Spatial Zoning Analysis for Sustainable Tourism Development in Shanxi Province

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Abstract: Achieving sustainable tourism is the pivotal motto of countries that have tourist revenue as an integral part of its economy. Analysis based on the spatial distribution of tourist elements is a primary factor to accomplish the sustainable development of tourism. This work focuses on investigating the spatial structure of tourist elements of Shanxi province into five zones, which are divided geographically. A holistic evaluation system is devised that explores the relationship between regional ecological environment and tourism elements of each spatial zone through the coupling coordinated model. This framework for the model is rooted on nine first class indexes with 31 base class indices which capture the characteristics of tourism elements as well as ecological traits. The study is based on data collected for a comprehensive period of about 20 years, primarily sourced from the China Statistical Yearbook (2001–2020), China Tourism Statistical Yearbook (2001–2020), and Shanxi Statistical Yearbook (2001–2020). The results indicate that the country is slowly and marginally heading towards achieving good coupling coordination degree despite the impact of industrial activity and rapid tourism development.

Keywords: Spatial structures, ecological environment, tourism elements, coupling coordination degree, entropy, environmental pressure

1. Introduction

Tourism has evolved as a chief revenue generating industry in China. The tourist activities have expanded dramatically over the last few decades as a result of the reforms in China. Easing the movement restrictions and emergence of newly rich middle class are two predominant factors that catalyst tourism in China by promoting high quality regional, economical and industrial development [1]. According to China Tourism Statistical Yearbook (2019–2021), the total tourism revenue in 2021 was 2919 in billion yarns but the revenue was as high as 6630 billion yarn in 2019 in the pre covid era. Fig 1 shows the tourist revenue of the country for past few years.

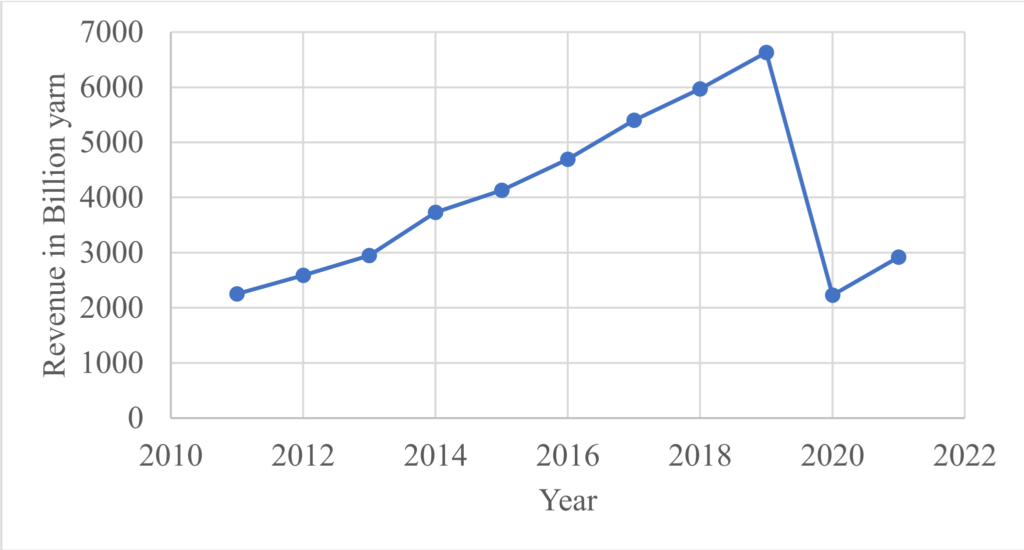


Fig .1. Tourism revenue of China

The vastness of the Chinese territory, which treasures great landscape and climatic diversity is a primary attraction element for world tourists. Another notable trait of China is that the country has remained closed for centuries, hence it still houses most refined and inventive civilization with a rich historical and cultural heritage. The Chinese land has a very strong mysterious history and hence the land is known for its abundance in historic places. So, the tourism flourished here as the world wishes to explore China, its culture and people. Apart from this, China houses countless tourist attractive spots, ranging from places like Great Wall, Forbidden City to Silk Road.

The state bodies of China have leveraged the tourist opportunities with commercial mindset, enabling China to become a world hub of trade and commercial activities. The country is well known for the production of minuscule items to giant machines and technologically advanced robots. Developments in tourism improves the economy of a country by escalating its GDP apart from upgrading the country's infrastructure. Nevertheless, high-quality ecological environment, world class infrastructure and urban services are few vital factors for the ensuring even development of tourism and they act as pivotal indicators for assessing the qualitative aspects of tourism environment in any country. However, the rapid increase in human activities under the canopy of tourism has led to ecological damage and environmental pollution. According to a study, around 70%–75% of global energy consumption and approximately 80% of CO_2 emissions are sourced from urban areas. In addition to this, water pollution, air pollution, overcrowding, increase in vehicular traffic and traffic jams are also gaining attention [2]. Adverse ecological environment impacts the tourism industry and it play a crucial role in boosting or hindering the development of tourism [3]. Regional and interregional tourism are gaining significant momentum especially in three dimensions namely cultural homology, resource complementarity and spatial integrity [4, 5]. The interregional tourism development is perceived as high revenue generating industry which depends on multitude of factors like resources, management policy, environmental conditions, transport facilities and traffic management. [6, 7]. The harmonious tourism development can be achieved only by cooperation and coordination to the regional development [8, 9].

China has taken precautionary measures to promote green development to improve the ecological aspects of tourism industry. However, the impact of these green measures on the tourism industry and vice versa is still under study. Therefore, the correct coordination between the tourism economy and tourism environment quality is a provocative task. A right balance in this, would bring sustainable development of tourism, and has received strong mindfulness from academicians and industrialists.

The change in the ecological conditions alters the dynamics of the tourism development, which has both advantages as well as disadvantages [10]. However, rapid and steeply escalated economic prosperity in short duration will impose adverse impacts on the have environment, by degrading the quality and sustainability of the ecological environment. The trade-off between ecological sustenance and tourism development can be accomplished by proper coordination of green economy and social development [11, 12]. The three systems namely urbanisation, tourism industry and ecological sustenance are three predominant elements for regional economic development. It is much more important to achieve coordinated development to ascertain the holistic but sustainable development of the economy of the region. The studies reveal that, there is great scarcity of research that couples the above mentioned factors.

Overview of the Shanxi Province and its spatial arrangement of its tourism elements

This study focuses on Shanxi Province which is in the central China with a land area of 60,700 square miles housing a population of 34,915,616 (as in 2020). Shanxi is an important province that connects north to south as well as east to west regions of the country. Fig 2 shows the geographical location of the province. The province is roughly rectangular that is bounded by Hebei in the east, Henan in the south and southeast, and Inner Mongolia Autonomous Region in its north. The Shanxi means rugged terrain and Taiyuan is the provincial capital [13]. The province is always a tourist destination because of its climatic, anthropogenic, vegetative and geomorphological value. The province of Shanxi is gateway to the fertile vegetative plains of Henan and Hubei [14]. This has testified the province as a primary route for trading and even military expeditions. Currently, it holds vast reserves of iron and coal thus facilitating the industrial development of the country.

