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Spatiotemporal Dynamics and Barriers to Eco-Culture-Tourism Coordination in the Middle Yellow River Basin, China

Yang Zhao

zhaoyang@sust.edu.cn

Zhengzhou University of Light Industry

Yuanbo Qi

Zhengzhou University of Light Industry

Hua Wei

Zhengzhou University of Light Industry

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Abstract: Integrating eco-environmental conservation with cultural tourism is increasingly important for sustainable regional development, yet the balance among ecological, cultural, and tourism subsystems often remains uneven. Using panel data from four provinces in the Middle Reaches of the Yellow River from 2010 to 2024, this study develops an ecology–culture–tourism indicator framework to evaluate regional coordination and identify its main structural barriers. We apply a coupling coordination model to assess changes in system performance over time and a barrier analysis to detect the factors that most strongly constrain balanced development. The results show marked spatial differences across the four provinces, confirming a persistently uneven regional pattern. Even so, overall coordination improved steadily during the study period, with the region moving from clear imbalance towards progressively higher levels of coordination. Among the three subsystems, cultural development and ecological conditions contributed more strongly to overall improvement, whereas weaknesses in tourism infrastructure remained a major constraint. These findings provide governance-relevant evidence for prioritizing differentiated infrastructure upgrading, tourism-supporting service provision, ecological restoration, and cultural development strategies to promote more balanced and sustainable regional transformation.

Keywords: ecology-culture-tourism; coupling coordination degree; spatiotemporal dynamics; barrier factors; the Middle Yellow River region

1. Introduction

Achieving sustainability in ecologically sensitive regions requires more than expanding economic activity under a green label. Tourism is often promoted as a pathway to regional transformation because it can generate employment, diversify local economies, and activate cultural resources. However, tourism growth can also intensify land-use pressure, infrastructure expansion, water consumption, and ecological disturbance (Anvarovich 2024; Collins 1999; Dubois et al. 2011; Hunter 2002; Karim 2014; Meng 2022; Stern, Common, and Barbier 1996; Turner et al. 2003; Wackernagel and Yount 2000; Wang, Fang, and Law 2018; Wei, Alvarez, and Martin 2013). In this sense, the central challenge is not whether tourism should develop, but how ecological protection, cultural vitality, and tourism expansion can be coordinated under conditions of uneven regional capacity. This challenge is particularly acute in regions where environmental fragility, historical development disparities, and strong policy expectations coexist.

The MYRB provides a highly revealing context for examining this governance problem (Li et al. 2023). Covering Inner Mongolia, Shanxi, Shaanxi, and Henan, the MYRB combines fragile ecological conditions (Sun et al. 2023), resource-based industrial legacies, rich cultural assets, and strong policy pressure for ecological protection and high-quality development. Under the basin-wide national strategy, all four provincial-level units are expected to advance coordinated transformation (Xi 2022). Yet they differ substantially in ecological carrying capacity, cultural development capacity, tourism-supporting infrastructure, and industrial restructuring burdens (Ye 2024). As a result, the MYRB should not be understood simply as a representative tourism region, but as a governance-critical arena in which coordinated development is necessary yet intrinsically difficult. Whether basin-wide sustainability strategies produce balanced regional transformation remains an open question (Du et al. 2023; Feng et al. 2023).

Existing research has generated important insights into the relationship between ecological protection, cultural development, and tourism growth, but several limitations remain. First, many studies still focus on binary relationships (Gao 2013; Shu 2015; Xu 2015), particularly tourism–ecology or culture–tourism couplings, while comparatively fewer examine ecology, culture, and tourism as an integrated triadic system. Second, even where triadic frameworks have been adopted, the analysis often remains descriptive, emphasizing whether coordination levels rise or fall over time, rather than explaining why structurally different regions follow divergent trajectories. Third, studies on the Yellow River Basin have mainly highlighted overall coordination improvement, subsystem evolution, or general policy significance, but have paid less attention to interprovincial divergence, differentiated structural barriers, and the uneven reconfiguration of coordination after external shocks and policy adjustment.

These gaps are analytically important because a rise in average coordination does not necessarily imply synchronized or balanced transition. Provinces embedded in the same basin-wide governance framework may still differ markedly in ecological restoration burdens, cultural resource conversion capacity, tourism reception conditions, and industrial transition pressure. Therefore, identifying the level of coordination alone is insufficient for governance-

oriented research; it is equally necessary to explain why coordination remains uneven and which structural barriers continue to shape interprovincial disparity.

Against this background, this study asks three questions:

(1) Does the ECT system in the MYRB evolve along a synchronized pathway, or does it exhibit differentiated provincial trajectories?

(2) Which structural barriers dominate the uneven coordination of the ECT system across provinces?

(3) What do these differences imply for differentiated regional governance under a shared basin-scale policy framework?

To address these questions, this study employs the Coupling Coordination Degree Model and the barrier degree model to examine the spatiotemporal evolution and structural constraints of the ECT system in the MYRB from 2010 to 2024. Rather than treating culture merely as a tourism input, the study conceptualizes it as a coordinating dimension linked to place identity, territorial development, and the broader sustainability agenda. By combining triadic system analysis with barrier diagnosis at the interprovincial scale, this study contributes to the literature in three ways. First, it shifts attention from binary couplings to a triadic framework that captures the joint interaction of ecology, culture, and tourism. Second, it connects spatiotemporal coordination trajectories with structural barrier analysis, thereby moving beyond descriptive stage classification. Third, it interprets ECT coordination in the MYRB as a differentiated governance process rather than a uniform regional trend, and thus offers a comparative basis for province-specific interpretation of coordinated development under a shared basin-scale policy framework.

2. Literature review and research gap

Recent scholarship has increasingly argued that coordinated regional development should be treated as a dynamic, multi-system process rather than as the parallel growth of separate sectors (Huang, Na, and Guo 2020; Wan et al. 2020; Xue and Liu 2023; Zhang et al. 2022). From the perspective of ecological civilization, Liu et al. contend that coupling coordination should be understood as a spatially differentiated process in which subsystems may improve simultaneously while still evolving unevenly across territories (Liu et al. 2022). Extending this line of thought, Yu et al. emphasize that studies of coordinated development should move beyond trend description and engage with the driving mechanisms that generate divergent regional trajectories (Yu et al. 2025). Similarly, Zhao shows that system co-evolution cannot be adequately captured by average coordination levels alone, because heterogeneous economic, social, and ecological drivers shape different resilience outcomes across space (Zhao, Yu, and Liu 2025). Together, these studies suggest that the key question is not merely whether coordination improves, but why coordination remains uneven under apparently shared developmental conditions (Li et al. 2021; Xiaomin et al. 2022; Zhao et al. 2022; Zhu, Huang, and Zhao 2022).

In tourism research, the relationship between tourism development and ecological conditions has moved from a narrow concern with environmental pressure toward a broader analysis of tourism–ecology interaction under sustainability transition. In the specific context of the Yellow River Basin, Huang et al. argue that tourism, ecological environment, and public services should be treated as an integrated system (Huang et al. 2022) , because the quality of ecological governance and public provision conditions the sustainability of tourism development. Building on a different ecological lens, he shows that the coupling coordination between tourism development and ecosystem services value in the Yellow River Basin improved over time, yet the spatial gap widened and tourism itself remained the dominant barrier in many cities (He et al. 2023). Their findings are particularly important because they demonstrate that rising overall coordination may coexist with deepening interregional imbalance. These studies have significantly enriched our understanding of tourism-related coordination in the basin, but they still focus primarily on binary or adjacent system combinations, such as tourism with ecological environment, ecosystem services, or public services.

A parallel stream of research has examined the relationship between culture and tourism (Jing et al. 2025; Li and Ju 2020; Tang et al. 2023; Xu et al. 2024), but here too the dominant tendency has been to treat culture either as a tourism resource or as an economic sector that supports destination attractiveness (Groizard and Santana-Gallego 2018; Kumar et al. 2019; Liu 2020; McKercher, Wong, and Lau 2006; Quaglione et al. 2020; Stanik, Aalders, and Miller 2018). More recent work has begun to move beyond this instrumental view (Li et al. 2025). In a study of the Yellow River Basin, Wang et al. argue that ecology, culture, and tourism should be analyzed as a triadic system (Wang and Wang 2025), because culture does not merely feed tourism demand; it also acts as a coordinating force that links territorial identity, ecological value, and development capacity (Huynh et al. 2022; Thompson et al. 2021). This is an important advance, yet the literature still remains underdeveloped in two respects. First, even triadic studies often privilege overall coordination trends and stage classification over explanation of why provinces embedded in the same policy framework follow different developmental paths. Second, relatively little attention has been paid to the structural barriers that

shape uneven coordination, especially in regions where ecological fragility, industrial transition burdens, and uneven tourism-supporting infrastructure coexist (Ran 2010).

These limitations are particularly important in the Middle Yellow River Basin. As a governance space that combines ecological vulnerability, strong cultural resources, and long-standing development asymmetries, the region cannot be adequately understood through generalized claims about tourism growth or ecological improvement. The existing literature has already shown that coordination in the broader Yellow River Basin tends to improve over time, but it has not sufficiently explained whether this reflects a synchronized regional transition or merely an increase in average values across structurally different provinces. Nor has it fully clarified which constraints continue to impede balanced development when provinces share the same basin-scale policy framework. Therefore, the present study addresses a more specific gap: it examines how ecology, culture, and tourism evolve as a triadic system in the Middle Yellow River Basin, why their coordination remains uneven across provinces, and which structural barriers continue to shape this differentiated transition. By doing so, the study seeks to move the discussion from descriptive coordination assessment toward a more governance-oriented explanation of regional sustainability.

3. Materials and Methods

3.1. Mechanistic analysis of coupling relationships

The ECT system is a dynamic and open system composed of three interrelated subsystems: ecology, culture, and tourism. These subsystems interact through mutual support, mutual constraint, and feedback effects (Figure 1). The ecological subsystem provides the environmental carrying capacity, resource base, and spatial conditions necessary for the development of cultural and tourism activities(Zhu et al. 2024). The cultural subsystem supplies symbolic value, place identity, and humanistic content, thereby enriching tourism products and strengthening regional distinctiveness. The tourism subsystem acts as a key channel through which ecological and cultural resources are transformed into economic and social value.

The relationship among the three subsystems is not always harmonious. Tourism development may increase pressure on ecological resources through land use, infrastructure expansion, and pollutant emissions, while ecological degradation may weaken the attractiveness and sustainability of tourism destinations (MacKerron and Mourato 2013). Cultural development can strengthen tourism competitiveness (Crouch 2012; Goffi, Cucculelli, and Masiero 2019; Kubickova and Martin 2020; Shoval and Birenboim 2019) and public recognition of ecological protection, but insufficient cultural investment or weak cultural vitality may also limit the overall coordination of the ECT system. Therefore, the ECT system in the MYRB should be understood as a process of dynamic interaction in which ecology, culture, and tourism jointly shape the trajectory of regional sustainable development (Xia 2000).

