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Spatiotemporal Evolution of the Coupling Coordination between Tourism Development and the Ecological Environment in Gansu Province, China

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Abstract: The coordination between tourism development and the ecological environment, together with its spatiotemporal differences, is of considerable practical significance for the high-quality development of tourism in ecologically fragile regions. Based on panel data for 14 prefecture-level cities and autonomous prefectures in Gansu Province from 2010 to 2019, this study constructed an evaluation indicator system for the coupling coordination between tourism development and the ecological environment and applied a coupling coordination model to measure and analyze its spatiotemporal evolution. The results indicate that: (1) tourism development in Gansu Province fluctuated overall during 2010-2019, with differentiated trajectories across prefecture-level units due to variations in the quality of tourism resources, tourism market size, and levels of economic development. The composite level of the ecological environment improved gradually, although regional disparities remained evident. (2) Most prefecture-level units remained in a state of moderate or mild imbalance throughout the study period, and the overall improvement in coupling coordination was limited. Jiuquan exhibited a relatively high level of coordination and reached the barely coordinated stage in both 2015 and 2019. (3) Spatially, the coupling coordination degree was generally higher in western Gansu and lower in the east, and this spatial pattern remained relatively stable during the study period. The findings suggest that the coordinated development of tourism development and the ecological environment in Gansu Province still requires more effective synergy among resource carrying-capacity constraints, ecological conservation investment, and regionally differentiated development strategies.

Keywords: Tourism Development; Ecological Environment; Coupling Coordination Degree; Spatiotemporal Evolution; Gansu Province.

1. Introduction

Tourism development is grounded in natural landscapes, cultural heritage, ecological spaces, and transport-service systems. Its expansion may stimulate regional economic growth, employment, and public-service improvement, but it may also place pressure on the ecological environment through visitor concentration, facility construction, and resource consumption. The ecological environment is an important foundation for tourism attractiveness and the sustainable development of destinations; changes in its quality can in turn affect tourism-resource value, visitor experience, and the direction of industrial transformation [1-2]. For Northwest China, where ecosystems are relatively fragile and regional development disparities are pronounced, tourism development and the ecological environment may form a coordinated relationship, but trade-offs in resource consumption and ecological security may also arise [3]. A more robust coordination mechanism between tourism development and ecological conservation is therefore needed.

International research paid early attention to the impacts of tourism activities on ecological elements such as soil, vegetation, landforms, water bodies, and wildlife habitats, and gradually extended to themes such as ecotourism, ecological footprints, and sustainable tourism [4-5]. Rather than treating tourism activities simply as positive or negative factors, these studies emphasized the complex relationships among tourism benefits, resource conservation, community participation, and climate and environmental risks [6-7]. In recent years, quantitative evaluation of the relationship between the tourism economy and the ecological environment has further expanded to ecosystem service value, all-for-one tourism and ecological civilization, high-quality development in ecologically fragile areas, and tourism ecological security [8-10], providing new analytical frameworks for identifying coordination, trade-offs, and stage-specific mismatches between tourism development and the ecological environment.

Domestic research has mainly examined interactions among the tourism industry, regional economy, ecological civilization, and ecological environment quality. The research scale has gradually expanded from typical tourism cities to national, provincial, urban-agglomeration, and economic-belt units, and commonly used methods include composite evaluation, coupling coordination degree models, spatial autocorrelation, obstacle-degree diagnosis, and spatial econometric analysis [11-14]. Recent studies have further introduced perspectives such as urban ecological resilience, spatial networks, tourism development intensity, and ecosystem functions [15-17]. The synergistic relationship among the cultural industry, tourism industry, and ecological environment in the Yellow River Basin has also received increasing attention [18]. In addition, studies of typical tourism cities, urban agglomerations, Beautiful China construction, and spatial differences in the tourism economy provide supplementary evidence for understanding regional differences in the relationship between tourism development and the ecological environment [19-22].

Northwest China has diverse tourism resources. Silk Road cultural heritage, desert and Gobi landscapes, oasis cities,

mountain grasslands, and ethnic cultures together form important tourism attractions, but water-resource constraints, ecological-restoration pressure, and differences in regional development foundations are also prominent. Existing studies have examined the sustainable development of tourism in ecologically fragile areas such as Gannan, as well as the coupling relationships among tourism, the economy, and the ecological environment in the five northwestern provinces and regions, Western China, the Silk Road Economic Belt, and arid areas of Xinjiang [23-26]. These studies provide a basis for understanding the relationship between tourism development and the ecological environment in ecologically fragile areas, but further discussion is still needed on long-term changes, spatial differentiation, and subsystem development rhythms at the prefecture-level scale within Gansu Province.

