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Towards Sustainability: Cultural-Ecological-Economic Systems Coupling in the Yellow River Basin Based on Service-Dominant Logic

Zhicai Wu [1,2], Jianwu Qi [1,*], Jialiang Xie [1] and Kai Zhang [3]

[1] Department of Tourist Management, South China University of Technology, Guangzhou 510006, China; zhcwu@scut.edu.cn (Z.W.); 202310191363@mail.scut.edu.cn (J.X.)
[2] Key Laboratories of Digital Village and Sustainable Development of Cultural Tourism, South China University of Technology, Guangzhou 510006, China
[3] Colleges of Architecture, Xi'an University of Architecture and Technology, Xi'an 710055, China; zhangk@xauat.edu.cn
* Correspondence: tdqijianwu715@mail.scut.edu.cn; Tel.: +86-198-7429-7741

Abstract: The level of coordination between cultural, ecological, and economic systems directly affects the sustainable development of the Yellow River Basin (YRB). However, researchers have neglected the importance of cultural elements in the social-ecological system and have paid insufficient attention to the interaction of cultural, ecological, and economic systems in the YRB. Therefore, a framework of coupled cultural-ecological-economic (CEE) systems was constructed based on service-dominant logic, and the spatiotemporal distribution, evolutionary trends, and factors influencing the coupled coordination of different systems in 76 major cities in the YRB were analyzed by using an entropy-weighted TOPSIS model, coupled coordination model, spatial Markov chain, and panel spatial Dubin model. The results were as follows: (1) the cultural, ecological, and economic systems of the YRB showed a growing trend, the economic system grew faster than the cultural system and the ecosystem, and the ecosystems dominated sustainable development in the YRB. (2) From 2011 to 2022, the type of coupled CEE system coordination in the YRB was mainly in a state of slight incongruity, with the different regions showing temporal consistency and synchronized growth, with the upstream area mainly in a state of moderate incongruity, the midstream area mainly in a state of slight incongruity, and the downstream area concentrating in general coordination. (3) The spatial coordination level of CEE system coupling in the YRB showed the characteristic of "gradually converging to coordination from upstream to downstream" and exhibited upstream low-value agglomeration and downstream high-value agglomeration. Meanwhile, there was a clear trend of spatial spillover in terms of balanced regional development, and 67.11% of the cities in the region and neighboring areas maintained stable development. (4) Tourism development (TD), foreign trade (FT), the human environment (HE), government control (GC), and other factors significantly positively impacted the sustainable development in the YRB. In the future, the focus should be on improving the transregional infrastructure and transportation service systems in the YRB, to enhance cooperation and exchanges between different regions. This research provides new insights and methods for the coordinated development of cultural, ecological, and economic systems at a watershed scale.

Keywords: service-dominant logic; CEE systems; service value; coupled coordination; Yellow River Basin

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1. Introduction

The coupling of cultural, ecological, and economic systems has become a crucial link in realizing the sustainable development in the YRB. However, although researchers have focused on the coordinated relationships among urbanization, economic activity, and ecological protection [1,2], insufficient attention has been paid to the important role of culture in social-ecological systems. Furthermore, the government has focused on top-down policy design of individual system dimensions of the YRB, with inadequate knowledge of the complex structure of watershed systems, which intensifies the interregional differences within the basin system, weakens the structural dimensions, weakens the correlation dynamics, and leads to a long-term imbalance between cultural protection, ecological governance, and economic development processes [3]. In 2019, the Chinese government proposed a national strategy for the ecological protection and high-quality development of the YRB, focusing on the management of floods, point-source pollution, and soil erosion in the basin, with the construction of an ecological civilization, as well as the vigorous implementation of soil and water conservation, the construction of the Three-North Protective Forests, the protection of natural forests, the return of farmland to forests and grasslands, and other major projects. Under the implementation of this policy, the water-sourcing capacity of the upperstream of the YRB has been significantly enhanced, the capacity of the Loess Plateau in the middlestream of the river to store water and conserve soil has been markedly increased, and the ecological and environmental protection of the YRB has seen initial progress. However, the ecological governance of the YRB is still faced with insufficient ecological water security, an imbalance of ecosystem functions, increased risks in the layout of industrial structure, and excessive pressure on the carrying capacity of resources and the environment [4,5]. In this context, from the perspective of the wholeness of the watershed system, it is important to explore the complex relationships among the cultural, ecological, and economic systems in the YRB, to promote the cultural protection, ecological governance, and economic development of the watershed system.

Using the value of services as a criterion to assess the harmonization of cultural, ecological, and economic systems can provide important support for recognizing the human–environment relationship and for promoting the conversion of the value of ecosystem services [6]. The service value of the watershed system contains both tangible values of the coupled and coordinated development of culture, ecology, and economy, such as economic, leisure, and living values, and intangible values in the watershed system, such as aesthetic, spiritual, and cultural values. The existence of tangible and intangible values in the watershed system is premised on the system’s corresponding ability to serve the subject’s needs, with the object’s ability to satisfy the subject’s needs, a two-way matching process that reflects the service-dominant logic (SDL) of value creation. The SDL emphasizes the co-creation of service value through continuous interactions between producers and consumers and other supply and value chain collaborators [7,8]. Under the influence of the SDL paradigm, the relationship between producers and consumers is reconfigured, with consumers being both co-producers of products and co-creators of value [9], and with interaction, holistic integration, independent production, and co-creativity as core features of SDL [10,11]. Based on an analysis of the mainstream view of co-creation [12,13], this study proposes that the co-creation of service values in watershed systems is an iterative and collaborative process in which producers, consumers, and other stakeholders participate in the material production (i.e., co-production) and social meaning creation (i.e., co-construction) of watershed systems in interaction with the natural environment. The SDL provides a new cognitive model for the relational interaction between human beings and ecosystems in watershed systems, with an emphasis on the two-way transformation and co-creation of the value of the system’s services, from the exchange of tangible goods to the exchange of intangible, specialized knowledge and skills, which involves values, the nature of relationships, and the rational use of resources.

Thus, it is important to mitigate the multiple pressures from the natural environment and to increase the resilience of ecosystems to external risks [14]. Researchers have gradually begun to shift their research perspectives to the landscape, energy, food, carbon sinks, natural disasters, land use, and other elements of ecosystems and to combine them with the urbanization, tourism development, population size, and digital economy of human social development [4,15–17], emphasizing the coupling of ecosystems with other systems [2,18]. Currently, research on ecosystem services, social-ecological system coupling, and ecosystem cultural service assessment has become a mainstream trend, and most related research involves urban development and ecological protection, spatial coupling, and coordination of the three biological functions [17,19,20]; the coupling of human and natural systems, and coordination of water resources, energy, and food [21,22]. Nevertheless, Chinese scholars continue to have ambiguous and biased understandings of the connotations of ecosystem cultural services [6]; moreover, fewer researchers have focused on the synergistic relationships among cultural, ecological, and economic systems in watersheds.

Social-ecological systems are an important part of the human–environment system, reflecting the elemental composition and process representation of human–environment interactions [23]. The linkages between society and ecology are complex, variable, and compound [24]. Therefore, social-ecological systems, as coupled systems in which human beings interact with the environment, have the basic characteristics of social systems and ecosystems but also embody the characteristics of non-linearity, uncertainty, and multilayered nestedness under the combined influence of climate change, human activities, and other factors [25]. Current research focuses on exploring the coupled social-ecological system process from an ecosystem services perspective through model simulations and case studies [26–28]. However, there has been a lack of attention on how ecosystem services interact with and influence processes in other elements of the human–environment system [29,30]. In the assessment of the coupled coordination among resources, the environment, and industry in a socioecological system framework [2,4,18], the assessment indicators of the coordinated development among different systems are critical. For the assessment of ecosystems, the ecosystem pressure, state, and response (PSR) framework was used as the main indicator [31,32], and factors such as forest cover and industrial wastewater emissions were also considered [17]. The assessment of social systems mainly includes basic indicators such as size of population, urbanization rate, urban disposable income, and rural consumer spending [33,34], whereas the assessment of cultural systems measures the non-instrumental values of cultural services, including aesthetic, leisure, and educational values [35], such as plant color richness, sidewalk density, and the number of cultural attractions [36–38]. Obviously, researchers focus on constructing assessment indicators within a single system and pay insufficient attention to the dynamic relationships between system elements and structural dimensions. Studies have emphasized exploration of the coupled water resource, energy, and food system, and payment for ecosystem services in the YRB [20,33,39,40], ignoring the importance of culture in coupled socio-ecological system relationships. In terms of research methodology, scholars have focused on exploring the spatiotemporal patterns and drivers of the coupled coordination of different systems with the TOPSIS method, coupled coordination model, variational function, and multiscale geographically weighted regression, geoprobe model, and obstacle degree model [17,18,41]. Additionally, there has been a lack of analysis of the dynamic transfer characteristics of the levels of coupled coordination of different systems, influencing factors, and spatial spillover effects.

Under the coupling effect of natural, economic, and social factors, the YRB forms a dynamic, complex, and open giant system, and the synergy between its cultural protection, ecological governance, and economic development is an important basis for influencing sustainable development. We attempted to propose a theoretical framework for the synergistic development of CEE systems and explored the coupled coordinated spatio-temporal pattern and the influencing factors of 76 cities in the YRB. We had three major objectives: (1) The SVC was introduced for exploring the relationships among cultural, ecological, and economic systems, and we attempted to construct a framework for the coupling of CEE systems in the YRB. (2) Based on the theory of value co-creation, an evaluation index system of the CEE system in the YRB was constructed and evaluated based on quantitative models. (3) To analyze the spatiotemporal pattern, we used major types of evolutionary characteristics and factors influencing the coupled CEE system coordination in the YRB, and put forward specific proposals for sustainable development.

2. Theoretical Framework and Study Area

2.1. Theoretical Framework

The ecosystem cascade (ESC) elucidates the recursive relationships between ecosystem structure, function, and social values [42], and is important in integrating values for human well-being. The ESC connects a natural system's framework to the socioeconomic or cultural advantages of human well-being through production chains, highlighting the hierarchical structure of various links [43,44]. The configuration where human and economic systems are viewed as integral components of the broader system, positioned at the transactional chain's end [10,45,46], features a structural framework centered on ecosystem process and output analysis. Unlike the ESC framework, the service value chain (SVC) has emerged as a product and service management system that focuses on the co-creation of service value from a whole-process perspective [47–49]. The comprehensive viewpoint of the SVC underscores the coherence and collaboration among the components of the "value creation" process, commencing with the input of "needs and opportunities" and concluding with the output of "products and services". The SVC emphasizes the integrity of the value creation process, beginning with the input of "needs and opportunities" and ending with the output of "products and services" and the synergy between the elements. The SVC provides a complete process and a stable activity model for the value creation process [50]. Based on this, we integrated the core connotations of the ESC and the SVC and synthesized and proposed a coupled CEE system framework based on an SDL (Figure 1). We took the demand and value interaction relationship as the basis of the framework and integrated, selected, perceived, and evaluated cultural, ecological, and economic subsystems [51,52]. The cultural, regulatory, provisioning, and supporting services provided by ecosystems are the main body and center on the products produced by the system attributes, functions and value added, and the transfer processes of product services to realize the co-creation of cultural, ecological, and economic system service values [53]. Products and services play separate roles in the co-creation of service value. For cultural systems interacting with ecosystems, products not only cascade the interaction between resources and producers but also indirectly intervene in the cultural and regulation services of ecosystems. Thus, products are the vehicles that link culture and ecosystems and form the value of intangible services. However, the interactions between ecosystems and economic systems can be presented directly through the services provided by products, such as the support and supply services provided by ecosystems. These services can be measured in the economic system in terms of money, prices, etc., which translates into a tangible service value. Overall, the constructed framework emphasizes holistic collaboration and value creation among systems and focuses on reshaping the producer-consumer co-creation relationship and the resource–asset synergy relationship.

