, so we used the parkland area per capita to express it. If the scale of urban land expands faster than the population growth, it can easily lead to "empty cities" and "ghost cities", so we used the ratio of the built-up area to total area to express the land use. The three indicators of per capita urban road area, land use for public facilities, and traffic density reflect people's travel convenience because the construction of spatial urbanization cannot be separated from the high-quality development of infrastructure. Finally, the size of the living area per capita reflects the degree of spatial agglomeration of the city, which is an important indicator of the sustainable development concept of the new type of urbanization. The specific indicators are shown in Table 2.

Social Urbanization

Social urbanization supports people's needs, and the new type of urbanization, characterized by equalization of public services, a sound social security system, and urban–rural integration, can create a fair and harmonious social environment and improve the comprehensive carrying capacity of cities [31,32]. In this study, the number of sanitation facilities per 10,000 people, public financial expenditure per capita, the proportion of social security and employment expenditure to total financial expenditure, the number of public transportation vehicles per 10,000 people, the proportion of urban basic medical insurance participants to the total population, and the urban registered unemployment rate were selected to reflect the level of public services and social security in the new type of urbanization. Engel's coefficient ratio of urban and rural households and the ratio of urban and rural residents' consumption expenditure are two indicators used to reflect the process of urban–rural integration. Finally, the indicator of total retail sales of consumer goods per capita reflects the promotion effect of the market consumption capacity on the economy. The new type of urbanization needs to reflect the changes in people's thinking, behavior, and technological progress to promote the sustainable development of society and nature. It is an element that must be considered in promoting ecological environmental protection. The specific indicators are shown in Table 2.

2.3.3. Ecological Environment Indicator System

The ecological environment is a relatively macro concept understood differently by different scholars [9,33]. In this study, the ecological environment mainly refers to the natural environment and resources on which humans depend. Previous studies have often used Pressure–State–Response (PSR) models, ecosystem services (ESs), and Vigor–Organization–Resilience (VOR) models to quantify environmental assessments [34]. In this study, the advantages of the PSR model and ESs were combined to establish the framework of Pressure–State–Response–Services (PSRS) of the ecological environment. This study refers to the World Development Indicators (WDI) [35], Environmental Performance Index (EPI) [36], and other scholars' research [9,26,37,38] and formulates an indicator system, as shown in Table 3. Specifically, the environmental pressure reflects whether the ecological environment can cope with the development of urbanization and is also an important indicator to study whether the ecological environment and urban development can be decoupled under the new type of urbanization. The ecological state reflects the ability of an ecosystem to maintain its structural stability in the face of human activity, and the environmental response emphasizes how the city or human system responds to the various environmental problems that arise due to urbanization. Ecosystem services emphasize the goods and services that the natural environment provides to humans and can be used to represent the ability of an ecosystem to meet human needs, as well as the main support base for urbanization.

Table 3. The ecological environment indicator system and its weights.

System	Indicator	Indicator Description	Unit	Objective Weight	Subjective Weight	Comprehensive Weight	Source
Environmental pressure	Wastewater discharge (-)	Sewage discharge divided by the total population	Cubic meters/person	0.173	0.126	0.150	China Statistical Yearbook
	Sulfur dioxide emissions (-)	So2 emissions divided by the total population	Kg/person	0.150	0.106	0.128	
	Cod emissions (-)	Cod (Chemical Oxygen Demand) emissions divided by the total population	Kg/person	0.173	0.111	0.142	
	Landscape fragmentation (-)	This is represented by the density of traffic lines. The denser the traffic network, the more fragmented the landscape.	Km/km^2	0.177	0.109	0.143	China Urban Statistical Yearbook
	General industrial solid waste generation (-)	General industrial solid waste generation divided by the total population	Ton/person	0.166	0.056	0.111	China Statistical Yearbook
	Ecological risk index (-)	Different land use types have different ecological risk intensity coefficients	Ecological risk index per square kilometer	0.171	0.267	0.219	See Section 3.1 below for details
	Habitat degradation (-)	This reflects the vulnerability of the ecological environment	Habitat degradation per square kilometer	0.172	0.225	0.199	See Section 3.3 below for details
Ecological status	Habitat quality	The habitat quality varies by land type	Habitat quality per square kilometer	0.212	0.374	0.293	See Section 3.3 below for details
	Forest cover rate	The forest area as a percentage of the total area	%	0.210	0.203	0.207	China Statistical Yearbook
	Per capita water resources	The total water resources divided by the total population	Cubic meters/person	0.162	0.227	0.195	China Water Resources Statistical Bulletin
	Per capita public green space	The urban green area divided by the total population	Square meters/person	0.205	0.074	0.140	China Environmental Statistical Yearbook
	Ecosystem resilience	Ecosystem restoration coefficients are different for different land use types		0.212	0.121	0.167	See Section 3.2 below for details
Environmental response	Domestic waste removal volume	The total waste divided by the total population	Tons/person	0.198	0.319	0.259	China Statistical Yearbook
	Comprehensive utilization rate of industrial solid waste	The amount of general industrial solid waste generated divided by the comprehensive utilization of general industrial solid waste	Percentage	0.205	0.283	0.244	
	R&D spending	R&D expenditure as a percentage of fiscal expenditure	%	0.201	0.131	0.166	China Science and Technology Statistical yearbook
	Expenditure on energy conservation and environmental protection	The proportion of energy conservation and environmental protection expenditure in fiscal expenditure	%	0.197	0.154	0.176	China Statistical Yearbook
	Completed investment in industrial pollution control	The ratio of completed investment in industrial pollution control to the total population	CNY/person	0.198	0.113	0.156	
Ecological services	Value of ecosystem services	Multiplies the value of ecosystem services by the corresponding area	CNY	1	1	1	See Section 3.3 below for details

Calculation of the Ecological Risk Index

The different types of land use result in varying risks. We assessed the risks of different land use types by constructing an ecological risk index [39]. In this study, the calculation of Equation (1) was used. The land use types were multiplied by the corresponding risk intensity coefficients, and risk accumulation was performed. The risk intensity coefficients in this study adopted the ecological risk intensity coefficients for the land use types established by Guoqing Yang in 2011 (Table 4, row 2) [39].

$$E = \sum_{i=1}^{m} \frac{\mathrm{T_i} \times \delta_i}{T} \quad (1)$$

where E denotes the ecological risk index; δ_i denotes the ecological risk intensity factor for land type i; T denotes the total land area of the sample area; T_i denotes the area of land type i.

Table 4. The ecosystem restoration coefficients for different land use types in China.

Indicators	Farmland	Woodland	Grassland	Water Area	Construction Land	Unused Ground
Ecological risk intensity coefficient	0.31	0.1	0.2	0.18	0.69	0.11
Ecosystem resilience coefficient	0.5	0.9	0.6	0.9	0.3	0.2

Ecosystem Resilience

In this study, the area multiplied by the ecosystem resilience factor was used to calculate ecosystem resilience based on the contribution and role of different land use types, drawing on the study by Tang et al. [3]. We believe that forests, water, and grasslands are more likely to recover from disturbances than, for example, cropland and building land disturbed by humans. We established the ecosystem restoration coefficients based on previous studies and expert ratings, as shown in row 3 of Table 4.

Calculation of Habitat Quality and Habitat Degradation

In this study, the InVEST model was used to calculate habitat quality [3], which was calculated by Equation (2):

$$Q_{ij} = H_j[k^Z/(D_{ij}^Z + k^Z)] \quad (2)$$

where Q_{ij} denotes the habitat quality of land type j of cell i; H_j denotes the habitat suitability of j; k is a half-saturation constant, whose value is half of D_{ij}; Z is usually assigned a value of 2.5; and D_{ij} is the degree of threat to land type j of cell i. D_{ij} can be calculated by Equation (3):

$$D_{ij} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} (\omega_r / \sum_{r=1}^{R} \omega_r) r_y \left(1 - \left(d_{iy}/d_{rmax}\right)\right) \beta_i S_{jr} \quad (3)$$

where R denotes the number of pressure sources; ω_r denotes the weight of pressure source r; y denotes the number of units of pressure source r; r_y denotes the pressure source value of unit y; Y_r denotes the number of units occupied by the pressure source on the land type layer; d_{iy} denotes the distance between unit i and unit y; d_{rmax} denotes the maximum impact distance of pressure source r; β_i denotes the accessibility of unit x; S_{jr} denotes the sensitivity of land type j to stressor r. We pressured sources and parameters based on previous studies and the characteristics of rapid urbanization, including the maximum threat distance, weights, and sensitive pressure sources for each land type [40–42], as shown in Tables 5 and 6.