Overall, existing research has provided a relatively mature methodological basis for measuring the coordinated relationship between tourism development and the ecological environment, but several issues can still be extended. First, many studies focus on national, provincial, urban-agglomeration, or typical tourism-city scales, and continuous examination of differences among prefecture-level units within Gansu Province can be deepened. Second, some studies emphasize composite-index and coordination-degree calculations, while discussion of differences in the evolutionary rhythms of the tourism development system and the ecological environment system and their regional contexts remains insufficient [14]. Third, development foundations, resource endowments, and environmental constraints in ecologically fragile areas of Northwest China show clear regional heterogeneity [26]. On this basis, this study takes the 14 prefecture-level administrative units of Gansu Province as its research objects, selects panel data for 2010-2019, constructs evaluation indicator systems for the tourism development system and ecological environment system, applies the entropy weighting method to determine indicator weights, and uses composite evaluation and coupling coordination degree models to measure their coordination status, with the aim of providing a reference for the coordinated advancement of tourism development and ecological conservation in ecologically fragile areas.

2. Study Area, Data, and Methods

2.1. Study Area

Gansu Province is located in inland Northwest China, where the Loess Plateau, Qinghai-Tibet Plateau, and Inner Mongolian Plateau intersect (Fig 1). Its long, narrow territory contains mountains, river valleys, oases, deserts, and grasslands, creating marked regional differences in ecosystems, water resources, transport conditions, urban development, and industrial foundations. These differences make ecological carrying capacity and restoration pressure important constraints on regional development.

The province contains 14 prefecture-level administrative units and diverse tourism resources, including Silk Road heritage, grotto temples, Danxia landforms, desert landscapes, wetlands, and ethnic cultures. Western areas such as Jiuquan, Zhangye, and Jiayuguan have recognizable tourism brands, whereas some central and eastern units rely more on urban services and historical-cultural resources. Because many attractions are located in ecologically sensitive areas, tourism development must be coordinated with ecological conservation at the prefecture-level scale.

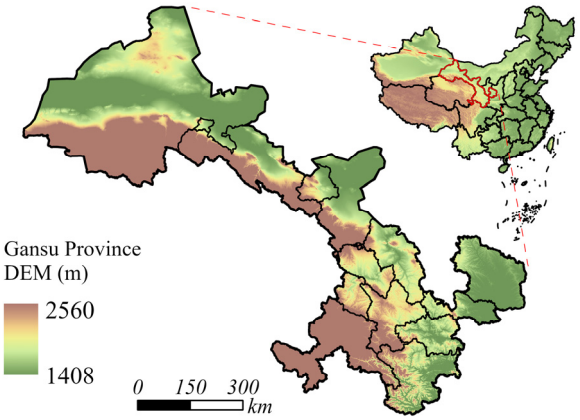

Fig 1. Study area

2.2. Data Sources

The study period was 2010-2019, and the research units were the 14 prefecture-level units of Gansu Province. Data for indicators related to the tourism development system and the ecological environment system were mainly obtained from the Gansu Statistical Yearbook, statistical bulletins on national economic and social development issued by each prefecture-level unit, environmental statistical bulletins, and other publicly available statistical sources. Given differences in statistical calibers at the prefecture-level scale, indicator names, years, and administrative units were standardized during raw-data compilation, and some missing values were interpolated using a moving-average method. The treatment of missing values was used only to maintain panel-data continuity and did not change the original major data, weights, or conclusions.

2.3. Evaluation Indicator System and Weighting Method

Tourism development and the ecological environment are both composed of multiple elements, and the two systems are mutually dependent and mutually constrained. Following the principles of scientific validity, operability, systematic representation, and data availability, an evaluation indicator system was constructed for the tourism development and ecological environment subsystems. The tourism development system comprised dimensions such as tourism resource abundance, current tourism development, tourism scale, and economic development level, focusing on the tourism-resource base, tourism reception facilities, tourism market size, and regional economic support capacity. Indicator selection mainly referred to studies on tourism resource development, the tourism economy, and tourism-ecological environment coupling evaluation [21]. The ecological environment system was constructed based on the pressure-state-response (PSR) framework [27-29]. The pressure layer reflects the impacts of human production and living activities on the ecological environment, the state layer reflects the basic status of the urban ecological environment, and the response layer reflects environmental governance and ecological-conservation investment. The evaluation indicator system is shown in Table 1. Because the indicators differ in measurement units and directions, this study used min-max normalization to make the raw data dimensionless. For positive indicators, a larger value indicates a higher system development level; for negative indicators, a larger value

indicates greater ecological-environmental pressure. After normalization, all indicator values were converted into comparable dimensionless values.

