Heliyon 9 (2023) e21359

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research on the evaluation system of "vegetation-atmosphere-water" environmental coordination development under ecological management

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A R T I C L E I N F O

Keywords:
Ecological management
Coordinated development of "vegetation-atmosphere-water" environment
Evaluation index system
Coupled coordination

A B S T R A C T

As environmental issues on a global scale continue to worsen, all regions are pursuing ecological management and sustainable development strategies. The coordinated development of the "vegetation-air-water" environment is one of the most essential research topics in ecological governance. The purpose of this paper is to develop an evaluation system for the development of environmental governance in Shaanxi Province, as well as to evaluate the benefits of environmental governance in Shaanxi Province from 2012 to 2021 and its influencing factors. An index system for the coordinated development of "vegetation-atmosphere-water" is constructed, and the benefits and influencing factors of environmental governance are comprehensively analysed by using comprehensive analysis methods such as the coupled coordination model of the system and entropy weight TOPSIS. The results indicate that the development trend of the coupling coordination degree has evolved through the stages of "uncoordinated development at the early stage of governance, transformed development at the middle stage of governance, and coordinated development at the first success stage of governance." In addition, we identify the obstacles to the coordinated development of the environment and suggest appropriate countermeasures. The efficacy of environmental policy governance provides recommendations for future enhancements. It is important to note that ecological governance is influenced by both policy and nature; political influences, such as the switch from "returning farmland to forests" to "returning forests to farmland," will result in the destruction of the original good vegetation growth, which will significantly reduce the coordinated benefits of ecological governance. The original coordinated system will also be fractured, which is a problem worth contemplating. And policymakers, researchers, and practitioners can use the evaluation system and analysis method proposed in this paper as an effective tool to promote sustainable development and ecological governance.

1. Introduction

In recent years, environmental protection and ecological governance have garnered a great deal of attention from the international community [1] as global concerns. Particularly, as one of the world's most populous nations, China's environmental concerns have far-reaching effects on the health and quality of life of its own people, as well as direct effects on the global ecological balance and climate change [2]. In this context, ecological governance has become a pillar of China's domestic policy. As an essential aspect of

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https://doi.org/10.1016/j.heliyon.2023.e21359
Received 31 May 2023; Received in revised form 19 October 2023; Accepted 19 October 2023
Available online 21 October 2023

ecological governance, the study of the coordinated development of the "vegetation-air-water" environment has important theoretical and practical value [3].

Vegetation, oxygen, and water are essential components of the earth's ecosystem, and their interrelationships are essential for maintaining ecological equilibrium [4]. Vegetation absorbs carbon dioxide and releases oxygen through photosynthesis to maintain the oxygen content of the atmosphere, and also influences ecosystem services such as rainfall, soil conservation and biodiversity maintenance [5]. Atmospheric pollution poses a direct threat to plant health and inhibits photosynthesis, whereas water is one of the essential conditions for plant survival [6]. Therefore, the coordinated development of vegetation, oxygen, and water is related to the health and sustainability of ecosystems and determines the sustainability of human society's development.

However, coordinated development of vegetation-air-water environments is difficult to accomplish due to the complex interactions and feedback mechanisms between these elements. For instance, atmospheric pollution damages vegetation, and the resulting reduction in vegetation effects the oxygen content and carbon dioxide absorption capacity of the atmosphere [7]. Furthermore, overexploitation and contamination of water resources can have a direct impact on the survival and growth of plants [8]. In order to guide environmental governance policies and enhance the sustainability of ecosystems, it is necessary to conduct an in-depth analysis of the interrelationships between these elements and their coordinated development trends.

Under China's national conditions, environmental problems and governance requirements range from region to region, necessitating the establishment of an adaptable environmental governance evaluation system in various regions. Located in the northwest of China, Shaanxi Province has a unique natural environment and resource conditions. It has a lengthy history and culture, as well as rich vegetation resources, diverse topography and geomorphology, an abundance of mineral resources, and distinctive climatic characteristics [9]. However, with the accelerated development of industrialization and urbanisation, Shaanxi Province is also confronted with significant environmental challenges, such as air pollution, water scarcity, and land degradation [10]. Consequently, an in-depth examination of environmental governance in Shaanxi Province can provide substantial support for the region's sustainable development as well as lessons and insights for ecological governance in other regions.

This study's primary objective is to establish a set of evaluation systems for the coordinated development of the "vegetation-air-water" environment applicable to Shaanxi Province in order to comprehensively evaluate the benefits and influencing factors of environmental governance in the region. Utilising various analytic techniques, such as the coupled system coordination model, the regression effect model, and the obstacle analysis model, we will examine the development trend of environmental governance in Shaanxi Province between 2012 and 2021, as well as the changes in coordination at various stages and the existing problems and challenges. By analysing the benefits and influencing factors of environmental governance, we will provide useful recommendations for improving environmental governance policies in Shaanxi Province and strong support for the sustainable development of ecosystems and the realisation of ecological governance. This study aims to provide strong support for a comprehensive evaluation of the coordinated development of the "vegetation-air-water" environment, as well as insights into the formulation and implementation of eco-governance policies, through an in-depth examination of environmental governance in Shaanxi Province. These findings will aid policymakers, researchers, and practitioners in understanding and addressing environmental challenges in northwestern China, as well as in promoting sustainable development and ecological governance.

2. Research review

2.1. Review of typical viewpoint studies

In light of the growing significance of ecological management, the evaluation system of "vegetation-air-water" environmental coordination development has become an essential area of study. Researchers have proposed a variety of evaluation systems and methodologies for assessing the degree of environmental coordination, which includes vegetation, air, and water.

Professor Li Xiaoying first proposed an evaluation index system based on the comprehensive evaluation of ecological, economic, and social benefits. He then utilized the gray system prediction model to analyze the indexes and predicted that the implementation of the new round of fallowing project in the northwest arid desert region should prioritize ecological construction and strengthen the connection between ecological compensation and rural revitalization strategy [11]. Second, scholar Wusheng Zhao introduced the exponential efficacy function model to measure the economic and social development of the Lanzhou-Xining urban agglomeration, assessed the ecosystem service level of the urban agglomeration using the In-VEST model, and applied the coupled coordination degree model to analyze the coupled coordination relationship of economic-social-ecological subsystems and spatial and temporal variation characteristics of the economic-social-ecological subsystems [12]. Third, Bao Xueying et al. constructed a "roadbed-environment" interaction network and introduced the barrel theory to construct a green element set so that four key elements, including slope vegetation protection, graben excavation size, embankment filling size, and slope protection, could be managed to realize the greening of railroad roadbed projects [13]. In addition, other researchers have proposed a variety of analytical techniques for determining the advantages and influencing factors of environmental management. Kong Fanbin et al. for instance, systematically sorted and reviewed the theoretical connotation of the modernization of ecological and environmental governance system and governance capacity, Chinese practice-related research results, and proposed the key directions and main contents for future research expansion [14]. Lv et al. developed regional environmental contamination indicators to assess regional environmental governance performance using principal component analysis [15]. Thus, the development of an evaluation system for "vegetation-air-water" environmental coordination under ecological management is an essential area of study.