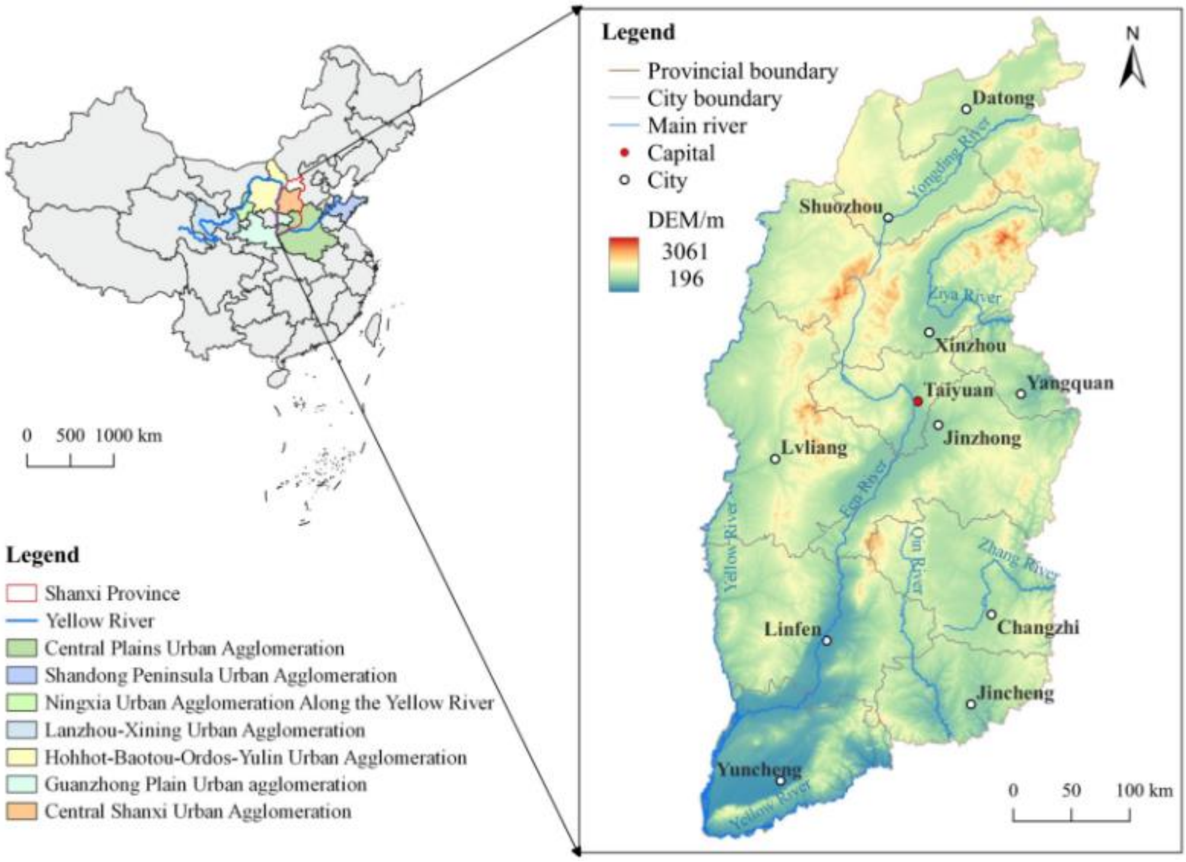


Fig .2. Geographical location of Shanxi province

Roughly, two thirds of Shanxi is plateau elevated to about 3,300 to 5,900 feet above the sea level of China. This plateau is fenced by Mount Wutai massif as well as Heng Mountains in the north, Taihang Mountains in east, and Lüliang Mountains in west [15]. The world famous Huang He commonly known as Yellow River runs through mountain gorge

and acts as western border while the Fenglingdu river turns eastwards to form southern border [16]. On the other hand, the southwest of Shanxi is partially a highland region from Gansu to Henan and is well known for its layer of loess. The popular Fen River valley, houses a well-connected chain of linked but loess-filled basins that cuts the province from northeast to southwest. Shanxi is very fertile region with the largest 160-km-long Taiyuan Basin.
Apart from the Yellow river, many other rivers like Hutuo, its tributaries, Fen and Sanggan runs through the province. The province has varied soil types ranging from light brown to brown soils with meadow-steppe variety at the peaks [17]. The fertile alluvial soils are found in the southern and central regions are primarily formed by depositions of calcareous brown soils by Fen River. This soil is rich in loess, lime deposits with excessive salinity.

The province of Shanxi houses semiarid climate with mean annual precipitation to about 16 - 26 inches. Nearly 80 % of annual rainfall is obtained during June to September with drought winters [18]. The province has versatile vegetation at various regions. The slopes in the south are largely covered by oaks, honey locusts, pines and buckthorns while lindens, ash, maples, and hazels, grow in north side slopes which are more humid [19]. The province is also a house for more than 2,700 plant species with a vast forest cover. The large stretch of the popular virgin forest is located in Zhongtiao Mountains. The environmentalists have made great efforts in reforesting the Shanxi province by planting trees adjacent to cultivated land and even on mountain slopes. The fauna in this province includes wild boars, ring-neck pheasants, and hares. In addition to this, around a dozen of endangered species also survive in the forest cover like brown eared-pheasants, sika deer, red-crowned cranes etc [20].

The chief urban areas are Taiyuan which is the capital city and a leading industrial as well as mining hub; Datong, which is a popular mining as well as rail transport centre. Few other manufacturing and transport centres that gain attraction are Yuci, Yangchuan, and Changzhi [21]. The census in the year 2021 indicates that the permanent residents in the province was more than 34.8 million, realising the regional GDP of around CNY 2259 billion with per capita GDP of roughly CNY 64,905.

Ecological and tourist traits of the Shanxi province

Shanxi is a resource-based city that engenders rich natural resources that are prone to human exploitation in various forms. The city of Shanxi especially is a great province of with abundant mineral resources that spreads around 11 cities, thus making the province a major contributor to the country's GDP. In addition to this, the unique geography, demographics, location, natural resources, scenic beauty, and historical places have ultimately led to irrational exploitation under the umbrella of tourism [22]. This overexploitation of the available natural resources imposes heavy ecological pressure on the province. As tourism has evolved as a major revenue generating industry of the province, it is quintessential to establish a strong link between the sustainable ecosystem development and tourism development. This ecotourism is widely acclaimed as environment friendly, but it comes with a cost of impacting the local culture [23]. To attain the goal of sustainable ecological development, it is essential to comprehend the complex connections and expansions between the spatial structure of tourism elements. Fig 2 illustrates the hierarchical spatial distribution of tourism elements that exist in highly attractive tourism destination like Shanxi.