For weight determination, this study used the objective entropy weighting method to determine indicator weights. This method includes the calculation of indicator proportions, information entropy, divergence coefficients, and weights. The entropy weighting method determines weights according to the degree of dispersion of indicators; the greater the dispersion, the stronger the indicator's discriminatory contribution to the composite evaluation results. The calculation procedure is as follows.

The indicator weights of the tourism development system and the ecological environment system were calculated using the above formulas, and the results are shown in Table 1. Overall, in the tourism development system, the share of 5A-rated tourist attractions, share of total GDP, share of per capita GDP, and share of tourism revenue had relatively high weights. In the ecological environment system, indicators such as the number of nature reserves and park green space per capita had relatively high weights, indicating that these indicators had strong discriminatory power for the composite evaluation results during the sample period.

Table 1. Indicator weights of the tourism development system and ecological environment system in Gansu Province.

Subsystem	Criterion	Indicator	Direction	Weight
Tourism development	Tourism resource abundance	Share of museums in the provincial total (%)	+	0.0289
	Current tourism development	Share of 3A-rated tourist attractions in the provincial total (%)	+	0.0572
		Share of 4A-rated tourist attractions in the provincial total (%)	+	0.0445
		Share of 5A-rated tourist attractions in the provincial total (%)	+	0.3293
		Share of hotels rated three stars or above in the provincial total (%)	+	0.0663
	Tourism scale	Tourism revenue as a share of the provincial total (%)	+	0.0990
		Tourist arrivals as a share of the provincial total (%)	+	0.0648
	Economic development level	Per capita GDP as a share of the provincial per capita GDP total (%)	+	0.1176
		Total GDP as a share of the provincial GDP total (%)	+	0.1192
		Urbanization rate (%)	+	0.0731
Ecological environment	Pressure	Industrial waste gas emissions per capita (t)	-	0.0281
		Industrial wastewater discharge per capita (t)	-	0.0222
		Daily water consumption per capita (m3)	-	0.0569
	State	Park green space per capita (m2)	+	0.2876
		Green coverage rate in built-up areas (%)	+	0.0942
	Response	Harmless treatment rate of domestic waste (%)	+	0.0621
		Comprehensive utilization rate of general industrial solid waste (%)	+	0.1030
		Number of nature reserves	+	0.3458

The indicator normalization formulas are as follows:

$$\mu_{ij} = \begin{cases} (X_{ij} - \beta_{ij})/(\alpha_{ij} - \beta_{ij}) & (X_{ij}\text{is a positive indicator}) \\ (\alpha_{ij} - X_{ij})/(\alpha_{ij} - \beta_{ij}) & (X_{ij}\text{is a negative indicator}) \end{cases} \quad (1)$$

where X_{ij} is the original indicator; μ_{ij} is the normalized value of the original indicator; and, following common practice in previous studies, α_{ij} and β_{ij} denote the upper and lower critical values of each sequence in the system under a stable state, generally represented by the minimum and maximum values during the study period.

The proportion P_{ij} of indicator i in year j was calculated as follows:

$$P_{ij} = \frac{\mu_{ij}}{\sum_{j=1}^{n} \mu_{ij}} \quad (2)$$

The information entropy E_i of indicator i was calculated as follows:

$$E_i = -K \sum_{j=1}^{m} P_{ij} * ln(P_{ij}) \quad (3)$$

where $K = 1/ln\ (m)$, m is the number of study years, and E_i is within [0, 1].

The divergence coefficient g_i of indicator i was calculated as follows:

$$g_i = 1 - E_i \quad (4)$$

The indicator weight W_i was calculated as follows:

$$W_i = g_i / \sum_{i=1}^{n} g_i \quad (5)$$

2.4. Composite Evaluation and Coupling Coordination Model

After indicator normalization and weight determination, this study calculated the composite evaluation indices of the tourism development system and the ecological environment system separately. The composite evaluation index reflects the relative status of the tourism development level and the composite ecological environment level of each prefecture-level unit in a given year.

$$\mu_1 = \sum_{j=1}^{n} a_i \mu_{ij},\ \mu_2 = \sum_{j=1}^{n} b_i \lambda_{ij} \quad (6)$$

where a_i and b_i are the corresponding weights of indicators in the tourism development system and ecological environment system, respectively, and μ_{ij} and λ_{ij} are the normalized values of indicators in the two systems.