From a holistic perspective, one of the shortcomings of existing studies is that they focus primarily on the evaluation system of the coordinated development of "vegetation-air-water" and its influencing factors, but do not analyze the development trend and obstacles to the coordinated development. This study is innovative in that it not only constructs the evaluation system of "vegetation-air-water" environmental coordination development, but also applies the system coupling coordination model, regression effect model, and obstacle factor diagnosis model to analyze the development trend and obstacles of "vegetation-air-water" environmental coordination

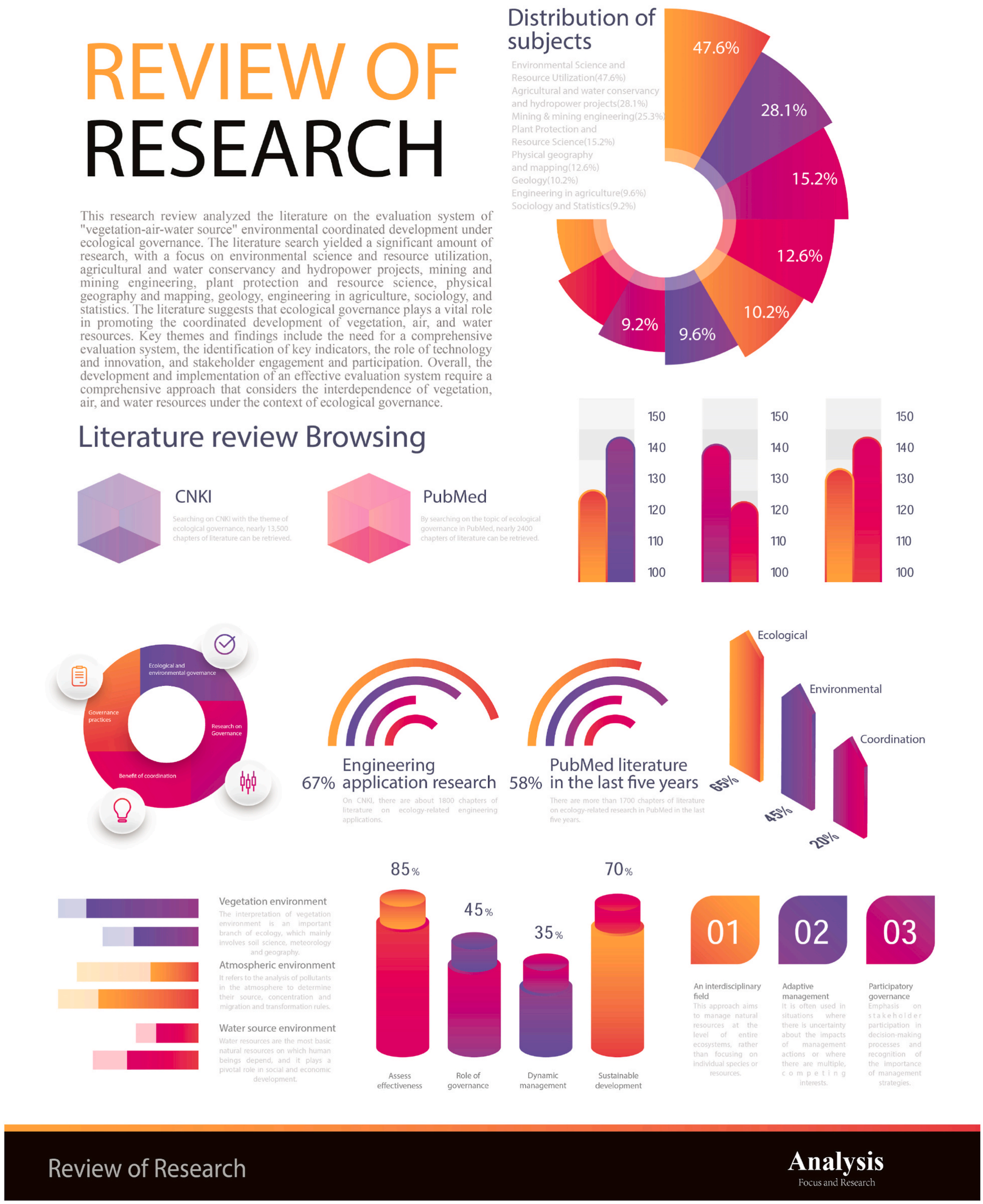

Fig. 1. Synthesis analysis of the literature studies.

development. In addition, the study offers recommendations for enhancing future environmental governance policies. As a result, it is anticipated that this study will provide a more comprehensive and practical analysis of the "vegetation-air-water" environmental evaluation system and its coordinated development under ecological governance, as well as address the extant research voids.

2.2. Review of literature search studies

This paper concentrates on the evaluation system of the environmental coordination development of "vegetation-air-water" under ecological governance. The purpose of this study was to identify the existing literature on this topic and analyze its main findings and themes. CNKI and PubMed were the two primary databases used for the literature search, and Fig. 1 displays a comprehensive analysis of the literature.

Both the CNKI and PubMed databases were queried using the key phrase "ecological governance" Approximately 13,500 CNKI chapters and approximately 2400 PubMed chapters were searched. There are more studies on ecological governance in China, with an emphasis on environmental science and resource utilization, agricultural water and hydropower engineering, mining engineering, plant protection and resource science, physical geography and mapping, geology, agricultural engineering, sociology, and statistics.

Findings and themes: The assessment system of "vegetation-air-water" environmental coordination is a complicated and multi-dimensional topic, as shown by the analysis of the recovered literature. Ecological management has been shown to be crucial in fostering the integrated growth of plant life, atmospheric quality, and water supplies [16].

Key themes and findings that emerged from the review of the literature include:1) The significance of ecological governance in promoting coordinated development of vegetation, air, and water resources.2) The necessity of integrated evaluation systems that take into account the interdependencies of vegetation, air, and water resources within the context of ecological governance.3) Identification of essential indicators for assessing the efficacy of ecological governance in promoting the coordinated development of vegetation, air, and water resources.4) The role of innovation and technology in the development and implementation of the evaluation system. 5) The significance of the involvement and participation of stakeholders in the development and implementation of the evaluation system.

Summary of the literature review: The evaluation system of the "vegetation-air-water" environment is intricate and multifaceted, necessitating extensive research. Literature indicates that ecological management promotes the coordinated development of vegetation, oxygen, and water resources. The development and implementation of an effective assessment system requires the identification of key indicators, the use of technology and innovation, as well as the participation and funding of stakeholders [17].

2.3. History of research on coupling and coordination coefficient

Coupling and coordination coefficient research has a colourful history, which reflects the unrelenting pursuit and ongoing investigation of academicians in the field of "vegetation-air-water" environmental coordinated development evaluation system. To describe this history in greater detail, we can divide it into distinct phases.