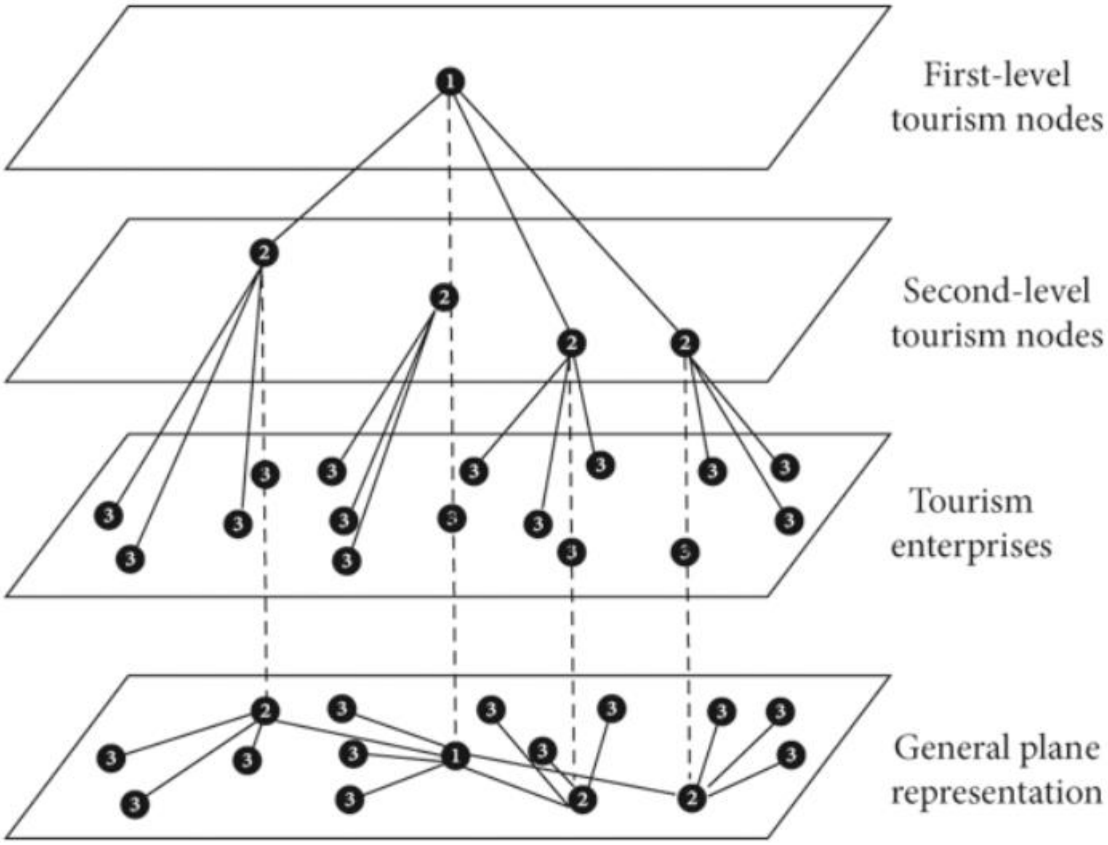


Fig .3. Hierarchical relationship between the Tourism nodes

The tourism industry operates in a hierarchical structure where the first level node is the place that attracts most visitors. The next level is the surrounding and neighbourhood places that are in proximity. The third level will be the enterprises and other third party agencies that are involved in facilitating the tourism industry by rendering tourism based products and services to the tourists. The last level houses the common locales who get benefitted out of tourism. In general, the tourism elements in Shanxi province is rooted on the components mentioned in Table 1.

Table 1: Component and Explanations

Component	Explanation
Accommodation	Hotels, motels, apartments, camps, guest houses, lodges, bed, boat houses, resorts, dormitories, hostels, villas etc are some of the common form of accommodation in the province. This also includes the catering facilities, local restaurants, cafeterias and other food outlets.
Transport	This includes airlines, road and rail transport, water commutation, rental taxis and much more. The choice of transport mode depends on the travel destination and budget
Attraction	This includes Shanxi's historical places, river basins, scenic beauties, forts, mountain peaks, water bodies, temples and other man made recreational facilities.
Travel agents	This is a highly fragmented sector that operate in both online and offline mode in almost all famous cities in Shanxi. Apart from providing the guidance and accommodation services, they also involve themselves in currency exchange, promoting business travels and conferences.
Tour operators	They interact more closely with tourists and plan their travel, accommodation and sight visits in Shanxi.

Coupling mechanism between the spatial structure of tourism elements and ecology

The economic development of China is fostered by continuous urbanization with tourism taking a lead seat [24]. Achieving harmonious relationship between human activity and nature has emerged as a key academic research area. Coupling originates from physics which testifies the physical relationship among elements [25, 26]. This phenomenon occurs within two or more indicators that affect each other through their interactions. Though this technique is widely used in the study of climate change, its role is gaining momentum in investigating the relationship between spatial structures of tourism elements and ecological environment [27]. It is true that rapid urbanization changes the spatial structures and increase the tourism value which in turn improves the coupling intensity between tourism and sustainable development. The study on coupling association between spatial structure tourism elements and ecological environment, primarily focus on investigating the temporal as well as the spatial coupling differences [28]. While the promotion of tourism results in creation of new jobs and enhances the well-being of the locales, it also faces issues like heavy soil contamination, erosion, water, land, and air pollution, environmental imbalance, decline in energy conservation etc. It is obvious that as tourism flourishes so do the environmental pressures thus deteriorating ecological balance and increasing carbon emissions that has cascading effects on the environment. Researchers imply that in most cases environment steps behind tourism elements, as promotion and development of tourism comes with a cost of increased carbon emissions, ecological pollution, degradation of natural resources and over exploitation of land resources [29]. A vast number of research in the area of spatial structure of tourism and environmental have been done to understand the relationships through coupling method that considers unidirectional factors. In addition to this, Shanxi is rich in its minerals which further accelerated the environmental degradation due to land use due to mining activity. This study focuses on exploring the coupling relation between the spatial structures of tourism elements and environmental impact using more dynamic but bidirectional influences. The primary objective of the research is as follows:

1. The work attempts to reveal the dynamism of the factors affecting the spatial structures of tourism elements and environment.
2. Assess the impact created by both primary and secondary indicators on the environment by identifying proper variables from the knowledge base.

The rest of the article is organised as follows: Section 2 gives a brief overview of the important research in the area and section 3 describes the coupling method of assessment. This also includes the explanatory variables and its impact on the environment. Section 4 briefs the results and important implications of the research work. Section 5 concludes the article.

2. Related Works

This section briefs few important works that were done in study. Fei Fu et al. explored the relationship between the tourism elements and ecological impact on Dujiangyan City, which houses few important historical monuments. The work provides a quantitative analysis of the spatial structures as well as the convenience of transportation network to places of tourist attraction [30]. Sports culture tourism is also gaining significance in the recent past. A detailed study by constructing an ecological sports tourism which considers the cultural connotation characteristics was done by Yinghua He et al. [31]. This work focussed on Beijing-Hangzhou Canal region and analysed the influential factors of sports tourism and the spatial structures. The results indicated that sports tourism has brought a social and economic development in the region of study. The results of the study on the tourism elements of the Huangshan Scenic and Jiuhuashan illustrated agglomerative development of tourism elements with remarkable increase in Gini index [32].

Yiyang Sun et al. studied the panel data of around 41 cities located in the Yangtze River Delta to construct a comprehensive evaluation indicators system for eco efficient tourism by analysing the spatial-temporal characteristics [33]. A study on the tourism development in the Altai-Sayan region to promote sustainable development was done by

Alexander N. Dunets et al [34]. The work considers functional zoning as a predominant method that optimises and balances the environment with proper landscape-adaptive principles. Another important work by the same author is developing a methodology-based framework to identify the infrastructural and economic elements of tourism [35]. The work focussed on structure analysis by isolating the salient features of tourism.

A new symbiosis theory is employed to examine the association between organic system and elements of tourism by Hong mu et al [36]. The relationship between the elements of organic tourism based on the original authenticity value orientation of the Three Gorges' spatial structure has been explored in this work. Dandan Liu et al. conducted a study that assessed the characteristics of temporal and spatial pattern, its evolution, influencing factors, driving mechanisms, and dynamic change of ecological security [37]. The work includes Driver-Pressure-State-Impact-Response (DPSIR) model to simulate multi-scenario model based on the data from Chinese provinces. Muhamad proposed a linkage approach between the visual and data objects of tourism [38]. This conceptual model was developed to study the relationship between tourism elements and cultural aspects in Yogyakarta city.

The supply-demand of eco-tourism destinations and its spatial structures are analysed by Shi-min Fang et al. [39]. Tao Zhang et al. proposed a complex evaluation index system based on the data obtained from Heilongjiang [40]. This work covers a detailed quantitative analysis of both spatial as well as temporal characteristics based on the coupling coordination degree between 2003-2017. Zhao Liu et al. analysed the bidirectional flow pattern of tourism factors in both rural and urban sectors by constructing a node-link-setting land use model [41]. This study was conducted on the data secured from smart phone signals integrated with geographical data from the Yichang region. The adaptability to produce complexity theory is employed by Li Lv et al. to analyse the spatio-temporal characteristics of tourism elements [42]. The rural provinces of Wuhan have been transformed from being a rural service provider to image of rural tourism is investigated in this work.