Table 5. The pressure sources and weights.

Threat	MAX_DIST	WEIGHT	DECAY
Paddy field	4	0.3	Exponential
Dry land	4	0.4	Exponential
Urban land	10	0.9	Exponential
Rural settlement	8	0.7	Exponential
Industrial land	12	1	Linear
Desert land	3	0.1	Exponential

Table 6. The sensitivity of each land type to each pressure source.

LULC	Name	Habitat	Paddy Field	Dry Land	Urban Land	Rural Settlement	Industrial Land	Desert Land
11	Paddy field	0	0.3	0.2	0.6	0.4	0.5	0.5
12	Dry land	0.3	0	0.2	0.6	0.4	0.5	0.5
21	Woodland	1	0.6	0.7	0.9	0.8	0.9	0.5
22	Bush	0.9	0.5	0.6	0.8	0.7	0.8	0.4
23	Open woodland	0.8	0.4	0.5	0.7	0.6	0.7	0.4

Table 6. *Cont.*

LULC	Name	Habitat	Paddy Field	Dry Land	Urban Land	Rural Settlement	Industrial Land	Desert Land
24	Other woodland	0.7	0.3	0.4	0.6	0.5	0.6	0.3
31	High-coverage grass	0.8	0.4	0.5	0.7	0.6	0.7	0.4
32	Medium-coverage grass	0.6	0.3	0.4	0.6	0.5	0.6	0.3
33	Low-coverage grass	0.4	0.2	0.3	0.5	0.4	0.5	0.2
41	Canals	0.8	0.8	0.8	0.9	0.8	0.9	0.7
42	Lake	1	0.8	0.8	0.9	0.8	0.9	0.7
43	Reservoir pond	0.9	0.8	0.8	0.9	0.8	0.9	0.6
44	Permanent glacier snow	0.7	0.8	0.8	0.9	0.8	0.9	0.6
45	Tidal flat	0.7	0.7	0.7	0.8	0.7	0.8	0.5
46	Beach	0.7	0.7	0.7	0.8	0.7	0.8	0.5
51	Urban land	0	0	0	0	0	0	0
52	Rural settlement	0	0	0	0	0	0	0
53	Other construction land	0	0	0	0	0	0	0
54	Land for scenic spots and facilities	0	0	0	0	0	0	0
61	Sandy ground	0.1	0	0	0	0	0	0
62	Gobi	0.1	0	0	0.1	0.1	0.1	0
63	Saline–alkali land	0.2	0.1	0.1	0.2	0.1	0.2	0.1
64	Wetlands	0.8	0.7	0.7	0.8	0.7	0.8	0.5
65	Bare earth	0.1	0.1	0.1	0.2	0.1	0.1	0.1
66	Bare rock texture	0	0	0	0	0	0	0
67	Other	0	0	0	0	0	0	0
99	Ocean	0.4	0.1	0.1	0.3	0.2	0.3	0.1

Meanwhile, the habitat degradation index is a degradation score map calculated based on Equation (3). The maps of the calculation results of habitat quality and habitat degradation are shown in Figure 4.

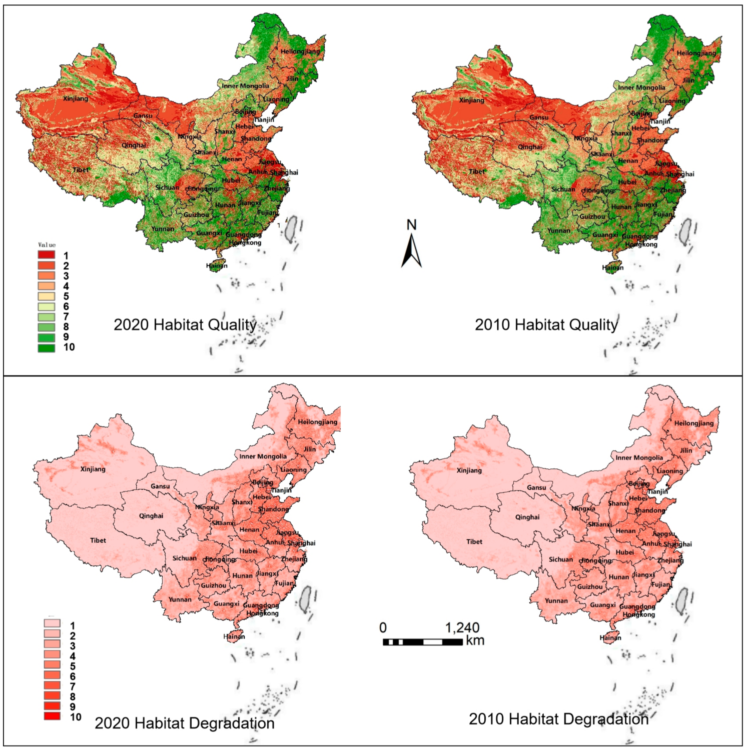

Figure 4. Habitat quality and habitat degradation in China in 2010 and 2020. Note: The higher the habitat quality score, the better the habitat quality; the higher the score of habitat degradation, the more serious the ecological degradation.

Value of Ecosystem Services

Ecosystem services are of inestimable value as a guarantee for maintaining human productivity and quality of life. They can offer supporting services (including soil maintenance and biodiversity maintenance), providing services (including food production and raw material provisioning), cultural services (including aesthetic landscapes), regulating services (including gas regulation, climate regulation, hydrological regulation, and waste treatment), and other functions [43]. This study draws on the research by Martínez-Sastre et al. [43–45], which quantified the ecosystem service value per hectare of land use by consulting 500 ecologists. Therefore, it is a more realistic reflection of the value of ecosystem services for each land use type in China. The details are shown in Table 7. By multiplying the ecosystem service value of each type in Table 7 by the land use area of the corresponding type, the overall ecosystem service value of each province can be obtained.

Table 7. The value of ecological services for each land use type.

System	Service Type	Ecosystem Service Value (CNY/hm^{-2})					
		Grassland	Woodland	Farmland	Wetlands	Water Body	Unused Land
Regulating services	Gas regulation	707.9	3097.00	515.89	1547.10	0.00	0.00
	Climate regulation	796.4	2389.10	569.09	14,697.50	407.00	0.00
	Hydrological regulation	707.9	2831.50	533.06	13,322.30	18,033.20	26.50
	Waste treatment	1159.2	1159.20	936.56	15,625.70	16,086.60	8.80
Providing services	Food production	265.5	88.50	267.98	257.90	88.50	8.80
	Raw material	44.2	2300.60	301.48	60.20	8.80	0.00
Supporting services	Soil maintenance	1725.5	3450.90	1261.87	1469.70	8.80	17.70
	Biodiversity maintenance	964.5	2884.60	652.33	2148.80	2203.30	300.80
Cultural services	Aesthetic landscapes	35.4	1132.60	92.62	4770.20	3840.20	8.80
	Total value	6406.5	19,334.00	5130.88	53,899.40	40,676.40	371.40

2.4. Research Method

2.4.1. Indicator Evaluation Method

To evaluate the indicator system, we used the linear weighted-sum method to evaluate the comprehensive level of the indicators. The details are shown in Equation (4):

$$U_i = \sum_{i=1}^{m} \sum_{j=1}^{n} \omega_j \times y_{ij} \quad (4)$$

where U_i represents the comprehensive value of various indicators in city i, ω_j represents the weight of indicator j in the corresponding indicator system, y_{ij} represents the normalized value of indicator j in city i, and m and n represent the number of provinces and indicators, respectively.