(1) From the first half of the 20th century to the 1970s: Coupling and coordination coefficients were first proposed at the turn of the 20th century, but their actual development began in the middle of the century. The pertinent literature on coupling and coordination coefficients can be traced back to the 1972 research of ecologists Lee A. Segel and Julius L. Jackson, who used the concept of coupling and coordination coefficients in the 1970s and attempted to describe the degree of coordination within ecosystems using mathematical methods [18]. During this time, researchers worked to elucidate the definitions of coupling and coordination coefficients and investigated various calculation methods. Early work concentrated primarily on the development of the theoretical framework, which provided a firm foundation for later research.

(2) Interdisciplinary research and technological development from the 1980s to the 1990s: With the development of computer technology and remote sensing technology, scientists were able to analyze the coupling and coordination relationships in various ecosystems in greater detail. Ecologists such as Bernard C. Patten began to apply coupling and coordination coefficients to the study of ecosystem interactions [19]; and Michael F. Goodchild, a pioneer in geographic information systems (GIS), supported spatial analysis methods for coupling and coordination [20]. During this time period, interdisciplinary research involving diverse disciplines such as ecology, GIS, and meteorology increased. The study of the influence of various factors on the coupling and coordination coefficients, thereby enhancing our comprehension of their connotations, shifted progressively away from focusing solely on calculation methods.

(3) Application and policy support in the 21st century and beyond: In the twenty-first century, research on coupling and coordination coefficients has shifted from theoretical discussions to practical applications and policy support. The work of climatologist James E. Hansen highlighted the significance of coupling and coordination coefficients in climate change adaptation [21]. The relationship between coupling and coordination coefficients and practical issues such as ecosystem restoration, resource management, and climate change adaptation has been investigated by scientists. The research in this period emphasised the practical application and policy significance of the indicators and provided more scientific support for environmental decision-making.

In recent years, research on coupling and coordination coefficients has shifted further towards global cooperation and frontier. Coupling and coordination coefficients are the subject of a growing number of international collaborative initiatives that aim to transcend geographical and ecosystem boundaries and increase our understanding of these variables. Future challenges, such as the

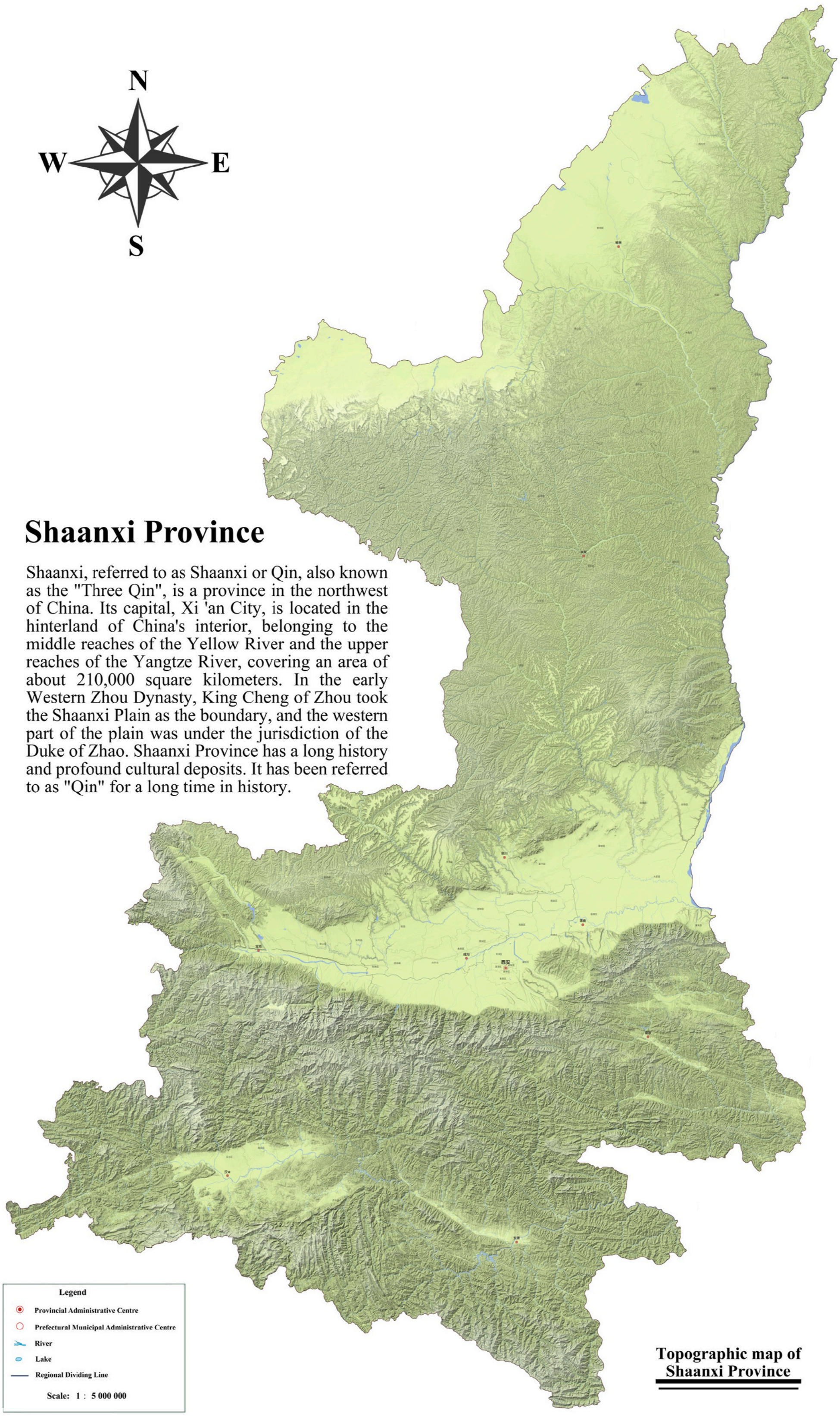

Fig. 2. Regional map of Shaanxi Province.

application of emerging technologies and the effects of global climate change on ECCD, are the focus of cutting-edge research.

In conclusion, the historical lineage of coupling and coordination coefficients research is an evolving process, from the conception of the concept and the development of methodology to practical applications and global frontier research, all of which contribute to the field's rich history. In addition to enhancing our understanding of the coordinated development of vegetation-air-water environments, these studies have also provided valuable experience and information for future research and policymaking.