The coupling degree model was used to describe the interaction degree between the tourism development system and the ecological environment system.

$$C = 2\sqrt{\mu_1 \times \mu_2}/(\mu_1 + \mu_2) \quad (7)$$

where C is the coupling degree and $0 \leq C \leq 1$. When $C = 0$, the two systems have no coupling relationship; when $C = 1$, their coupling relationship is the closest, and the closer C is to 1, the better the coupling relationship. μ_1 and μ_2 denote the composite indices of the tourism development subsystem and the ecological environment subsystem, respectively.

To further reflect the composite levels and coordination status of the two systems, this study introduced a coupling coordination degree model and set the importance of the tourism development system and ecological environment system at 0.5 each. A higher coupling coordination degree indicates a more coordinated composite development status of the two systems.

$$D = \sqrt{C \times T}, T = \alpha\mu_1 + \beta\mu_2 \quad (8)$$

where D is the coupling coordination degree, T is the composite evaluation index, and alpha and beta denote the importance of the tourism development subsystem and the ecological environment subsystem, respectively. Because the two systems are considered equally important, alpha and beta were both set to 0.5 with reference to previous studies.

Finally, after considering the calculated coupling coordination degree between the tourism development system and the ecological environment system in Gansu Province and referring to relevant studies and the results of this study [30-31], the coupling coordination degree was divided into seven levels. The classification criteria are shown in Table 2.

Table 2. Classification criteria for the coupling coordination degree between tourism development and the ecological environment.

Value interval	Coupling coordination degree
[0, 0.30)	Severe imbalance
[0.30, 0.40)	Moderate imbalance
[0.40, 0.50)	Mild imbalance
[0.50, 0.60)	Barely coordinated
[0.60, 0.70)	Primary coordination
[0.70, 0.80)	Intermediate coordination
[0.80, 1.00]	Good coordination

3. Results

3.1. Temporal Changes in Tourism Development

Table 3 shows that the composite tourism development scores of prefecture-level units in Gansu Province differed markedly in 2010, 2015, and 2019, with an overall fluctuating pattern.

Table 3. Composite tourism development scores and ranks of the 14 prefecture-level units in Gansu Province.

	2010		2015		2019	
Unit	composite score	rank	composite score	rank	composite score	rank
Lanzhou	0.47383	4	0.46550	2	0.46228	2
Jiayuguan	0.54375	1	0.43053	4	0.38017	5
Jinchang	0.12323	9	0.12306	11	0.12871	10
Baiyin	0.12299	10	0.11464	12	0.11195	13
Tianshui	0.51365	2	0.44079	3	0.39606	4
Wuwei	0.12824	8	0.12473	9	0.14385	8
Zhangye	0.23370	6	0.23688	6	0.45473	3
Pingliang	0.49894	3	0.40212	5	0.33979	6
Jiuquan	0.34108	5	0.54469	1	0.48066	1
Qingyang	0.13154	7	0.12541	8	0.11836	11
Dingxi	0.08590	13	0.08831	14	0.08503	14
Longnan	0.09635	12	0.12324	10	0.16493	7
Linxia	0.05908	14	0.10101	13	0.11602	12
Gannan	0.10194	11	0.12820	7	0.13446	9
Mean	0.24673		0.24637		0.25122	

Jiuquan recorded the highest composite tourism development score in 2015, at 0.54469, whereas Linxia

recorded the lowest score in 2010, at 0.05908. Most prefecture-level units had composite scores below the relatively high provincial level at the three selected time points, indicating strong inter-unit differentiation in tourism development across the province. Among typical units, Lanzhou, Jiayuguan, Tianshui, Pingliang, and Jiuquan had relatively high composite tourism development scores in some years. As the provincial capital, Lanzhou had advantages in tourism market size, total GDP, and service-facility foundations. Jiayuguan's per capita GDP and high-grade tourist-attraction resources supported its tourism development level. Tianshui had certain advantages in tourist arrivals, tourism revenue, and regional economic foundations within the province. Jiuquan had relatively prominent high-grade tourist attractions and cultural-tourism resources, and its composite score reached the highest value among the sample time points in 2015. At the same time, the tourism development level of some prefecture-level units declined or fluctuated during the study period, which may be associated with changes in the spatial distribution of high-grade tourist attractions, tourism market size, transport-service capacity, and regional economic support conditions.