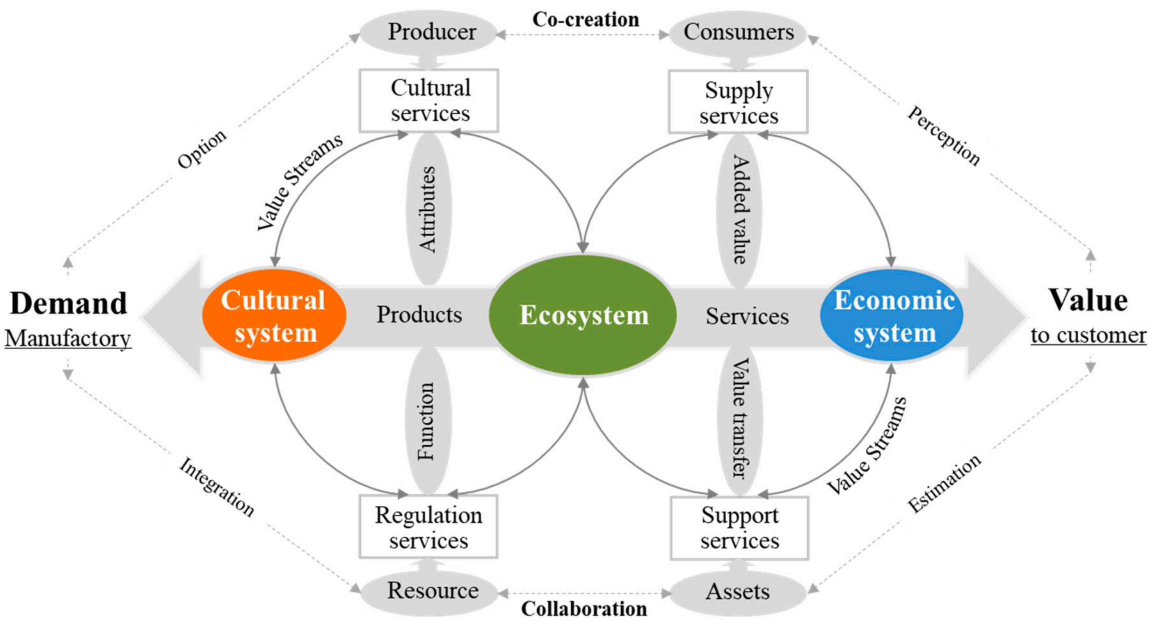

Figure 1. Coupled cultural-ecological-economic (CEE) system framework.

2.2. Study Area

The Yellow River Basin (YRB) stretches across both the eastern and western regions of China, commencing in the Bayan Har Mountains in Qinghai Province in the west, near Yueguzonglie Qu, and concluding in the east at Kenli District, Dongying City, Shandong Province. The YRB spans 5464 km in length, with an east–west span of 1900 km and a north–south width of 1100 km. Its basin area covers 7.95 × 10^5 km^2, ranking it as the world's seventh-longest river. The YRB experiences a temperate continental climate, characterized by perennial drought and minimal rainfall. Its average annual temperature stands at 9.4 °C, accompanied by an average precipitation of 466.6 mm per year, which gradually increases from the northwest to the southeast. Terrain within the basin varies greatly, featuring high elevations in the west and lower elevations in the east. The landscape is complex and diverse, dominated by high mountains, glaciers, and loess formations. Due to the impact of global warming, the total water resources of the YRB have decreased sharply, floods and droughts are frequent, and the basin's ecological environment and resource utilization have been seriously constrained. The annual runoff of the YRB is 5.74 × 10^{10} m^3, decreasing at a rate of approximately 0.721 × 10^8 m^3 per year [33], with an area of 2.555 × 105 km^2 of soil erosion and a soil and water conservation rate of 67.85%. As of 2024, the gross regional product (GRP) of the YRB amounts to 31.64 × 10^{12} yuan, with a per capita of 7.16 × 10^4 yuan. The resident population totals 4.21 × 10^8 people, while the per capita disposable income stands at 3.21 × 10^4 yuan. Affected by climate change, soil erosion, and other ecological and environmental problems, historical relics in the YRB have been damaged to varying degrees, such as insect pests and mildew on silk weaving cultural relics, weathering of stone and ancient building materials of cultural relic components, and damage to important murals and statues. According to the Department of Antiquities, the number of immovable cultural relics in the YRB is more than 300,000, which accounts for 39.73% of the country, among which there are 11 world cultural heritage sites, accounting for 19.29% of the country. The provided data illustrate the abundant cultural resources and robust socioeconomic foundation of the YRB. However, the region faces significant challenges due to its sensitive and fragile ecological environment, which poses constraints on its development. Consequently, a total of 76 cities within the YRB were selected as the focus of this study (Figure 2), to evaluate the coordination level of the coupled CEE system.

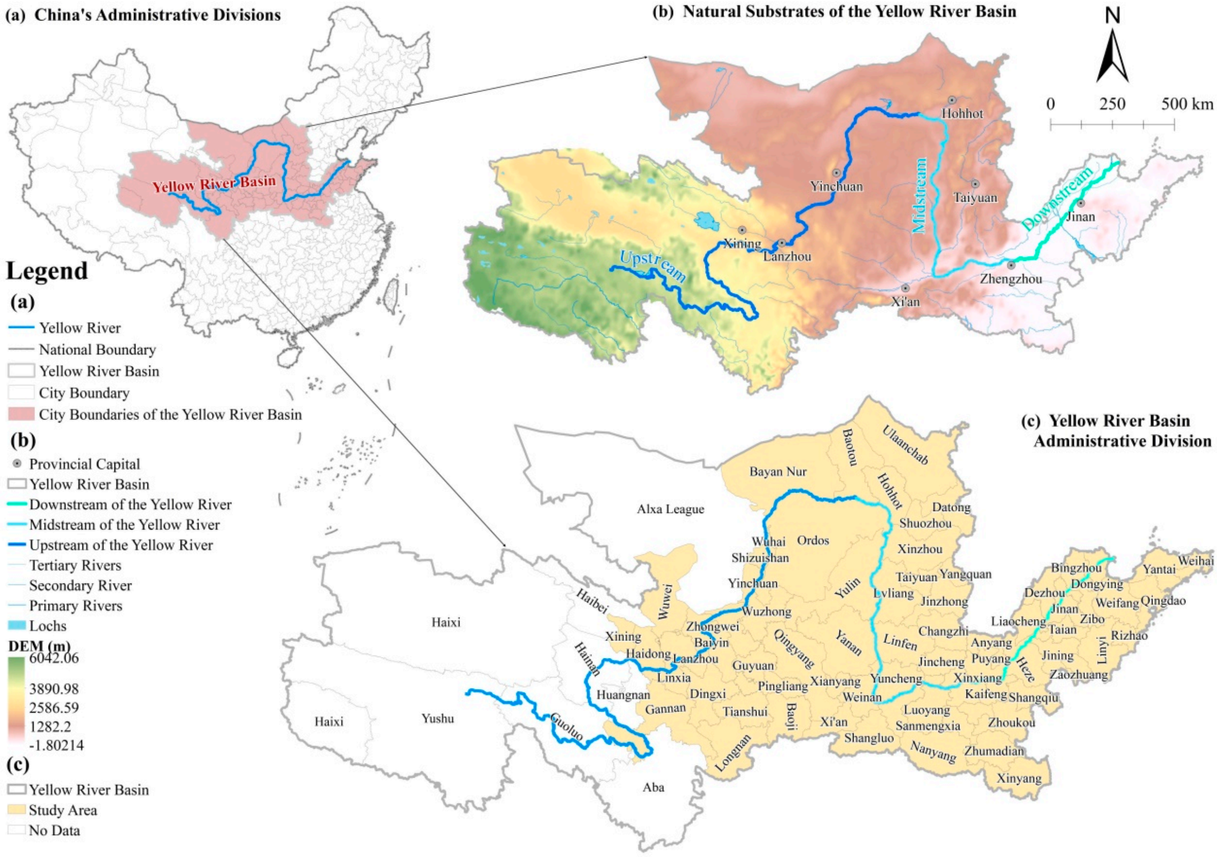

Figure 2. Study area. (**a**) Shows the geographic location of the YRB in China's administrative divisions; (**b**) shows the natural basic conditions of the YRB, including elevation, major rivers and lakes, watershed segments, and boundaries; (**c**) shows the city zoning of the YRB, which contains a total of 84 central cities, of which 8 cities with missing data were excluded from the study, and the 76 prefecture-level cities forming the subject of the study. There are a total of 20 cities in the upperstream section in the YRB, the midstream contains 34 cities, and the downstream 22 cities.

3. Methodology and Data

3.1. Technical Framework

Based on the above discussion, a technical framework for the assessment of the coupled CEE system coordination in the YRB was constructed (Figure 3). The framework consisted of the following major elements: (1) based on the theory of value co-creation, a coupled CEE system coordination evaluation index system in the YRB was constructed. (2) The coupled coordination of CEE systems in the YRB was assessed using an entropy weight TOPSIS model and coupled coordination model, and its spatio-temporal pattern was explored. (3) The spatiotemporal dynamic evolution of the coupled coordination level was characterized via spatial Markov chain modeling. (4) Based on the panel spatial Durbin model, the influencing factors that cause spatial differences in coupled coordination and their spatial spillover effects were analyzed.