A notable work on rural spatial restructuring is studied by Chunliu Gao at al. based on the leisure consumption demand especially in the metropolitan cities [43]. The data is sourced from fieldwork and GIS to explore the dynamics of rural spatial restructuring. A detailed investigation using the Super-SBM model to find the eco-efficiency of China's local tourism [44]. The works reveals that Guangdong, Jiangsu, and Shandong provinces have much elevated closeness centrality and centrality degree. Shu Yu et al. deployed computer aided metrics like Gini index, nearest neighbor index, and other statistical methods to study the sports tourism and its spatial structures [45].

The region of Gannan, a Tibetan territory is taken as a case study by Libang Ma et al. to analyse the subjective and objective tourism spatial structure [46]. The results reveal that both the types exhibit agglomerative relationship with poor connectivity between them. A resilience based evaluation index system for analysing the economic, social, and ecological aspects of tourist elements is proposed by Xiuping Yang et al. [47]. Around 14 cities located in the Gansu Province were analysed in this work.

Sumanth et al. (2024) explored advanced communications and networking for environmental protection in remote wilderness areas, underscoring the role of ICT in sustainability [50]. Suganya Sri and Rajaram (2024) proposed a coupled-optimization based master node selection and path finding approach in mobile ad hoc networks for smart environment monitoring, which can be adapted to tourism regions requiring real-time ecological data [51]. Similarly, Arulselvan and Rajaram (2022) developed an optimized data accumulation technique for ad hoc networks applied to environmental monitoring [52], while Baskar and Rajaram (2022) introduced a multipath-based optimum routing method for air pollution monitoring [53 These works demonstrate how robust communication and optimization strategies can complement spatial tourism–environment coupling studies by enabling more accurate and continuous ecological monitoring.

To strengthen the theoretical framework, recent studies highlight the dynamic interplay between economic growth, environmental pressures, and technological development. Li and Lei (2024) [54] emphasize the impact of climate change on circular economy development via green total factor productivity, while Li and Lei (2025) [55] analyze the role of new urbanization policies in mitigating agricultural non-point source pollution. Beyond traditional economic-environment models, sustainability research has expanded to design and innovation perspectives, with Tang (2023) [56] proposing operational methods for continuous sustainability-driven design. The digital economy also plays a crucial role, as shown by Jin et al. (2023) [57], who demonstrate that digital investment improves corporate environmental performance, and Jin, Li, and Lei (2024) [58], who provide evidence of digitalization's positive effect on marine economy green development. Furthermore, Lei and Xu (2024) [59] illustrate how shocks such as typhoons affect innovation, echoing the vulnerability of tourism–environment coordination to global financial crises and pandemics. Complementary research in environmental remediation (Murtaza et al., 2025) [60] further underscores the need for integrated approaches to sustainability. Collectively, these works strengthen the theoretical foundation for applying coupling coordination analysis to tourism–environment systems.

Jiang and Yuan (2025) [61] examined the role of green credit in promoting real economic development, emphasizing that financial mechanisms can encourage both scale efficiencies and sustainable practices. Their findings suggest that tourism zoning strategies can be designed to align with green financing opportunities, enabling more resilient and environmentally conscious development in tourism-dependent regions.

From an environmental perspective, Zhao et al. (2025) [62] analyzed the spatiotemporal patterns of the urban thermal environment and the influence of human activities in low-latitude plateau cities. Their study demonstrates how climate-sensitive spatial data can inform land-use planning, which is particularly relevant for tourism zoning in Shanxi Province, where visitor comfort and ecological sustainability depend heavily on thermal and environmental conditions.

In addition, Zhou et al. (2025) [63] investigated the perceived benefits and tourists' willingness to pay (WTP) in national forest parks, showing that cultural values such as ecocentrism, collectivism, and power distance moderate tourist behavior. Their findings underscore the importance of considering social and cultural factors in zoning policies, as zones with stricter conservation measures or higher-quality services may be more acceptable if supported by tourists' willingness to contribute financially.

Together, these studies highlight that sustainable tourism zoning should be finance-aware, environmentally adaptive, and socially responsive. Building on this body of work, the present study develops a spatial zoning analysis for Shanxi Province, aiming to balance ecological protection, financial feasibility, and visitor demand in the pursuit of sustainable tourism development. The brief literature survey on the various methods of analysing the spatial structure of tourist elements and ecological environment are briefed in this section. Not many works consider multi variate analysis of the factors using the coupling method.

3. Methodology

Coupling Coordinated Model

Coupling coordination model explains the intensity of interaction among two or even more subsystems. The coupling degree elucidates the strength of interaction and coordination degree indicates the level of cooperative development. This theory is gaining more significance in recent years as many researchers have employed this to examine the coordination of tourism elements, urbanization, and ecological sustenance. The present work attempts to shed light on the following:

1. To design a framework of the coupling coordinated model.
2. To empirically explain the coupling coordinated relationship between the spatial structure of tourism elements and the ecological environment confined to Shanxi province.
3. To explore the evolution of this relationship through proper indexing systems.

The coupling coordinated model with the indicators are mentioned in Fig 4.

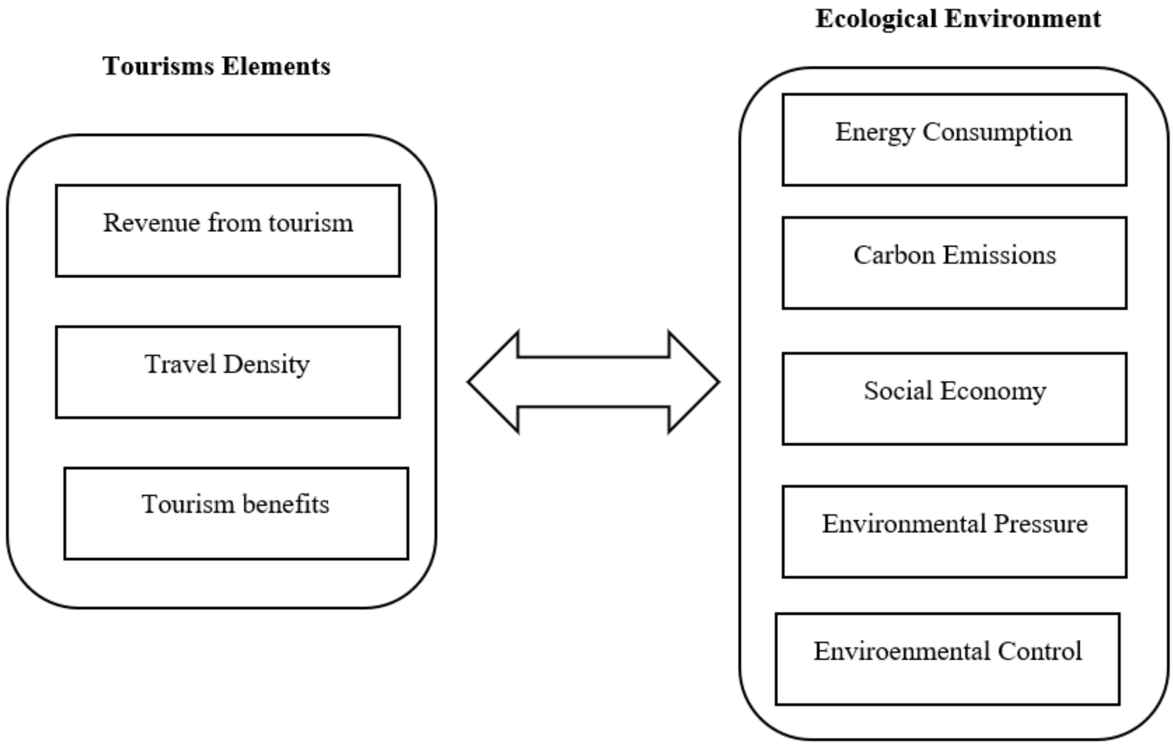


Fig .4. Coupling coordinated framework for spatial analysis of tourism elements and ecological environment in Shanxi province

The assessment for ecological aspects of the coupling model is based on the five parameters namely energy consumption, carbon emissions, social economy, environmental pressure, environmental control and lifestyle. The spatial dimensions of tourism elements that are considered in this study includes revenue from tourism, travel density and tourism benefits. Table 2 shows the primary indicators for analysing the spatial structure of tourism elements and their mode of measurement while Table 3 shows the same in the context of ecological environment.