Overall, the tourism development system in Gansu Province did not show a one-way continuous upward trend; instead, under the combined influence of tourism-resource grades, market size, and economic development level, it exhibited inter-unit differences and stage-specific fluctuations. At the provincial average level, the composite tourism development scores in 2010, 2015, and 2019 were 0.24673, 0.24637, and 0.25122, respectively, indicating only limited changes across the three time points and suggesting that provincial tourism development was in a phase of fluctuating adjustment on a relatively stable basis. Most prefecture-level units scored below the mean, and higher levels were mainly concentrated in areas with stronger resource, market, or economic foundations, such as Jiuquan, Lanzhou, Zhangye, and Tianshui. The relative positions of Jiuquan and Zhangye improved, whereas Jiayuguan and Pingliang showed some decline.

3.2. Temporal Changes in The Ecological Environment Level

The evaluation results for the ecological environment system are shown in Table 4. Compared with the tourism development level, the composite ecological environment level changed more smoothly and generally improved slowly during the study period, although differences among prefecture-level units remained.

Table 4. Composite ecological environment scores and ranks of the 14 prefecture-level units in Gansu Province.

	2010		2015		2019	
Unit	composite score	rank	composite score	rank	composite score	rank
Lanzhou	0.29436	11	0.28174	13	0.37047	9
Jiayuguan	0.26312	14	0.33749	9	0.38272	7
Jinchang	0.26342	13	0.27853	14	0.32315	14
Baiyin	0.37586	7	0.39341	6	0.42495	5
Tianshui	0.27155	12	0.32632	10	0.33994	13
Wuwei	0.40535	5	0.41296	5	0.35199	12
Zhangye	0.59766	2	0.47581	2	0.39221	6
Pingliang	0.32170	10	0.32370	11	0.37951	8
Jiuquan	0.64539	1	0.71772	1	0.64162	1
Qingyang	0.34313	9	0.31762	12	0.35519	11
Dingxi	0.41550	4	0.44078	3	0.47566	3
Longnan	0.41912	3	0.41458	4	0.50309	2
Linxia	0.38297	6	0.36551	8	0.36770	10
Gannan	0.34506	8	0.36886	7	0.45083	4
Mean	0.38173		0.38965		0.41136	

In 2010 and 2019, Zhangye had relatively high composite ecological environment scores, and Jiuquan remained at a high level at all three time points. Lanzhou, Jinchang, Qingyang, and some other areas had relatively low composite scores in certain years. The long-term high composite ecological environment score of Jiuquan may be associated with the strong discriminatory power of indicators such as the share of the number of nature reserves. Zhangye, Dingxi, and Longnan had certain advantages in park green space per capita, which supported their composite ecological environment levels. Jiayuguan and Gannan showed upward trends in composite score and rank, indicating improvements in related ecological-environment indicators. It should be noted that the composite ecological environment level mainly reflects the relative performance of prefecture-level units within the indicator system and cannot be fully equated with natural ecological quality. The existing indicators include pressure indicators such as industrial wastewater, industrial waste gas, and water consumption per capita, as well as state and response indicators such as park green space, green coverage rate, and the number of nature reserves.

Their changes are therefore influenced by ecological conservation and urban construction, as well as statistical caliber and the development stage of each prefecture-level unit. The provincial mean composite ecological environment score increased from 0.38173 in 2010 to 0.38965 in 2015 and then to 0.41136 in 2019, showing a more stable improvement rhythm than the tourism development system. Jiuquan ranked first at all three time points, with scores of 0.64539, 0.71772, and 0.64162. Dingxi, Longnan, and Gannan improved their relative positions in the later study period, whereas Zhangye and Wuwei experienced stage-specific declines, indicating that ecological-environment improvement did not advance synchronously across all prefecture-level units.

3.3. Temporal Evolution of the Coupling Coordination Degree

According to Table 5, in 2010, 2015, and 2019, the coupling coordination degree between tourism development and the ecological environment in most prefecture-level units of Gansu Province was in moderate imbalance or mild imbalance, and the overall coordination level still had room for improvement. Linxia was in severe imbalance in 2010, whereas Jiuquan reached the barely coordinated stage in 2015

and 2019; most other prefecture-level units did not enter the coordinated-development stage. In temporal terms, Jiuquan ranked among the leading units in coupling coordination degree at all three time points and reached barely coordinated status in 2015 and 2019, indicating that its tourism development level and composite ecological environment level were relatively matched. Jiayuguan's coupling coordination degree was relatively stable and remained in mild imbalance over the long term. Linxia shifted from severe imbalance in 2010 to moderate imbalance in 2019, reflecting an improvement in its coordination status. Longnan and Gannan also showed upward trends at the three time points, although they generally remained in moderate imbalance.