There are subjective weighting methods and objective weighting methods for determining indicator weights. In this study, we combined subjective and objective evaluation and used the entropy method (Equation (1)) and the Analytic Hierarchy Process for comprehensive calculation. The entropy method is an objective weighting method that uses the amount of information provided by the entropy value of an indicator to determine the weight of that indicator, i.e., the lower the information entropy, the higher the weight [46,47]. However, the entropy method is highly objective and tends to ignore the errors in the data itself, thus deviating from the true situation. The Analytic Hierarchy Process uses the concept of hierarchy to layer the indicators, which are evaluated by relevant experts, so as to obtain the weight value of the evaluation indicators. Nonetheless, the results of subjective methods are prone to bias due to subjective factors [48]. In order to reflect the intrinsic connection between data, we combined subjective evaluation with objective evaluation and used the arithmetic mean to express the indicator weights (Equation (5)), making the evaluation results more accurate and realistic.

Equation (5) based on the entropy method is written below:

$$\begin{aligned} Y_{ij} &= \frac{X'_{ij}}{\sum_{i=1}^{m} X'_{ij}} \\ H_j &= \frac{1}{\ln m} \sum_{i=1}^{m} Y_{ij} \ln Y_{ij} \\ \eta_j &= \frac{1 - H_j}{n - \sum_{i=1}^{n} H_j} \end{aligned} \tag{5}$$

where X'_{ij} denotes the standard value of indicator j in the ith province; m and n denote the number of provinces and indicators, respectively; Y_{ij} denotes the proportion of indicator j in the ith province; H_j denotes the information entropy of indicator j; η_j denotes the weight of indicator j (the specific calculated weights are in the 5th column of Tables 1–3).

Equation (6), based on the indicator weight calculation method, is written below:

$$\varphi_j = (\eta_j + \nu_j)/2 \tag{6}$$

where φ_j is the comprehensive weight of indicators of the entropy method and Analytic Hierarchy Process; ν_j is the weight of the indicators in the Analytic Hierarchy Process.

Analytic Hierarchy Process

The weights of the Analytic Hierarchy Process are mainly used to build the matrix by comparing the relative importance of the indicators to each other. Afterward, each value in the normalized matrix is divided by the sum of values in its column. Further, the average of the values of each row of the new matrix is calculated and used as the weights of the indicators (as demonstrated by Equation (7)). The comparison of indicators in this study was obtained by consulting fifteen experts (the specific calculated weights are in the sixth column of Tables 1–3).

$$\begin{Bmatrix} 1 & 3 & 5 \\ 1/3 & 1 & 1/2 \\ 1/5 & 2 & 1 \end{Bmatrix} \xrightarrow{\text{Column vector normalization}} \begin{Bmatrix} 0.65 & 0.5 & 0,77 \\ 0.22 & 0.17 & 0.08 \\ 0.13 & 0.33 & 0.15 \end{Bmatrix} \xrightarrow{\text{sum by row}} \begin{Bmatrix} 1.92 \\ 0.46 \\ 0.62 \end{Bmatrix} \xrightarrow{\text{Normalized}} \begin{Bmatrix} 0.64 \\ 0.15 \\ 0.21 \end{Bmatrix} \tag{7}$$

According to Equations (1)–(4), we can obtain a comprehensive assessment of demographic indicators (the specific calculated weights are in the 7th column of Tables 1–3) (the comprehensive weight is the average of the subjective weight and the objective weight). For the assessment of urbanization indicators, we used the linear weighted-sum method above to evaluate their comprehensive level under the new type of urbanization, and we considered economic urbanization, spatial urbanization, and social urbanization to be of equal importance, so each of them was given a one-third weight in the calculation of the weighting method. To evaluate the ecological environment, we also assigned the same weight to environmental pressure, ecological status, environmental response, and ecological services and thus obtained the comprehensive index value of the ecological environment.

2.4.2. Coupling Coordination Degree Model

We employed the coupling degree and coupling coordination degree to quantify the interactions among the population, urbanization, and ecological environment. The coupling degree emphasizes the strength of the interaction among various systems, and the coupling coordination degree emphasizes the positive interaction among various systems, which reflects the dynamic correlation trend in various subsystems from disorder to coordination [26,46,49,50]. Equation (8) represents the coupling degree among water, energy, and food subsystems.

$$C = \left\{ \frac{\theta_1 \times \theta_2 \times \theta_3}{\left(\frac{\theta_1+\theta_2+\theta_3}{3}\right)^3} \right\}^{\frac{1}{3}} \tag{8}$$

where C denotes the coupling degree. The larger the value of C, the stronger the coupling between the subsystems; θ_1, θ_2, and θ_3 distributions indicate the comprehensive index value of the population, urbanization, and ecological environment.

Equation (9) represents the coupling coordination degree of population, urbanization, and ecosystem subsystems.

$$D = \sqrt{C \times (a\theta_1 + b\theta_2 + c\theta_3)} \tag{9}$$

where D denotes the degree of coordination, and a higher value of D indicates a higher degree of coordination, meaning that there is a strong spatial relationship among population, urbanization, and ecosystem subsystems. We can take the same value for a, b, and c, i.e., one-third [51].

According to the existing research, the evaluation results of the coupling coordination degree can be divided into eight types, namely, extreme disorder (0–0.125), serious disorder (0.125–0.25), moderate disorder (0.25–0.375), mild disorder (0.375–0.5), primary coupling coordination (0.5–0.625), moderate coupling coordination (0.625–0.75), favorable coupling coordination (0.75–0.875), and quality coupling coordination (0.875–1). The classification of the coupling coordination level types aims to diagnose whether the population, urbanization, and ecological environment are developing in a coordinated manner—that is, to clearly understand the problems and limitations among the population, urbanization, and ecological environment so as to explore appropriate solutions. Then, each indicator system can also be measured by the pairwise coupling coordination degree, which, in turn, allows the conflict and coordination between urbanization and the ecological environment to be explored from within the system.

2.4.3. Decoupling Index

The concept of decoupling originates from physics and is mainly used to indicate that the interaction between variables no longer exists. It was later introduced to economic growth, energy consumption, environment, and urbanization. The Organization for Economic Co-operation and Development (OECD) defines decoupling as the breaking of the link between environmental pressure and economic effectiveness [52]. Absolute decoupling means that with economic development, the ecological environment will be improved or kept stable; relative decoupling means that with economic development, the growth rate of the ecological environment is slower than the economic growth rate [52,53]. In this study, a decoupling index based on the coupling coordination degree of the population, urbanization, and ecological environment was constructed, as shown in Equation (10).

$$\mathrm{E_t} = \frac{\Delta \mathrm{f(y)}}{\Delta \mathrm{s(x)}} = \frac{(\mathrm{f(y)_i} - \mathrm{f(y)_j})/\mathrm{f(y)_j}}{(\mathrm{s(x)_i} - \mathrm{s(x)_j})/\mathrm{s(x)_j}} \tag{10}$$

where $\mathrm{E_t}$ denotes the decoupling degree of the population, urbanization, and ecological environment from each other in time period t; $\Delta\mathrm{f(y)}$ and $\Delta\mathrm{s(x)}$ denote the development indices of the population, urbanization, and ecological environment in time period t, respectively; and $\mathrm{f(y)_i}, \mathrm{f(y)_j}, \mathrm{s(x)_i},$ and $\mathrm{s(x)_j}$ denote the values of the end year i and the beginning year s of each indicator, respectively. We classified decoupling into weak decoupling, moderate decoupling, and strong decoupling, and classified coupling into weak coupling, moderate coupling, and strong coupling using the four quadrants in Figure 5.