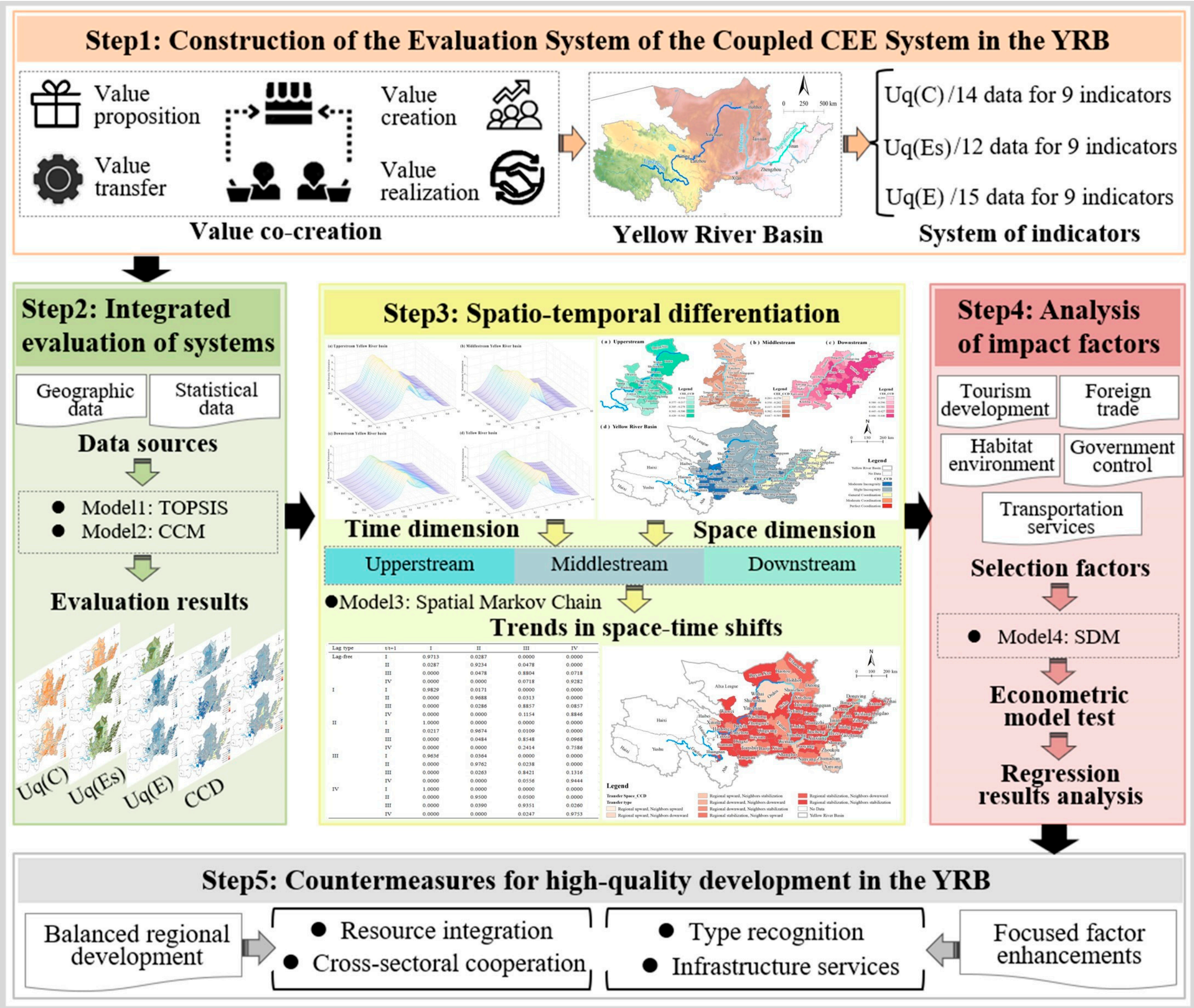

Figure 3. Technical framework of the research.

3.2. Methods

3.2.1. Entropy Weight TOPSIS Model

To eliminate the influence of subjective factors produced by the traditional TOPSIS model in determining the weights of evaluation indicators, the TOPSIS model needed to be improved based on the entropy weight method, which has been adapted to the measurement and evaluation of indicators in different contexts [54,55]. The major calculations are described below.

1. Data standardization. The polar normalization method was chosen for the evaluation indicators to determine the status of the value of an indicator in relation to the weighting of that indicator.

Positive indicators:

$$X'_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \tag{1}$$

Negative indicators:

$$X'_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \tag{2}$$

Standardized matrix:

$$R = \left(X'_{ij}\right)_{m\times n} \tag{3}$$

where X_{ij} and X'_{ij} denote the original and normalized values for city i and indicator j; m and n denote the number of cities and indicators, respectively.

2. Indicator information entropy and weights.

$$e_j = -k\sum_{i=1}^{m} P_{ij} \times \ln\left(P_{ij}\right) \tag{4}$$

$$P_{ij} = X'_{ij}/\sum_{j=1}^{n} X'_{ij} \tag{5}$$

$$\omega_j = 1 - e_j/\left(\sum_{j=1}^{n} 1 - e_j\right) \tag{6}$$

where e_j ($0 < e_j < 1$) denotes the entropy value of indicator j, $-k$ denotes information entropy coefficient, $k = 1/ln\ (m)$.

3. Normalized decision matrix.

$$V = R \times \omega_j = \left(V_{ij}\right)_{m\times n} \tag{7}$$

4. Seek ideal solutions (V^+ and V^-).

$$V^+ = \left\{\max V_{ij}\middle|i = 1,2,3,\cdots,m\right\}\ V^- = \left\{\min V_{ij}\middle|i = 1,2,3,\cdots,m\right\} \tag{8}$$

5. Measurement of the distance from the ideal solutions to the object of evaluation. ($D^+{}_j$ and D_j^-).

$$D_j^+ = \sqrt{\sum_{i=1}^{m}\left(V_{ij} - V_i^+\right)^2}\ (i = 1,2,3,\cdots,m) \tag{9}$$

$$D_j^- = \sqrt{\sum_{i=1}^{m}\left(V_{ij} - V_i^-\right)^2}\ (i = 1,2,3,\cdots,m) \tag{10}$$

6. Proximity of the optimal program to the object of evaluation.

$$C_j = D_j^-/\left(D_j^+ + D_j^-\right)\ \left(0 \le C_j \le 1\right) \tag{11}$$

3.2.2. Coupled Coordination Model

As an effective means for measuring the level of mutual synergy between systems in the development process, the coupled coordination model has become an important tool for assessing the level of coupled coordination of ecosystems with cultural, economic, energy and social systems [2,4,18]. Below is the formula:

$$D = \left[\left[\frac{\prod_{q=1}^{p} U_q}{\left(\frac{1}{p}\sum_{q=1}^{p} U_q\right)^p}\right]^{\frac{1}{p}} \times \sum_{q=1}^{p} \alpha_q U_q\right]^{\frac{1}{3}} \tag{12}$$

where p is the number of evaluation systems; U_q denotes system development; and α_q denotes the weight coefficient, considering that culture, ecology, and economy are equally important in complex systems [17]; thus, the weight coefficients were all taken as 1/3. According to classifying types of coupled coordination in studies [2,56], development processes between CEE systems were classified into 6 categories according to extreme, moderate, and slight degrees (Table 1). Among them, the CCD of the extreme incongruity type was 0, indicating that the cultural, ecological, and economic systems of the YRB are in a state of extreme disorganization, with different systems hindering each other and developing independently; however, extreme incongruity seldom exists in real-life situations. Moderate incongruity indicates the dominant role of a single system in the regional development process, which is the main factor causing the inherent differences in regional development [4]. Slight incongruity is an important type that affects a region's sustainable development, is a critical state of incongruity and coordination type, and has the highest percentage in the coupling process of different systems [18]. General coordination is the key to measuring the development gaps inherent in the cultural, ecological, and economic systems of regions. Moderate coordination reflects the consistency of the speed of development between different systems and determines the dominant direction of balanced regional development [57]. The CCD of the extreme coordination type is 1, which is the ideal state for the coupling of CEE systems, indicating mutual promotion and synergistic development among different systems.

Table 1. Coupled cultural-ecological-economic (CCE) system coordination assessment level.

Range of D Value	CCD Classification	System Development Level Ratio	Type of Development
D = 0	Extreme incongruity	Uq(C)/Uq(Es) < 0.2	Cultural systems hinder ecosystem
		Uq(E)/Uq(C) < 0.2	Economic systems hinder cultural systems
		Uq(Es)/Uq(E) < 0.2	Ecosystem hinders economic systems
0 < D ≤ 0.3	Moderate incongruity	0.2 ≤ Uq(C)/Uq(Es) < 0.4	Ecosystem dominates cultural systems
		0.2 ≤ Uq(E)/Uq(C) < 0.4	Cultural systems dominate economic system
		0.2 ≤ Uq(Es)/Uq(E) < 0.4	Economic system dominates ecosystem
0.3 < D ≤ 0.5	Slight incongruity	0.4 ≤ Uq(C)/Uq(Es) < 0.6	Accelerated development of the cultural system
		0.4 ≤ Uq(E)/Uq(C) < 0.6	Accelerated development of the economic system
		0.4 ≤ Uq(Es)/Uq(E) < 0.6	Accelerated development of ecosystems
0.5 < D ≤ 0.7	General coordination	0.6 ≤ Uq(C)/Uq(Es) < 0.8	Reduction in the development gap between the ecosystem and the cultural system
		0.6 ≤ Uq(E)/Uq(C) < 0.8	Reduction in the development gap between the economic and the cultural system
		0.6 ≤ Uq(Es)/Uq(E) < 0.8	Reduction in the development gap between the ecosystem and the economic system
0.7 < D ≤ 0.9	Moderate coordination	0.8 ≤ Uq(C)/Uq(Es) < 1	Cultural system and ecosystems develop at the same pace
		0.8 ≤ Uq(E)/Uq(C) < 1	Economic systems and cultural systems develop at the same pace
		0.8 ≤ Uq(Es)/Uq(E) < 1	Ecosystems and economic systems develop at the same pace
0.9 < D ≤ 1	Extreme coordination	Uq(C)/Uq(Es) = 1	Synergistic development of ecosystems, cultural and economic systems
		Uq(E)/Uq(C) = 1	
		Uq(Es)/Uq(E) = 1	

The ratio of U_q between systems indicates the relative difference in the level of development of the systems, with a larger ratio indicating greater intersystem coordination.

3.2.3. Spatial Markov Chain Model

This model is a method of dynamic analysis that reflects the state of development of the research unit and its tendency to shift [58]. On this basis, a spatial Markov chain with spatial lag [59] was further introduced by considering the spatial effects of complex systems and the influence of geographic location factors, to reveal the trends in the degree of coupling between systems at the spatial and temporal levels. A spatial Markov chain is formed by dividing the region into l different types and in this way forming $l \times l \times l$ probability transfer matrices. T_{lij} is the probability of transferring from state i at stage t to state j at stage (t + 1), which is conditional on neighborhood b. Below is the spatial effect test formula:

$$H = -2log\left\{\prod_{k=1}^{l}\prod_{i=1}^{l}\prod_{j=1}^{l}\left[\frac{m_{ij}}{m_{ij}(S)}\right]^{n_{ij}(S)}\right\} \tag{13}$$

where l denotes the number of coupled coordinated state transfer types, and l = 4 in this study. $n_{ij}(S)$ is the number of cities where the neighborhood type S has shifted; $m_{ij}(S)$ denotes the transfer probability for the neighboring type S.