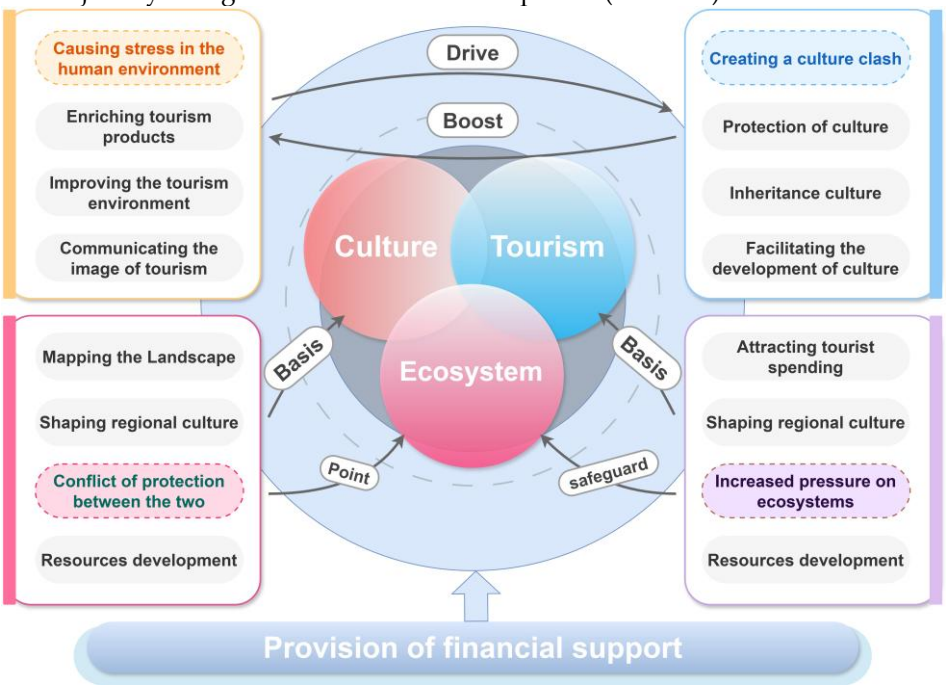


Figure 1. Mechanism map of coupled coordination relationships

3.2. Study area

The Yellow River originates in the northeastern part of the Qinghai–Tibet Plateau and flows through nine provincial-level regions before emptying into the Bohai Sea. The middle reaches of the Yellow River extend from Hekou Town in Inner Mongolia to Tao Huayu in Zhengzhou, Henan(Huang and Xue 2024). This section covers approximately 1,206 km and includes four provincial-level units: Inner Mongolia, Shanxi, Shaanxi, and Henan. The watershed area of the middle reaches is about 344,000 km², accounting for approximately 43.27% of the total area of the Yellow River Basin (Figure 2) (Ren 2021).

The MYRB contains diverse geomorphological units, including the Ordos Plateau, Jinzhong Basin, northern Shaanxi Plateau, Guanzhong Plain, Jinnan Basin, and western Henan Basin. It is an important agricultural, energy, and ecological transition zone in China. At the same time, the region possesses rich historical and cultural resources and a dense distribution of heritage-related tourism assets(An 1992; Zhang 2012). However, it also faces prominent ecological challenges, including soil erosion, water-related environmental stress, and ecosystem degradation (Q. Wang et al. 2024). These characteristics make the MYRB a representative case for examining the coordinated development of ecology, culture, and tourism.

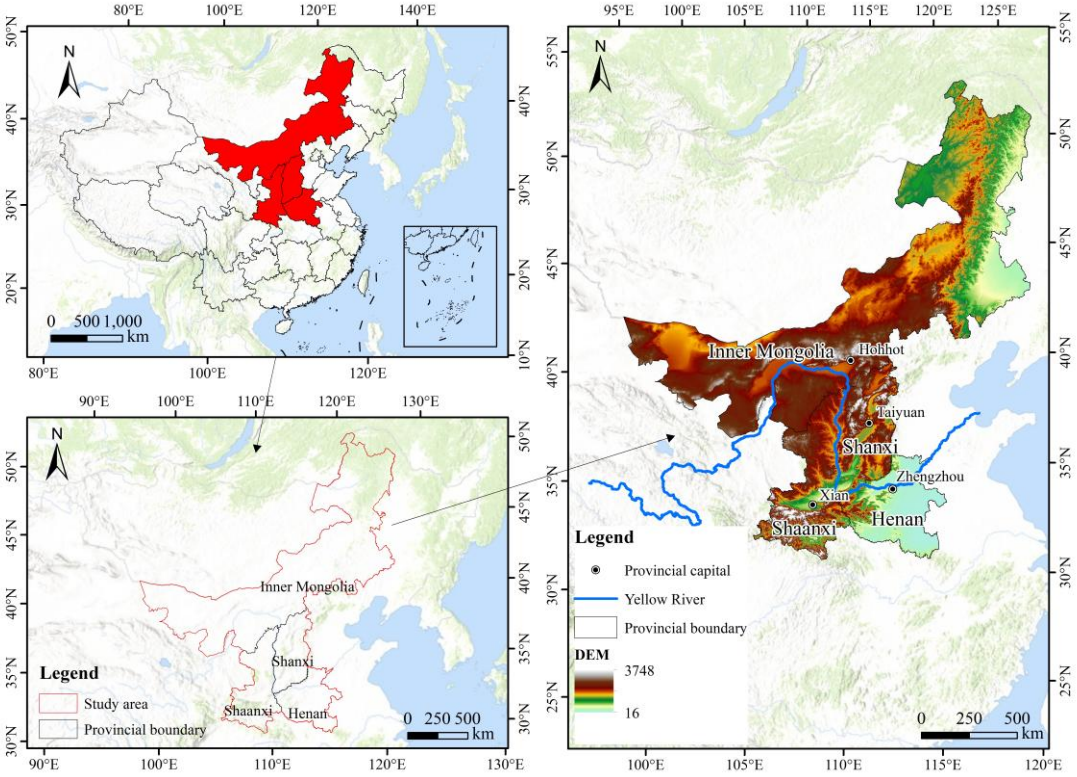


Figure 2. Geographical location of the study area

3.3. Data sources

The primary data cover the period 2010–2024 and were compiled from successive editions of the China Environmental Statistics Yearbook, China Culture and Related Industries Statistics Yearbook, China Tourism Statistics Yearbook, China Culture and Tourism Statistics Yearbook, and provincial statistical bulletins for the four provincial-level units in the MYRB. Additionally, official yearbooks, government websites, and bulletins of each province and city were consulted to gather development data on the culture industry, tourism industry, and ecosystem from 2010 to 2024. To minimize data discontinuity, the study first cross-checked provincial yearbooks, statistical bulletins, and official government releases before applying any imputation. Linear interpolation was used only for a small number of isolated observations that remained unavailable after source triangulation and only where adjacent-year values were available. No long consecutive missing sequences or whole-indicator gaps were interpolated. Most of these adjustments concerned scattered late-period observations rather than systematic omissions, which reduces the risk that interpolation materially distorted the overall spatiotemporal pattern. To enhance transparency and reproducibility, all province-year indicator data, variable definitions, interpolation records, and calculation files were archived and provided for peer review through a repository link.

3.4. Research methodology

3.4.1. Construction of the indicator system

An initial pool of indicators was collected from previous studies and official statistical systems. Indicators were then screened against four criteria: theoretical relevance to ECT coordination, basin specificity, annual data continuity for 2010–2024, and interprovincial comparability. After removing redundant or weakly comparable indicators, 7 cultural, 11 ecological, and 10 tourism indicators were retained. To evaluate the development level and coupling coordination of the ECT system, this study constructed an indicator system based on the principles of scientific validity, comprehensiveness, representativeness, and data availability. Drawing on existing studies and adapting them to the characteristics of the MYRB, the indicator system includes three subsystems: culture, ecology, and tourism.

Based on previous coupling-coordination and regional sustainability studies in the Yellow River Basin, the indicator system was constructed according to four criteria: theoretical relevance, basin specificity, data availability, and interprovincial comparability. The ECT system was divided into three subsystems. The cultural subsystem includes seven indicators measuring industrial scale, industrial foundation, and industrial benefits; the ecological subsystem includes eleven indicators covering ecological pressure, ecological status, and ecological response; and the tourism subsystem includes ten indicators reflecting industry scale, industry level, and industry benefits. This structure follows prior research that treats ecology, culture, and tourism as interrelated but analytically distinguishable dimensions of regional coordinated development. The final indicator system and entropy-derived weights are reported in Table 1.

For the ecological subsystem, the selected indicators were designed to reflect both ecological pressure and ecological response in the Middle Yellow River Basin. Given the region's ecological fragility, pollution-control demands, and long-term restoration pressure, the ecological subsystem includes indicators related to wastewater emissions, industrial air pollutants, urban greening, forest coverage, solid-waste utilization, sewage treatment, waste-gas treatment capacity, domestic garbage treatment, and environmental pollution-control investment. Among them, the greening coverage rate of built-up areas and park green space per capita were retained to capture the urban ecological environment and public green-space provision, while forest coverage reflects broader vegetation conditions and ecological restoration capacity. This indicator structure is consistent with the basin-scale characteristics of the MYRB and with previous studies emphasizing pollution control, ecological restoration, and environmental governance capacity in Yellow River Basin sustainability assessment.