3. Construction of "vegetation-atmosphere-water" coordinated development model

3.1. Overview of the study area

This paper uses Shaanxi Province as the research object to investigate the ecological construction and development of Shaanxi Province in detail. The following is a geographical overview of the Shaanxi Province region:

Shaanxi Province, abbreviated as "Shaanxi" and "Qin" (Fig. 2), is located in the middle reaches of the Yellow River in central China, and is separated from Shanxi Province by the Yellow River in the east, adjacent to Inner Mongolia Autonomous Region in the north, adjacent to Ningxia Hui Autonomous Region and Gansu Province in the west, and bounded by the main ridges of the Micang Mountains and the Dabashan Mountains, as The administrative division of Shaanxi Province is 205,624.3 square kilometres in size. At the end of 2022, the province had 39.56 million permanent residents. Shaanxi Province is one of China's most significant birthplaces. The lengthy history, rich culture, and unique geography of China gave rise to a civilization that has endured and flourished throughout the ages. Over the past thousand years, more than ten regimes or dynasties, including the Qin, Han, and Tang, have constructed their capitals in Shaanxi. The Mausoleum of the Yellow Emperor, the Terracotta Warriors and Horses, the Pagoda of Yan'an, the Qinling Mountains, and the Huashan Mountains, among others, are spiritual and natural markers of Chinese civilization, the Chinese Revolution, and Chinese geography.

3.2. "Vegetation-atmosphere-water" coupling relationship

Important to the function of an ecosystem, the "vegetation-atmosphere-water" coupling mechanism involves interactions and feedbacks between vegetation, atmosphere, and water (Fig. 3). The function of vegetation in modulating atmospheric composition and maintaining the hydrological cycle is essential [22]. By absorbing atmospheric carbon dioxide through photosynthesis and transforming it into organic matter, vegetation can lower greenhouse gas concentrations and mitigate climate change. Additionally, vegetation regulates the water cycle by capturing precipitation, decreasing surface discharge, and preventing soil erosion, thereby enhancing water quality and quantity. The interaction between vegetation and the atmosphere is also essential for plant development and growth. The atmosphere provides essential nutrients for plant growth, such as carbon, nitrogen, and oxygen, and modulates temperature and humidity, influencing plant growth and survival [23].

Another crucial part of the connected "vegetation-atmosphere-water" system is water sources. Vegetation development and the many ecosystem services it provides rely on the availability of both surface and groundwater [24]. Vegetation, in turn, has the power to control the water cycle by moderating surface runoff, improving infiltration, and boosting water storage capacity. Vegetation also

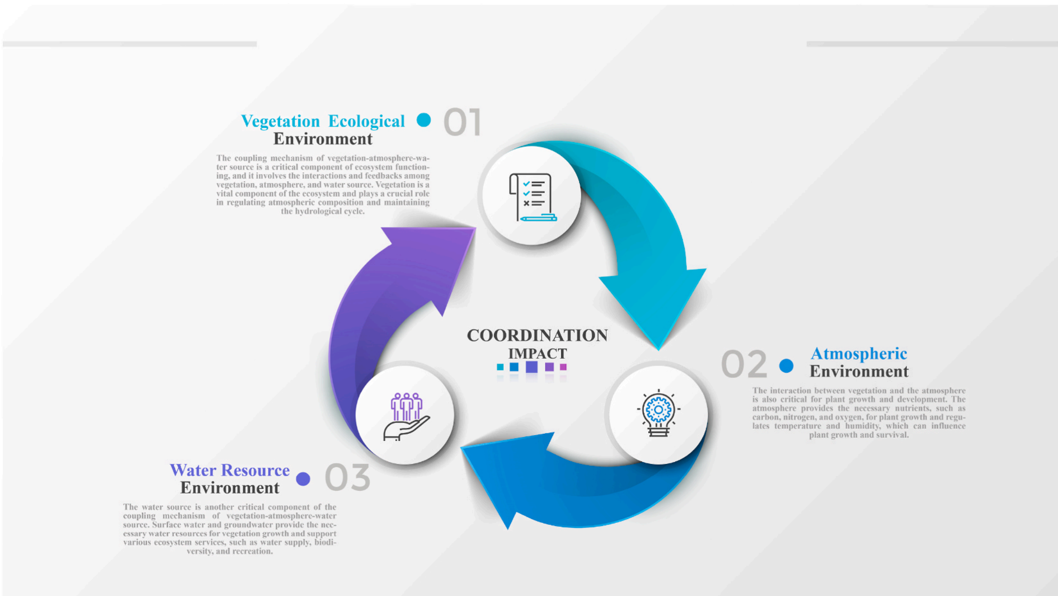

Fig. 3. "Vegetation-atmosphere-water" coupling mechanism.

mitigates erosion, decreases sedimentation, and filters out contaminants, all of which contribute to higher water quality [25]. Vegetation-atmosphere interactions also rely heavily on the water cycle. Plant growth and development may be affected by the amount of precipitation and humidity in the air, both of which are influenced by transpiration.

Vital to the health and longevity of ecosystems is the “vegetation-atmosphere-water” process. It manages and maintains environmental equilibrium through managing carbon and water cycles, reducing the effects of climate change, and supporting ecosystems. Sustainable development and ecological governance need an understanding of the feedbacks and interactions between plants, the atmosphere, and water. Therefore, to maintain ecosystem sustainability and resilience, it is important to evaluate the degree of coordination between these components and create effective ways to increase coupled vegetation-atmosphere-water source coordination.

The coupling mechanism of “vegetation-atmosphere-water” is shown in Fig. 3.

3.3. Indicator system construction

In constructing the indicator system, three subsystems were chosen at the guideline level: the vegetation ecological environment subsystem, the atmospheric environment subsystem, and the aquatic environment subsystem. In the subsystem of vegetation ecological environment, four evaluation indicators were chosen, including the area of closed forests, the number of environmental emergencies, the area of forest insect infestations, and the area of park green space. These indicators reflect the overall condition of the vegetation ecological environment, including preservation of vegetation, restoration of the ecological environment, and construction of park green space. The atmospheric environment subsystem selected three evaluation indicators, including sulfur dioxide (SO2) emissions, nitrogen oxide emissions, and haze (dust) and particulate emissions, from the dimensions of emissions, quality, and impact. These indicators reflect the level of pollution in the atmosphere and its impact on human health. For the water source environment subsystem, four evaluation indicators were chosen, including the total amount of ecological water replenishment, ammonia nitrogen emissions from industrial wastewater, COD emissions from industrial wastewater, and the quantity of subterranean water resources. These indicators represent the preservation of the water source environment and the use of water resources in a sustainable manner. In conclusion, a system of indicators for the coordinated development of the “vegetation-atmosphere-water” environment is constructed, and the pertinent data is presented in Tables 1 and 2.

(1) The rationale behind the selection of these indicators:

These indicators reflect the overall status of the vegetation ecological environment, including vegetation protection, ecological environment restoration, and park green space construction. These indicators were chosen because they are essential for the long-term development and enhancement of the vegetation ecosystem.

The atmospheric environment subsystem selected three evaluation indicators, including sulfur dioxide (SO2) emissions, nitrogen oxides emissions, and haze (dust) and particulate emissions, from the dimensions of emissions, quality, and impact. These indicators reflect the level of pollution in the atmosphere and its impact on human health. These indicators were selected because they are the fundamental indicators of the quality of the atmospheric environment and are crucial for monitoring and enhancing air quality.