3.2.4. Panel Space Durbin Model

Panel spatial econometric modeling takes full account of the spatial effects of variables, while effectively utilizing multidimensional data, which fits with the context of regional linkages and synergistic development trends [60]. Among these, the spatial panel Durbin model (SPDM), which accounts for the spatial correlation of explanatory variables while combining the effects of the spatial panel error model (SPEM), spatial panel lag model (SPLM), and that can be further decomposed into direct and spillover effects by partial differentiation methods, has become an effective tool for detecting the influences of coupled and coordinated influences of systems [61]. Therefore, the SPDM was used for the analysis, and its base model was set as follows:

$$Y_{it} = \rho\sum_{j=1}^{n} W_{ij}Y_{jt} + \alpha X_{it} + \varphi\sum_{j=1}^{n} W_{ij}X_{jt} + \eta_t + \mu_i + \varepsilon_{it} \tag{14}$$

where Y_{it} denotes the composite value of city i in stage t, and X_{it} is the influence of the composite value of city i in stage t. W_{ij} is usually expressed as a matrix of economic geographic distance (W_{ge}) and inverse geographic distance (W_g) weights [62]. $W_{ij}Y_{jt}$ and $W_{ij}X_{jt}$ are the spatial lags of the coupled coordination level and the influencing factors, respectively. ρ and φ denote the spatial lag parameters, α denotes the coefficient, and ε_{it} is the error term; η_t and μ_t are the time effect and spatial effect.

3.3. Establishing Evaluation Indicators

In the modern service industry and the development of the commodity economy, the connotation of service has gradually shifted to the effective use of resources and value creation for the benefit of others or organizations [63]. On this basis, the theory of value co-creation breaks through the traditional logic of commodity-dominated value; emphasizes producers, consumers, managers, and stakeholders as value dominant; participates in value creation; and focuses on highlighting the process of value generation with an SDL [64,65]. Therefore, based on the understanding of the problems of what kinds of services are provided by different systems in the YRB, how the services are perceived by the subjects, and how these values are created, an evaluation index system for the development of CEE systems in the YRB was constructed from the different links of value co-creation (Table 2). In the construction of indicators, we followed the principles of scientificity, dynamism, and completeness. The indicator system mostly included the following parts:

(1) Value proposition guidelines for different systems. When value is co-created, both parties in a product transaction are service subjects of supply and consumption. Thus, the value proposition is the beneficiary's realization of value acquisition through the interactive process in the exchange of services [66]. In layman's terms, the value proposition in cultural, ecological, and economic systems denotes the advantages and possibilities of profitability that the system can offer. There are six indicators under the value proposition criterion, including cultural brand awareness, cultural landscape diversity, and resource recycling potential. Among them, cultural landscape diversity

is obtained by calculating the ratio of the number of humanistic landscapes to the total number of landscapes within the region. The number of humanistic landscapes includes historical relics, classical gardens, religious temples, ethnic neighborhoods, etc., in different areas. The total number of landscapes is the sum of humanistic and natural landscapes, and the number of natural landscapes includes forest parks, nature reserves, etc., in different regions.

(2) Value transfer guidelines for different systems. When resources are not utilized, their value cannot be reflected, and only when resources are transformed into products and products are transformed into capital can the value of resources and products be effectively transferred [67]. Thus, value transfer covers activities such as matching supply and demand and transferring value between resources and products. There are seven indicators under value proposition guidelines, including the supply rate of cultural resources, the production efficiency of cultural products, and the supply rate of land resources. Among them, the supply rate of cultural resources is obtained by calculating the ratio of total cultural resources to the resident population, and the productivity of cultural products is determined by the output value of the cultural industry and the number of cultural resources together. The source of cultural industry output value includes the total business income and assets of the three major categories of business enterprises: manufacturing, cultural wholesale and retail trade, and the cultural service industry. The number of cultural resources refers to the sum of the number of cultural relics, museums, libraries, cultural centers, entertainment venues, and performing arts venues within the region.

(3) Value creation guidelines for different systems. Value creation is the combination of values put forward by service providers in creating or generating value propositions [68]. During value creation, the joint role of government, business, and individuals is an important source of value formation. A total of seven indicators are included under the value creation guidelines, including government public service inputs, business management effectiveness, residential consumption contribution, and environmental governance inputs.

(4) Value realization guidelines for different systems. The value created by the service subject is accepted and recognized by the stakeholders or the market, which is the embodiment of the successful transformation of a complex system's service element input into the output of service value [9]. A total of seven indicators are included under the value realization guidelines, including market scale intensity, consumer price index, ecological carbon sink capacity, and market service price.

Table 2. Evaluation indicator system for the development of CEE systems.

System	Categories	Indicator	Calculation of Indicators	Unit	Attributes	Weights
Cultural systems	Value proposition	Cultural brand awareness	Number of World Heritage Sites	-	+	0.165
		Diversity of cultural landscapes	Ratio of human landscapes to total landscapes in the region	-	+	0.082
	Value transfer	Rate of supply of cultural resources	Ratio of total cultural resources to resident population	-	+	0.318
		Productivity of cultural goods	Ratio of cultural industry output to total cultural resources	%	+	0.140

Table 2. *Cont.*

System	Categories	Indicator	Calculation of Indicators	Unit	Attributes	Weights
Cultural systems	Value creation	Government public service inputs	General public budget expenditure (culture, sports and media)	yuan	+	0.058
		Enterprise management benefits	Output value of cultural industry/number of cultural industry organizations	yuan	+	0.085
		Consumption contribution	Average per capita consumption expenditure (education, culture and recreation) for urban and rural residents	yuan	+	0.045
	Value realization	Market size intensity	Household term and other deposits/resident population	yuan/person	–	0.105
		Consumer price index CPI	CPI (education, culture and recreation)	-	+	0.002
Ecosystems	Value proposition	Resource recycling potential	Utilization rate of industrial solid waste	%	+	0.049
		Ecological performance	Carbon emissions/GDP	g/yuan	–	0.012
	Value transfer	Land resource availability	Ratio of total land resources to resident population	km^2/person	+	0.158
		Efficiency of production of material goods	Gross value of agriculture, forestry, and fisheries/total land resources	yuan/km^2	+	0.217
	Value creation	Environmental governance inputs	Expenditures on energy conservation and protection	yuan	+	0.126
		Resource and environmental pressure	Industrial wastewater discharge/gross industrial output value above scale	t/yuan	–	0.034
	Value realization	Ecological carbon sink capacity	Area covered by greenery	m^2	+	0.016
		Market prices for services	Total output from agroforestry and fisheries/combined output of agriculture, forestry, and fisheries	yuan/kg	+	0.055
		Scale of transfer payments	Special funds for forestland protection by national and local governments	yuan	+	0.333
Economic systems	Value proposition	Level of income and expenditure of the population	Disposable income per capita in urban and rural areas/consumption expenditure per capita in urban and rural areas	-	+	0.072
		Economic development potential	GDP	person/yuan	+	0.037
	Value transfer	Energy utilization	Total energy consumption/GDP	kgce/yuan	–	0.001
		Product demand	Average year-end ownership of major consumer durables per 100 urban and rural households	-	+	0.064
		Industrial structure	Tertiary value added/GDP	-	+	0.258
	Value creation	Quality of medical services	Number of hospital beds/doctors	-	+	0.111
		Talent employment guarantee	Number of laid-off unemployed persons re-employed	person	+	0.071
	Value realization	Digital infrastructure	Mobile cell phone ownership/total population	-	+	0.052
		Scientific and technological research and innovation	Internal expenditure on R&D and share of GDP	%	+	0.334

3.4. Data Collection

The data involved in the study mostly included geospatial and statistical panel data. The geospatial data included vector data of the administrative boundaries of the YRB, administrative quarters of prefectural-level cities, rivers, roads, water systems, etc. The data were downloaded from the National Geographic Data Cloud (https://www.gscloud.cn/, accessed on 5 June 2024) and were obtained via ArcGIS 10.2 software calibration and cropping. To ensure the scientificity and operability of the research results, 2011–2022 was chosen as the time scale to organize and analyze the socioeconomic statistical data, historical and cultural data, and ecological and environmental data of 76 central cities in the YRB during this period. The sources of cultural, ecological, and economic data involved in the study were as follows: (1) the official data platforms of scientific research institutions, such as CSMAR database (https://data.csmar.com/, accessed on 10 June 2024), were used. (2) Statistical yearbooks published by government statistical departments at all levels, such as the China Urban Statistical Yearbook (2001–2021) and the Statistical Yearbook of the Provinces (2002–2023). (3) National statistical bulletin for cities (2001–2022). Moreover, some of the indicators were obtained via calculations based on relevant formulas, and a few missing values were supplemented and improved via interpolation.

4. Analysis of Results

4.1. Evaluation of the CEE System Coordination in the YRB

4.1.1. Assessment of the Level of Integrated System Development

Regarding the basin system as a whole, the integrated development in the YRB from 2011 to 2022 exhibited a prominent trend of ecosystem-driven, synergistic growth across cultural and economic systems (Figure 4). The different subsystems developed with a significant growth trend, and the growth rate was “economic system > cultural system > ecosystem”. During the period 2011–2022, the average change range of the development level of the ecosystem was centered at 0.217–0.296, indicating that while the comprehensive development of the ecosystem played a pivotal role in the overall development of the YRB, regional disparities were gradually widening. The average change interval of the cultural system’s comprehensive development level fell predominantly within the 0.100–0.189 range, indicating a phase of sluggish growth. Moreover, considerable regional disparities in development persist within the basin. The comprehensive development level of the economic system, ranging from 0.070 to 0.166, indicated a larger scope for advancement compared to the ecological and cultural systems. It underscored efficiency, while also stressing inter-regional equilibrium.

4.1.2. Levels and Major Types of Coupled Coordination

Figure 5 shows that from 2011 to 2022, the coupled coordination value of CEE systems in the YRB ranged from 0.324 to 0.438, with most of the cities in a state of slight incongruity. Spatially, for the overall performance of the “low west and high east, increasing step by step” trend, the spatial distribution of the city showed a slight state of incongruity > general state of coordination > moderate state of incongruity trend; moreover, the coupling coordination level in time showed a low rate of linear growth. For example, in 2013, the coupling coordination of moderate incongruity regions in the YRB ranged from 0.190 to 0.295, and these regions were concentrated in Gannan, Linxia, Haidong, Dingxi, Tianshui, Longnan, and other regions, accounting for 28.947% of the cities. The slight incongruity regional coupling coordination values were distributed between 0.306 and 0.491 and were concentrated in Hohhot, Taiyuan, Lvliang, Baoji, Weinan, Luoyang, etc., with cities accounting for 64.474%. The general coordination of the regional coupling coordination value distribution ranged from 0.504 to 0.577 and was mostly distributed in Xi’an, Zhengzhou, Jinan, Weifang, and Qingdao, accounting for 6.579%. In 2022, the proportion of moderate incongruous cities in the YRB decreased to 1.316%, with Gannan Tibetan Autonomous Prefecture being the main city. The proportion of slight incongruity regional cities grew to 80.263%, concentrated in Xining, Lanzhou, Zhongwei, Yinchuan, Baotou, Hohhot, Xianyang, Weinan, and other cities. The proportion of cities in the general coordination region increased to 17.105%, mostly in Yulin, Taiyuan, Zhengzhou, Luoyang, Nanyang, Jinan, Qingdao, Yantai, and other cities. Furthermore, the city of Xi'an transitioned gradually from a state of general coordination to moderate coordination, standing as the sole city in the YRB to achieve moderately coordinated development.