Table 1. Indicator system and indicator weights for subsystems in the MYRB region

subsystems	Primary Indicators	Secondary Indicators/Unit	Types	Weights
Cultural Industry System	Industry Scale	A1 Fixed Asset Investment in Cultural Industries (billion yuan)	+	0.211
		A2 Value added of cultural industries (billion yuan)	+	0.081
	Industrial base	A3 Number of public libraries (pcs)	+	0.149
		A4 Number of museums (pcs)	+	0.137
		A5 Visits to museums (10^4 person time)	+	0.074
		A6 Number of performing arts organizations (pcs)	+	0.121
	Industry Benefits	A7 Per capita expenditure on cultural and entertainment consumption by residents (yuan)	+	0.209
Ecosystem	Ecological Pressure	B1 Wastewater emissions (10^4 tons)	-	0.086
		B2 Industrial SO^2 emissions (10^4 tons)	-	0.088
		B3 Industrial smoke (dust) emissions (10^4 tons)	-	0.057
	Ecological Status	B4 Greening coverage rate of built-up areas (%)	+	0.053
		B5 Park green space per capita (m^2 /person)	+	0.039
		B6 Forest coverage rate (%)	+	0.144
		B7 Comprehensive utilization of general industrial solid waste (10^4 tons)	+	0.073
	Ecological Response	B8 Centralized treatment rate of sewage treatment plants (%)	+	0.037
		B9 Capacity of industrial waste gas treatment facilities (10^4 $m^{3/h}$)	+	0.275
		B10 Harmless treatment rate of domestic garbage (%)	+	0.075
		B11 Investment in environmental pollution control as a share of GDP (%)	+	0.075
Tourism Industry	Industry Scale	C1 Domestic tourist trips (10^4 person time)	+	0.105

subsystems	Primary Indicators	Secondary Indicators/Unit	Types	Weights
System		C2 Inbound tourism trips (10^4 person time)	+	0.089
		C3 Total tourist trips (10^6 person time)	+	0.104
	Industry Level	C4 Number of A-grade scenic spots (pcs)	+	0.081
		C5 Number of star-rated hotels (pcs)	+	0.092
		C6 Number of travel agencies (pcs)	+	0.069
	Industry Benefits	C7 Total Tourism Income as a Share of GDP (%)	+	0.123
		C8 Domestic Tourism Income (billion yuan)	+	0.123
		C9 Foreign exchange earnings from tourism (million dollars)	+	0.089
		C10 Total Tourism Income (billion dollars)	+	0.123

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3.4.2. ***Data preprocessing*** 194

Because the selected indicators differ in units and magnitude, all raw data were standardized before further analysis. Positive indicators were standardized so that larger original values corresponded to larger standardized values, whereas negative indicators were standardized in the reverse direction. 195 196 197

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$$ For positive indicators: (1)

$$x'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$$ For negative indicators: (2)

In the formulas, x_{ij} denotes the original value of indicator j for observation i, x'_{ij} denotes the standardised value, and $\max(x_j)$ *and* $\min(x_j)$ *denote* the maximum and minimum values of indicator j, respectively. 198 199

After standardization, the entropy method was used to determine indicator weights in order to reduce subjective bias in weight assignment. Let p_{ij} denote the proportion of indicator j in observation i, e_j the entropy value of indicator j, d_j the difference coefficient of indicator j, and w_j the final weight of indicator j. Here, n denotes the number of observations and m denotes the number of indicators. 200 201 202 203

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^{n} x'_{ij}}$$ The proportion of each indicator is calculated as: (3)

$$e_j = -1 \sum_{i=1}^{n} p_{ij} \ln(p_{ij})$$ The entropy value of indicator j is then calculated as: (4)

$$d_j = 1 - e_j$$ The difference coefficient of indicator j is: (5)

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}$$ The final weight of the indicator j is: (6)

where n denotes the number of observations and m denotes the number of indicators. 204

3.4.3. Level of subsystem development 205

After obtaining the standardized data and entropy weights, the development level of each subsystem was calculated as the weighted sum of its indicators. 206 207

$$U_{ik} = \sum_{j=1}^{m_k} w_j x'_{ij}$$ The subsystem development index is expressed as: (7)

In the formula, $U_{\{ik\}}$ denotes the development level of subsystem k for observation i, w denotes the weight of indicator$j$, and $x'_{\{ij\}}$ denotes the standardized value of indicator j for observation i. In this study, $U_{\{i1\}}$, $U_{\{i2\}}$, and 208 209

$U_{\{i3\}}$ represent the development levels of the cultural, ecological, and tourism subsystems, respectively. A larger value of $U_{\{ik\}}$ indicates a higher level of subsystem development.

3.4.4. Coupled Coordination Degree Model (CCDM)

Based on the subsystem development indices, the Coupled Coordination Degree Model was used to measure the degree of interaction and coordinated development among the three subsystems.

$$C = \left[\frac{U_1 U_2 U_3}{\left(\frac{U_1 + U_2 + U_3}{3}\right)^3}\right]^{1/3}$$ The coupling degree is defined as: (8)

$$T = \alpha U_1 + \beta U_2 + \gamma U_3$$ The comprehensive coordination index is: (9)

$$D = \sqrt{C \times T}$$ The coupled coordination degree is calculated as: (10)

In the model, C denotes the coupling degree, T denotes the comprehensive coordination index, and D denotes the coupled coordination degree. The comprehensive coordination index is calculated as $T = \alpha U_1 + \beta U_2 + \gamma U_3$, where U_1, U_2, and U_3denote the development levels of the cultural, ecological, and tourism subsystems, respectively. The coefficients α, β, and γrepresent the contribution weights of the three subsystems. In this study, the three subsystems were assigned equal importance, and therefore $\alpha = \beta = \gamma = 1/3$. Following the classification criteria proposed by Liao, the CCD values were grouped into different coordination stages, as shown in Table 2.

3.4.5. Robustness test of the weighting scheme

To examine whether the evaluation results are sensitive to the choice of weighting method, this study conducted a robustness test by comparing the entropy-weighting scheme with an equal-weighting scheme. Specifically, under the equal-weighting approach, all indicators within each subsystem were assigned identical weights, while the data standardization procedure, subsystem aggregation process, coupling coordination degree model, and barrier degree model remained unchanged. In this way, the influence of the weighting scheme could be isolated without altering the overall analytical framework (Ni et al. 2023).

The consistency between the two weighting schemes was assessed from three aspects: temporal evolution, interprovincial ranking, and coordination-stage classification. First, the annual trajectories of subsystem scores and CCD values were compared to determine whether the overall trend remained stable. Second, the provincial rankings under the two weighting schemes were examined to assess whether the relative spatial pattern changed substantially. Third, the coordination-stage classifications were compared to determine whether the substantive interpretation of the results was altered. In addition, the correlation between the entropy-based CCD results and the equal-weighted CCD results was calculated to provide a quantitative assessment of robustness. If the two sets of results exhibit highly similar temporal trends, comparable provincial rankings, and strong correlation, the main findings can be considered robust to alternative weighting specifications.

Table 2. Criteria for the classification of coordination degree

D range	D classification	Max f(m) - Min f(m)	Type
(0.000~0.099]	Extreme Imbalance	Max f(m) - Min f(m) > 0.5	Extreme Imbalance; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Extreme Imbalance; With synchronous development
(0.100~0.199]	Severe Imbalance	Max f(m) - Min f(m) > 0.5	Severe Imbalance; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Severe Imbalance; With synchronous development
(0.200~0.299]	Moderate Imbalance	Max f(m) - Min f(m) > 0.5	Moderate Imbalance; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Moderate Imbalance; With synchronous development
(0.300~0.399]	Mild Imbalance	Max f(m) - Min f(m) > 0.5	Mild Imbalance; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Mild Imbalance; With synchronous development
(0.400~0.499]	Near Imbalance	Max f(m) - Min f(m) > 0.5	Near Imbalance; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Near Imbalance; With synchronous development
(0.500~0.599]	Forced coordination	Max f(m) - Min f(m) > 0.5	Forced coordination; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Forced coordination; With synchronous development
(0.600~0.699]	Elementary coordination	Max f(m) - Min f(m) > 0.5	Elementary coordination; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	

			Elementary coordination; With synchronous development
(0.700~0.799]	Intermediate coordination	Max f(m) - Min f(m) > 0.5	Intermediate coordination; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Intermediate coordination; With synchronous development
(0.800~0.899]	Good coordination	Max f(m) - Min f(m) > 0.5	Good coordination; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Good coordination; With synchronous development
(0.900~1.000)	Quality coordination	Max f(m) - Min f(m) > 0.5	Quality coordination; Existence subsystem lagging behind
		Max f(m) - Min f(m) ⩽ 0.5	Quality coordination; With synchronous development

3.4.6. Barrier Degree Model

To identify the major factors constraining the coordinated development of the ECT system, this study employed the barrier degree model ((Yin 2017).

$$L_{ij} = \frac{(1 - x'_{ij})w_j}{\sum_{j=1}^{m}(1 - x'_{ij})w_j} \times 100\% \qquad \text{The barrier degree is calculated as:} \qquad (11)$$

In this model, L_{ij} denotes the barrier degree of indicator j for observation i, x'_{ij} denotes the corresponding standardized value, and w_j denotes the indicator weight. A larger value of L_{ij} indicates a stronger constraining effect on the coordinated development of the ECT system.

4. Results

4.1. General dynamics of subsystem development

The developmental trajectories of the three subsystems across the four provinces in the MYRB from 2010 to 2024 are shown in Figures 3 and 4. Overall, all three subsystems exhibited upward trends over the study period, although their growth paths and interprovincial disparities differed markedly. The cultural subsystem improved steadily, with its mean composite index increasing from 0.00964 in 2010 to 0.267 in 2024. The ecological subsystem also showed a general upward trend, but from a relatively low baseline. By contrast, the tourism subsystem displayed greater volatility, with alternating growth and decline during 2010–2015, relative stability during 2015–2019, and an overall upward trajectory across the full study period. After 2019, the COVID-19 pandemic disrupted all subsystems, with the tourism economy experiencing the most pronounced setback. In 2020, many conventional culture-and-tourism projects were suspended, accelerating the reconfiguration of cultural consumption toward online and digital formats, which expanded despite broader economic uncertainty. By contrast, ecological governance in the Yellow River Basin largely maintained policy continuity during the pandemic, resulting in comparatively stable subsystem performance. The tourism market, however, underwent a cliff-like contraction in 2020, followed by a phase of structural adjustment and gradual reopening. Contactless travel formats expanded, self-driving tourism increased, and the tourism economy gradually recovered by 2022. These results indicate that the ECT system improved over time, but the development of the three subsystems remained spatially uneven.

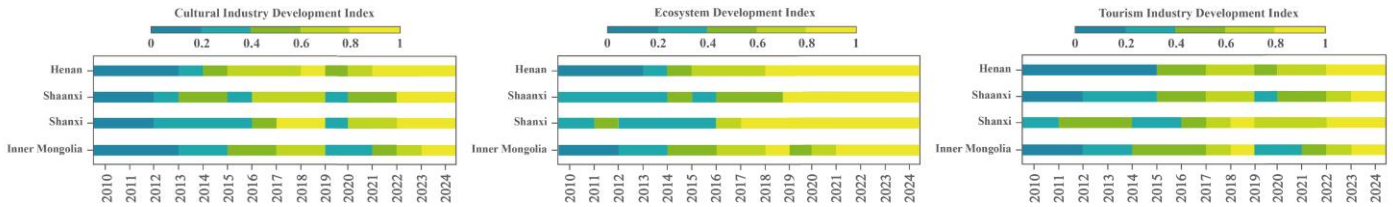


Figure 3. Subsystem industry development level

The mean ecological development index increased from 0.041 in 2010 to 0.275 in 2024, while the associated standard deviation widened from 0.012 to 0.130. This pattern indicates not only an overall improvement in ecological development, but also increasing interprovincial heterogeneity in ecological performance. Spatially, the distribution of high-value areas shifted across the observed time nodes (Figure 3-4). In 2010, the high-value area was concentrated in Shaanxi; by 2013, Shanxi had risen above the four-province average; in 2016, the high-value area shifted to Henan; and by 2019, Shaanxi again occupied a leading position. These shifts are consistent with differences in industrial structure, pollution-control intensity, and the timing of environmental governance initiatives, particularly those targeting air and water pollution in the Fenwei Plain and adjacent basins.