Table 5. Coupling coordination degrees, categories, and ranks of the 14 prefecture-level units in Gansu Province.

	2010			2015			2019		
Unit	CCD	Category	Rank	CCD	Category	Rank	CCD	Category	Rank
Lanzhou	0.43213	Mild imbalance	6	0.42553	Mild imbalance	4	0.45488	Mild imbalance	3
Jiayuguan	0.43488	Mild imbalance	3	0.43657	Mild imbalance	2	0.43672	Mild imbalance	4
Jinchang	0.30014	Moderate imbalance	13	0.30425	Moderate imbalance	14	0.31933	Moderate imbalance	13
Baiyin	0.32788	Moderate imbalance	8	0.32586	Moderate imbalance	10	0.33024	Moderate imbalance	10
Tianshui	0.43213	Mild imbalance	5	0.43547	Mild imbalance	3	0.42833	Mild imbalance	5
Wuwei	0.33763	Moderate imbalance	7	0.33686	Moderate imbalance	7	0.33542	Moderate imbalance	9
Zhangye	0.43228	Mild imbalance	4	0.40971	Mild imbalance	6	0.45952	Mild imbalance	2
Pingliang	0.44757	Mild imbalance	2	0.42473	Mild imbalance	5	0.42373	Mild imbalance	6
Jiuquan	0.48435	Mild imbalance	1	0.55913	Barely coordinated	1	0.52694	Barely coordinated	1
Qingyang	0.32592	Moderate imbalance	9	0.31590	Moderate imbalance	11	0.32019	Moderate imbalance	12
Dingxi	0.30735	Moderate imbalance	11	0.31408	Moderate imbalance	12	0.31710	Moderate imbalance	14
Longnan	0.31698	Moderate imbalance	10	0.33618	Moderate imbalance	8	0.37951	Moderate imbalance	7
Linxia	0.27424	Severe imbalance	14	0.30996	Moderate imbalance	13	0.32136	Moderate imbalance	11
Gannan	0.30623	Moderate imbalance	12	0.32974	Moderate imbalance	9	0.35086	Moderate imbalance	8

Overall, the improvement in the coupling coordination degree in Gansu Province was limited, suggesting that tourism-resource advantages had not yet been fully transformed into synergistic advantages between tourism development and ecological conservation. Some prefecture-level units had relatively insufficient tourism development levels, which made it difficult to support system coordination improvement. Others may have faced constraints from ecological-environmental pressure or governance capacity, leading to differences in development rhythms between tourism development and the composite ecological environment level. In terms of transitions among coordination categories, although prefecture-level units improved during the study period, cross-level shifts were not pronounced. In 2010, only Linxia was in severe imbalance, while Jinchang, Baiyin, Wuwei, Qingyang, Dingxi, Longnan, and Gannan were mainly in moderate imbalance. In 2015, Linxia improved to moderate imbalance, and Jiuquan shifted from mild imbalance to barely coordinated. In 2019, Jiuquan remained the only prefecture-level unit reaching barely coordinated status, and most areas were still concentrated in moderate imbalance and mild imbalance.

3.4. Spatial Differentiation of The Coupling Coordination Degree

Fig 2 shows the spatial differentiation of the coupling coordination degree between tourism development and the ecological environment in Gansu Province in 2010, 2015, and 2019. Overall, the spatial configuration of the coupling coordination degree in Gansu Province remained relatively stable during the study period, showing a spatial pattern characterized by higher coordination in the west and lower coordination in the east. In 2010, seven prefecture-level units were in moderate imbalance, six were in mild imbalance, and only Linxia was in severe imbalance. In 2015, Jiuquan improved from mild imbalance to barely coordinated, and Linxia shifted from severe imbalance to moderate imbalance. In 2019, Jiuquan remained the only prefecture-level unit in the barely coordinated category.