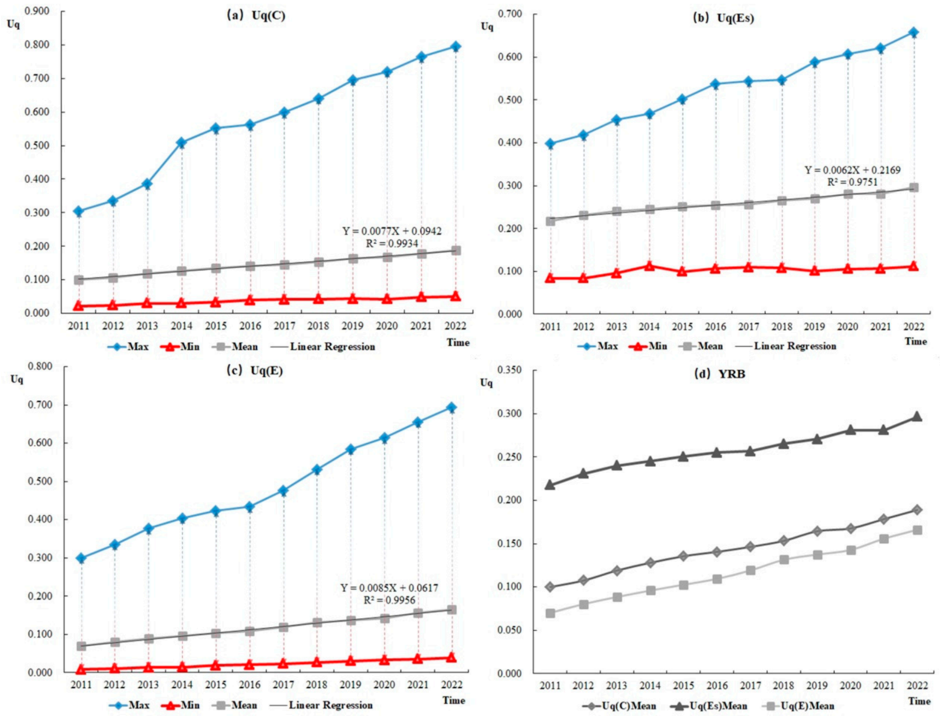

Figure 4. Development across various systems in the YRB.

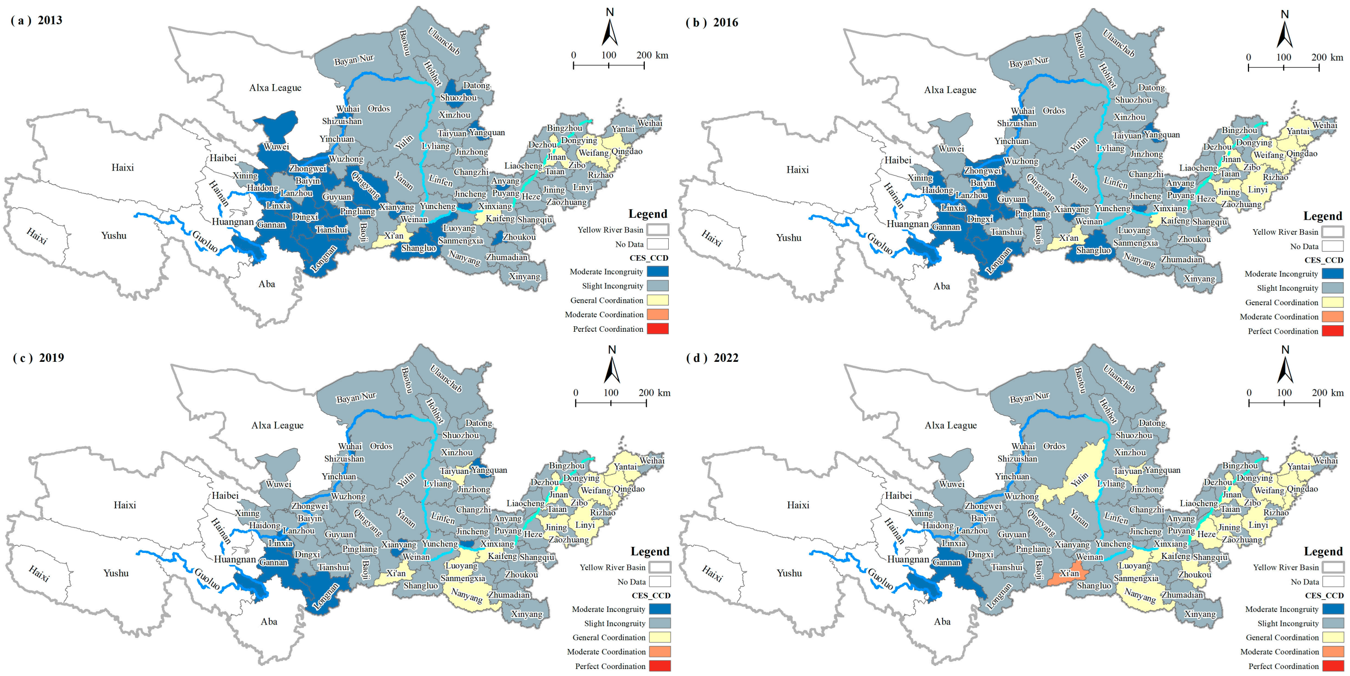

Figure 5. Level of coordinated development of coupled CEE systems in the YRB.

4.2. Spatiotemporal Pattern of Coupled CEE System Coordination in the YRB

4.2.1. Time Pattern

Temporal trends in the upperstream, middlestream, and downstream YRB all revealed an intensified dynamic agglomeration process (Figure 6). Curve distribution-wise, the central position and change interval of nuclear density in the upperstream, middlestream, and downstream closely mirrored the regional change trend. Over time, they uniformly shifted to the right, indicating synchronized growth in the coordination level of the coupled CEE system across the YRB. In the curve distribution patterns, the upperstream nuclear density curve typically showed an "N"-shaped trajectory of "rising-declining-rising". In the middlestream, it exhibited a "peak"-shaped pattern of "fluctuating changes-rising-declining", due to urban scale and spatial disparities. Similarly, in the downstream area, the kernel density curve's main peak showed a stable downward trend. In terms of the extension of the curve distribution, there was a "double peak" phenomenon in both the upperstream and downstream nuclear density distribution curves, i.e., a secondary peak was derived from the right side of the main peak, which indicated that there was a clear trend of bipolar agglomeration in the upperstream and downstream regions of the YRB. Despite the generally high level of coupling coordination in the midstream region, indicated by the kernel density distribution curve, there was a distinct trailing phenomenon on the right side. This suggests that cities like Xi'an, Zhengzhou, Luoyang, and Kaifeng maintained absolute leading advantages even within this environment.

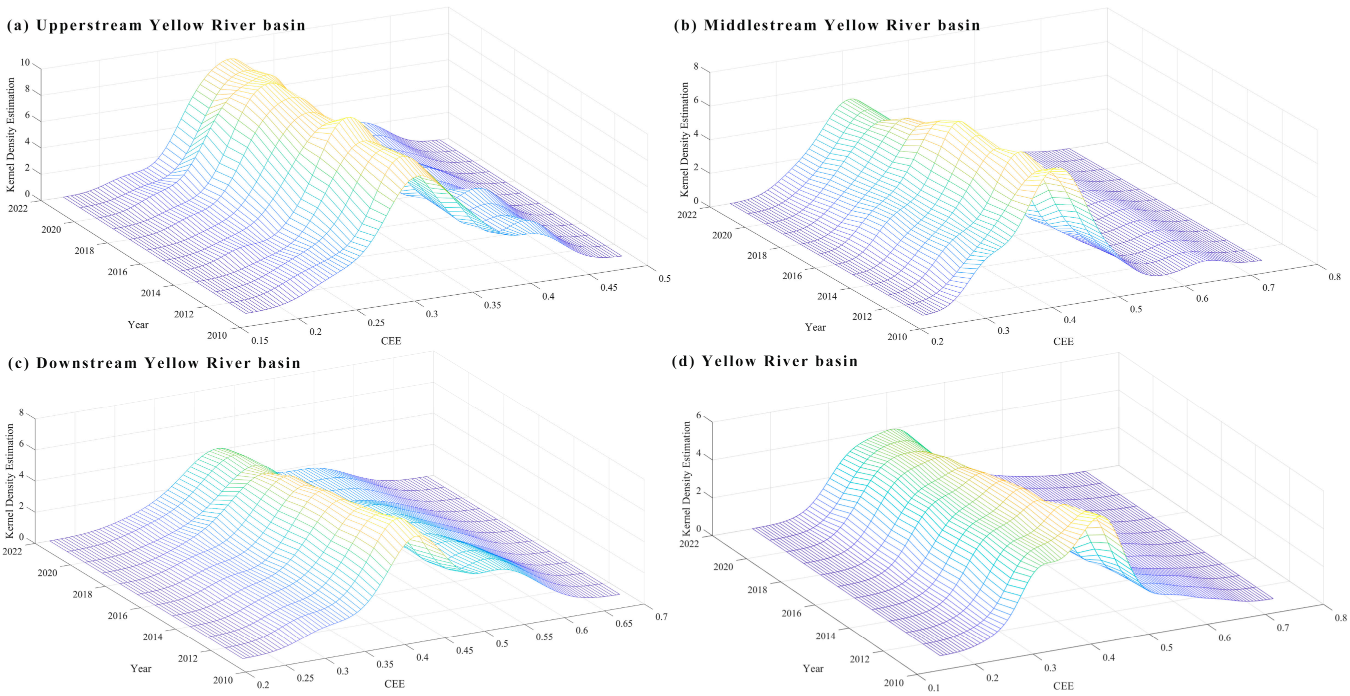

Figure 6. Temporal evolution of the coupled CEE system's coordination level in the YRB (2011–2022).

Looking at the fundamental trend of the YRB's overall evolution, the coordination level of the coupled CEE system demonstrated a relatively stable growth trajectory from 2011 to 2022, albeit with a slight indication of discoordination. Regarding the curve distribution position, the central position of the nuclear density distribution curve in the YRB gradually shifted to the right over time, with the change interval primarily concentrated in the range 0.3–0.6. This suggests an overall growing trend in the degree of coupling coordination. In terms of the curve distribution pattern, the overall regional kernel density distribution curve showed a trajectory of "long-term decline—transient rise", indicating that the incongruity state was weakening and developing toward the general coordination state. Moreover, with 2020 as the inflection point, the distribution curve of nuclear density changed from a long-term decreasing trend to a transient rising state, which was attributed to the influence of the COVID-19 epidemic [69]. In terms of curve extension, no trailing phenomenon was observed in the kernel density distribution curve, indicating a more balanced development trend in the YRB, with relatively small spatial differences in the coupling coordination level.