After 2019, the tourism subsystem showed the strongest fluctuation, which is consistent with the disruption of tourism mobility and destination consumption during the COVID-19 period. By contrast, ecological governance

showed greater continuity, and the ecological index continued to improve after 2019. At the same time, the widening standard deviation suggests that ecological gains were not evenly distributed across provinces. These results suggest that the three subsystems responded differently to external shocks, with tourism being more sensitive than ecology and culture. This post-2019 pattern is consistent with the strengthened multi-level policy framework for ecological protection and high-quality development in the Yellow River Basin. At the national level, ecological protection and high-quality development of the Yellow River Basin were elevated as a strategic priority in 2019, followed by the release of the basin-wide planning outline in 2021 and the institutionalization of basin-scale ecological governance through the Yellow River Protection Law, which came into effect in 2023. These policy developments are consistent with the relative stability of ecological governance after 2022, although the present study does not isolate their causal effects.

At the provincial level, Shaanxi's ecological-index improvement is consistent with intensified air-pollution prevention and control efforts and sustained joint governance in key airsheds. More broadly across the MYRB region, national clean-air campaigns—such as *the 2013 Air Pollution Prevention and Control Action Plan* and *the 2018 Three-Year Action Plan for Winning the Blue-Sky Defense Battle*—together with annual heavy-pollution action plans that explicitly cover the Fenwei Plain (including Shanxi, Shaanxi, and Henan), form a continuing policy backbone. The relative stability of ecological governance after 2022 is consistent with the continuation of basin-related and national environmental policy frameworks.

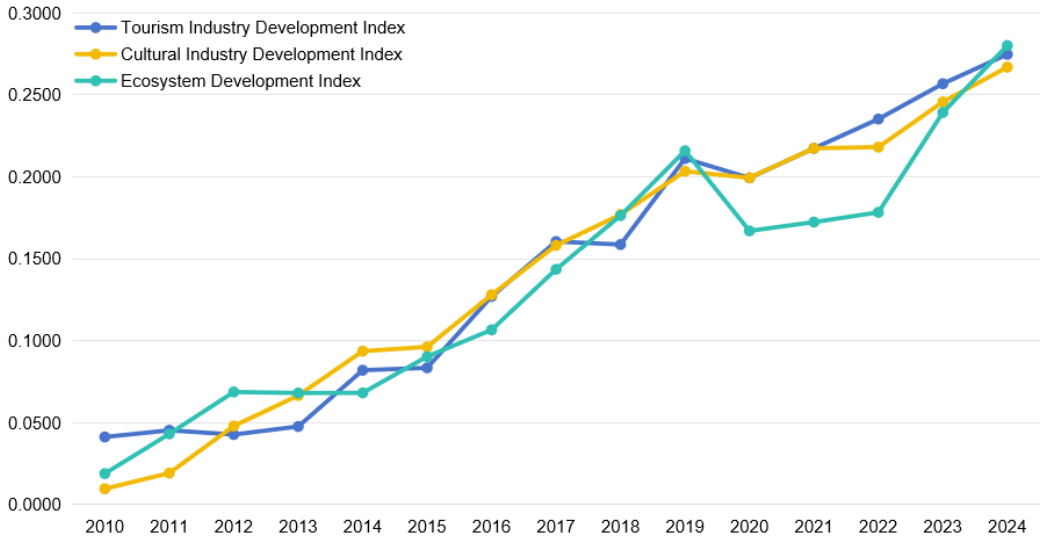


Figure 4. Level of integrated subsystem development

The mean cultural development level index increased steadily from 0.010 (2010) to 0.267 (2024), with standard deviations of 0.014, 0.019, 0.014, 0.022, and 0.035 at the five benchmark years (2010, 2013, 2016, 2019, and 2024), indicating both sustained improvement and a gradual widening of interprovincial differences. Spatially, the cultural subsystem shows a relatively stable pattern with incremental re-ranking across time nodes (Figures 3–4). In 2016, Henan recorded the highest cultural index, while Inner Mongolia ranked lowest. From 2016 onward, the contrast among provinces became more pronounced: Henan and Shanxi tended to remain in the leading tier through 2022, supported by stronger cultural industry value added, higher per-capita cultural and entertainment consumption, and richer supply of cultural venues and events. Henan's relatively strong cultural performance may reflect the interaction between its Central Plains cultural resources, active performing-arts ecosystem, and province-wide efforts to integrate culture, tourism, and creative industries. This pattern is consistent with official policy agendas that have promoted culture–tourism–creative integration and destination branding, including the "Walking Henan, Understanding China" campaign and related initiatives to strengthen cultural-tourism identity, diversify consumption scenarios, and expand project pipelines. Shanxi's comparative advantage appears to be closely associated with its dense heritage base, especially its ancient architectural resources, cultural relics, and intangible cultural assets. Provincial policy packages aimed at high-quality culture-and-tourism development and the broader "culture–tourism+" agenda may have supported the conversion of heritage resources into cultural and tourism competitiveness. Shaanxi exhibited accelerated cultural growth in 2023–2024, a trend consistent with intensified provincial efforts to expand the cultural-tourism industry cluster, improve supporting facilities and markets, and strengthen financing support for cultural-tourism enterprises. This also coincided with broader national efforts to promote culture-and-tourism upgrading and cultural digitalization.

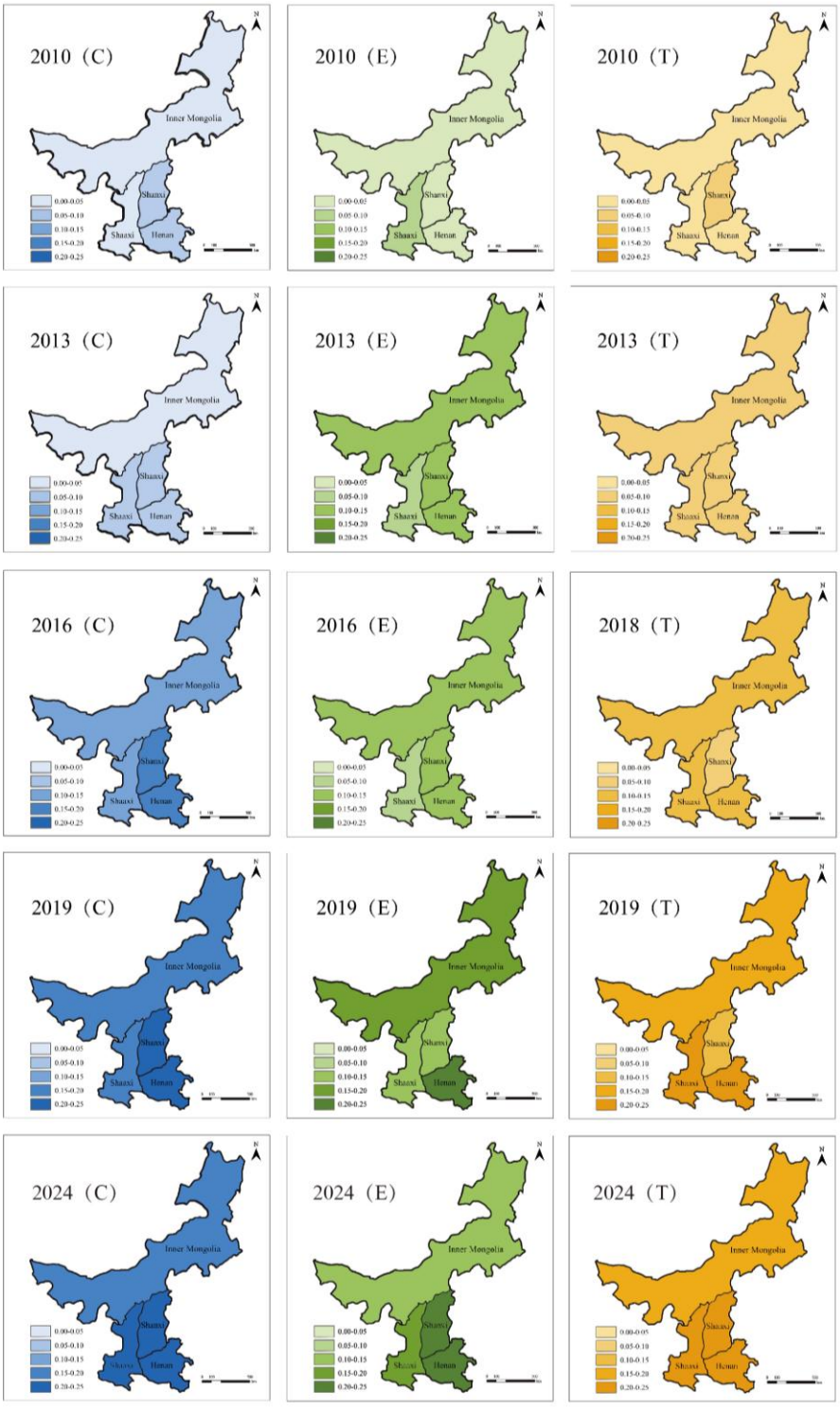


Figure 5. Level of development of the 3 subsystems

Regarding tourism development, the mean values of the Tourism Development Level Index in 2010, 2013, 2016, 2019, and 2024 are 0.019, 0.068, 0.107, 0.216, and 0.280, with corresponding standard deviations of 0.021, 0.011, 0.015, 0.026, and 0.115, respectively. Overall, the tourism subsystem in the MYRB region started from a low baseline and improved steadily over time, but it remained spatially uneven, as evidenced by the widening dispersion after 2016 and especially after 2019. This divergence is consistent with the heterogeneous resource endowments and infrastructure conditions across provinces, as well as differentiated recovery trajectories following the COVID-19 shock. These results indicate that tourism development in the MYRB strengthened over time, but also became more spatially differentiated, especially after 2019. Across the four provincial-level units, Inner Mongolia, Shaanxi, and Henan generally recorded

above-average tourism development levels, whereas Shanxi improved more gradually and only slightly exceeded the four-province average by 2024.

The tourism industry in the Inner Mongolia Autonomous Region experienced robust growth during the period from 2010 to 2015. This pattern is plausibly associated with Inner Mongolia's comparative advantage in large-scale nature- and experience-oriented tourism products (e.g., grassland and desert landscapes and related outdoor/ethnic-cultural offerings), which form a strong and differentiated market appeal. Shaanxi's relatively strong performance is supported by its mature heritage-urban tourism system anchored by Xi'an and world-renowned archeological attractions, which provide stable demand and high visibility in domestic tourism markets. Henan benefits from a dense portfolio of heritage destinations and a large domestic visitor base, but its tourism performance—like Shanxi's—remains more sensitive to infrastructure capacity, product upgrading, and inter-city connectivity. Notably, Shanxi rises slightly above the four-province average by 2024. Beyond structural factors, this uptick may also reflect short-term, culture-driven demand shocks: the release of the AAA video game Black Myth: Wukong (August 2024) was reported to trigger sharp increases in online attention and travel interest for multiple Shanxi heritage sites. This late-period uptick may also reflect short-term culture-driven attention shocks reported in public media.