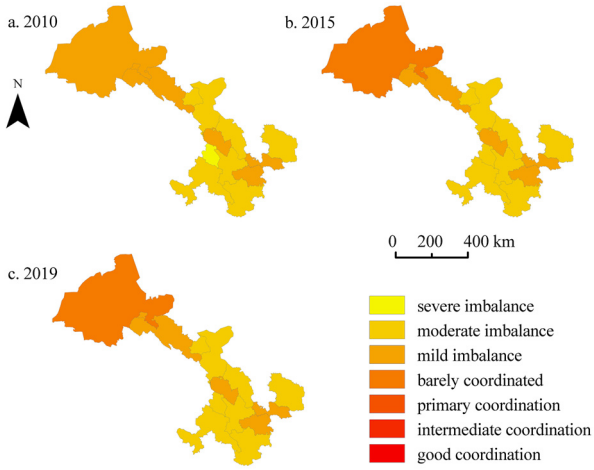

Fig 2. Spatial differentiation of the coupling coordination degree between tourism development and the ecological environment in Gansu Province

Spatially, western prefecture-level units such as Jiuquan, Zhangye, and Jiayuguan had certain advantages in tourism resources, nature reserves, and tourism brands, and their coupling coordination degrees were relatively high. In parts of central and eastern Gansu, population and industrial activities were more concentrated, and differences existed in tourism-resource transformation capacity, tourism service facilities, and ecological-environmental pressure, leading to relatively low coupling coordination degrees. A comparison across years shows that areas with higher coordination were relatively stable. Jiuquan remained at the highest provincial level throughout the study period, while Jiayuguan and Zhangye also maintained relatively high coordination in most years, forming a relatively continuous high-value area in parts of the Hexi Corridor. Dingxi, Qingyang, and Jinchang remained at relatively low levels for a long period. Although Linxia shifted from severe imbalance to moderate imbalance, it did not change the basic pattern of relatively higher levels in the west and relatively lower levels in parts of central and eastern Gansu.

4. Discussion

4.1. Asynchronous Evolution of Tourism Development and the Ecological Environment

Tourism development level and composite ecological environment level showed different rhythms of change during the study period. The tourism development level generally fluctuated and was readily influenced by market demand, scenic-area construction, tourism reception capacity, transport conditions, and macroeconomic changes. By contrast, ecological-environmental governance, ecological restoration, and ecological-quality improvement are cumulative and partly lagged processes, and they do not necessarily change in synchrony with short-term fluctuations in the tourism market. Related studies on urban ecological resilience, karst ecologically fragile areas, and tourism-economy-ecology systems in arid areas have also found that the improvement speeds and response mechanisms of different subsystems are not fully consistent [15,26].

The coupling coordination degree results show that most prefecture-level units in Gansu Province remained in moderate imbalance or mild imbalance for a long period, indicating that tourism-resource advantages had not been fully transformed into synergistic advantages between tourism development and ecological conservation. Some areas possess favorable ecological resources but lack sufficient tourism infrastructure and market-transformation capacity, whereas other areas have better tourism-development foundations but are still constrained by ecological-environmental pressure or governance investment. Compared with the coexistence of coordination and contradiction revealed by national-scale research on tourism ecological security, the present results place greater emphasis on differences in development foundations and stage-specific mismatches among prefecture-level units within the province [3].

It should be emphasized that studies differ in indicator systems, weighting methods, spatial scales, and classification standards. Therefore, this study can only be compared with related studies at the level of trends, and the absolute values of the coupling coordination degree should not be directly compared. The coupling coordination degree model is more suitable for describing the relative development status and coordination level of two systems than for directly revealing the causal mechanisms through which tourism development improves or degrades the ecological environment. Future improvement of coordination in Gansu Province requires simultaneous attention to tourism development quality, ecological-conservation investment, and differences in development foundations among prefecture-level units, rather than explaining changes in coordination degree solely by the expansion of tourism scale.

4.2. Regional Differences and The Formation of the West–East Spatial Pattern

The coupling coordination degree in Gansu Province generally exhibited a spatial differentiation pattern characterized by higher coordination in the west and lower coordination in the east. This pattern was not determined by a single natural condition; rather, it reflected the combined effects of resource endowments, industrial foundations, ecological-conservation investment, urban development level, and the stage of tourism development. Studies of the five northwestern provinces and regions, Western China, and the Silk Road Economic Belt have all shown clear regional differences among tourism, economic, and ecological-environmental systems, and resource foundations, transport accessibility, and industrial organization capacity can influence the spatial expression of coordination levels [24-25].