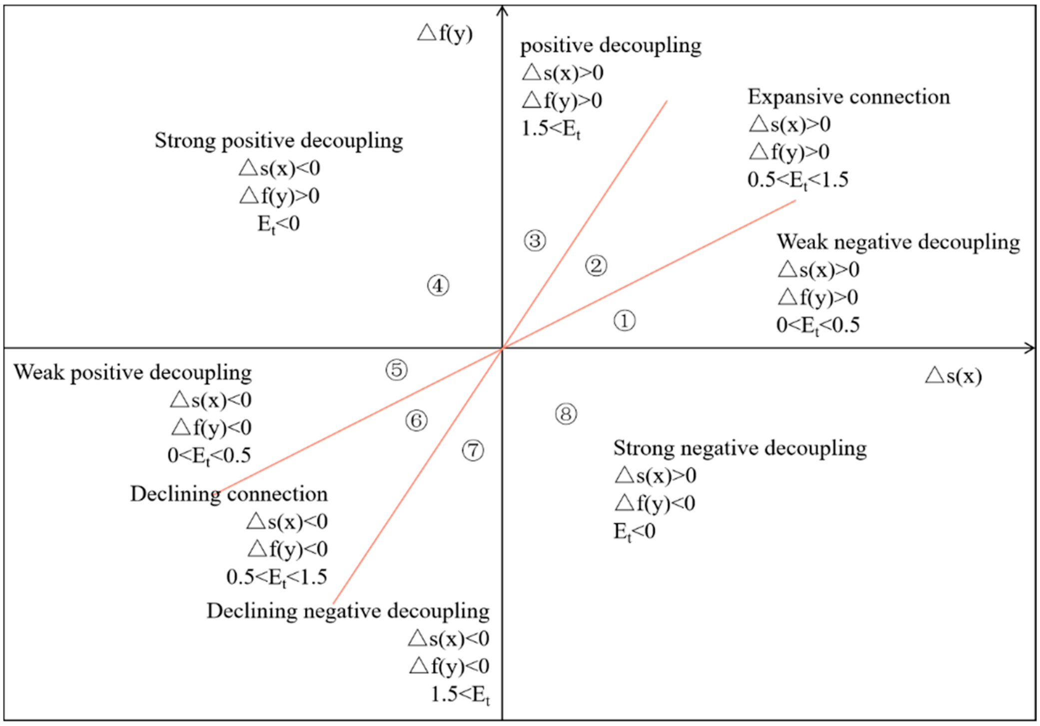

Figure 5. The identification and area of decoupling.

2.4.4. Types of Combination of Coupling Coordination Degree and Coupling Index

The coupling coordination degree is used to compare the coupling coordination situation of the population, urbanization, and ecological environment in each province across space. At the same time, the decoupling index is adopted to compare the decoupling situation of population, urbanization, and ecological environment in each province across time. Regarding the method coordination degree and decoupling index mentioned in this article, the impact of the human and land configuration on population changes, urbanization levels, and ecological environment changes can be explored across time and space (Figure 6). For example, when the coupling coordination degree is used and the obtained urban development is found to be incompatible with the ecological environment, we can use the decoupling index to further investigate which types of indicators contribute to the incompatible results and then obtain the contribution values of various indicators that lead to this incompatibility, providing a basis for formulating differentiated urban development policies. We used the Tobit model to quantify their relationship, as shown in Equation (11).

$$\begin{array}{c} D_i^* = \beta x_i + \varepsilon_i, i = 1, 2 \ldots n \\ D_i = D_i^* \ if \ D_i^* > 0 \\ D_i = 0 \ if \ D_i \leq 0 \end{array} \quad (11)$$

where D_i^* and D_i refer to the decoupling index value for each province. β is the vector of estimable parameters; x_i denotes the corresponding indicator above; ε_i is a random disturbance term. With the Tobit model, we can find the contribution values of the indicators that mitigate environmental pressure.

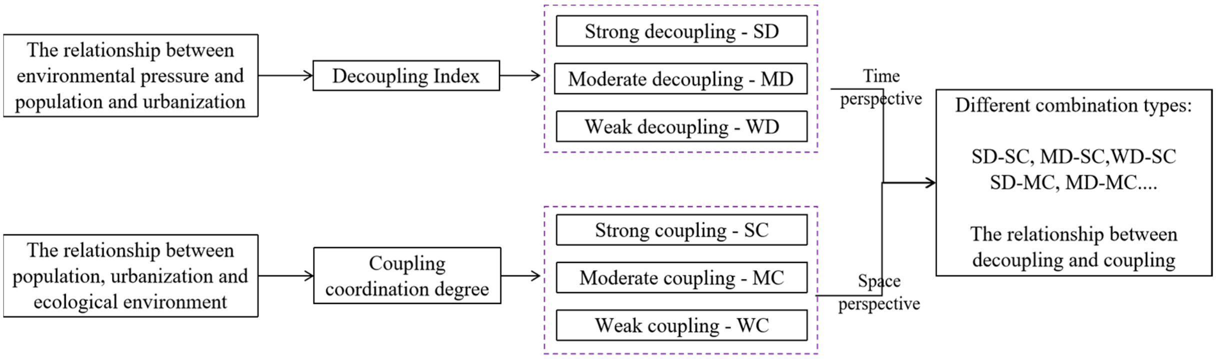

Figure 6. The different combinations of the coordination degree and decoupling index.

3. Results

3.1. Population–Urbanization–Ecological Environment Coupling Analysis

The overall coupling coordination degree of the population–urbanization–ecological environment (Figure 7a) in 2020 is 0.6, which is a moderate coupling state, indicating that 10 years of the new type of urbanization construction has effectively improved the relationship between the population, urbanization, and ecological environment and promoted their sustainable development. However, it is at a moderate coupling level overall, which indicates that the new type of urbanization is still in the development stage and needs to consider the impact of demographic and land use factors on urbanization. The reason why the coupling coordination degree has improved in the past 10 years is that urbanization has changed from a relatively lagging state in 2010 to a relatively synchronized state, while the ecological environment has also made significant progress. The degree of coupling coordination varies considerably across provinces. We found that only Beijing, Shanghai, and Guangdong have a coordination degree above 0.7, with Shanghai exceeding 0.8, indicating that all three have taken positive and effective actions in terms of the population, urbanization, and ecological environment and have significantly improved the quality of the ecological environment, population quality, and urbanization. However, the coupling coordination degree in Gansu, Xinjiang, Sichuan, and Yunnan provinces is still low, and the improvement is not obvious, which may be due to the influence of lagging urbanization. Furthermore, the coupling coordination degree has grown faster over the decade in Anhui (19%), Guizhou (18%), Chongqing (16%), and Hubei (16%), indicating that these four provinces have made greater efforts to promote the new type of urbanization, effectively improving the balance between urban systems. Overall, in 2010, there were 6 mild disorder types, 21 primary coupling coordination types, and 4 moderate coupling coordination types, while in 2020, there was 1 mild disorder type, 23 primary coupling coordination types, and 7 moderate coupling coordination types. Overall, 10 years of the new type of urbanization has improved the quality of urbanization and furthered the sustainable development of the city.

From the perspective of the relationship between the population and urbanization (Figure 7b), the coupling coordination degree between the two was the lowest in both 2010 and 2020, which was mainly caused by rapid urbanization, where the expansion of cities was much greater than the urbanization rate of the population, thus leading to a lower degree of coordination between the two. For example, in 2010, there were 21 provincial capitals with the mild disorder type, and the coupling coordination degree of the mild disorder type in 2020 was only 0.58, which was obviously lower than other types. However, in general, the 10 years of new type of urbanization effectively promoted the coordination between the two, and the overall coordination degree increased by 16% (Figure 7c). As indicated by the relationship between urbanization and the ecological environment (Figure 7d), the 10 years of the new type of urbanization has increased the coupling coordination degree of both from 0.52 to 0.62, an increase of 18%, which is the fastest increase among all coupling types. This indicates that urbanization has a compelling or promoting effect on the ecological environment through technological progress, economic development, energy consumption, and urban management. At the same time, the ecological environment also has a constraining or carrying capacity. However, overall urbanization is still classified as the moderate coupling type, and there is still a contradictory relationship between urbanization and the ecological environment.