For the water source environment subsystem, four evaluation indicators were chosen, including the total amount of ecological water replenishment, ammonia nitrogen emissions from industrial wastewater, COD emissions from industrial wastewater, and the quantity of subterranean water resources. These indicators reflect the degree to which the water source environment is protected and water resources are utilized in a sustainable manner. They were selected because they encompass important aspects of the water environment, aid in assessing the sustainability of water resources, and serve as essential resources for comprehending water quality.

Table 1
Coordinated development index system of “vegetation-atmosphere-water” environment.

Target layer	Guideline layer	Indicator layer	Unit	Characteristic
Ecology Governance under Environment Coordination Coordination Development (A)	Vegetation Ecosystem (B_1)	Closed forest area (C_{11})	10^3 Hectare	+
		Number of environmental emergencies (C_{12})	1/times	–
		Area of forest pest occurrence (C_{13})	10^4 Hectare	–
		Park green area (C_{14})	10^4 Hectare	+
	Atmospheric Environment (B_2)	Sulfur dioxide (SO2) emissions (C_{21})	10^4 ton	–
		Nitrogen oxide emissions (C_{22})	10^4 ton	–
		Fume (dust) and particulate matter emissions (C_{23})	10^4 ton	–
	Water Environment (B3)	Total ecological water recharge (C_{31})	$10^8 m^3$	+
		Ammonia nitrogen emissions from industrial wastewater (C_{32})	1/ton	–
		COD emissions from industrial wastewater (C_{33})	1 ton	–
		Groundwater Resources (C_{34})	10^8 m^3	+

Note: The nature is positive +, negative -.

Table 2
Raw data of indicators.

Year	Closed forest area	Number of environmental emergencies	Area of forest pest occurrence	Park green area	Sulfur dioxide emissions	Nitrogen oxide emissions
2012	65.6	−23	−27.01	0.96	−84.38	−80.81
2013	74.25	−118	−30.84	1.01	−80.62	−75.89
2014	52.24	−82	−30.9	1.1	−78.1	−70.58
2015	69.8	−58	−30.49	1.17	−73.5	−62.74
2016	63.87	−45	−29.33	1.22	−25.02	−39.44
2017	58.4	−32	−27.51	1.36	−18.58	−35.49
2018	75.22	−27	−24.39	1.41	−14.72	−33.94
2019	79.43	−26	−23.72	1.45	−14.33	−32.89
2020	84.98	−10	−23.65	1.66	−9.37	−26.62
2021	181.46	−9	−21.54	1.8	−8.11	−21.02

Year	Smoke (dust) and particulate matter emissions	Total ecological water recharge	Ammonia nitrogen emissions from industrial wastewater	COD emissions from industrial wastewater	Groundwater Resources
2012	−46.21	1.7	−8653	−98456	130.2
2013	−53.77	2.3	−8346	−95400	118.5
2014	−70.91	2.5	−8675	−95565	124.1
2015	−60.36	2.9	−9215	−109271	120.6
2016	−56.74	3.1	−1806	−20297	107.4
2017	−41.72	3.5	−821	−13870	141.6
2018	−31.2	4.8	−666	−9783	125
2019	−29.93	4.5	−536	−9489	139.4
2020	−28.43	5.2	−328	−9461	146.7
2021	−23.14	5.9	−297	−7121	200

(2) Listed below are the justifications for not selecting other indicators:

In constructing the indicator system, we analysed in depth the characteristics of each subsystem and the important factors for evaluating the environment's coordinated development. In order to guarantee the comprehensiveness and efficacy of the evaluation, we chose the indicators with the highest relevance and most direct impact. The following are reasons for not selecting other indicators.

A) Relevance and significance: the selected indicators have a high level of relevance and significance in their respective subsystems. They provide a comprehensive picture of the ecosystem of vegetation, the atmosphere, and the water, including quality, pollution levels, and sustainability. Therefore, these indicators are adequate to support environmental development assessment and decision-making.
B) Data Availability: Our evaluation is supported by data published by the government's statistics department over the years. Although there are other potential indicators to choose from, we need to ensure that the data for the selected indicators are continuously available within a certain timeframe in order to establish a reliable assessment system.
C) Simplicity and operationalization: Choosing the appropriate number of indicators can aid in simplifying the assessment procedure and enhancing operationalization. Too many indicators may result in complexity and unneeded difficulty, diminishing the indicator system's utility.

To assure the validity and practicability of assessing the coordinated development of the environment, our selection was deliberate. Other indicators were not chosen to maintain the assessment's focus and manageability.

Note: The data in the article are from the 2012–2022 China Environmental Statistical Yearbook, Shaanxi Statistical Yearbook, and other data published by government statistical departments in previous years.

3.4. Data dimensionless processing model

To eradicate the dimensionality and physical significance of each indicator, the normalization method was applied to raw data to dimensionless them. " Equation (1) ":

$$MMS_{C_i} = \frac{x - x_{Min}}{x_{Max} - x_{Min}} \tag{1}$$

Note: xMax denotes the maximum value and xMin denotes the minimum value.

Equation (1): Where MMS_ Ci represents the outcome of eleven secondary indicators without quantitative steel processing. Normalization is a method for simplifying calculations, in which the expression with a quantitative dimension is transformed into a dimensionless expression, which becomes a pure quantity. For example, the complex impedance can be normalized and written: Z = R + jωL = R (1 + jωL/R), the complex part becomes a pure quantity now, without a measure.

3.5. Comprehensive evaluation model

3.5.1. Entropy weighting method to determine objective weights

1) Calculation of the indicator entropy ei " Equation (2)":

$$e_i = -k \sum_{j=1}^{n} f_{ij} \ln f_{ij} \tag{2}$$

Equation (2): In the formula: $= \frac{1}{\ln n}$, $f_{ij} = \frac{u_{ij}}{\sum_{j=1}^{n} u_{ij}}$, and when $f_{ij} = 0$, $f_{ij} \ln f_{ij} = 0$.

2) Calculation of indicator weights Wi " Equation (3)":

$$w_i = \frac{1 - e_i}{m - \sum_{i=1}^{n} e_i} \tag{3}$$

3.5.2. TOPSIS evaluation model

1) Determine the positive and negative ideal solutions

Let y_k^+、y_k^- are the maximum and minimum values of each index, respectively, Then the positive ideal solution y_k^+and the negative ideal solution y_k^- are obtained. "Equation (4) and (5)":

$$y^{+} = \left(y_1^{+}, y_2^{+}, \cdots, y_m^{+}\right) \tag{4}$$

$$y^{-} = \left(y_1^{-}, y_2^{-}, \cdots, y_m^{-}\right) \tag{5}$$

2) Calculate the distance between the data of each indicator to the positive and negative ideal solutions "Equations (6) and (7)":

$$d_j^{+} = \sqrt{\sum_{i=1}^{m} \left(y_{ij} - y_k^{+}\right)^2} \tag{6}$$

$$d_j^{-} = \sqrt{\sum_{i=1}^{m} \left(y_{ij} - y_k^{-}\right)^2} \tag{7}$$

3) Calculate the closeness c_j "Equation (8)":

$$c_j = \frac{d_j^{-}}{d_j^{-} + d_j^{+}} \tag{8}$$

The greater the degree of closeness, the higher the level of the evaluation scheme.