4.2.2. Spatial Pattern

Overall, the spatial coordination level of the coupled CEE systems in the YRB demonstrated a fundamental pattern of "higher in the east and lower in the west, gradually converging to coordination from west to east" (Figure 7). Differences in coupling coordination levels were observed in the upperstream, middlestream, and downstream reaches of the YRB. Moderate incongruity predominated in the upperstream, slight incongruity in the middlestream, while general coordination characterized the downstream development. Regarding the spatial differentiation in the upperstream reaches concerning changes in coupling coordination level, the cities in the Qinghai and Gansu sections of the upperstream reaches of the YRB were in a state of moderate incongruity, with the value of the coupling coordination ranging from 0.216 to 0.277, and the major cities including Gannan, Haidong, Longnan, Baiyin, etc. The upperstream areas of the YRB were concentrated in a state of moderate incongruity. The moderate incongruity region was concentrated in the ecologically fragile area in the upperstream reaches of the YRB, which was affected by natural disasters, a reduction in biodiversity, and the melting of glacial permafrost. Changes in the ecological environment had a greater impact on social, cultural, and economic systems, which increased the systematic risks faced by cities in this region. The coupling value of middlestream reaches was 0.270–0.647, and the whole area was in a state of slight incongruity, mostly including the cities of Baotou, Datong, Yangquan, Jincheng, and Yuncheng. Spatially, the coupling value in the downstream area exhibited a trend of "from west to east, gradually increasing", with values ranging between 0.295 and 0.606. Most cities were in a general state of coordination. Furthermore, with the southern cities of the downstream reaches of the YRB as the core, the initial formation of the belt development mode with strong radiation-driven effects, such as Jining, Jinan, Linyi, Weifang, Qingdao, Yantai, and other cities, comprised an important region.

Furthermore, to analyze the structural characteristics of the coupling value across the entire spatial domain, the global Moran's I values were calculated for each subsystem in the YRB from 2011 to 2022 [62]. Table 3 indicates that from 2011 to 2022, the Moran's I values for the coupling value of CEE systems in the YRB consistently exceeded 0. Additionally, the Z-statistic values surpassed the two-sided test threshold of 2.58 at the 0.01 significance level. This suggests a significant, positive spatial autocorrelation in the coupled coordination level, indicating a tendency for spatial agglomeration between high–high and low–low values. The spatial manifestation was upperstream moderate incongruity low-value agglomeration and downstream general coordination high-value agglomeration. Over time, Moran's I gradually decreased, indicating a narrowing development gap among regions within the YRB and a shift toward balanced regional development.

Table 3. Moran's I calculation and parametric test results.

Year	Moran's I	$E[I]$	sd	Z	p
2011	0.3170	−0.0133	0.0791	4.2477 ***	0.01
2012	0.3188	−0.0133	0.0795	4.2642 ***	0.01
2013	0.3066	−0.0133	0.0790	4.1421 ***	0.01
2014	0.3011	−0.0133	0.0794	4.0533 ***	0.01
2015	0.3107	−0.0133	0.0798	4.1640 ***	0.01
2016	0.3092	−0.0133	0.0793	4.1567 ***	0.01
2017	0.3087	−0.0133	0.0786	4.1924 ***	0.01
2018	0.2796	−0.0133	0.0791	3.7834 ***	0.01
2019	0.2469	−0.0133	0.0795	3.3591 ***	0.01
2020	0.2468	−0.0133	0.0793	3.3734 ***	0.01

Table 3. *Cont.*

Year	Moran's *I*	*E[I]*	*sd*	*Z*	*p*
2021	0.2520	−0.0133	0.0779	3.4876 ***	0.01
2022	0.2348	−0.0133	0.0778	3.2772 ***	0.01

*** indicate rejection of the original hypothesis at 1% significance levels, respectively.

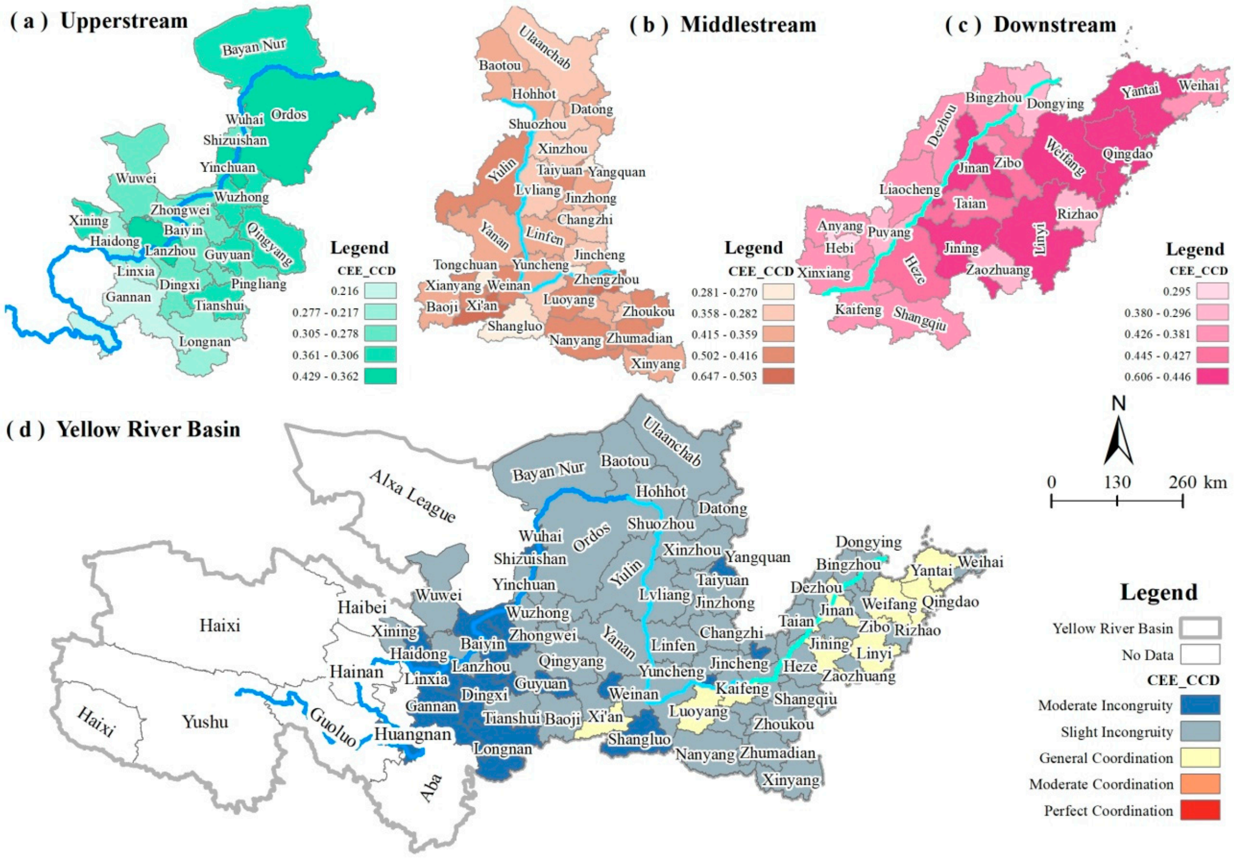

Figure 7. Segmentation pattern of coupled and coordinated CEE systems in the YRB. The figure depicts multi–year averages of coupled coordination levels.

4.2.3. Space-Time Trend Simulation

Utilizing the quartile method described by Wang et al. (2018), the coupled CEE system coordination level in the YRB was classified into four states: I (low), II (lower), III (higher), and IV (high). This classification facilitated the creation of a Markov transfer probability matrix (Table 4) and enabled the examination of the spatial trend in coupled coordination level transfers (Figure 8). Additionally, a comparison was made between the spatial evolution trends of the traditional Markov chain (without lag) and the spatial Markov chain (with and without lag), aiming to simulate the spatial and temporal evolution of the coupled CEE system in the YRB. From the traditional Markov transfer probability matrix (without lag), it was observed that (1) the diagonal element, representing the probability of maintaining the original state, was notably higher (88.04%) compared to the nondiagonal element, indicating a high stability in the transfer of coupled coordination levels. (2) The stability of the low state (97.13%) and high state (92.82%) at the top of the diagonal was significantly greater than that of the lower (92.34%) and higher state (88.04%) in the middle, indicating that there was a polarization trend in the successive enhancement of the coupling value. However, the upward transfer probability of the lower and higher states (4.78% and 7.18%, respectively) was greater than the downward transfer probability (2.87% and 4.78%, respectively), indicating that there was a positive trend of upward transfer in the cities of the lower and higher coupling coordination levels, especially in the cities of the higher state.

Table 4. Markov transfer probability matrix.

Type	t/t + 1	I	II	III	IV
Lag-free	I	0.9713	0.0287	0.0000	0.0000
	II	0.0287	0.9234	0.0478	0.0000
	III	0.0000	0.0478	0.8804	0.0718
	IV	0.0000	0.0000	0.0718	0.9282
I	I	0.9829	0.0171	0.0000	0.0000
	II	0.0000	0.9688	0.0313	0.0000
	III	0.0000	0.0286	0.8857	0.0857
	IV	0.0000	0.0000	0.1154	0.8846
II	I	1.0000	0.0000	0.0000	0.0000
	II	0.0217	0.9674	0.0109	0.0000
	III	0.0000	0.0484	0.8548	0.0968
	IV	0.0000	0.0000	0.2414	0.7586
III	I	0.9636	0.0364	0.0000	0.0000
	II	0.0000	0.9762	0.0238	0.0000
	III	0.0000	0.0263	0.8421	0.1316
	IV	0.0000	0.0000	0.0556	0.9444
IV	I	1.0000	0.0000	0.0000	0.0000
	II	0.0000	0.9500	0.0500	0.0000
	III	0.0000	0.0390	0.9351	0.0260
	IV	0.0000	0.0000	0.0247	0.9753

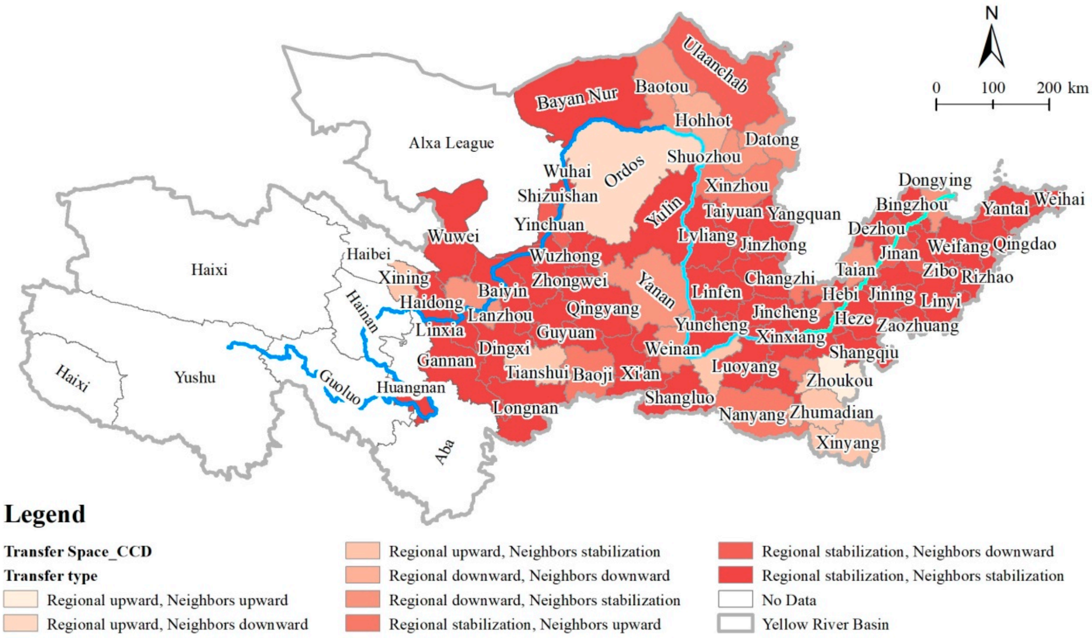

Figure 8. Simulation of the spatial trend of coupled CEE system coordination in the YRB.