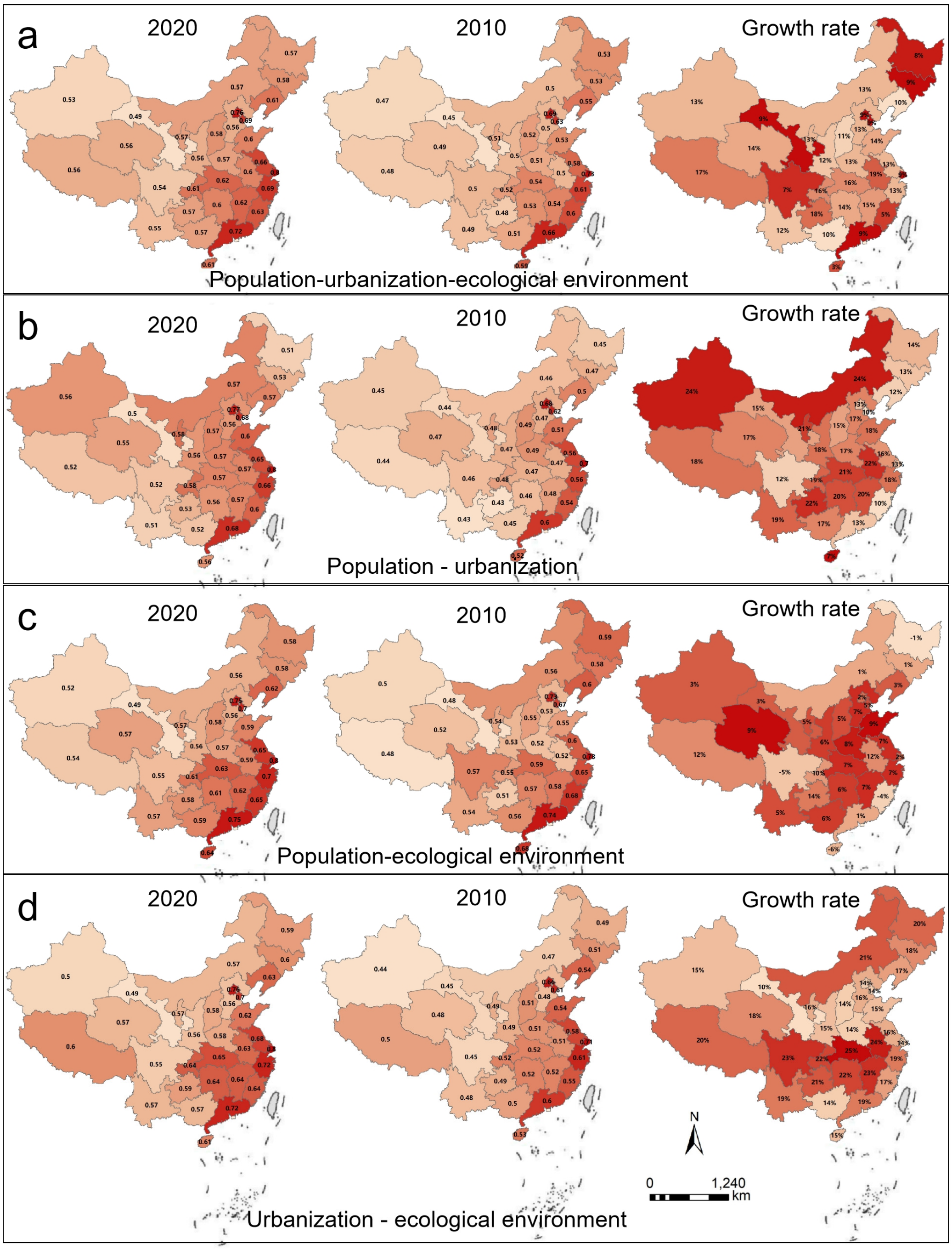

Figure 7. Coupling coordination degree analysis between the population–urbanization–ecological environment system and each subsystem. Note: The darker the red color, the higher the coupling coordination or the greater the growth rate.

3.2. Comparison of Coupling Coordination Degrees under Different Urbanization Types

We compared the coupling coordination degree under the six different urbanization types of economic urbanization–population, economic urbanization–ecological environment, spatial urbanization–population, spatial urbanization–ecological environment, social urbanization–population, and social urbanization–ecological environment, and found that the coupling coordination degree under social urbanization–population and social urbanization–ecological environment was the fastest (Figure 8), up 21% and 24%, respectively. This indicates that the 10-year construction of the new type of urbanization has effectively improved social assurance, significantly raised people's living standards and education levels, and enhanced the dissemination of ecological protection knowledge and public awareness of environmentally friendly lifestyles.

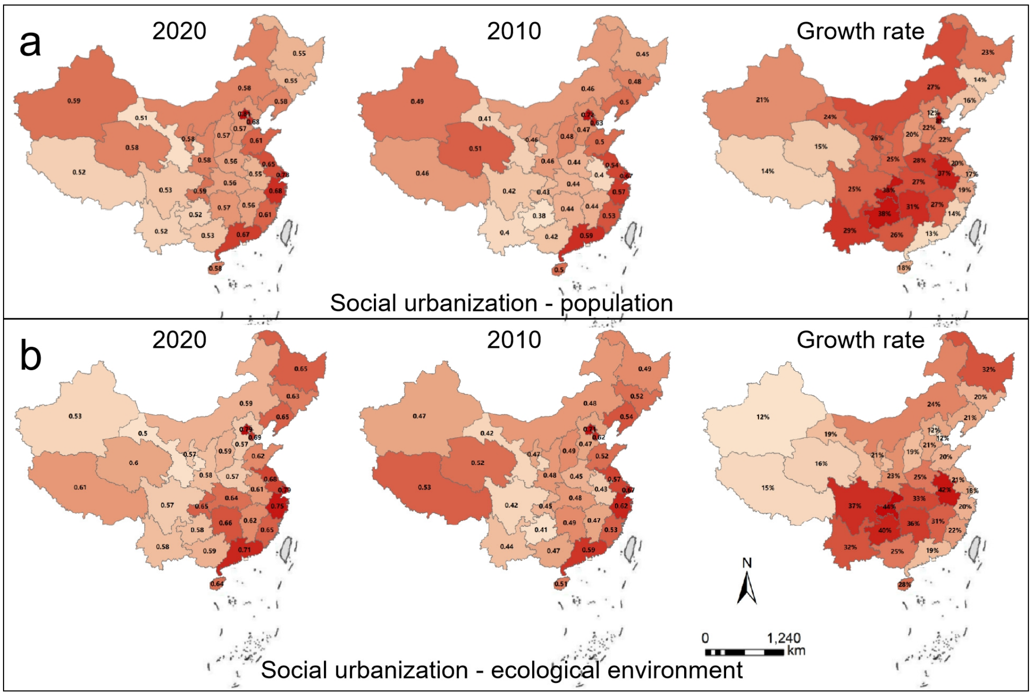

Figure 8. The comparison of the coupling coordination degree under social urbanization.

The coordination degree of economic urbanization and the ecological environment is high (Figure 9), rising from 0.54 in 2010 to 0.63 in 2020, indicating that the 10-year construction of the new type of urbanization has strengthened the construction of green infrastructure; promoted the transformation, optimization, and upgrading of industrial structure; improved the bearing capacity of resources and the environment; and effectively promoted ecological restoration. The provinces with higher coupling coordination degrees are Shanghai (83%), Beijing (0.79), Zhejiang (0.75), Guangdong (0.74), and Tianjin (0.72), all of which are among the more developed coastal provinces in China, showcasing that these provinces have made full use of their economic advantages to promote environmental protection awareness. The coordination degree of spatial urbanization–population is low, and the rapid development of spatial urbanization is the main reason for the incoordination between the two. In 2010, the coupling coordination degree of spatial urbanization–population was the mild disorder type. By 2020, the coupling coordination degree was only 56%, indicating that 10 years of urbanization construction caused a significant waste of land resources. The government should conduct reasonable spatial planning to avoid blind urban expansion, improve land use efficiency, and increase the population carrying capacity of urban land. Regarding spatial urbanization–ecological environment (Figure 10b), the coupling coordination degree of Shanghai and Guangdong is higher, which indicates that these two provinces considered the spatial layout when urbanizing, avoided large-scale urban expansion, and performed a lot of ecological restoration work. In general, the coupling coordination degree of different urbanizations has improved in the past 10 years. China's new type of urbanization is on the path of economic development, population quality, and ecological environment sustainability.