The degree of disparity in subsystem development across provinces is illustrated in Figs. 5 and 6. Culture showed the highest degree of variance, followed by ecology and tourism. Henan's tourism development level was consistently higher than its ecological and cultural development levels, reflecting its relatively strong tourism market and reception capacity. Shanxi, by contrast, displayed a stronger cultural subsystem than ecological or tourism subsystems, which is consistent with its dense distribution of ancient buildings and cultural relics. Overall, the three subsystems in the MYRB improved during the study period, but their relative strengths differed across provinces. This confirms that ECT development in the MYRB was characterized by shared improvement accompanied by persistent spatial imbalance.

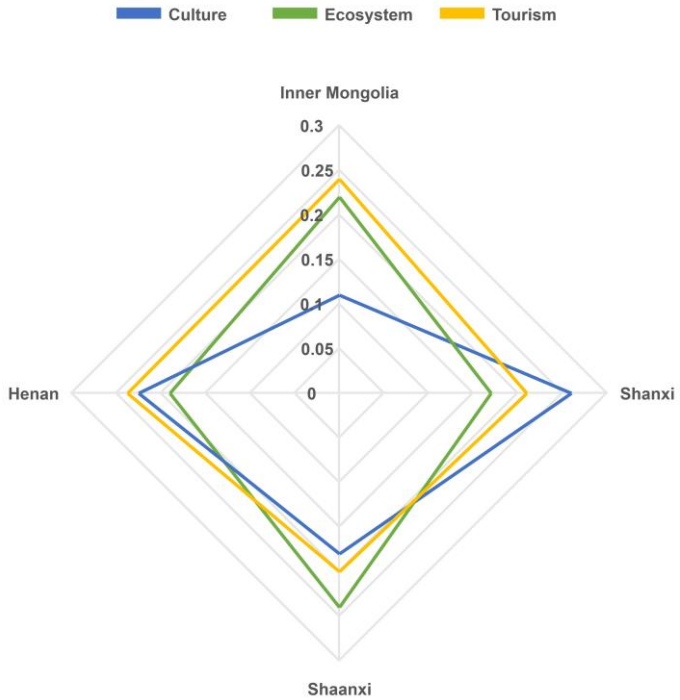


Figure 6. Degree of divergence in the level of development of the three major subsystems

4.2. Coupling coordination degree analysis

Using the indicator data and the formulas presented in the previous section, the annual mean CCD values of the MYRB from 2010 to 2024 were calculated as 0.158, 0.264, 0.411, 0.441, 0.539, 0.588, 0.670, 0.746, 0.781, 0.839, 0.856, 0.872, 0.892, 0.906, and 0.921, respectively. Overall, these values indicate a clear and sustained upward trend in the coupled coordination degree of the eco-culture-tourism system during the study period, as shown in Figure 7. The results suggest that the overall coordination level in the MYRB improved continuously from a low base and gradually moved toward higher levels of integration.

The CCD of each province and region from 2010 to 2024 is depicted in Table 3. To clearly show the trends in spatial distribution and temporal changes in CCD in the four provinces of the MYRB region during the study period, the cultural-ecological-tourism system CCD of each region was mapped using ArcGIS as shown in Figure 8, with varying

levels distinguished by different colors. This visualization allows for the observation of the level differences among the four provinces and regions in the MYRB area over the specified timeframe. From 2010 to 2013, all four provinces remained in states of serious or moderate imbalance, indicating weak coordination among the ecological, cultural, and tourism subsystems in the early stage. In 2014, the coordination level improved noticeably, with most provinces entering the stage of forced coordination or above. By 2016, all four provinces had moved into coordinated states, although the degree of coordination still differed across provinces. After that, the regional average CCD continued to rise, and by 2024 all four provincial-level units had entered either good coordination or quality coordination stages.

The provincial trajectories, however, were not uniform. Inner Mongolia and Henan generally occupied the leading positions in the CCD ranking over much of the study period, while Shanxi and Shaanxi improved more gradually. Inner Mongolia showed the most pronounced long-term improvement, progressing from severe imbalance in 2010 to quality coordination by 2019 and maintaining this position thereafter. Henan also exhibited a strong upward trajectory, reaching intermediate coordination by 2016 and quality coordination after 2020. Shaanxi followed a relatively stable path of improvement, entering good coordination by 2019 and quality coordination by 2023. Shanxi improved more slowly than the other provinces, but still advanced from severe imbalance in 2010 to good coordination by 2023–2024. These results indicate that, although the MYRB experienced an overall increase in CCD, substantial interprovincial differences persisted throughout the process.

From a regional perspective, the evolution of CCD in the MYRB can be characterized by overall upgrading accompanied by uneven provincial trajectories. On the one hand, the continuous rise in the regional mean CCD indicates that the interaction among ecology, culture, and tourism became increasingly coordinated over time. On the other hand, the differences in coordination stages and transition speeds across provinces suggest that the process of integrated development was spatially differentiated rather than uniform. In other words, the MYRB did not follow a single synchronized pathway toward higher coordination; instead, it exhibited a pattern of shared improvement with persistent interprovincial disparity.

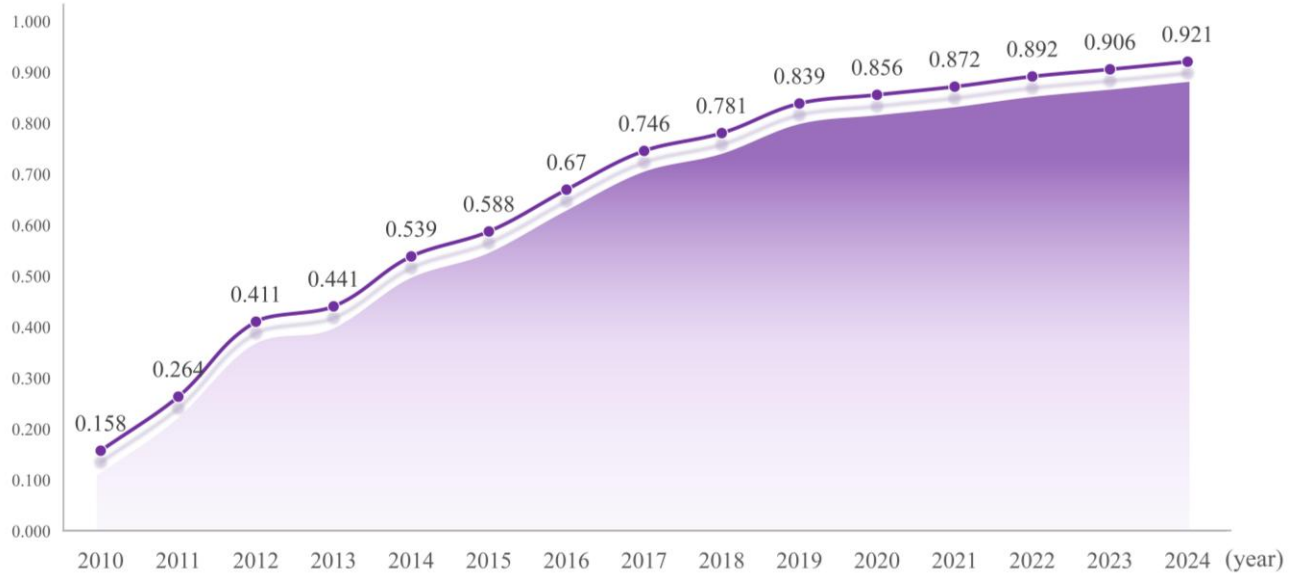


Figure 7. Composite Index of CCD in MYRB region

The post-2020 period reveals stronger policy-driven divergence in CCD trajectories, as provinces leveraged different governance and investment pathways under the national strategy of Yellow River Basin ecological protection and high-quality development. Basin-level coordination was reinforced by the Outline Development Plan (released in 2021, targeting 2030) and later institutionalized by the Yellow River Protection Law (effective April 1, 2023), both of which strengthened cross-sector requirements for ecological restoration, water governance, and spatially differentiated development. Within this framework, IMAR's upward shift is consistent with long-running grassland protection and restoration policies—most notably the grassland ecological conservation subsidy/reward and grazing-ban mechanisms implemented since 2011—together with sustained desertification control in key wind–sand source regions. Shaanxi's improvement aligns with intensified river-basin pollution control and ecological remediation in the Weihe River Basin and, after 2021, an innovation-oriented governance agenda exemplified by the establishment of the Qin Chuang yuan Innovation-driven Platform, which has aimed to accelerate technology transfer and enterprise incubation relevant to green transition. Shanxi's CCD performance reflects the constraints of a coal-dominated industrial structure, yet its

rebound after 2020 is consistent with the province's status as a pilot for comprehensive energy-revolution reforms (designated in 2019) and with emerging practices that repurpose mining subsidence land for renewable-energy deployment and ecological rehabilitation. Henan, in contrast, tends to maintain a more balanced trajectory, plausibly supported by strengthened basin-scale water and ecosystem governance capacities—where "digital" decision-support and centralized regulation in the Yellow River system have been promoted as part of broader modernization efforts—alongside continued pollution-control and ecosystem-management programs under the Yellow River strategy.