3.6. System coupling coordination model

Coupling is the degree of interaction between two elements. The degree of coupling reflects the degree of interaction between the vegetation-atmosphere-water systems, but it cannot accurately quantify the synergistic effect of their overall development. In light of this, the article introduces a more scientific coupled coordination model, which is calculated using equation (9) below:

Table 3
Criteria for the classification of coupling coordination levels.

Coupling coordination degree D value interval	Coordination level	Degree of coupling coordination
(0.0–0.1)	1	Extremely dysfunctional
[0.1–0.2)	2	Severe disorders
[0.2–0.3)	3	Moderate disorder
[0.3–0.4)	4	Mild disorder
[0.4–0.5)	5	On the verge of disorder
[0.5–0.6)	6	Barely coordinated
[0.6–0.7)	7	Primary coordination
[0.7–0.8)	8	Intermediate coordination
[0.8–0.9)	9	Good coordination
[0.9–1.0)	10	Quality coordination

$$D = \sqrt{C \times T} \tag{9}$$

In the formula: $C = \left[\frac{c_1 c_2 c_3}{(c_1 + c_2 + c_3)^3}\right]^{1/3}$, C is the coordination index. c_1、c_2、c_3 are the posting progress of the 3 subsystems respectively. $T = \alpha c_1 + \beta c_2 + \gamma c_3$, T is the composite evaluation index; α, β and γ are the weights of each subsystem determined by the entropy weighting method, respectively.

The larger the D value, the better the coordination coupling.

The article draws on Wang Yuan et al.'s study of the grades of coordination and their classification criteria [26] to classify coupled coordination into 10 subcategories (Table 3).

4. Processing and analysis

4.1. Standardization of data

As can be seen in the subsequent table (Table 4), after the summation normalization for dimensionless processing, there are no outliers in the current data; therefore, the next stage of analysis is conducted directly on the data.

4.2. Entropy-weighted TOPSIS data weighting

(1) Entropy value method to calculate the weight results

Using the entropy value method to calculate the weights of a total of 11 items such as MMS_C11, it can be seen from the following table (Table 5) that a total of 11 items, MMS_C11, MMS_C12, MMS_C13, MMS_C14, MMS_C21, MMS_C22, MMS_23, MMS_C31, MMS_C32, MMS_C33, MMS_C34. Their weights are 0.146, 0.041, 0.118, 0.087, 0.102, 0.077, 0.059, 0.076, 0.108, 0.092, 0.093, and the weights of each item are relatively uniform, and they are all in the vicinity of 0.091. The weights were determined by the entropy method to assign weights to the data of the coupled analysis.

From the following table (Table 6), it can be seen that TOPSIS analysis was performed using the data generated by the entropy weighting method post-weighting (done automatically by the algorithm) for 11 indicators (MMS_C11, MMS_C12, MMS_C13, MMS_C14, MMS_C21, MMS_C22, MMS_23, MMS_C31, MMS_C32, MMS_C33. MMS_C34) for TOPSIS evaluation, while the number of evaluation objects is 10 (the number of sample size is the number of evaluation objects); TOPSIS method firstly finds out the positive and negative ideal solution values (A+ and A-) of the evaluation index, and then calculates the distance values D+ and D-of each evaluation object from the positive and negative ideal solutions, respectively.

Based on the D+ and D-values, the proximity of each evaluation object to the optimal solution (C-value) is finally calculated and can be ranked with respect to the C-value.

4.3. Analysis of coupling coordination

4.3.1. Analysis of the evolutionary trajectory of "vegetation-atmosphere-water" environmental correlation and coordination degree

The degree of coupling coordination between the integrated system and subsystems in the study area for the period 2012–2021 was determined using the formula for calculating the degree of coupling coordination, and the results of the calculation are displayed in Fig. 4.

As shown in Fig. 4, the coupling coordination degree of "vegetation-atmosphere-water" in the study area has a value of D of 01, with an average value of 0.408, which is on the verge of disorder, indicating that the proximity degree of the 11 indicators of the three subsystems is inconsistent with the state of increasing or decreasing in different years, which leads to a state of disorder.

In addition, between 2012 and 2021, the ecological coupling coordination degree's development trend in Shaanxi is expected to improve continuously. The T-value of the "vegetation-atmosphere-water" environment coordination index in Shaanxi increases from

Table 4
Data standardization processing base data.

Indicators	Sample size	Min	Max	Average value	Standard deviation	Median
MMS_C11	10	0.000	1.000	0.219	0.285	0.153
MMS_C12	10	0.000	1.000	0.688	0.316	0.812
MMS_C13	10	0.000	1.000	0.423	0.367	0.389
MMS_C14	10	0.000	1.000	0.421	0.327	0.393
MMS_C21	10	0.000	1.000	0.573	0.440	0.821
MMS_C22	10	0.000	1.000	0.550	0.371	0.725
MMS_23	10	0.000	1.000	0.558	0.335	0.564
MMS_C31	10	0.000	1.000	0.462	0.331	0.381
MMS_C32	10	0.000	1.000	0.592	0.465	0.886
MMS_C33	10	0.000	1.000	0.611	0.448	0.902
MMS_C34	10	0.000	1.000	0.302	0.277	0.218

Table 5
Summary of the results of the entropy value method for calculating weights.
(2) TOPSIS evaluation calculation results

item	Information entropy value e	Information utility value d	Weighting factor w
MMS_C11	0.7896	0.2104	14.60 %
MMS_C12	0.9407	0.0593	4.11 %
MMS_C13	0.8304	0.1696	11.77 %
MMS_C14	0.8742	0.1258	8.73 %
MMS_C21	0.8525	0.1475	10.23 %
MMS_C22	0.8886	0.1114	7.73 %
MMS_23	0.9152	0.0848	5.88 %
MMS_C31	0.8910	0.1090	7.57 %
MMS_C32	0.8438	0.1562	10.84 %
MMS_C33	0.8667	0.1333	9.25 %
MMS_C34	0.8661	0.1339	9.29 %

Table 6
TOPSIS evaluation calculation results.