Combining the spatial Markov transfer probability matrix (with lag), it becomes evident that (1) there was a noticeable spatial spillover effect on the coupled CEE system coordination level in the YRB. In contrast to the traditional Markov transfer probability matrix (without lag), which does not consider geographic context, cities with different neighborhood types exhibited varying probability transfer characteristics. (2) Diagonal elements in the spatial Markov transfer probability matrix across different neighborhood types exhibited greater stability than nondiagonal elements. In particular, the stability of top elements exceeded that of middle ones, suggesting spatial dependence of coupling coordination levels on high-value regions, alongside spatial disparities between high and low values. (3) The impact of various neighborhood types on coupling coordination varied. Neighboring a city of lower status increased the likelihood of an upward shift in coordination level and reduced the probability of a downward shift. For instance, adjacency to a lower-status city increased the probability of upward transfer from a higher state from 7.18% to 8.57%, while decreasing the probability of downward transfer from 4.78% to 2.86%. (4) The city that shifted upward in both the region and neighborhood was Zhoukou city, and the city that shifted upward in the region and downward in the neighborhood was Ordos city. The proportion of cities in which both regions and neighborhoods remained stable was 67.11%, which were mostly Taiyuan, Jinan, Qingdao, Zhengzhou, Luoyang, and Xi'an.

To further verify the statistical significance of spillover effects in coupled coordination at the spatial level, a hypothesis test was conducted using Equation (13), and the results ($H = 26.401^{*}$, $p = 0.091$) did not support the original hypothesis that the coupled coordination level shifts were spatially independent of each other from 2011 to 2022; considering the significant spatial correlation between regional and neighboring state types, we deemed a comprehensive and integrated spatial analysis both reasonable and necessary.

4.3. Factors Influencing the Development of the Coupled CEE System in the YRB

Utilizing a spatial panel model informed by previous research, we examined the intrinsic factors driving spatial and temporal disparities of coupled CEE systems in the YRB from 2011 to 2022. This analysis involved selecting influencing factors, testing the econometric model, and analyzing regression results.

4.3.1. Selection of Influencing Factors

Drawing from research on the coordinated development of cultural, ecological, and economic subsystems in the YRB, we identified five factors for analysis: tourism development (*TD*), foreign trade (*FT*), human habitat (*HE*), governmental control (*GC*), and transportation services (*TSs*). (1) *TD* serves as a vital link between cultural, ecological, and economic systems, driving the sustainable development in the YRB [56]. We gauged this impact using gross domestic tourism revenue. (2) *FT* reflects the region's openness and its capacity for innovation, serving as an external force that promotes coordination among different systems [5]. We measured this using the total retail sales of consumer goods. (3) *HE* reflects variations in the daily living environment across different regions, playing a pivotal role in coordinating various systems in the YRB [39]. We assessed this using the area of green space in urban parks. (4) *GC* reflects the process of government involvement in system interactions through macroregulation and policy intervention instruments in the conversion of service values of the watershed system [19], which was measured using the government's public finance budget expenditures. (5) *TSs* reflect regional spatial accessibility, structural rationality, and mobility of resource elements and are an important support for the coordinated development of different systems [22], as measured by the ratio of road area to road length. All variables were logarithmically transformed to weaken the effect of heteroscedasticity, and there was no serious problem of multicollinearity (all VIFs were less than 5).

4.3.2. Econometric Model Testing

The regression results obtained using the neighbor distance matrix (W_g) and the inverse geographic distance matrix (W_d) (Table 5) produced consistent outcomes for SPAR, SPEM, and SPDM with the panel spatial autocorrelation spatiotemporal fixed effects model (SAC) under both matrices. This indicated the reliability and robustness of the findings.

Table 5. Spatial panel Durbin model point estimation results.

Variables	W_g				W_d			
	SAR1	**SEM1**	**SDM1**	**SAC1**	**SAR2**	**SEM2**	**SDM2**	**SAC2**
ln*TD*	0.0113 *** (7.31)	0.0133 *** (7.687)	0.0156 *** (7.634)	0.0084 *** (5.369)	0.0115 *** (7.407)	0.0132 *** (7.554)	0.0148 *** (7.089)	0.0114 *** (6.845)
ln*FT*	0.0299 *** (4.694)	0.0311 *** (4.479)	0.0150 ** (2.038)	0.0252 *** (4.354)	0.0309 *** (4.809)	0.0321 *** (4.635)	0.0183 ** (2.441)	0.0308 *** (4.817)
ln*HE*	0.0161 *** (4.255)	0.0161 *** (4.232)	0.0160 *** (4.258)	0.0157 *** (4.385)	0.0167 *** (4.400)	0.0164 *** (4.262)	0.0167 *** (4.377)	0.0168 *** (4.409)
ln*GC*	0.0499 *** (7.952)	0.0499 *** (7.856)	0.0475 *** (7.587)	0.0427 *** (6.608)	0.0509 *** (8.059)	0.0509 *** (7.942)	0.0498 *** (7.854)	0.0509 *** (8.066)
ln*TSs*	0.0119 *** (2.643)	0.0112 ** (2.480)	0.0105 ** (2.351)	0.0114 *** (2.653)	0.0111 ** (2.445)	0.0105 ** (2.299)	0.0109 ** (2.406)	0.0111 ** (2.451)
time	Yes				Yes			
spatial	Yes				Yes			
Observations	912				912			
R-squared	0.8876	0.8489	0.9079	0.9114	0.9043	0.8504	0.9354	0.9059

Values in parentheses are *Z*-statistics, and **, and *** indicate rejection of the original hypothesis at 5%, and 1% significance levels, respectively.

The test results from both spatial weight matrix models (Table 6) indicated that (1) the LM and Robust_LM tests under W_g and W_d rejected the original hypothesis at the 1% significance level, favoring the selection of the SPDM. (2) Both the LR and Wald tests, at the 1% significance level, rejected the original hypothesis that the SPDM degenerates into either a SPEM or a SPLM. Thus, indicating that the SPDM was the preferred option. (3) Both the Hausman test and the LR test passed, indicating that spatio-temporal fixed effects outperformed time or spatial fixed effects and random effects. (4) According to the BIC criterion, the SAC worked better than the SPDM. Therefore, we ultimately adopted a panel spatial autocorrelation spatio-temporal fixed effects model (SAC).

Table 6. Model test results.

Test Methods	W_g	W_d	**Test Methods**	W_g	W_d
Moran' *I*	0.9292 ***	1.4523 ***	LR-lag	22.92 ***	16.45 ***
LM-lag	109.9356 ***	4.0146 **	LR-sem	33.60 ***	25.25 ***
LM-sem	1489.7541 ***	1476.1962 ***	Wald-lag	33.87 ***	25.18 ***
Robust-LM-lag	959.7501 ***	32.0345 ***	Wald-sem	23.15 ***	16.50 ***
Robust-LM-sem	2339.5686 ***	1504.2161 ***	LR-ind	114.90 ***	34.07 ***
Hausman	48.46 ***	61.08 ***	LR-time	2162.48 ***	2149.98 ***

, and * indicate rejection of the original hypothesis at 5% and 1% significance levels, respectively.

4.3.3. Analysis of Regression Results

Given the test results, it is possible that the findings were biased and failed to capture the spatial spillover effects of the variables, as the coefficients of the SPDM may not represent the marginal effects of traditional nonspatial models [70]. Therefore, the direct, indirect (spillover) and total effects of the drivers needed to be decomposed with the help of partial differentiation (Table 7). By analyzing the results of the effect decomposition of the spatial weight matrix of neighboring distance [62], it was found that the direct, indirect, and total effects of *TD*, *FT*, *HE*, and *GC* were all significantly positive, indicating that the factors of *TD*, *FT*, *HE*, and *GC* promoted the coupled development of different systems in the YRB, and at the same time regulated the intrinsic differences among different regions with significant positive spillover effects. The direct and total effects of *TSs* were both statistically significant at the 1% level, while the indirect effect, although at 0.0099, remained significant at the 5% level. This indicated that transportation facilities played a positive role in enhancing coupling within the local region and exerted a minor radiation-driven effect on neighboring regions. In addition, the direct, indirect, and total effects under the inverse geographic distance matrix showed a significant overall trend, indicating that the spatial effect decomposition results were robust.

Table 7. Results of the decomposition of spatial effects.

Variables	W_g			W_d		
	Direct	Indirect	Total	Direct	Indirect	Total
ln*TD*	0.0090 *** (5.561)	0.0073 *** (4.039)	0.0163 *** (5.897)	0.0117 *** (6.825)	0.0067 ** (2.176)	0.0184 *** (5.058)
ln*FT*	0.0266 *** (4.629)	0.0216 *** (3.468)	0.0482 *** (4.624)	0.0310 *** (4.977)	0.0179 ** (2.043)	0.0490 *** (4.010)
ln*HE*	0.0171 *** (4.661)	0.0142 *** (2.768)	0.0313 *** (3.900)	0.0174 *** (4.667)	0.0103 * (1.765)	0.0277 *** (3.338)
ln*GC*	0.0455 *** (7.355)	0.0372 *** (3.950)	0.0827 *** (6.735)	0.0516 *** (8.417)	0.0302 ** (2.041)	0.0818 *** (4.703)
ln*TSs*	0.0121 *** (2.757)	0.0099 ** (2.284)	0.0220 *** (2.668)	0.0112 ** (2.538)	0.0065 (1.569)	0.0177 ** (2.289)

Lag and sem denote spatial lag and spatial error, respectively; ind and time denote spatial and temporal effects, respectively; *, **, and *** denote rejection of the original hypothesis at the 10%, 5%, and 1% significance levels, respectively.