Table 3. CCD Index in the MYRB region, 2010-2024

Provinces	Year	*C*	*T*	*D*	Level	Provinces	Year	*C*	*T*	*D*	Level
Inner Mongolia	2010	0.1126	0.1231	0.1178	Severe Imbalance	Shaanxi	2010	0.1765	0.1542	0.1650	Severe Imbalance
	2011	0.1498	0.1461	0.1479	Severe Imbalance		2011	0.4982	0.2095	0.3231	Mild Imbalance
	2012	0.5889	0.2339	0.3711	Mild Imbalance		2012	0.5806	0.2909	0.4110	Near Imbalance
	2013	0.5617	0.2935	0.4061	Near Imbalance		2013	0.6209	0.3592	0.4723	Near Imbalance
	2014	0.7508	0.4761	0.5979	Forced coordination		2014	0.7370	0.4917	0.6020	Elementary coordination
	2015	0.8554	0.5643	0.6947	Elementary coordination		2015	0.6912	0.4981	0.5867	Forced coordination
	2016	0.6706	0.5663	0.6162	Elementary coordination		2016	0.7500	0.6233	0.6837	Elementary coordination
	2017	0.8536	0.7067	0.7767	Intermediate coordination		2017	0.7207	0.6534	0.6862	Elementary coordination
	2018	0.8627	0.7660	0.8129	Good coordination		2018	0.7781	0.7016	0.7389	Intermediate coordination
	2019	0.9576	0.8697	0.9126	Quality coordination		2019	0.9162	0.8090	0.8609	Good coordination
	2020	0.9612	0.8814	0.9203	Quality coordination		2020	0.9245	0.8237	0.8731	Good coordination
	2021	0.9735	0.8921	0.9318	Quality coordination		2021	0.9318	0.8372	0.8839	Good coordination
	2022	0.9817	0.9033	0.9415	Quality coordination		2022	0.9423	0.8516	0.8952	Good coordination
	2023	0.9892	0.9156	0.9514	Quality coordination		2023	0.9537	0.8639	0.9076	Quality coordination
	2024	0.9948	0.9279	0.9603	Quality coordination		2024	0.9624	0.8785	0.9193	Quality coordination
Shanxi	2010	0.2647	0.1227	0.1802	Severe Imbalance	Henan	2010	0.2271	0.1266	0.1695	Severe Imbalance
	2011	0.4322	0.2316	0.3164	Mild Imbalance		2011	0.4169	0.1727	0.2683	Moderate Imbalance
	2012	0.6284	0.3164	0.4459	Near Imbalance		2012	0.6408	0.2722	0.4177	Near Imbalance
	2013	0.6003	0.3394	0.4514	Near Imbalance		2013	0.6166	0.3072	0.4352	Near Imbalance
	2014	0.5254	0.3544	0.4315	Near Imbalance		2014	0.6875	0.4006	0.5248	Forced coordination
	2015	0.5568	0.3629	0.4495	Near Imbalance		2015	0.7788	0.4942	0.6204	Elementary coordination
	2016	0.7714	0.4962	0.6187	Elementary coordination		2016	0.9504	0.6099	0.7613	Intermediate coordination
	2017	0.7765	0.6187	0.6931	Elementary coordination		2017	0.9528	0.7194	0.8279	Good coordination
	2018	0.8254	0.7211	0.7715	Intermediate coordination		2018	0.8546	0.7503	0.8008	Good coordination
	2019	0.6300	0.7367	0.6813	Elementary coordination		2019	0.9283	0.8718	0.8996	Good coordination
	2020	0.6723	0.7584	0.7150	Intermediate coordination		2020	0.9417	0.8892	0.9149	Quality coordination
	2021	0.7149	0.7812	0.7470	Intermediate coordination		2021	0.9534	0.9026	0.9271	Quality coordination
	2022	0.7632	0.8056	0.7825	Intermediate coordination		2022	0.9628	0.9153	0.9385	Quality coordination

2023	0.8097	0.8319	0.8154	Good coordination	2023	0.9719	0.9287	0.9498	Quality coordination
2024	0.8523	0.8594	0.8459	Good coordination	2024	0.9806	0.9412	0.9603	Quality coordination

Overall, the CCD results show a steady improvement in ECT coordination from 2010 to 2024. However, this improvement should be interpreted as index-based upgrading rather than evidence of fully synchronized development, because provincial trajectories and transition speeds remained uneven throughout the study period. Over the decade, Inner Mongolia transitioned from serious dissonance to high-quality coordination, while Henan province achieved good coordination. Similarly, the coupling coordination development level between Shanxi and Shaanxi province strengthened, with both provinces progressing from serious dissonance to intermediate coordination. However, internal competition persists, with Shaanxi province demonstrating higher coupling coordination, eventually reaching good coordination by the latter part of the period. In contrast, Shanxi province slightly lags in transitioning to primary coordination by 2019, primarily due to its abundance of ancient buildings and cultural relics, which enhance its cultural influence. However, environmental governance pressure and underdeveloped public transportation constrain the coordinated development of its ecosystem. The CCD results indicate progressively stronger coordination among the three subsystems over time. This should be interpreted as index-based improvement rather than direct evidence of fully synchronized development. Although the overall level of coordination remained relatively low in the earlier period. This implies a low level of development but close relationships between subsystems, with a slower growth rate and development process.

After 2020, the CCD trajectories appear to have been influenced by both exogenous shocks and policy-led recoupling. The COVID-19 outbreak created an abrupt contraction in the tourism subsystem, which temporarily weakened the synergy between tourism and the other subsystems. However, ecological governance and basin-wide institutional coordination remained comparatively stable and increasingly standardized, which helped prevent a persistent deterioration of system-level coordination. This post-2020 pattern coincides with strengthened national frameworks for the Yellow River Basin, including the Outline for ecological protection and high-quality development through 2030 released in 2021 and the subsequent Yellow River Protection Law, which took effect on April 1, 2023, reinforcing cross-sector requirements for ecological restoration, water governance, and spatially differentiated development. From 2014 to 2024, policies such as the "*Beautiful China"* initiative and *the promotion of high-quality culture – tourism integration*, together with increased environmental investment and rising household incomes, contributed to further improvement in ECT coordination in the MYRB.

Within this policy environment, interprovincial divergence in CCD became more policy sensitive. IMAR's sustained advantage is consistent with long-running grassland conservation and desertification-control instruments, notably the national grassland ecological subsidy-and-incentive scheme introduced in 2011 that has continued to guide grazing pressure management and ecological restoration in key pastoral areas. Henan's relatively synchronized performance can be interpreted considering its persistent culture–tourism integration agenda and destination branding (e.g., the "Walking in Henan, Understanding China" strategy), alongside broader governance modernization efforts that support stable subsystem interactions. Shanxi's post-2020 recovery is plausibly linked to its role as a pilot province for comprehensive energy-revolution reforms (initiated in 2019), which has accelerated energy-structure adjustment and facilitated a greener development pathway relevant to eco–industry coordination.

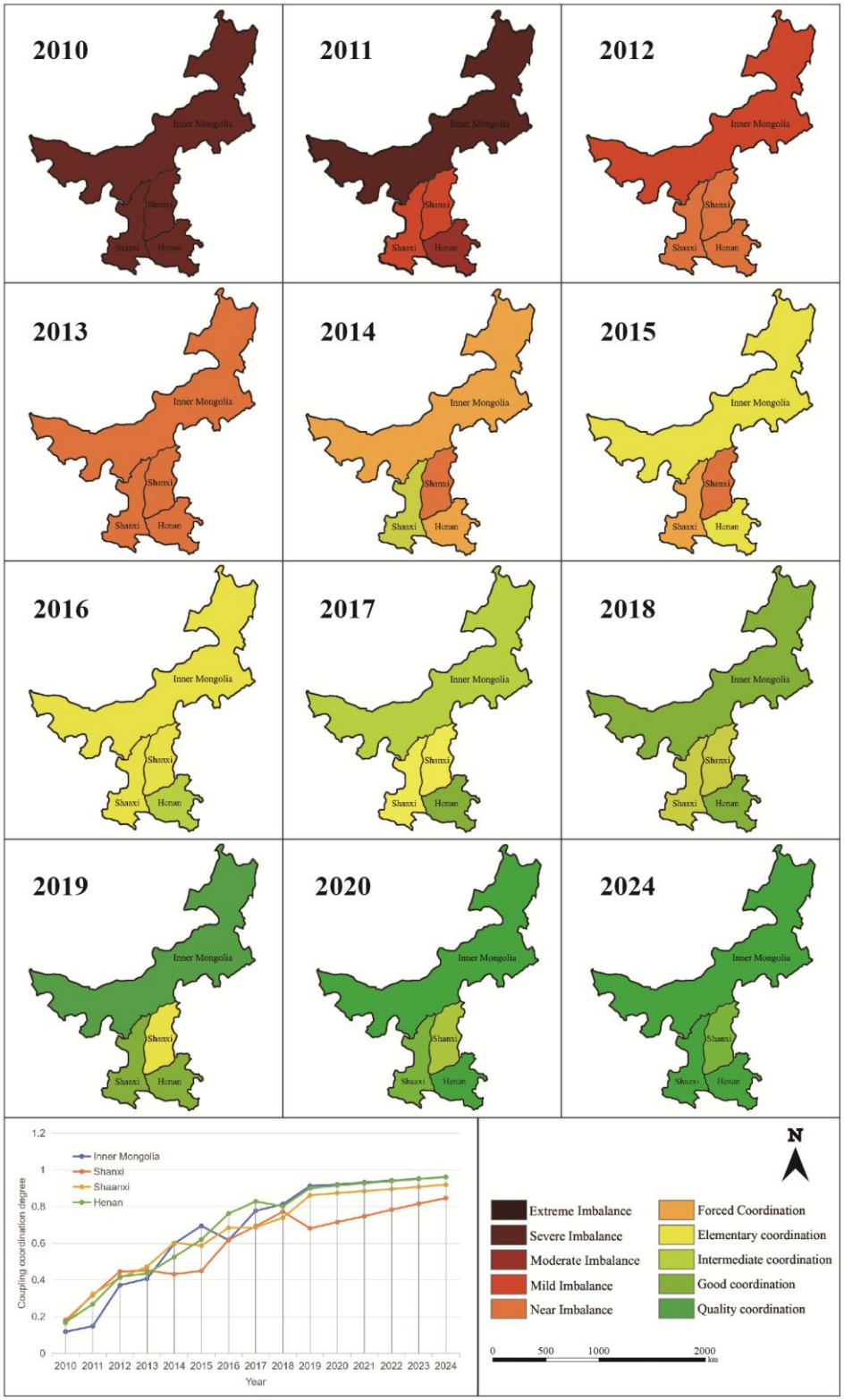


Figure 8. Evolution of spatial patterns of CCD in the MYRB region

By 2024, the four provinces displayed a clearer movement toward higher coordination. However, the persistence of structural constraints, especially infrastructure and governance-capacity differentials, suggests that further improvement is likely to depend on targeted interventions that raise tourism-system resilience while consolidating ecological gains under the basin-scale policy regime. From 2010 to 2024, the three subsystems generally moved toward higher levels of coordination rather than persistent divergence. However, this pattern should be interpreted as an aggregate tendency rather than evidence of fully harmonized development, given the continued interprovincial

disparities observed throughout the study period.

To further assess whether the observed spatiotemporal pattern is sensitive to the weighting specification, a robustness test was conducted by comparing the entropy-weighted results with those derived from an equal-weighting scheme.

4.3. Robustness check

The robustness test confirms that the main findings are not sensitive to the weighting scheme. The entropy-weighted and equal-weighted CCD values are highly consistent, with a Pearson correlation of 0.9995 and a Spearman correlation of 0.9977. In addition, 57 out of 60 province-year observations remain in the same coordination stage, yielding a classification consistency rate of 95.0%. The annual mean CCD values under the two weighting schemes show nearly identical upward trajectories from 2010 to 2024, and the overall provincial ranking remains unchanged. These results indicate that the spatiotemporal evolution pattern reported in this study is robust rather than being driven by a specific weighting method.

Table 4. Robustness test results under alternative weighting schemes

Robustness Check Summary		
Metric	Value	Interpretation
Pearson correlation	0.9995	Very high linear consistency between entropy-weighted and equal-weighted CCD values
Spearman correlation	0.9977	Very high rank-order consistency between the two weighting schemes
Same coordination-stage classifications	57	Out of 60 province-year observations
Classification consistency rate	95.0%	Only three observations crossed a stage threshold
Overall provincial ranking consistency	Consistent	Average provincial ranking is identical under both schemes
Year-by-year exact ranking matches	8	Exact same provincial ordering in 15 annual comparisons
Year-by-year exact ranking rate	53.3%	Remaining differences are limited to adjacent swaps
Mean absolute difference in CCD	0.0080	The average gap between the two CCD series is very small
Maximum absolute difference in CCD	0.0109	Largest pointwise deviation remains limited
Overall judgement	Robust	Main findings are not sensitive to the weighting scheme

5. Analysis of Barrier Factors Affecting CCD

5.1. Selection of barrier factors

Driver analysis is crucial for uncovering the underlying causes of changes in the CCD of the ECT system. The intricate interplay among regional culture, ecology, and tourism underscores that the CCD of the three systems is collectively influenced by a myriad of factors (Jia 2021). In this study, we utilized the barrier degree model to compute the barrier degree of each indicator (A1-C10) listed in Table 1, enabling a systematic analysis of the impact of various driving factors on regional ECT system coupling coordination (Figure 9). Considering the number of secondary indicators, the indicator with the highest average level of barriers was identified as the main barrier factor for focused analysis.