Year	Positive ideal solution distance D+	Negative ideal solution distance D-	Relative proximity C	Sort Results
2012	0.273	0.074	0.214	7
2013	0.282	0.041	0.126	9
2014	0.290	0.036	0.112	10
2015	0.275	0.055	0.166	8
2016	0.213	0.164	0.434	6
2017	0.183	0.193	0.513	5
2018	0.155	0.219	0.586	4
2019	0.142	0.226	0.614	3
2020	0.126	0.244	0.660	2
2021	0.000	0.315	1.000	1

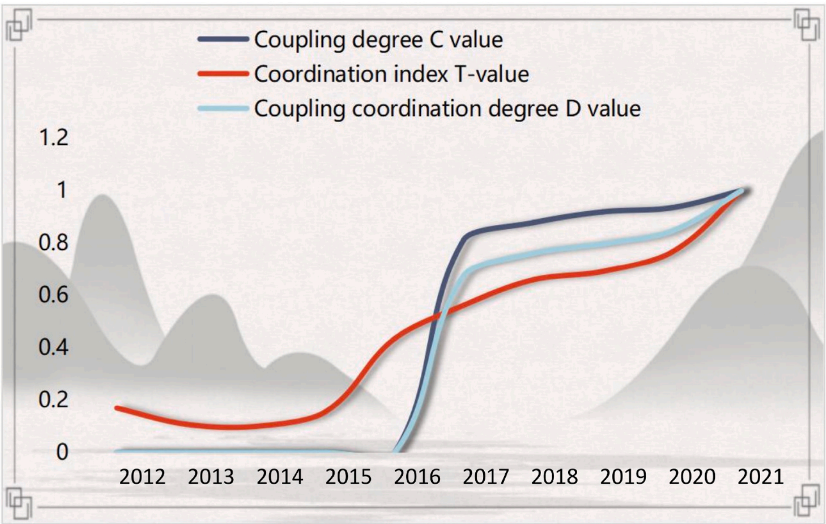

Fig. 4. Folding line diagram of coupling coordination coefficients.

0.17 in 2012 to nearly 1 in 2021, and the coupling coordination level shifts from "severe disorder" in 2012 to "high-quality coordination" in 2021. The level of coupling coordination transforms from "extremely dysfunctional" in 2012 to "high quality coordination" in 2021, and the coordination effect transforms from feeble to strong.

4.3.2. Analysis of the evolutionary stages and types of coupling coordination

Table 7 shows that the ecological coordination benefits in Shaanxi from 2012 to 2021 have gone through three major categories, each of which has five subcategories of coordination levels, from the uncoordinated development stage in the early stage of governance to the coordinated development stage in the middle stage of governance.

(1) Uncoordinated development in the early stages of government (2012–2016). The T-value of the coordination index increased from 0.17 in 2012 to 0.434 in 2016, with an average annual growth rate of 5.3 % and an overall sluggish upward trend, but the coupling coordination level is low and in the stage of uncoordinated development.
(2) Transformation development era during the midst of governance (2017–2019). In the stage of transformational development, the level of coupling coordination changes from feeble to strong, and the D value of coupling coordination raises to 0.79 in 2019, with a larger overall upward trend and a higher degree of coordination year by year.
(3) In the midst of governance, during the transformation development stage (2017–2019). Coordination between couplings improves from a low base to a high peak as the transformational development stage progresses, with the D value of coupling coordination reaching 0.797 in 2019.

5. Analysis of results

Since 2012, Shaanxi Province has made substantial strides in the coordinated development of its “vegetation-air-water” environment, as evidenced by the results presented above. The trend of the degree of coupling coordination’s development ranges from uncoordinated development to transitional development to coordinated development and preliminary governance outcomes. This suggests that the province of Shaanxi’s environmental management policies have had a positive effect on the ecosystem. Nevertheless, the research demonstrates that coordinated environmental development still faces obstacles. Interaction between policy influence and natural regulation is one of the most influential aspects of ecological governance. For instance, policies such as “returning farmland to forests” and “returning forests to ploughs” may hinder the development of extant vegetation, thereby diminishing the coordinated benefits of ecological governance. However, newly reclaimed farmland may not produce soil suitable for crop growth in the near future, thereby disrupting the original coordination system. This emphasises the necessity for policymakers to carefully consider the potential impacts of their policies on ecosystems and to implement measures to mitigate any negative effects.

In addition to policy influence and natural regulation, institutional arrangements, technological innovation, public participation, and economic development influence ecological governance. Environmental governance can be supported by institutional arrangements such as the establishment of environmental protection agencies and the creation of environmental regulations. Innovation in technology can provide new answers to environmental problems, while public participation can increase environmental protection measures’ visibility and support. In addition to influencing resource allocation and environmental regulation, economic growth can influence ecological governance. The evaluation system and analytical methods proposed in this study provide policymakers, researchers, and practitioners with valuable instruments to assess the efficacy of environmental governance policies and identify improvement opportunities. Incorporating multiple indicators and exhaustive analysis techniques, such as the coupled system coordination model, entropy weight is able to assess the state of a system’s entropy. The evaluation system, TOPSIS, facilitates a more in-depth comprehension of the influencing factors of ecological governance and the effects of environmental policies on ecosystems. The study of the factors affecting the coordinated development of the “vegetation-air-water” environment in Shaanxi Province generates novel concepts for ecological governance research. Future research on sustainable development and ecological governance may use the study’s findings as a deciding factor.

Simultaneously, ecological governance is a complex and multifaceted concept that is gaining importance as a means of promoting sustainable development and environmental protection. The coordinated development of “vegetation-atmosphere-water” is an essential aspect of ecological governance, and the evaluation system proposed in this paper provides a valuable tool for assessing the efficacy of ecological governance. The adaptability and flexibility of ecological governance to local environmental conditions and social contexts is one of its primary advantages. This means that eco-governance policies can be adapted to the unique requirements and challenges of various regions and communities, which is crucial for promoting sustainable development in a variety of contexts.

Table 7
Calculated results of coupling coordination.

Year	Coupling degree C value	Coordination index T-value	Coupling coordination degree D value	Coordination level	Degree of coupling coordination	Coordination phase
2012	0.000	0.170	0.000	1	Extremely dysfunctional	Early stage of governance
2013	0.000	0.108	0.000	1	Extremely dysfunctional	
2014	0.000	0.100	0.000	1	Extremely dysfunctional	
2015	0.000	0.155	0.000	1	Extremely dysfunctional	
2016	0.000	0.434	0.000	1	Extremely dysfunctional	
2017	0.813	0.562	0.676	7	Primary Coordination	Mid-term governance
2018	0.878	0.659	0.761	8	Intermediate Coordination	
2019	0.919	0.691	0.797	8	Intermediate Coordination	
2020	0.935	0.766	0.846	9	Good coordination	The first signs of governance effective
2021	1.000	1.000	1.000	10	Quality Coordination	

Nonetheless, the applicability and efficacy of eco-governance vary considerably across regions and contexts. For instance, factors such as political stability, institutional capacity, and socioeconomic development can impact the success of eco-governance policies, and these factors can vary considerably between regions and countries.