5. Discussion

The spatial and temporal evolution patterns, evolutionary trend, and factors influencing coordination from 2011 to 2022 were investigated on the basis of constructing a framework for the coupled and coordinated CEE system in the YRB. However, the following aspects need to be explored.

5.1. Intrinsic Relationships between Cultural, Ecological, and Economic Systems

According to research, ecosystem services encompass the provisioning, regulating, habitat, and cultural services that ecosystems provide in terms of “goods” and “services” [53]. Ecosystem cultural services are the result of co-generation and co-creation between human societies and ecosystems, which emphasizes the spiritual importance of ecosystems as cultural products for the development of human societies [71]. In contrast, social-ecological systems are coupled systems formed by complex interactions between natural ecosystems and humans [44,72], and their complexity, territoriality, nonlinearity, and multilayered nestedness characterize social-ecological systems as being in a dynamic state of evolution. In the process of interaction between ecosystems and cultural and social systems, the main body of ecosystem services gradually shifts from natural environmental elements to material activities and the nonmaterial cultural needs of human society, and the system structure completes the transition to social and cultural dimensions [6]. As a result, a complex system forms around these ecological, social, and cultural relationships, despite the consistent association between factor flow and structural integration due to the vulnerability of the ecosystem and adaptive limitations [14]. When responding to systemic risks brought about by changes in external environmental conditions [73], the systems, due to the endogenous dynamics of disparity, service value differences, and other factors, increase structural risks within and outside the system. Therefore, at the watershed scale, exploring the coupling and coordination of the CEE system, which consists of multiple geographic elements and processes, from a holistic perspective is the main issue in reducing the ecological risk of the watershed system and mitigating the resource and environmental sensitivity of the watershed.

5.2. The Process of CEE System Coupling in the YRB

We assessed the coupled CEE system in the YRB by selecting 27 indicators from different aspects of the development of cultural, ecological, and economic subsystems through the value proposition, transfer, creation, and realization links of value co-creation theory. The major indicators chosen for the study included general factors such as government public service input, residents' consumption contribution, consumer price index, resource and environmental pressure, residents' income and expenditure level, industrial structure, medical service quality, and scientific and technological research and development innovation [18,56]; factors such as the diversity of cultural landscapes, ecological environmental performance, and environmental governance input; and the transfer payment scale, which are important indicators for measuring coupled coordination. Synthesizing relevant studies in the YRB, in terms of the construction of indicators, we expanded the measurement indicators of ecosystem services, with the coupling of different systems, and provided a reference for the evaluation of the coupled coordination of cultural, ecological, and economic systems in the basin.

In terms of the temporal pattern of the coupled coordination in the YRB, the upperstream, middlestream, and downstream reaches of the river showed temporal consistency and synchronized growth trends, and the coupled coordination level as a whole had a relatively stable growth trend, showing a slight incongruity state. According to studies, this process aligns with the reality of sustainable development in the YRB [2]. The spatial pattern of changes in the level of coupled coordination varied between the upperstream, middlestream, and downstream regions in the YRB. The upperstream region showed moderate incongruity, with a variation range of 0.216–0.277 in CCD; the middlestream region displayed slight incongruity, with a variation range of 0.270–0.647 in CCD; and the downstream region exhibited general coordination, with a variation range of 0.295–0.606 in CCD. This result is consistent with the findings of previous research, such as the coupled coordination among resource, economic, and ecological in the YRB showing a transfer trend from the middlestream and upperstream reaches to the downstream reaches [18]. However, unlike established studies, in the upperstream region, Gannan Tibetan Autonomous Prefecture was in a state of moderate incongruity, with a variation range of 0.169–0.248 in CCD from 2011 to 2022. Although Gannan Tibetan Autonomous Prefecture has continued to increase ecological environmental protection and vigorously develop cultural and tourism industries in recent years, Gannan Tibetan Autonomous Prefecture, as an important ecologically fragile area in China, has been included in the national ecological main function area, and more than 90% of its land area belongs to restricted and prohibited development zones. As a result, the unique geographic location and ecological resource endowment of Gannan State have led to a high level of ecological sensitivity [74], leaving its cultural, ecological, and economic systems at a perennial level of dissonance.

It was found that factors such as *TD*, *FT*, *HE*, and *GC* directly influenced the coupled coordinated of the CEE system in the YRB, which was similar to our results. For example, researchers indicated that the scale of tourism and the economic benefits of tourism are important factors affecting development in the YRB [1]; another study found that human habitat, technological innovation, and governmental capacity positively impact the coupled coordination of different systems in the YRB [18]. However, due to the different influences of *FT* on resource utilization, ecological protection, and cultural inheritance in the YRB, foreign trade increases the pressure of resource utilization but is more favorable for cultural inheritance and exchange. In addition, it was found that the direct and total effects of the *TSs* factor were 0.0121 and 0.0220, respectively, which is significant at the 1% level, while the indirect effect was 0.0099, which is important at the 5% level. It is suggested that the *TSs* factor drives the coupled coordination of different cities, but the radiation effect on the neighboring regions was not obvious. Therefore, the focus should be on strengthening cross-regional infrastructure construction in the YRB to enhance the level of transportation services.

5.3. Policy Implications

Through an analysis of the spatio-temporal pattern and influencing factors of the coupled coordinated of the CEE system in the YRB, this study aimed to explore realistic strategies for future development. These strategies should focus on promoting balanced regional development and enhancing major factors for sustainable growth.

(1) In terms of balanced regional development, there are large differences in the current development of different areas in the YRB. Therefore, local government departments at the provincial and municipal levels should integrate resource advantages, establish structural and functional subdivisions, and clarify the roles of the upperstream, middlestream, and downstream reaches in the coordinated development of the CEE systems. Specifically, the upperstream should pay attention to the protection of the ecological environment and the construction of ecological civilization in revitalizing the use of cultural resources and economic development. The middlestream must make full use of the advantages of cultural resources to achieve effective governance of the ecological environment driven by economic development. The downstream has a more balanced development of cultural, ecological, and economic systems, and it is important to minimize the development gap between the south and north bank areas of the YRB.

(2) Regarding the enhancement of major factors, it is necessary to clarify the major types and spatial differences in the coupled coordination of CEE systems in the YRB, to identify typical moderate incongruous and slightly incongruous cities and to formulate a development strategy according to local conditions by accounting for the influence of regional tourism development, foreign trade, and human habitat factors. For moderate incongruity regions, the focus should be on ecosystem function protection, focusing on the development of the service industry through the protection of characteristic cultural resources. For regions with moderate incongruity, the focus should be on infrastructure service upgrading, technological and institutional innovation, and foreign trade development.

5.4. Research Limitations

Although this study constructed a framework for the coordination of the coupled CEE system coordination in the YRB, the framework was mostly based on the ESC and SVC, which needs to be further demonstrated, expanded, and developed in different contexts. At the same time, the different links of value co-creation were taken as the major dimensions for constructing evaluation indicators in the selection of indicators. Therefore, the indicator system is applicable only for evaluating the development level of different systems under the SDL. Furthermore, due to the limitations of the paper structure, the functions of the factors influencing the level of coupled coordination were not analyzed. In future research, the focus will be on the influence mechanism of the coupled CEE system coordination in the YRB. On this basis, this study focused only on the adaptation of policy and society in top-down processes, ignoring the local development needs from the cultural and environmental perspectives, and it lacks a micro perspective to explore the policy well-being and community autonomy of different localities within the scope of the YRB. Therefore, research on integrating local policy and society at a small scale from bottom-up processes is an important direction that needs to be refined in the future.

6. Conclusions

Based on the SDL, we analyzed the interaction relationships, coupling and coordination status, temporal and spatial change patterns, and factors influencing the CEE systems in the YRB using the entropy-weighted TOPSIS model, coupling coordination model, spatial Markov chain, the panel spatial Durbin model. The study ultimately resulted in the following conclusions:

(1) From the perspective of SDL, a coupled CEE system framework was constructed through the ESC and SVC. The framework emphasized that in a complex system

composed of different elements, producers and consumers participate in the co-creation of the system's service values through multiple interactions between demand and value, as well as products and services. The framework of coupled CEE systems can effectively deconstruct the coupling mechanism of different system interactions in watershed units and at large scales, and enhance the applicability of ecosystem services in other research contexts.

(2) From 2011 to 2022, the sustainable development in the YRB mostly manifested in a development model dominated by the ecosystem and synergized by cultural and economic systems. The average change interval of the integrated development of water in the ecological subsystem was 0.217–0.296, the average change interval of the integrated development of water in the cultural subsystem was 0.100–0.189, and the average change interval of the integrated development of water in the economic subsystem was 0.070–0.166. The values showed that the subsystems were developing with a linear growth trend between them, and the growth rate was manifested as "economic system > cultural system > ecosystem".

(3) From 2011 to 2022, the coupled coordination type of the CEE system in the YRB was mainly slight incongruity, with the value of coupled ranging from 0.324 to 0.438, and the spatial distribution of areas was characterized as "slight incongruity >general coordination > moderate incongruity". In 2013, moderate incongruity cities were mainly distributed in the upperstream, accounting for 28.947% of the cities; slight incongruity areas were distributed in the middlestream and downstream, such as Hohhot, Taiyuan, Baoji, Luoyang, and Jining, accounting for 64.474% of all cities. In 2022, the moderate incongruity cities were mainly in the Tibetan Autonomous Prefecture of Gannan, and the slight incongruity cities, such as Xining, Lanzhou, Yinchuan, Hohhot and Xianyang, which accounted for 80.263% of all cities, were distributed in the upperstream and middlestream.

(4) Over time, the coupled coordination of the CEE systems in the YRB showed temporal consistency and synchronized growth in the upperstream, middlestream, and downstream areas. Most of the cities in the upperstream area were transitioning from moderate incongruity to slight incongruity, while some cities were transitioning from slight incongruity to general coordination. The coupled coordination in the middlestream of the region was relatively high overall, with individual cities showing a trend of agglomeration development. Most cities in the downstream region were in a state of slight incongruity and general coordination.

(5) From 2011 to 2022, the CEE system coupling in the YRB was spatially manifested as "high in the east and low in the west, gradually converging towards harmonization from west to east". This system presented the obvious characteristics of moderate incongruity low-value agglomeration in the upperstream, and general coordination high-value agglomeration in the downstream. Moreover, through the spatial Markov chain transfer probability matrix, we found that there was a spatial spillover effect of the coupled coordination of the CEE system in the YRB, and the number of cities that maintained stability in the region and the neighboring areas accounted for 67.11% of the cities. This indicated that the coupled coordination level maintained a relatively stable change trend in space but relied on high-value areas, and a spatial difference between high and low values was present.

(6) Among the factors influencing the changes in coupled coordination of CEE systems in the YRB, factors such as tourism development, foreign trade, the human habitat environment, and government regulation regulated the intrinsic developmental differences among regions through significant positive spillover effects, while the transportation service factor, although effective in promoting a significant increase in the coupled coordination in the local region, did not have a strong spatial spillover effect on neighboring regions.

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