Table 2: Indicators and weights for spatial structure analysis of tourism in Shanxi province

Element	Metrics	Weights
Revenue from tourism	International tourism revenue/10,000 yuan	0.784
	Domestic tourism revenue/10,000 yuan	0.634
	Fraction of total tourism revenue to tertiary industry revenue %	0.238
Travel Density	Number of international tourists/10,000 people	0.376
	Number of domestic tourists/10,000 people	0.279
Tourism benefits	Number of star-rated hotels	0.783
	Number of travel agencies	0.864
	Number of scenic spots	0.462

	Occupational share of travel agencies	0.745
	Occupational share of star hotels	0.562
	Total retail sales of social consumption	0.451

Table 3. Indicators and their weights for ecological environment in Shanxi province

Element	Metrics	Weight
Energy Consumption	Total energy consumption / day (ton of standard coal)	0.752
	Water consumption/ GDP unit (cubic meters/10000 yuan)	0.687
	Electricity consumption/ GDP unit (watts/10000 yuan)	0.639
Carbon emissions	Total carbon emissions into the atmosphere (tons of CO_2)	0.823
	Carbon emissions/ person (ton/person)	0.679
	Carbon production (10000 yuan/ ton of carbon)	0.346
Social economy	Investments made in fixed assets (100 million yuan)	0.229
	GDP per capita	0.592
	Employability (million persons)	0.285
Environmental Pressure	SO_2 discharge (tons)	0.026
	Smoke and dust discharge (tons)	0.756
	Discharge of wastewater (tons)	0.642
	Discharge of Ammonia and Nitrogen components (tons)	0.326
	Discharge of solid wastes (tons)	0.438
Environmental control	Green coverage in built up areas	0.672
	Sewage disposal system	0.524
	Treatment of industrial solid waste	0.142
Lifestyle	Income of residents (yuan / person)	0.263
	Housing area (sq.m/ person)	0.437
	Basic civic facilities	0.327

The selection of indicators in this study follows established literature on tourism–environment linkages, ensuring both ecological and economic relevance [48]. The entropy weighting method was adopted because it minimizes subjectivity by assigning weights according to information entropy. However, as the entropy method can be sensitive to indicator variability and may overemphasize highly dispersed variables, we conducted a sensitivity analysis by comparing results with equal-weighting and Analytic Hierarchy Process (AHP) schemes. The consistency of the coordination outcomes across these approaches validates the robustness of the chosen weighting scheme.

Data Collection and Normalization

The data for the comprehensive study is aggregated from authoritative and publicly available sources, including the China City Statistical Yearbook (2001–2020), Shanxi Statistical Yearbook (2001–2020), and the China Tourism Statistical Yearbook (2001–2020), published by the National Bureau of Statistics of China and the China Tourism Academy. Supplementary data on ecological indicators were obtained from the China Environment Yearbook (2001–2020). All data sources were cross-verified with provincial government reports and are accessible via the National Bureau of Statistics database (http://www.stats.gov.cn/). It is evident from the table 2 and 3 that the study includes multiple heterogeneous evaluation indexes that must be normalised for better understanding and semantic comparison by mitigating the impact units and its magnitudes. The normalization of the positive indicators and negative indicators are done differently according to Equations 1 and 2 respectively.

$$X'_{ijt} = \frac{X_{ij} - (X_{ij})_i^{min}}{(X_{ij})_i^{max} - (X_{ij})_i^{min}} \quad (1)$$

$$X'_{ijt} = \frac{(X_{ij})_i^{max} - X_{ij}}{(X_{ij})_i^{max} - (X_{ij})_i^{min}} \quad (2)$$

The term X_{ijt} refers to the value of the i-th index of the province j at time t. The values are scaled between [0,1]. The max and min values refer to the maximum and minimum value of the particular index between the years 2001-2020.

Comprehensive weight estimation of the indices

Once, the data is normalised, is it important to estimate the indexes and its corresponding weights. The choice of weights in this study is done by entropy method, which is a popularly used information-weighting method [48]. In this research the weights of different indexes are calculated based on the dispersion degree where smaller the entropy, greater will be the dispersion degree of the index and vice versa. In addition to this, this method of obtaining the weights eliminates the limitations of subjective weighing. The sequence of steps in calculating the weights for the indices are given through Equations 3-5.

$$R_{ij} = \frac{X'_{ijt}}{\sum_i X^i_{ijt}} \quad (3)$$

$$IE_{ijt} = -\delta \sum_i R_{ijt} \ln R_{ijt} \quad (4)$$

$$w_{ijt} = \frac{(1 - IE_{ijt})}{\sum_j (1 - IE_{ijt})} \quad (5)$$

The value of j in all the three above equations belongs to set of class index. The term R_{ijt} is the ratio of the index i at time t in the city j. The constant value δ is estimated as $(\ln n)^{-1}$, where n is the total number of samples considered for the study. The weight (w_{ijt}) is the significance of the index at time j between the years 2001 to 2020. The weights of the indexes are shown in Table 2 and table 3.

Six first class indexes with twenty base class indexes are considered for the analysis of ecological environment. The primary careers considered in this study are energy consumption, carbon emissions, social economy, lifestyle, environmental pressure and control of the Shanxi province. Within each first-class index multiple base classes were considered. For example, under environmental pressure the industrial emissions like SO_2, smoke, dust, ammonia, nitrogen, wastewater and solid wastes were considered. As the province of Shanxi is well known for its mining activity, it is quintessential to consider all these base classes.

Regarding the spatial tourism analysis the study considers three first class indexes namely revenue from tourism industry, travel density and benefits reaped from the tourist activity. These classes in turn have eleven base classes. Again, considering the provincial significance, the benefit of tourism includes the count of star hotels, travel agencies, scenic attractions, occupations from these ventures and even retail sales. The impact of tourist on culture as well as ecological environment are very obvious. However, the intensity and scope of the impacts created by these elements are tightly coupled with the number of tourists. In addition to this, the employment and other benefits of star hotels and travel agencies are also very much vital in exploring the association between the elements.