In conclusion, the evaluation system proposed in this paper is capable of evaluating the efficacy of ecological governance policies in the region. Nevertheless, it is essential to recognise that the applicability and effectiveness of eco-governance depend on a variety of factors, including cultural norms, political structures, and economic development. In addition, our findings suggest that there may be significant disparities in the efficacy of ecological governance policies in various regions, depending on the specific environmental and ecological challenges encountered by different regions. For instance, policies aimed at improving water resource management and conservation may be more effective in regions where water scarcity is a major issue, whereas policies aimed at reducing industrial and transport emissions may be more effective in regions where air pollution is a major issue. This evaluation system is a useful instrument for assessing the efficacy of ecological governance policies for the coordinated development of vegetation-atmosphere-water in Shaanxi Province and elsewhere. Nonetheless, it is essential to recognise the complexity and multifaceted character of ecological governance and to tailor policies and strategies to the unique requirements and challenges of different regions and communities.

6. Exploration

(1) Policy Effects Study

A) Consequences for existing policies: This study's evaluation system and model provide a scientific foundation for current environmental governance policies. In particular, by analysing the coordinated development of the three subsystems of vegetation, atmosphere, and water, we can identify policy flaws and potential improvement areas. These findings can be used to revise and optimise existing policies in order to more effectively achieve the objective of coordinated ecosystem development.

B) Possible routes for policy effects: In addition to influencing the modification of existing policies, policy effects can also inspire the creation of new policy initiatives. The findings of this study could inform the formulation of new environmental governance policies. For instance, if the study reveals that vegetation ecosystems in a specific region are closely associated with atmospheric quality and water conservation, policymakers may consider implementing measures that place a greater emphasis on vegetation conservation.

C) Utilising international experience: When conducting policy impact analyses, it is beneficial to consider international experience. There may be variations in the environmental governance policies of various nations and regions, but successful policy practises can be shared. The findings of this study can serve as a foundation for international exchanges of knowledge and assist nations in addressing global environmental challenges collectively.

In general, policy impact analysis involves not only ruminating on and enhancing current policies, but also inspiring and guiding future policies. By examining how the findings of this study interact with environmental governance policies, we can accomplish environmentally coherent development and contribute to sustainable development more effectively. Analyses of policy impact will be a crucial step in translating research results into applicable policies and actions.

(2) Limitations of this research

A) Limited Number of Available Indicators

In constructing the indicator system, we chose three subsystems at the level of the guidelines, but only a few evaluation indicators. For instance, for the subsystem of the vegetation ecosystem, we chose indicators such as the area of closed forests, the number of environmental emergencies, the area of forest pests, and the area of park green space. Despite the fact that these indicators reflect a particular vegetation ecological environment, they still need to be expanded to encompass the diversity and complexity of the vegetation system more thoroughly.

B) Consideration of socioeconomic considerations

This study focuses primarily on natural environmental factors, but socioeconomic factors influence the coordinated development of the environment. Future research could examine the impact of socioeconomic factors on coordinated environmental development in a more unified fashion. Population growth, urbanisation, and industrial structure, for instance, may have a significant impact on the efficacy of environmental governance. For a comprehensive understanding of the dynamic process of coordinated environmental development, researchers can investigate how to integrate natural environmental factors and socio-economic factors.

C) Exhaustive investigation of subsystem interactions

Although we developed evaluation indicators for each subsystem, future research could delve deeper into the intricate interactions between these subsystems. This will aid in the comprehension of their interactions and synergies in ecological governance. For instance, how changes in vegetation influence the purity of the atmosphere and how changes in the water environment impact vegetated ecosystems.

(3) Future Directions of Research

A) Variations in Vegetation Ecosystems

Future research could investigate the dynamic variations of vegetation ecosystems in greater detail. Increasing climate change and human intervention [27] are likely to present vegetation ecosystems with more challenges. In order to maintain and enhance the stability and resilience of vegetation ecosystems, extensive research is required. This includes research on the efficacy of various vegetation varieties, such as forests, grasslands, and wetlands, under varying climatic and soil conditions.

B) Implementation of New Technologies and Procedures

Researchers can investigate the application of new technologies and methods to the evaluation of coordinated environmental development as a result of the continuous advancement of science and technology. For instance, the continuous development of remote sensing technology and satellite data enables more precise monitoring of vegetation cover and atmospheric pollution [28]. Complex datasets can also be analysed using big data analysis techniques and artificial intelligence algorithms to improve the accuracy and timeliness of assessments. Future research could concentrate on how to optimise the use of these new technologies to enhance environmental assessment techniques for coordinated development.

C) Regional variations and policy modification

Environmentally consistent development may vary not only between nations, but also between regions within the same nation. Future research could focus more on regional differences in order to comprehend the effects of environmental governance under varying geographical, climatic, and social conditions. In addition, researchers could investigate how to develop policies and measures for coordinated environmental development that are more regionally adaptive [29]. This includes gaining a deeper comprehension of environmental challenges and SDGs in various regions and adapting policies to local circumstances.

In conclusion, future research can bolster and expand this study's foundation in a number of ways. These research directions and enhancements can provide additional scientific support for the formulation and implementation of environmental governance policies, thereby contributing to the advancement of ecological governance and sustainable development. We can better safeguard the natural environment while attaining sustainable socioeconomic development if we continue to focus on these issues.

7. Conclusion

In this study, we highlight the significance of ecological governance for the harmonious development of the "plant-air-water" ecosystem. We conducted an in-depth study on the benefits and influencing factors of environmental governance in Shaanxi Province by constructing an evaluation system and deploying comprehensive analysis methods. The study's findings demonstrate that the trend of coordinated development has progressively evolved from initial uncoordinated development to transformed development and then to coordinated development, exhibiting the first indications of governance. Despite these positive results, coordinated environmental development still confronts a number of obstacles, including the impact of policy changes and natural laws. We propose solutions to eliminate these obstacles and enhance the efficacy of environmental governance policies in order to address these obstacles.

This study contributes significantly to our understanding of ecological governance and its effect on coordinated development. Our evaluation system and analytical methodology can serve as a useful instrument for policymakers, researchers, and practitioners to promote ecological governance and sustainable development. In the future, it is essential to continue monitoring environmental governance and adjusting policies as necessary to ensure that we are on course to achieve our objectives. We can create a better future for our planet and all of its inhabitants by collaborating and implementing evidence-based strategies.

Data availability statement

The data used to support the findings of this study are in cluded within the article.

CRediT authorship contribution statement

Weidi Zhang: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Conceptualization. **Lei Wen:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Weidi Zhang reports a relationship with Shaanxi University of Science and Technology that includes: employment. No If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The support of the following projects is gratefully acknowledged: "Project of Youth Fund for Humanities and Social Sciences, Ministry of National Education of China: Research on Cultural Genetics and Contemporary Remodelling of Landscape Formation of Han and Tang Villages (23XJC760003), Project of Social Science Foundation of Shaanxi Province, China: Research on Survey Data Mining and Resource Value of Revolutionary Cultural Relics in Shaanxi (2023GM03), Construction Project of Philosophy and Social Science Key Research Base of the Department of Education (Colleges and Universities) of Shaanxi Province, China: Research on the External Communication of Shaanxi's Excellent Culture and Mutual Appreciation of Civilisations in the Age of 5G (21JZ018)".

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