Within Gansu Province, western areas such as Jiuquan, Zhangye, and Jiayuguan have Silk Road cultural heritage, Danxia landforms, desert landscapes, frontier-pass culture, nature reserves, and other resources. Their tourism brands are relatively recognizable, and they have certain relative advantages in both tourism development and composite ecological environment evaluation. Research on the coupling among the cultural industry, tourism industry, and ecological environment in the Yellow River Basin also suggests that the coordination degree of different subsystems is often jointly affected by the transformation of regional cultural resources, industrial foundations, and ecological-environmental constraints [18]. By contrast, population and industrial activities are relatively concentrated in some central and eastern prefecture-level units, where ecological-environmental pressure, tourism service facilities, and resource-transformation capacity occur in different combinations; as a result, improvements in the coupling coordination degree were relatively slow.

Accordingly, the pattern of higher coordination in the west and lower coordination in the east should be understood as a relative pattern jointly produced by the composite indicators during the study period. It should not be interpreted as being determined solely by natural resources, nor does it imply that all western prefecture-level units have achieved coordinated development. Areas with favorable tourism resources but insufficient development capacity should improve transport accessibility and public-service capacity. Areas with relatively high development intensity or ecological pressure should strengthen environmental governance and capacity management. Because indicator systems, weighting methods, and classification standards differ across studies, regional comparisons should focus on explaining structural differences and evolutionary directions rather than making simple numerical comparisons.

4.3. Limitations and Future Research

This study still has certain limitations. First, the indicator system was constrained by the availability of prefecture-level statistical data. Some indicators are more closely related to the urban built environment, pollution control, and statistical-yearbook calibers. They can reflect socioeconomic and environmental-governance conditions at the prefecture-level scale, but their direct representation of natural ecosystem quality, ecosystem service value, and ecological processes remains limited. Recent studies have begun to describe ecological-environmental status using ecosystem service value, ecological resilience, tourism ecological security, and tourism development intensity-ecosystem function frameworks [3,15,17]. Future research could incorporate indicators such as NDVI, remote-sensing ecological indices, ecosystem service value, and tourism carbon emissions to strengthen the characterization of changes in natural ecosystem functions.

5. Conclusion and Policy Implications

5.1. Conclusion

Based on panel data for 14 prefecture-level units in Gansu Province from 2010 to 2019, this study evaluated the temporal and spatial evolution of tourism development, the ecological environment, and their coupling coordination. Tourism development exhibited an overall fluctuating pattern, whereas the composite ecological environment level improved gradually, indicating different temporal trajectories between the two subsystems. The coupling coordination degree increased only modestly, and most prefecture-level units remained in moderate or mild imbalance. Jiuquan maintained the highest relative coordination level and reached the barely coordinated stage in 2015 and 2019, while substantial improvement was limited in most other areas. Spatially, the coordination pattern remained broadly stable, with relatively higher values in western Gansu and lower values in parts of central and eastern Gansu. Overall, tourism development and the ecological environment in Gansu Province had not yet achieved a broadly coordinated state by the end of the study period, and marked differences persisted among prefecture-level units.

5.2. Policy Implications

For areas with relatively strong foundations in both tourism development and the ecological environment, tourism development should shift from scale expansion to quality improvement. Jiuquan, Zhangye, Jiayuguan, and similar areas could build on their advantages in cultural heritage, natural landscapes, and ecological protected areas to improve tourism-product systems and public-service systems. At the same time, they should strengthen resource carrying-capacity management, ecological-space use control, and scenic-area capacity control to avoid weakening the ecological-environmental foundation through high-intensity development.

For areas where tourism development is relatively rapid but ecological-environmental pressure is high, ecological-conservation constraints should be embedded throughout the tourism development process. Relevant prefecture-level units could strengthen pollution control, waste treatment, sewage treatment, and water-resource management in key scenic areas, peri-urban recreation areas, and tourism transport nodes. They could also establish tourism-capacity monitoring and zoned-control mechanisms and explore ecological compensation and green infrastructure construction to reduce the cumulative pressure of tourism activities on the ecological environment.

For areas with favorable ecological resources but insufficient tourism development capacity, resource-transformation capacity should be improved under the premise of prioritizing ecological conservation. Linxia Hui Autonomous Prefecture, Gannan Tibetan Autonomous Prefecture, Longnan, and similar areas could combine transport conditions, ethnic culture, mountain ecology, and rural tourism resources to improve public tourism services and community-participation mechanisms and develop low-impact, distinctive, and community-based ecotourism. During development, low-level repetitive construction and homogeneous competition should be avoided, and ecological conservation, local employment, and culture-tourism integration should be incorporated into unified planning to gradually improve the synergy between tourism development and the ecological environment.

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