Assessment of comprehensive development index of tourism and ecological environment

The method of linear weighting is deployed to compute the comprehensive holistic development index of spatial structure of tourism and ecological environment. Equation 6 estimates the comprehensive development index of the system in i^{th} index in j city. This index X_{ij} gives the comprehensive evaluation index of the two subsystems considered in this study namely spatial structure of tourism elements and ecological environment.

$$X_{ij} = \sum_{i=1}^{n} w_{ijt} * X'_{ijt} \tag{6}$$

Coupling coordination of the two sub systems

The coupling coordination model constructed between the subsystems is estimated according to the equation 7. When the estimated Coupling Degree (CD) is at value 1, it indicates a close connection between the sub systems, while a CD value near to 0 indicates a loosely connected subsystem. It is evident that CD takes the range of values between [0,1]. CD is a direct implication of the intensity of interaction between the subsystems.

$$CD = \left(\frac{X_1 \text{ x } X_2 \text{x } \ldots \text{x } X_n}{\Pi\ (X_i + X_j)}\right)^{\ n^{-1}} \tag{7}$$

The term X_i indicates the comprehensive index the i^{th} subsystem where n is the number of subsystems considered in the research. The overall coordination between the subsystems is estimated according to Equation 8.

$$OC_{it} = \sqrt{CD_{it}\ x\ X_{it}} \tag{8}$$

OC_{ijt} indicates the complete holistic coordination degree of i^{th} province at time period of t. After estimating both coupling degree (CD) and overall coordination degree (OC), the intensity coupling and coordination are categorised into ten classes as mentioned in table 4. We conducted a quartile-based statistical validation, which confirmed that the distribution of coordination values naturally aligns with the proposed thresholds. This statistical grounding enhances the objectivity of the classification system. Many researchers have employed subjective threshold values to categorize the coupling and the coordination level of the sub systems. But this method is seldom successful as the decisions are not comparable. Hence, this study uses objective quartile method to make the research more objective.

Table 4. Classification chart for categorising the coupling coordination degree [49]

Coupling Coordination degree	Coupling coordination class	Coupling Coordination degree	Coupling coordination class
0.00-0.09	Totally disorder	0.05-0.59	Slight coordination
0.10-0.19	Serious disorder	0.60-0.69	Primary coordination
0.20-0.29	Tolerable disorder	0.70-0.79	Tolerable coordination
0.30-0.39	Mild disorder	0.80-0.89	Satisfiable coordination
0.40-0.49	Verge of disorder	0.90-1	Extreme coordination

To validate the robustness of the coupling coordination degree, we compared results with the TOPSIS method and grey relational analysis, both widely used in tourism-environment studies. The consistency of trends across methods, with variations remaining below 5%, confirms the reliability of the findings. Additionally, a threshold sensitivity analysis of classification cut-offs demonstrated that coordination levels remained stable under ±10% changes, further validating the categorization.

4. Result and Discussion

Empirical analysis of spatial distribution of tourism elements and ecological environment in Shanxi province

The framework for the coupling coordination model for assessing the evolution between the tourism elements and ecological environment is established in the previous section. Now, using that system, the entropy-based weights for each base level indexes are estimates and are mentioned in Table 2 and Table 3. After this, the coupling as well as the coordination degree between the two subsystems are estimated according to Equation 7 and 8 respectively. As the research is focussed on spatial distribution of tourist elements of Shanxi province, eight prominent zones namely Datong, Wutai, Taiyuan, Pingyao, Chanzhi, Hukou, Jincheng and Yuncheng were analysed between the years 2001 to 2020. This study makes spatial as well as temporal analysis based on the proposed coupling coordination model.

The results indicate that the coupling degree of the cities ranged between 0.6099 and 0.8165, while the coordination degree was between 0.3085 and 0.5491. Yuncheng recorded the lowest coupling degree, whereas Datong showed the highest. Similarly, Jincheng demonstrated the highest coordination, followed by Hukou, while Wutai exhibited the lowest. The average coupling and coordination degree between the two subsystems of the eight zones between 2001 and 2020 is shown in Fig 5. It is evident that through Datong has exhibited good coupling effect it shows relatively lower coordination between the two sub systems. However, Jincheng and Yuncheng zones shows better trade off in both coupling as well as coordination degree.

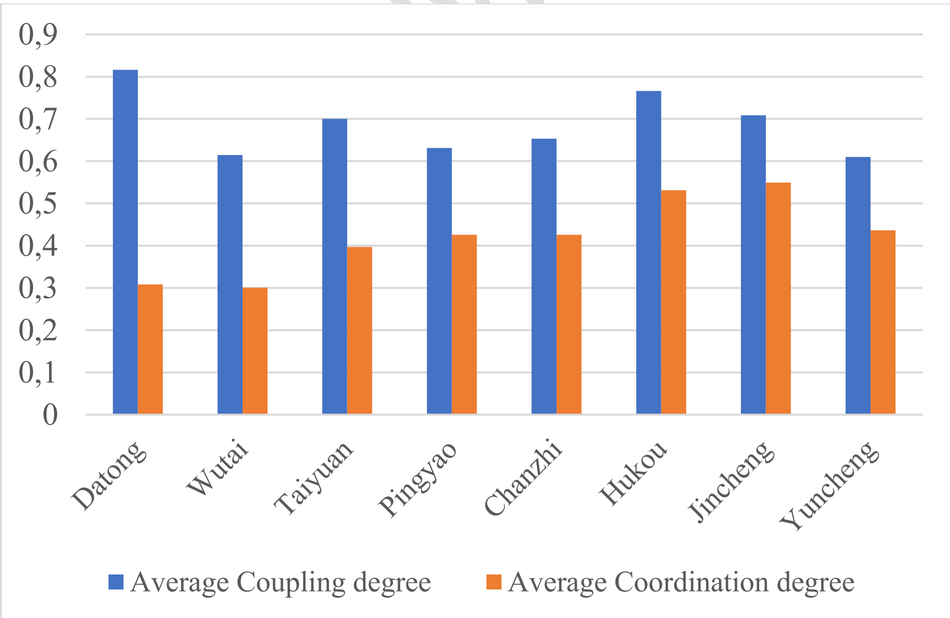
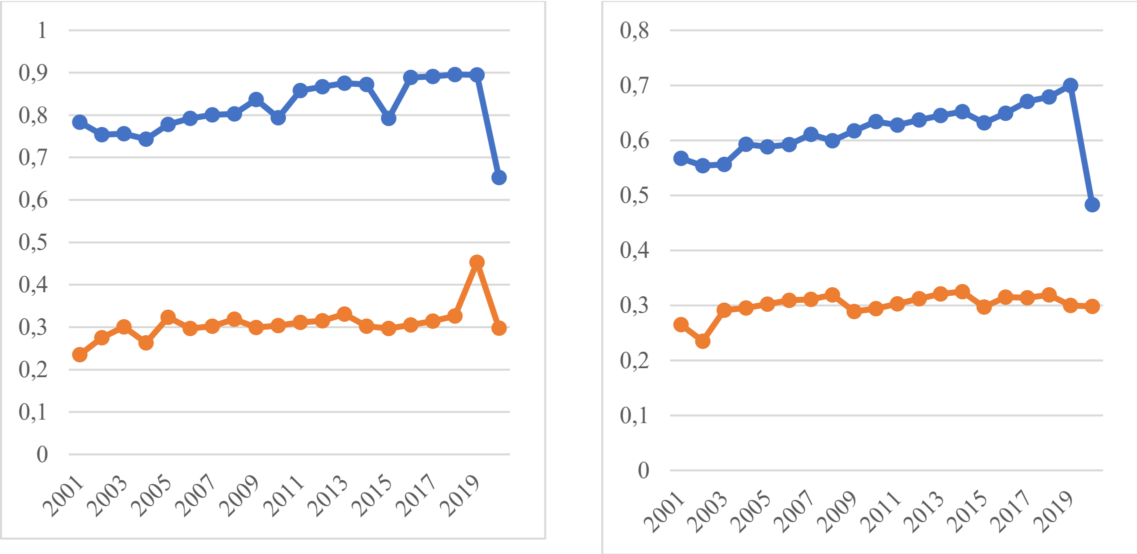