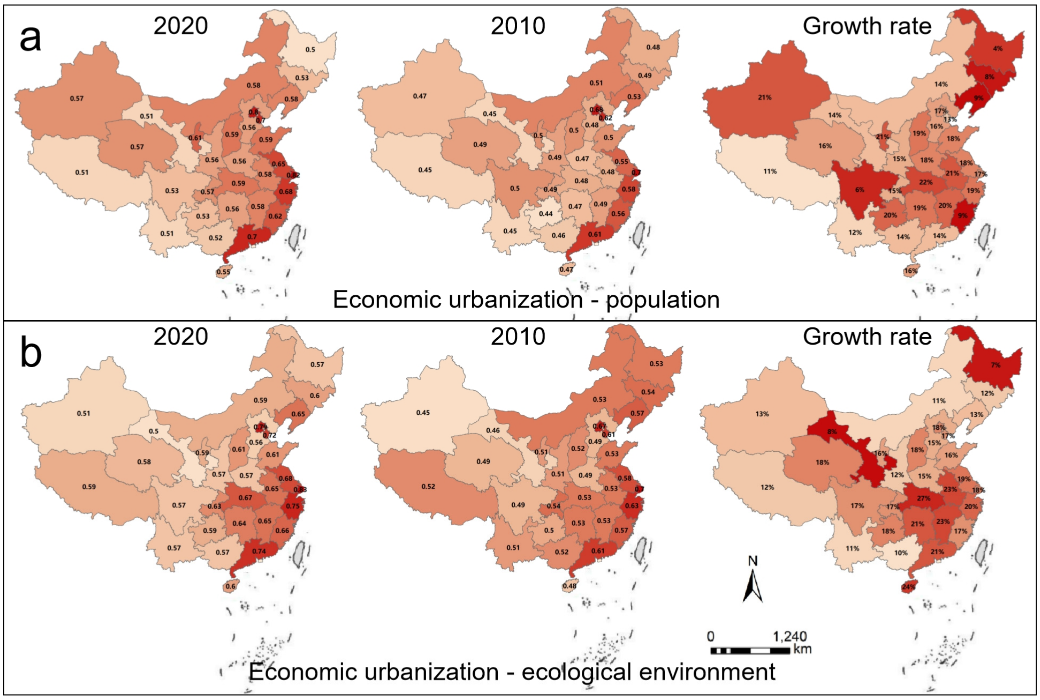

Figure 9. The comparison of the coupling coordination degree under economic urbanization.

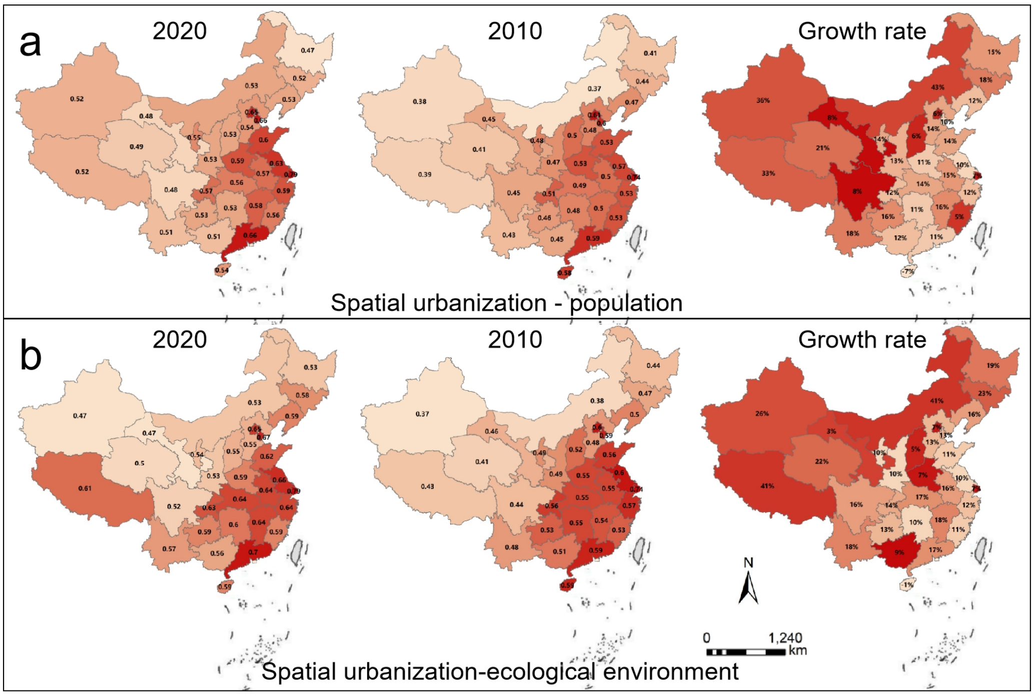

Figure 10. The comparison of the coupling coordination degree under spatial urbanization.

3.3. Decoupling Analysis

Regarding the decoupling analysis between population–urbanization–ecological environment subsystems, firstly, the average decoupling index between population and urbanization is 3.7, which indicates that the urbanization process is significantly faster than the population urbanization process. Figure 11a also shows that all provinces are in the upper part of the first quadrant and on the second quadrant, and the provinces are in a strong decoupling state, with Jilin, Heilongjiang, Fujian, Guangdong, Hainan, and Sichuan in the second quadrant, indicating that the 10-year population index assessment is declining. In Jilin, Heilongjiang, and Sichuan, there is a strong decoupling of urbanization and population processes, mainly due to population outflow and stagnant or negative population growth, while Fujian, Guangdong, and Hainan are in a period of rapid coastal development, with a large influx of population, causing the quality of the population to decrease and urban development to expand. Therefore, the disorderly urban expansion needs to be further curbed in order to protect the sustainable development of cities. Secondly, the average decoupling index between population–ecology and the environment is 0.79, demonstrating that overall, the impact coefficient of the population urbanization index continues to rise, and the negative impact on the ecological environment is increasing. Looking at the provinces (Figure 11b), the differences among provinces are still large, among which Shandong, Henan, Hunan, Yunnan, Shaanxi, and Ningxia are in the lower part of the first quadrant and are weakly decoupled, indicating that the population growth is faster than the improvement in the ecological environment, which is not conducive to the sustainable development of the new type of urbanization. Inner Mongolia, Gansu, Guangxi, and Xinjiang are in the fourth quadrant, which indicates strong decoupling. This shows that the expansion of the population leads to the consumption of regional energy resources, an increase in pollutant emissions, and the consumption of the ecological environment. This increases the burden of the regional environmental capacity, further increases the ecological risk, and also leads to the deterioration of ecological environment quality. Heilongjiang, Jilin, Guangdong, Fujian, Hainan, and Sichuan are in the third quadrant, while Beijing, Tianjin, and Liaoning are in the upper part of the first quadrant, which is the strong decoupling type, indicating that the development of the population and ecological environment is on the road of sustainable development and the environmental problems are constantly improving. Finally, from the perspective of urbanization and the ecological environment (Figure 11c), most provinces are located in the lower part of the first quadrant and the fourth quadrant, except Tianjin and Henan, which shows that the process of urbanization has exerted great pressure on the environment and affected the sustainable development of regional ecosystems. Among them, Inner Mongolia, Guangxi, Gansu, and Xinjiang are in a state of strong decoupling, and ecological environment retrogression appears. The development mode of urbanization is unsustainable or the ecological environment needs to be repaired urgently.

Next, we analyzed from the perspective of environmental pressure. As demonstrated by environmental pressure–population and environmental pressure–urbanization, most provinces of the two are in an expansion state, indicating that most provinces face the dual pressure of environmental pressure and urbanization and population expansion. However, at the same time, we also found that Yunnan, Shanghai, Ningxia, and Xinjiang are in the second quadrant (Figure 11d,e), which is strong decoupling. Thus, after 10 years of urbanization, the environmental pressure is decreasing, and the overall development is moving toward a mode conducive to symbiosis with the environment. According to environmental pressure–economic urbanization, environmental pressure-spatial urbanization, and environmental pressure–social urbanization (Figure 11f–h), the average score of the environmental pressure–social urbanization's decoupling index is the highest, 8.14, indicating that the impact of social urbanization on environmental pressure is mainly positive. The development of social public services and residents' increasing disposable income help reduce environmental pressure. Figure 11g also shows that most provinces are in the upper part of the second and first quadrants, indicating that the growth rate of environmental pressure is lower than that of social urbanization; that is to say, the new type of urbanization promotes infrastructure construction. This plays a huge role in improving social security, urban–rural integration, and public services. Figure 11g shows that most provinces are located in the upper part of the second quadrant and the first quadrant, indicating that the growth rate of environmental pressure is less than that of social urbanization and that the new type of urbanization plays a huge role in promoting infrastructure construction, sound social security, urban–rural integration, and public service improvement. As seen in Figure 11f, the impact of economic urbanization on environmental pressure is gradually weakening, and most provinces are in the first quadrant of strong coupling, the upper part of the first quadrant, and the second quadrant of strong decoupling. This indicates that the impact of industrial restructuring and technological improvement on environmental pressure in most provinces is gradually coming to the fore, which strongly promotes the development of the environment for the better. Still, we should be alert to the increased demand created by rapid economic growth, which exerts more pressure on the environment. Figure 11g shows that the spatial urbanization of most provinces continues to exert pressure on the environment with the expansion of urban construction and increased ecological risks. However, Yunnan, Shanghai, Ningxia, and Xinjiang are in the second quadrant, indicating that the environment is improving and the economy is sustainable. In general, the decoupling status varies across provinces, and the results of our analysis help targeted measures to be taken to promote the high-quality development of the new type of urbanization in each province.