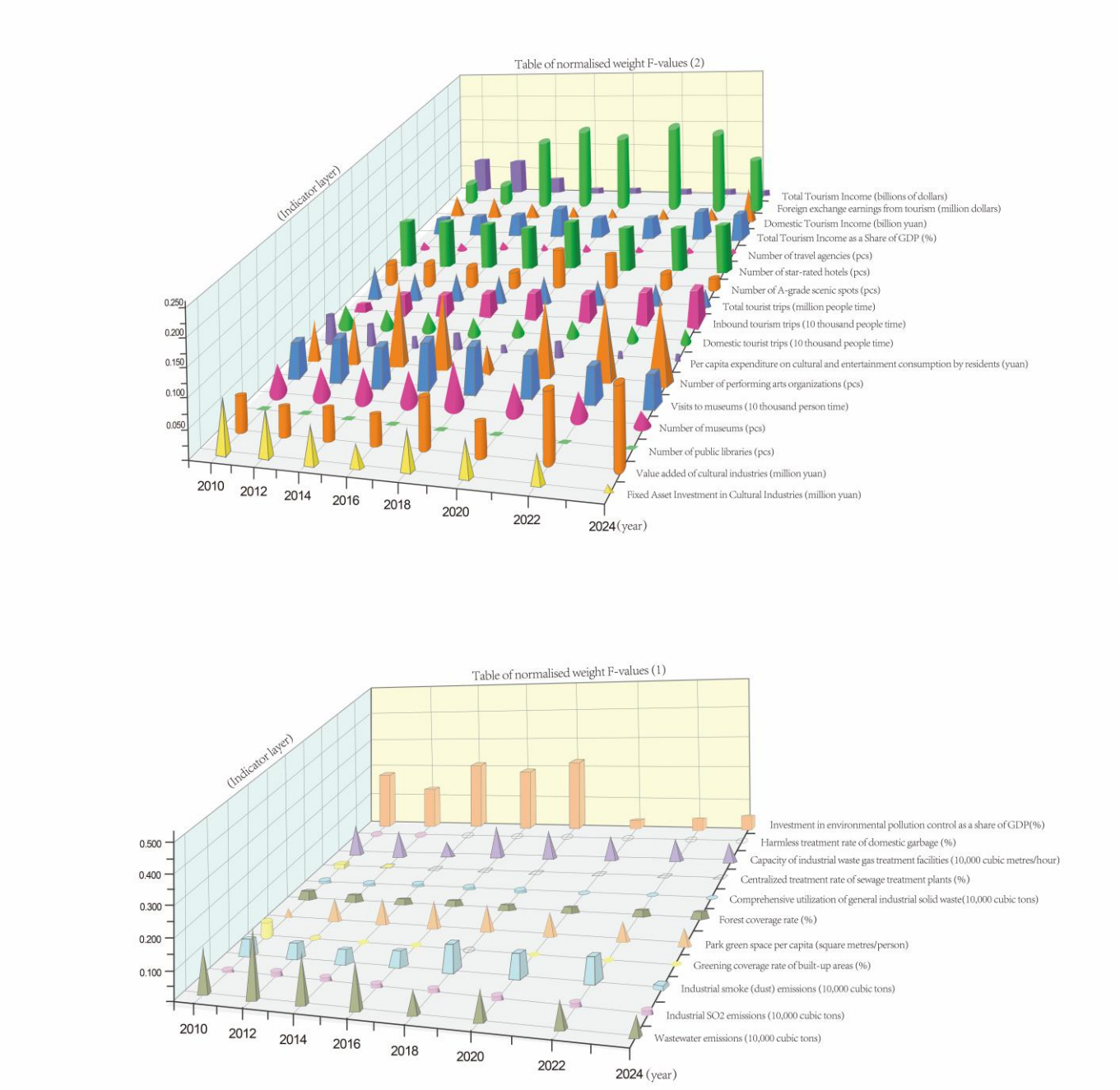


Figure 9. The barrier Factors affecting the CCD in the MYRB region

5.2. Analysis of barrier factors affecting

The barrier analysis identifies the main indicators constraining the coordinated development of the ECT system. Rather than treating these indicators as direct causal drivers, the results should be understood as a diagnostic ranking of limiting conditions within the selected indicator framework. Overall, the major barriers were concentrated in three domains: ecological governance capacity, cultural service provision, and tourism-supporting infrastructure.

The first major barrier factor is forest coverage (B6), which is closely related to ecological quality. Higher forest coverage generally supports biodiversity and enhances the attractiveness of natural landscapes for ecotourism. The second barrier factor is the treatment capacity of industrial exhaust gas treatment facilities (B9), which directly affects the air quality of the surrounding environment and the health of the ecosystem. In Shanxi, the rise of B9 as a barrier

should be interpreted in relation to the province's coal-dependent industrial legacy and the delayed synchronization between pollution-control infrastructure and tourism-supporting transformation. If the treatment capacity is insufficient, the industrial exhaust may pollute the neighboring attractions, cultural heritage, and natural landscapes, thus affecting the experience and attractiveness of ecotourism. The third barrier factor is wastewater discharge (B1), which is also directly related to the quality of water bodies and the health of the surrounding ecosystems, and may affect the sustainable development of ecotourism. The first three barriers belong to the ecosystem, and the fourth barrier is the number of performing arts groups (A6), which reflects the level of cultural activity and the development of the cultural industry in a region, and a rich variety of performing arts activities can enrich the tourists' experience, promote cultural exchanges, and enhance the cultural connotation of ecotourism.

The change from rising to falling of these barrier factors indicates that culture and ecology are important barriers to the coordinated development of cultural and ecological tourism systems. However, as the development speed and level of both culture and ecosystem have increased, their limiting effects have gradually weakened. Culture and ecosystem should be fully emphasized to promote the coupled coordination and sustainable development of ecological and cultural tourism systems. More ecological indicators have become the main influencing factors, especially the ecological index industrial waste gas treatment facilities' treatment capacity of the barrier index, which has increased by 1.46 times in fifteen years. The fifth barrier factor is the investment in environmental pollution control as a proportion of GDP (B11), an indicator that reflects the degree of importance the government attaches to environmental governance. This suggests that stronger environmental investment can improve ecological conditions and thereby support coordinated development across culture, ecology, and tourism. The sixth barrier factor is the number of museum visits (A5). Museums are an important bearer of cultural heritage and an important attraction for tourists, and the increase in the number of visits represents interest and attention to local history and culture. The government should strengthen the management and service level of museums, enrich the exhibits and cultural activities of museums, enhance the attractiveness and influence of museums, attract more tourists to visit, and promote the development of cultural tourism. The ninth barrier factor is the area of public green space per capita under the ecosystem (B5), public green space is an important place for leisure and fitness in the city and an important part of safeguarding the ecological balance of the city. This reflects ecological pressure at the regional level, while insufficient public-service provision also constrains coordinated development. However, the Yellow River ecosystem has been overburdened by supporting the rapid development of the whole basin over the years. Regions also need to increase ecological protection to promote the simultaneous development of the economy and ecology, while environmental improvement will effectively increase the attractiveness of the regional tourism industry, improve comprehensive competitiveness, and help tourism development.

Over the study period, the relative importance of selected ecological and cultural indicators changed noticeably, indicating that the main constraints on ECT coordination were not fixed. In particular, industrial waste-gas treatment capacity and performing arts organizations became more prominent in the later period, suggesting that both ecological governance capacity and cultural-service provision continued to shape interprovincial differences in coordination. The rapid expansion of both underscores the significance of cultural vitality and infrastructure as crucial drivers for achieving high-quality development in a region's tourism industry. They also play a pivotal role in promoting sustainable development within local tourism. The eighth barrier factor is the number of star-rated hotels (C5), and the number and quality of star-rated hotels are directly related to the reception capacity and service level of tourism destinations. Tourist comfort and satisfaction are enhanced by high-quality hotel resources, thereby facilitating greater participation in tourism activities and indicating that continuous infrastructure improvements provide a sustained impetus for tourism development. Multiple industries are involved in infrastructure development, and the healthy, orderly growth of tourism is promoted by the comprehensive advancement of each sector. At the same time, the visitor experience at destinations is enhanced by improvements in urban infrastructure, which directly influence tourism development. In recent years, the increasing attractiveness of China's inbound tourism has been accompanied by rising international tourism revenue; coupled with policy promotion of dual domestic and international circulation, significant growth has been observed in the domestic tourism sector. The interconnected and coordinated advancement of the cultural ecotourism system is underpinned by contributions from both international and domestic tourism revenues. Therefore, the coordinated development of the ECT system can be strengthened when the cultural, ecological, and tourism subsystems are advanced in a mutually coordinated manner. Taken together, the barrier analysis indicates that ecological governance capacity, cultural service provision, and tourism-supporting infrastructure remained unevenly distributed across provinces and continued to constrain balanced ECT coordination.

6. Discussion

This study shows that the coordination of the ECT system in the MYRB improved substantially from 2010 to 2024, but the process was not synchronized across provinces. Although the regional mean CCD rose steadily, the four provincial-level units did not follow a uniform transition pathway. This finding suggests that coordinated development in the MYRB should not be interpreted simply as a continuous upward trend, but rather as a differentiated transition process shaped by uneven ecological burdens, cultural conversion capacity, and tourism-supporting conditions. In this respect, the MYRB case adds to the literature by demonstrating that basin-wide policy alignment does not automatically produce spatially balanced coordination outcomes.

A key implication of the results is that the improvement of average coordination can coexist with persistent structural unevenness. On the one hand, the long-term rise in CCD indicates that ecological governance, cultural development, and tourism growth became increasingly interconnected across the basin. On the other hand, the persistence of provincial disparities suggests that coordination remained conditioned by historically accumulated differences in industrial structure, ecological restoration pressure, public service capacity, and infrastructure endowment. Therefore, the MYRB does not represent a case of fully synchronized regional upgrading. Rather, it illustrates how a shared policy framework can generate common directional improvement while still accommodating multiple and unequal provincial transition logics. This finding is consistent with previous Yellow River Basin studies that reported an overall upward trend in coordination, but it extends them by showing that average improvement coexisted with persistent interprovincial divergence.