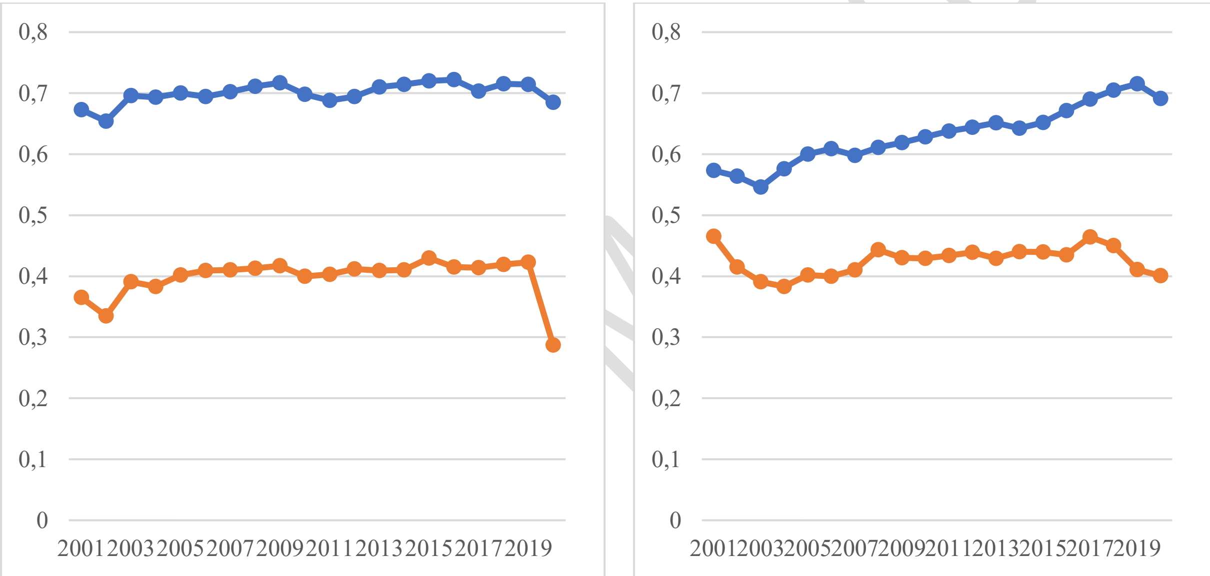
Fig .5. Average coupling and coordination degree of the eight cities in Shanxi province

Though, Fig 5 gives a comprehensive overview of the average coupling and coordination degrees of the eight spatial zones of tourist interest in inclination with ecological environment, it is quintessential to learn the spatial and temporal changes in various zones.



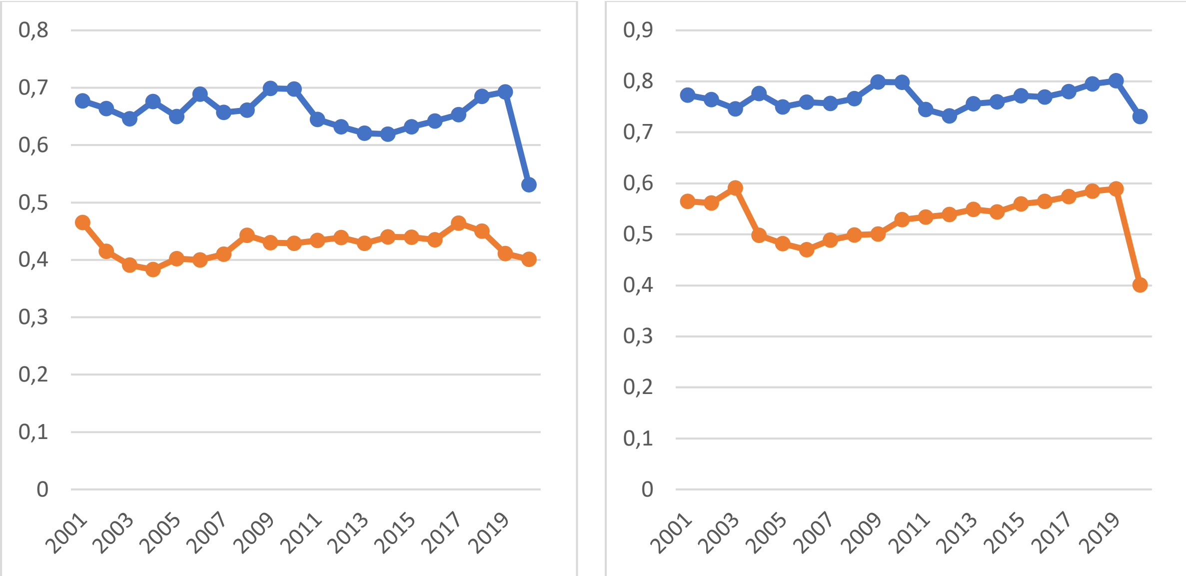
(a) Datong Zone (b) Wutai Zone

Fig .6. Coupling and coordination degree of Datong and Wutai Zones of Shanxi



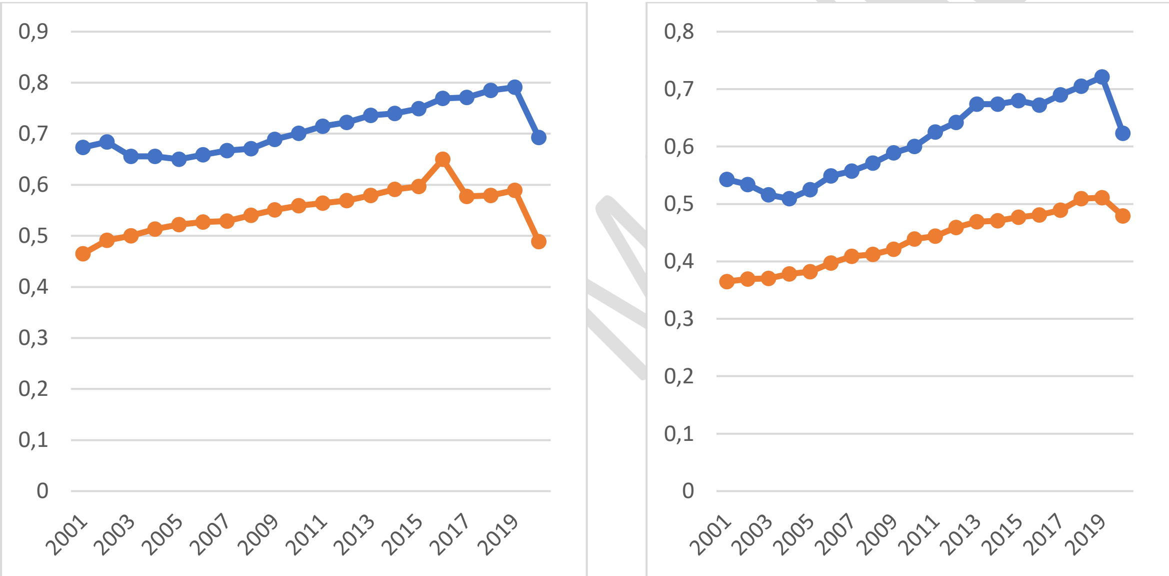
(a) Taiyuan Zone (b) Pingyao Zone

Fig .7. Coupling and coordination degree of Taiyuan and Pingyao Zones of Shanxi



(a) Chanzhi Zone (b) Hukou Zone

Fig .8. Coupling and coordination degree of Chanzhi and Hukou Zones of Shanxi



(a) Jincheng Zone (b) Yuncheng Zone

Fig .9. Coupling and coordination degree of Jincheng and Yuncheng Zones of Shanxi

It can be noted from Fig 6 to 9 that there is a steady increase in the coupling and coordination degree every year except 2020. This is due to the pandemic situation during which the tourist places did not have any significant human activities. Hence, no profound implication can be drawn from the data obtained in 2020. However, the coupling degree shows an inclined trend in almost all zones over every year period of China. But some zones like Chanzhi, Pingyao, Taiyuan and Datong shows declined trend in 2008 and 2009. This is because the country has witnessed heavy snowfall in addition to the financial crisis dur to global recession. These zones are well known for its industrial activity and hence the severity of these issues was felt more in these zones. The coordination trend between the subsystems is not very obvious. However, a more granular analysis made on different spatial zones reveals that almost all the zones are now coordinated with the development of tourism and preservation of ecological environment. There is only incremental change observed in every zone as this measure can be improved in incremental fashion. Also, the changes in the indexes are primarily due to the implementation of ecological policies and opening the tourism doors of the country especially after the 10th-13th five-year plans.