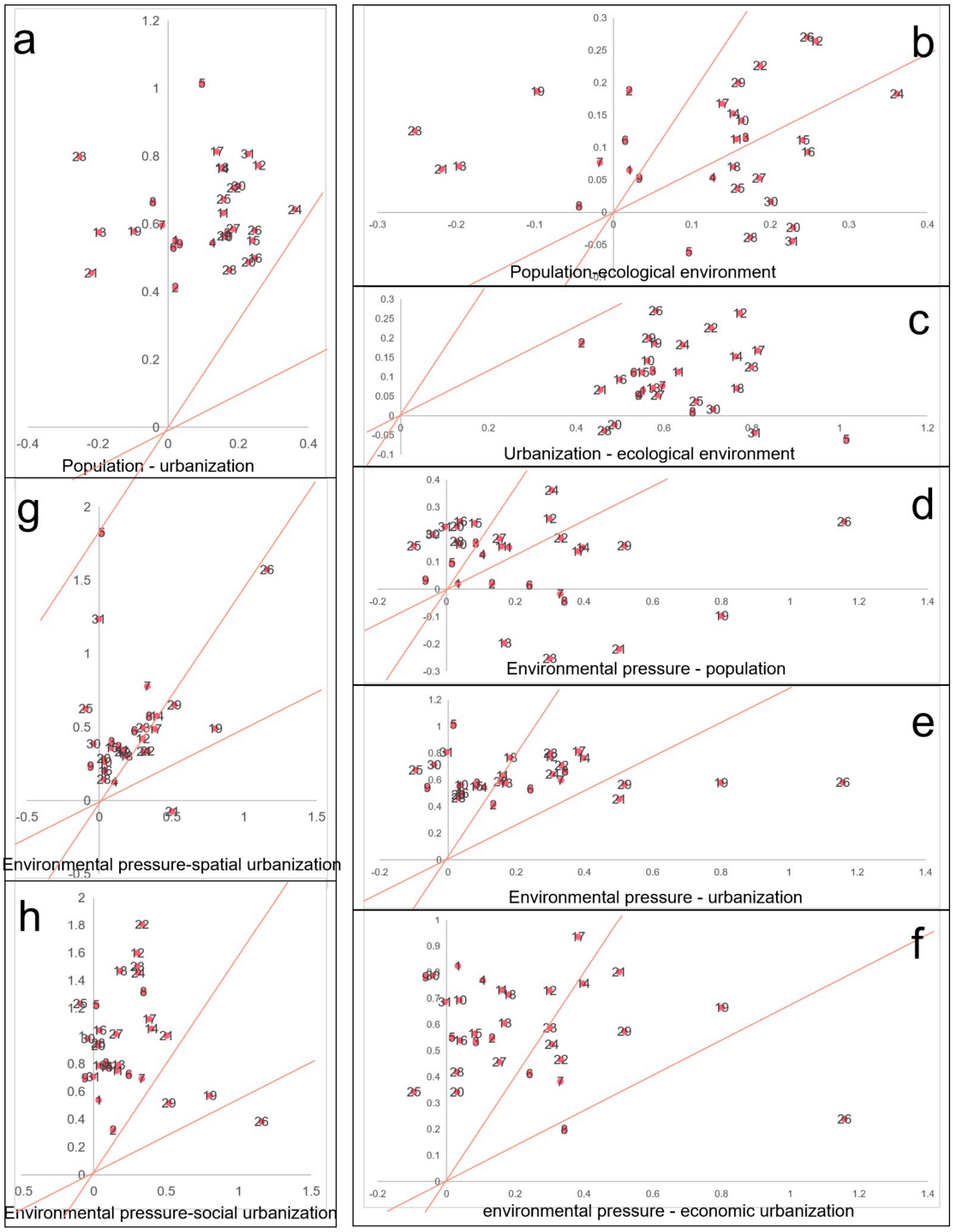

Figure 11. The decoupling analysis of the population–urbanization–ecological environment and environmental pressure.

3.4. Comprehensive Analysis of Coupling Coordination Degree and Decoupling Index

The coupling coordination degree of the population–urbanization–ecological environment in this study is gradually rising, which shows that with the strengthening of national ecological governance, the pressure of urbanization on the ecological environment in China has gradually reduced, and the ecological environment has been improved to some extent. Further, the decoupling index of environmental pressure shows that the overall environmental pressure is decoupled from urbanization. This shows that decoupling from environmental pressure is beneficial to improving the coupling coordination degree of the population–urbanization–ecological environment and the sustainable development of cities. Overall, the decoupling index indicates that the pressure of urbanization on the ecological environment is gradually decreasing, and the green development route of the new type of urbanization has become an important force of sustainable development, as well as a guarantee of the development of the population–urbanization–ecological environment coupling coordination degree.

As shown by the Tobit analysis, there is a significant negative correlation between economic urbanization and spatial urbanization and the decoupling index of environmental pressure, which demonstrates that economic and spatial urbanization has destroyed ecological land and diverted it to construction land, thus reducing the vitality and resilience of the ecosystem and increasing the pressure on the environment. However, there is a positive correlation between social urbanization and the decoupling index of environmental pressure, which shows that the improvement in the living environment, quality of life, and environmental awareness of residents has improved the environment. The Tobit analysis of the decoupling model of environmental pressure–economic urbanization (columns 3 and 4 of Table 8) shows that the increase in fiscal expenditure, per capita income, and R&D investment can promote the decoupling of environmental pressure from economic urbanization. Still, an increase in secondary and tertiary industries and fixed asset investment leads to increased environmental pressure. In other words, technological improvements and investments in environmental protection, as well as the improvement in living standards, provide the conditions for environmental improvement. At the same time, industrial development increases the plundering of environmental resources. In general, this study quantifies the contribution of various indicators of environmental pressure mitigation, provides a basis for the differentiated formulation of urban development policies, and is also a powerful means to improve the coupling coordination degree of the population–urbanization–ecological environment.

Table 8. The Tobit analysis of influencing factors.

Environmental Pressure–Urbanization		Environmental Pressure–Economic Urbanization		Environmental Pressure–Spatial Urbanization		Environmental Pressure–Social Urbanization		Population–Environmental Pressure	
Variable	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**
Economic urbanization	−35.3	The local fiscal revenue/per capita	22.4	Land use	151.9	The number of sanitation facilities per 10,000 people	1455.5	Population agglomeration	−293.6
Spatial urbanization	−113.4	The per capita disposable income of urban and rural residents	175.8	Infrastructure	−201.0	The public finance expenditure/per capita	330.6	Employment structure	−33.4
Social urbanization	83.8	The added value of the secondary industry as a share of GDP	−851.1	Per capita park green space	−297.2	The urban registered unemployment rate	−855.0	Educational level	−106.6
		The added value of the tertiary industry accounting for the proportion of GDP	−1145.4	Per capita living area	282.6	The total retail sales of consumer goods per capita	414.6	Population of other provinces	−2058.7

Table 8. *Cont.*

Environmental Pressure–Urbanization		**Environmental Pressure–Economic Urbanization**		**Environmental Pressure–Spatial Urbanization**		**Environmental Pressure–Social Urbanization**		**Population–Environmental Pressure**	
Variable	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**
		Fixed asset investment per unit of GDP	−241.5	Traffic line density	−89.9	The proportion of social security and employment expenditure in the total fiscal expenditure	−846.9	Population density by Province	786.4
		R&D expenditure as a percentage of fiscal expenditure	391.4	Public facilities	52.7	The number of public transport vehicles per 10,000 people	−67.9	Aging population	−183.9
						The proportion of urban basic medical insurance participants in the total population	452.3	Size of family	−497.2
						Engel's coefficient ratio of urban and rural households	−2205.4	Illiterate population	1992.7
						The proportion of consumption expenditure of urban and rural residents	−50.5	Population growth rate	29.0
R-squared	0.25	R-squared	0.20		0.22		0.21		0.55

4. Discussion

Sustainable urbanization is an integrated system that can effectively resolve conflicts among the population, land, and environment [54]. However, the different evolutionary processes of these elements across time and space make it difficult to effectively regulate urbanization and balance human development and environmental protection. This study establishes the temporal and spatial dynamics and relationships among the population, urbanization, and ecological environment, providing a quantitative analytical basis for the transformation of traditional urbanization into a new type of urbanization that focuses on quality improvement.