From a provincial perspective, Shanxi appears to represent a transition pathway constrained by the heavy legacy of resource-dependent industrial development. Compared with the other provinces, its slower improvement in coordination is likely related to the combined pressure of ecological remediation, industrial restructuring, and the relatively slower upgrading of tourism-supporting facilities. In this sense, Shanxi's trajectory reflects not simply weaker tourism growth, but a more complex transition burden in which environmental governance and industrial transformation compete for policy attention and investment resources (B. Wang et al. 2024).

Inner Mongolia, by contrast, appears to follow a pathway in which ecological governance plays a particularly central role in shaping long-term coordination. The province's vast ecological space, fragile landscapes, and governance demand associated with grassland and environmental protection make the balance between conservation and tourism expansion especially delicate. Its improvement in CCD suggests that sustained ecological management can support coordinated development over time, but also indicates that such coordination remains strongly dependent on whether tourism growth can be aligned with ecological carrying capacity rather than pursued through simple expansion.

Shaanxi presents a somewhat different pattern, one that is more closely associated with the interaction between cultural resources, ecological remediation, and tourism quality upgrading. As a province with a relatively strong cultural and heritage base, Shaanxi's development pathway suggests that cultural assets can contribute positively to system coordination when they are effectively linked with environmental improvement and service enhancement. However, the results also imply that cultural endowment alone is insufficient; without corresponding ecological support and tourism service capacity, cultural advantages cannot automatically translate into balanced ECT coordination.

Henan shows the clearest evidence of the benefits and limits of a relatively strong tourism base. Its stronger tourism development helped accelerate overall coordination, yet the results also suggest that tourism expansion did not always proceed in full synchrony with ecological and cultural development. In other words, Henan's pathway demonstrates that tourism strength can raise the level of coordination, but that long-term balance still depends on whether ecological governance and cultural vitality keep pace with tourism-led expansion.

The emergence of water-use intensity and afforestation-related indicators as important ecological constraints further suggests that coordinated transition in the MYRB depends not only on pollution control, but also on whether provinces can improve resource-use efficiency while sustaining long-term ecological restoration(Guan et al. 2025). This is particularly relevant in the basin context, where water scarcity, ecological fragility, and uneven restoration burdens remain structurally significant.

The barrier analysis suggests that museum visitation, performing-arts capacity, and hotel infrastructure remained important limiting conditions in several provinces. These patterns point to uneven cultural service capacity and tourism-supporting provision rather than to a single dominant bottleneck across the whole region. Taken together, these provincial differences indicate that the main barriers identified in this study should not be treated as isolated technical indicators. They reflect deeper regional development logics. Ecological constraints point to uneven restoration pressure and environmental governance capacity; cultural barriers reflect differences in the ability to convert symbolic and institutional resources into stable public participation and destination value; and tourism-supporting barriers reveal persistent mismatches between resource endowment and reception capacity (Ma and Yang 2024). This interpretation

helps move the analysis beyond descriptive barrier ranking toward a more governance-oriented understanding of why coordinated transition remains uneven in the MYRB. Unlike earlier studies that focused on trend description, the present analysis links spatial differentiation to structural barriers associated with ecological governance, cultural conversion capacity, and tourism-supporting infrastructure.

Another important implication concerns the role of culture in regional sustainability. In many coupling studies, culture is treated mainly as an economic input for tourism or as a static background resource. The MYRB case suggests a broader interpretation. Here, cultural vitality appears to function not only as a source of attraction, but also as a coordinating resource that strengthens place identity, supports local legitimacy for transformation, and helps connect ecological protection with development-oriented strategies ((Han et al. 2023). This finding reinforces the idea that ECT coordination is not merely a technical matter of balancing subsystem indices, but also a territorial process in which symbolic, environmental, and infrastructural capacities interact.

The MYRB should be understood as a differentiated governance space rather than a uniformly evolving region. The rise in coordination is real, but it does not eliminate the need for province-specific policy design. Future governance should therefore move beyond generalized integration rhetoric and focus instead on how ecological restoration, cultural revitalization, and tourism-supporting investment can be aligned with the distinct structural conditions of each province.

7. Conclusions and recommendations

7.1. Conclusions

This study examined the spatiotemporal evolution and structural constraints of ECT coordination in the MYRB from 2010 to 2024. Based on the Coupling Coordination Degree Model and the barrier degree model, three main conclusions can be drawn.

The overall coordination level of the ECT system in the MYRB improved significantly during the study period. The regional mean CCD increased steadily from a state of severe imbalance to high-level coordination, indicating that the interaction among ecology, culture, and tourism became increasingly integrated over time. However, this improvement did not occur in a fully synchronized manner. The four provincial-level units followed differentiated trajectories, and interprovincial disparities remained evident throughout the process.

The three subsystems developed unevenly. The cultural subsystem and the ecological subsystem both showed sustained improvement, while tourism displayed stronger volatility and greater sensitivity to external shocks. Although all three subsystems improved over time, their relative strengths differed across provinces. This confirms that ECT coordination in the MYRB should be understood not as a uniform upgrading process, but as a spatially differentiated transition shaped by uneven development conditions.

The main barriers to ECT coordination were concentrated in ecological governance and tourism-supporting infrastructure. Indicators such as forest coverage, wastewater discharge, industrial waste-gas treatment capacity, forest coverage, wastewater discharge, industrial waste-gas treatment capacity, public green-space provision, performing arts organizations, museum visits, and hotel infrastructure, performing arts organizations, museum visits, and hotel infrastructure emerged as important constraints. These findings suggest that coordinated development in the MYRB is still limited not only by ecological pressure, but also by uneven environmental restoration capacity, insufficient tourism-supporting facilities, and differentiated cultural vitality across provinces.

Overall, the MYRB has made substantial progress in improving ECT coordination, but the region has not yet entered a uniformly balanced stage of development. The findings suggest that further improvement is likely to depend less on generalized integration rhetoric and more on differentiated governance strategies adapted to province-specific ecological, cultural, and infrastructural conditions.

7.2. Recommendations

Based on the empirical findings, this study offers several policy implications for improving ECT coordination in the MYRB. These implications should be understood as planning-oriented suggestions derived from coordination diagnostics rather than as causal prescriptions.

(1) Ecological governance should be differentiated across provinces.

Ecological governance remained a central constraint on coordinated development in the MYRB. The findings suggest the need for more differentiated ecological restoration and environmental management strategies according to local resource conditions and environmental pressures. In areas with stronger ecological fragility, policy attention should focus on soil erosion control, pollution reduction, afforestation and vegetation restoration, water-use efficiency, and ecological carrying capacity. At the basin scale, cross-provincial coordination mechanisms should be

strengthened to reduce fragmentation in environmental management and consolidate the ecological foundation of cultural and tourism development.

(2) Tourism-supporting infrastructure and public service capacity require targeted upgrading.

The results indicate that tourism-supporting infrastructure remained one of the main bottlenecks in several provinces. Future planning should therefore move beyond the simple expansion of tourism demand and pay greater attention to the quality, accessibility, and spatial allocation of tourism-supporting facilities. Priority areas include transport connectivity, accommodation capacity, scenic-area services, public information systems, and visitor reception facilities. Infrastructure investment should also be better aligned with the distribution of ecological and cultural resources, so as to reduce mismatches between tourism growth and service provision.

(3) Cultural vitality should be strengthened as a coordinating resource.

Culture should not be treated merely as a tourism attraction, but as a key coordinating dimension in regional sustainable development. The findings suggest that museums, performing arts organizations, public cultural services, and heritage-based cultural industries can help connect ecological protection with tourism development when they are supported by effective public participation and place-based branding. Provinces in the MYRB should therefore strengthen the conversion of cultural resources into stable development capacity through improved accessibility, cultural programming, public engagement, and cultural-tourism integration. This is particularly important in provinces where rich heritage resources have not yet been fully translated into coordinated development capacity.

(4) Promote province-specific rather than uniform regional policy design.

Given the persistent interprovincial disparities identified in this study, policy intervention in the MYRB should be province-sensitive rather than uniform. Inner Mongolia should focus on balancing ecological protection with the sustainable development of nature- and experience-oriented tourism. Shanxi should give greater attention to tourism-supporting infrastructure, ecological remediation, and the transition pressure associated with its resource-dependent industrial structure. Shaanxi should further strengthen the integration of ecological restoration, heritage resources, and high-quality tourism services. Henan should consolidate its relatively strong tourism base while improving the synchronization of tourism growth with ecological governance and cultural vitality. In short, differentiated planning is essential for improving the long-term coordination of the ECT system across the MYR.

7.3. Limitations and future research

This study has several limitations. First, although the indicator system was designed to capture the coordinated development of ecology, culture, and tourism in the MYRB, some region-specific dimensions could not be fully incorporated because of data availability and interprovincial comparability constraints. In particular, certain ecological pressures and cultural characteristics unique to the Yellow River Basin may not be completely reflected by the selected statistical indicators. Although interpolation was restricted to isolated observations after source triangulation, future research would benefit from a fully archived indicator-level dataset to provide a more explicit audit trail for data continuity.

This study relies on panel data at the provincial level, which is suitable for examining broad spatial differentiation and long-term temporal evolution, but less effective for capturing finer intra-provincial variation. Considerable heterogeneity may still exist among cities, counties, or specific cultural and tourism destinations within the same province. Therefore, the provincial scale used here is more appropriate for identifying macro-level coordination patterns than for explaining micro-level local differences.

Although the CCD model and barrier degree model are useful for revealing development trends and structural constraints, they remain essentially descriptive tools. They can identify the relative level of coordination and the main barrier factors, but they cannot by themselves establish causal relationships among policy intervention, subsystem interaction, and coordinated development outcomes. The findings should therefore be interpreted as pattern-based and diagnosis-oriented rather than strictly causal.

Future research can be extended in three directions. First, more refined spatial units, such as prefecture-level cities, county-level areas, or representative heritage and tourism destinations, could be incorporated to examine multi-scalar differences within the MYRB. Second, coupling coordination analysis could be combined with causal inference, spatial econometric methods, or comparative case studies to better explain how ecological governance, cultural vitality, and tourism infrastructure interact (Li et al. 2024). Third, future studies could incorporate more direct indicators of cultural participation, visitor mobility, public-service accessibility, and ecological restoration outcomes to provide a more detailed and policy-relevant understanding of sustainable regional transformation.

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Author contributions

These authors jointly supervised this work.

Competing interests

The authors declare no competing interests.

Ethics statement

This study used aggregated secondary data compiled from publicly available statistical yearbooks, official bulletins, and government sources. It did not involve human participants, identifiable personal data, animals, clinical materials, or field intervention. Therefore, ethics approval and informed consent were not required.

Data statement

The datasets supporting the findings of this study, including the compiled provincial-year indicator dataset, cleaned analytical dataset, interpolation records, and calculation files for entropy weighting, subsystem indices, coupling coordination degree, robustness testing, and barrier-degree analysis, are provided as supplementary materials for peer review. Further information is available from the corresponding author upon reasonable request.

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