Datong zone, a well-known mining area houses some tourist spots with shallow caves. Despite the implementation of the green policies, the zone does not show good coordination between the sub systems, as the zone is marked as highly pollutes area. So, the effects of the measures taken by the state are progressing in a more regressive pace. Though a peak coordination value between the sub systems is witnessed during 2018, it did not have any significant research implication. On the other hand, Wutai, a mountainous region did not reveal positive coordination. A very marginal increase in coordination has been sensed. As this region is devoid of any industrial activity, the coupling between the systems is showing an uplifted trend.

Taiyuan region is well connected with other parts of China, thus inviting tourists is one of the highly polluted cities in the world. As it has high industrial and human activity only Tolerable coordination is achieved in the zone. Pingyao, an ancient city known for its tourist's attractions has been the primary focus of the state in implementing the environmental policies and tourism development activities and is managed by UNESCO World Heritage Centre. Hence, it has shown good coupling relation with steady coordination degree over the time. Changzhi, known as water town, is a big commercial and industrial centre of China. Because of its intensive industrial operation, there is a declination in the coupling degree between the two sub systems. The Huzhou region is popular for its fertile lands and water resources. The region has shown good improvement in the coordination degree between the two sub systems. Jincheng zone houses few important scenic attractions with good industrial activity. The temporal analysis shows improvement in both coupling and coordination degree between both the subsystems. A similar trend is observed in the Yuncheng zone also. Table 5 shows the coordination class of each spatial region considered in the study.

Table 5. Result of the coupling coordination analysis

Spatial Zone	Coupling coordination class
Datong	Satisfiable
Wutai	Primary
Taiyuan	Tolerable
Pingyao	Primary
Chanzhi	Primary
Hukou	Tolerable
Jincheng	Tolerable
Yuncheng	Primary

The observed decline in coordination degree during 2008–2009 is attributed not only to the global financial crisis but also to concurrent domestic factors: a sharp contraction in coal exports reduced foreign direct investment and a slowdown in industrial activity in Shanxi, which heavily depends on mining. These factors collectively suppressed tourism demand while increasing ecological stress, amplifying the downturn in the coordination index. Although each zone was analyzed independently, tourism-environment dynamics are not spatially isolated. Neighboring zones may exhibit spill over effects: for instance, ecological degradation in Taiyuan's industrial belt can affect downstream water quality in Yuncheng, while strong cultural tourism in Pingyao may generate complementary flows into adjacent regions. Future research should incorporate spatial econometric tools to capture these interdependencies and strengthen the interpretation of zone-level results.

Policy Implication

This research provides practical guidance for regional policymakers seeking to balance tourism growth with ecological sustainability. Given the varying levels of coordination across Shanxi's spatial zones, the following tailored strategies are recommended:

- ***Datong Zone:*** Enforce strict ecological restoration and pollution controls in mining areas; promote low-carbon tourism infrastructure.
- ***Wutai Zone:*** Implement visitor limits and sustainable transport to protect religious and natural heritage.
- ***Taiyuan Zone:*** Integrate smart urban mobility and renewable energy in tourism development.
- ***Pingyao Zone:*** Strengthen cultural preservation via heritage funds and tighter regulation of tourism commercialization.
- ***Changzhi Zone:*** Control industrial emissions alongside tourism growth; establish eco-compensation mechanisms.
- ***Hukou Zone:*** Support agri-tourism linked with water conservation and ecological farming initiatives.
- ***Jincheng Zone:*** Encourage public-private partnerships for eco-tourism; maintain clean energy and waste management investments.
- ***Yuncheng Zone:*** Develop interprovincial tourism circuits for balanced ecological and economic outcomes.

These differentiated strategies enable context-sensitive tourism governance aligned with each zone's unique ecological and economic profile.

Limitations

While this study offers meaningful insights into the relationship between tourism and the ecological environment in Shanxi Province, it is not without limitations. First, the impact of the COVID-19 pandemic in 2020 cannot be overlooked. Tourism activities came to an abrupt halt, leading to a sharp decline in visitor numbers and related economic indicators. This disruption may have caused unusual fluctuations in the degree of coordination between tourism and the environment. Although 2020 is included in the analysis for completeness, the results from that year should be treated with caution, as they likely reflect a temporary shock rather than long-term trends. Second, the study relies on the entropy weighting method to construct the evaluation index. While this approach minimizes subjectivity, it has its drawbacks. The method is highly sensitive to the variability of indicators, meaning that variables with greater dispersion can disproportionately influence the results. As a result, indicators with lower variability but high practical importance such as those reflecting cultural heritage, may be undervalued. Future research could incorporate alternative or hybrid weighting methods, like the Analytic Hierarchy Process (AHP), to test and strengthen the reliability of the findings. Finally, the scope of this study is limited to Shanxi Province. Although the results provide valuable insights at the regional level, they may not apply directly to other provinces with different ecological systems and tourism structures. To achieve a broader perspective, future studies could extend the analysis to include cross-provincial comparisons.

5. Conclusion and Future Work

This research aims to establish a holistic evaluation system of the spatial structures of tourism elements and ecological environment of Shanxi province. The entropy method is employed in the work to assess the information significance and the coupling coordination model is deployed to analyze the relationships between two subsystems by considering 9 first level classes and 31 base classes of the eight important tourist zones in Shanxi namely Datong, Wutai, Taiyuan, Pingyao, Chanzhi, Hukou, Jincheng and Yuncheng. The coupling and coordination degree between the subsystems is not obvious in the end years of the study as there was very limited human activity during the pandemic. The study concludes that all the zones considered are positioned within acceptable coupling coordination classes, with Datong recording the highest value. Importantly, the robustness checks using alternative weighting and evaluation methods confirmed the stability of the reported coordination degrees, enhancing the reliability of the findings. However, the impact of COVID-19 on 2020 data and the inherent biases of the entropy weighting method should be recognized as limitations, warranting cautious interpretation of the results. Also, the research implies that the cities in which mining activity is more pronounced does not show good coordination degree. Despite the efforts taken by the state by implementing environmental policies in all its five-year plans, these regions suffer from heavy ecological degradation. This effect is evident from the consistent coordination degree which does not show any significant improvement. As China has opened doors to the world tourist, the rapid tourism activity has eventually improved the lifestyle of people but at the cost of exploitation of resources and increase in carbon emissions. At the national level, China should concentrate on promoting eco-tourism while tailoring strategies to the unique ecological and industrial contexts of each zone. By linking tourism growth with zone-specific ecological safeguards, the province can achieve both sustainable tourism development and improved environmental resilience.

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