The population is the core factor of urban–rural transformation and the basis for studying the relationship between people and land. This study uses the population census data in 2010 and 2020 to provide a reliable database for whether China's new type of urbanization has successfully transformed into an ecology-first and green development-focused development model. The overall coupling coordination degree of the population–urbanization–ecological environment increased from 53% in 2010 to 60% in 2020, indicating that 10 years of the new type of urbanization construction has achieved certain results. Moreover, the decoupling index of environmental pressure–social urbanization is high, and the influence of economic urbanization on environmental pressure is gradually weakening, which further verifies that China's new type of urbanization is on the way to "reduce pollution and increase efficiency". However, the spatial urbanization–population coupling coordination degree has only increased by 13%, indicating that population agglomeration does not match urban expansion. The decoupling index also indicates that the urbanization process is significantly faster than the population urbanization process, so we need to be alert to the rapid spatial expansion exerting more pressure on the environment. In general, due to different urban development and ecological optimization policies adopted in different regions, the coupling and decoupling states vary among provinces. Still, our findings show that the decoupling of environmental pressure and urbanization is conducive to improving the coupling coordination degree of the population–urbanization–ecological environment, which helps cities to move toward a sustainable development path.

Traditional urbanization usually sacrifices social equity, national interests, environment, and resources to support economic development, and this model of blindly pursuing scale expansion and neglecting quality development makes urbanization unsustainable [55].

Based on this, the Chinese government has proposed a new urbanization path in the past 10 years, which calls for a shift from focusing on the growth rate to quality improvement. This study validates the conflict and coordination of 10 years of the new type of urbanization. In terms of population–spatial urbanization, the coupling coordination degree of these two was the lowest in both 2010 and 2020, indicating that the mismatch between population agglomeration and urban expansion leads to serious "diseconomies", but the coupling coordination degree rose by 13% over 10 years, indicating that the intensive urban development model still has an effect. The coupling coordination degree of social urbanization–population has increased by 21%, and environmental pressure and population are in an expansive coupling state in most provinces, indicating that most provinces are facing environmental pressure and are under the dual pressure of urbanization and population expansion. However, there are still some provinces that have strong decoupling. From the perspective of social urbanization–ecological environment, the new type of urbanization over 10 years has increased the coupling coordination degree from 0.52 to 0.62, and its decoupling index is also the highest, indicating that the accelerated urbanization of society has strengthened the concept of environmental protection and sustainable development. In terms of economic urbanization and ecological environment, their coordination is high. However, environmental pressure is still not decoupled from urbanization, showcasing that although green infrastructure construction and industrial structure transformation have achieved certain results, the pressure of environmental protection is still high. Overall, the 10 years of the new type of urbanization construction have not yet exceeded the development model of economic urbanization, spatial urbanization, and environmental pressure decoupling, but social urbanization has made some achievements. The improvement in the living environment, quality of life, and environmental awareness of residents has effectively contributed to the reduction in environmental pressure.

Currently, most studies only focus on the interaction between urbanization and the environment, ignoring the conflicting and coordinating relationships and internal mechanisms among the population, urbanization, and ecological environment. For example, some scholars established the nonlinear quantitative relationship between economic development and environmental quality through the environmental Kuznets curve (EKC). Still, this method can only reveal the results of the coupling and fails to explore the causes of how they form a mutual coupling [2,56]. Therefore, this study differs from the previous ones in that it establishes a framework for assessing the population–urbanization–ecological environment by combining the coupling coordination degree model and the decoupling index. The innovation of this study is that, firstly, this study combines the practicality of each index, proposes a Pressure–State–Response–Service ecological environment index system, and combines the population census index and urbanization index to measure the relationship between humans and the land under the new type of urbanization more comprehensively. Secondly, this study combines the coupling coordination degree model with the decoupling index to comprehensively and systematically understand the coupling coordination degree relationship and decoupling relationship of the population–urbanization–ecological environment and explores the human–land configuration effects of population change, urbanization level, and ecological environment change across time and space, thus providing a basis for the differentiated formulation of urban development policies. Finally, this study quantified the contribution value of various indicators for alleviating environmental pressure, deepened the understanding of the coupling interaction of the population–urbanization–ecological environment, and provided a scientific basis for diagnosing the inconsistency of the internal mechanism of the population–urbanization–ecological environment. This research can provide a new research perspective for discovering internal problems related to new urbanization and can also provide China's quantitative data and development path reference for the United Nations Sustainable Development Goals. At the same time, this study provides a methodological reference for future research on regions with the same regional characteristics, such as the study of ecology and environment, spatial coupling of water resources, and global trade transfer.

However, this study only clearly illustrates the relationship between the population, urbanization, and ecological environment from the typical angle of human activities. Therefore, it has the following limitations: (1) future studies should fully recognize the complexity and comprehensiveness of human activities, land change, and ecological impacts and construct more comprehensive measurement indicators; (2) the spatial scale of this study is province-based, and subsequent studies need to consider spatial transformation and scale effects so that the research questions can be more focused on local reality. (3) The research data have certain limitations. This study did not consider the impact of Earth observation data, land use and urbanization simulation results, mobility data, etc. Subsequent research is needed to integrate more extensive data in order to more realistically present the relationship between urbanization and natural systems.

5. Conclusions

China's urbanization not only determines the future development of its own country but also influences the global urbanization development process. Due to the differences in population, land use, and ecological environment, different urbanization systems have different characteristics. This study analyzes the coupling coordination degree and decoupling relationship between the population, urbanization, and ecological environment, which provide effective support for promoting the coordinated development of the population, land, and environment in specific regions.

The conclusions of this study are as follows. (1) This study established a comprehensive index system using the population, economy, society, space, environmental pressure, ecological governance, ecological status, ecological services, etc. It combined the coupling coordination degree model and the decoupling index to establish the evaluation framework of the population–urbanization–ecological environment. (2) During the construction of the new type of urbanization in China over the past 10 years, the coupling coordination degree has increased from 0.54 to 0.60. The coupling coordination degree of different urbanizations has been improved to a certain extent, indicating that China's new type of urbanization is on the road to sustainable economic development, population quality, and ecological environment. (3) The decoupling relationship between China's overall population–urbanization–ecological environment indicates that the decoupling of population and social urbanization from environmental pressure is more obvious. In contrast, the economy and spatial urbanization are still relatively extensive, which creates a certain environmental pressure. (4) This study found that the greater the decoupling of environmental pressure from urbanization and population, the more conducive it is to improving the coupling coordination degree of the population–urbanization–ecological environment, and the more conducive it is to the balance between the population, land, and nature. In general, rational urbanization development strategies can optimize demographic, social, ecological, and economic sustainability.

The relationship between the population, urbanization, and the ecological environment is an important topic in studying natural and human-influenced processes in sustainable development. This study verifies the conflict and coordination among the three components of the new type of urbanization in China. Although the new type of urbanization has achieved some success, China still has a long way to go before achieving the Sustainable Development Goals (SDGs) set by the United Nations from economic, social, and environmental perspectives [22,57]. In addition, the basic conditions and urbanization paths vary among countries, and it is necessary for developing countries to learn from the lessons of the past in the urbanization process and to develop a green development path that is different from the old "pollute first, treat later" path of the West.

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