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Comprehensive Evaluation and Coupled Coordinated Development Study of Water–Economic–Ecological Systems in the Five Northwestern Provinces of China

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Abstract: The five northwestern provinces face numerous challenges in sustainable development, particularly water scarcity, economic imbalances, and ecological degradation. This study aims to deeply assess the region's water resource conditions, the current status of economic development, and the health of the ecosystem while exploring the relationships and coupling mechanisms among them. Using the obstacle model, the research analyzes the primary barriers affecting these three significant factors in the region. The study further reveals a continually improving trend of coordinated development within the water–economic–ecological system in the five northwestern provinces of China, indicating that water usage per ten thousand GDP is the primary obstacle. This research enriches our understanding of the development in China's five northwestern provinces and provides a theoretical foundation for achieving sustainable development.

Keywords: five northwestern provinces; water–economic–ecological systems; analyzes the primary barriers

Citation: Shi, J.; Yang, H.; Wang, F.; Sun, D.; Run, Y. Comprehensive Evaluation and Coupled Coordinated Development Study of Water–Economic–Ecological Systems in the Five Northwestern Provinces of China. *Water* **2023**, *15*, 4260. https://doi.org/10.3390/w15244260

Academic Editors: Francisco De Borja Montaño Sanz and Joaquin Melgarejo

Received: 3 November 2023
Revised: 14 November 2023
Accepted: 6 December 2023
Published: 12 December 2023

1. Introduction

Water resources, economic development, and ecosystems are three crucial aspects of regional sustainable development. As an integral part of China's western region, the five northwestern provinces and regions (Gansu, Ningxia, Qinghai, Shaanxi, and Xinjiang) possess abundant natural resources and unique geographical advantages [1]. However, the long-term impacts of natural conditions and human activities have led to increasingly prominent challenges in water supply–demand conflicts, imbalanced economic development, and ecosystem degradation, severely constraining the area's sustainable development [2].

Over the past few decades, the five northwestern provinces and regions have achieved significant development in industry, agriculture, and urbanization [3]. However, this development often comes at the cost of sacrificing the environment and ecosystems. Issues such as water scarcity, water pollution, land degradation, and deteriorating ecological conditions have become urgent and significant challenges to be addressed [4]. Moreover, with the increasing severity of global environmental problems, the region faces even more formidable tests in balancing economic growth and environmental protection [5].

Researchers have proposed various evaluation index systems to quantify the interactions between water resources, socio-economics, and ecosystems. These systems typically include indicators such as water resource availability, water use efficiency, economic development levels, social welfare, and ecosystem health. Through these indices, researchers can evaluate the degree of coupling and coordination in different regions and time periods.

To more accurately assess the relationships between water, socio-economics, and ecosystems, various mathematical models have been introduced by researchers. These models can predict based on historical data and can also be used to simulate the impact of different management strategies on the coupled system. There have been numerous empirical studies worldwide that analyze the coupling and coordination relationships of water, socio-economics, and ecosystems under different geographical, climatic, and economic conditions. These empirical findings provide valuable references for decision-makers, aiding them in formulating more rational water resource management strategies. Based on the research results of coupling and coordination evaluations, many scholars have proposed specific management strategies and policy recommendations. These suggestions aim to achieve sustainable utilization of water resources, promote healthy socio-economic development, and protect the integrity of ecosystems.

In summary, while significant progress has been made in research on the coupling and coordination evaluation of water, socio-economics, and ecosystems, there remain numerous challenges, such as accurately quantifying interactions between systems and developing more effective management strategies. Therefore, in-depth research on the comprehensive evaluation and coupling coordination of water resources and comprehensive consideration of sustainable development strategies, economic development, and ecosystems in the five northwestern provinces and regions is of great significance for formulating scientifically reasonable development strategies, promoting rational resource allocation, improving the ecological environment, and achieving sustainable development [6].

Firstly, this paper will conduct an in-depth evaluation of water resources in the five northwestern provinces and regions [7–10]. Water is the source of life, and in such arid areas, the scarcity of water resources is particularly pronounced. By studying the total water resources, the distribution pattern of water resources, and the utilization of water resources in each province and region, we can gain a comprehensive understanding of the current situation and challenges facing the water resources in the five northwestern provinces and regions. Special attention needs to be paid to the rationality and sustainability of water resource development and utilization, as well as the impact of water resources on the ecosystem, to ensure the reasonable distribution and efficient utilization of water resources [11–13]. Secondly, this research will conduct a comprehensive evaluation of economic development in the five northwestern provinces and regions. While the region has achieved rapid economic growth in the past few decades, imbalances in economic development still exist. Some provinces have made significant breakthroughs in economic development, while others lag behind. Therefore, it is necessary to analyze the economic structure, industrial layout, and driving factors of economic growth in different provinces and regions to find effective ways to promote coordinated economic development. In addition, this paper will also assess the state of ecosystems in the five northwestern provinces and regions. The degradation of the ecological environment has become a major factor constraining the region's sustainable development. We will focus on the integrity of natural ecosystems, the protection of biodiversity, and the stability of ecosystem functions. In-depth understanding of the threats and pressures on ecosystems will help formulate corresponding strategies for ecological protection and restoration to achieve a win-win situation for the economy and the ecosystem. Lastly, this research will focus on exploring the interrelationships and coupling mechanisms among water resources, economic development, and ecosystems in the five northwestern provinces and regions. These three aspects have close interconnections and feedback relationships. Economic development requires a considerable amount of water resources, while excessive exploitation and pollution of water resources can also negatively impact economic sustainable development and people's quality of life [14–16]. At the same time, ecosystem deterioration also affects water resources and the economy negatively [16,17]. Therefore, we need to find a path of coordinated development among water resources, economic development, and ecosystems and explore the feasibility of protecting the ecological environment while promoting economic growth [18].

In conclusion, this paper aims to conduct an in-depth analysis of the current situation of water resources, economic development, and ecosystems in the five northwestern provinces and regions, exploring their interrelationships and coupling mechanisms, and proposing corresponding development strategies and recommendations based on practical conditions. By comprehensively assessing the integrated development of water resources, economic development, and ecosystems and providing comprehensive consideration of the interaction between indicators, we hope to provide theoretical references and practical guidance for promoting the sustainable development of the five northwestern provinces and regions and enhancing the overall development level of China's western region.

2. Materials and Methods

2.1. Study Area

The five northwestern provinces of China are located in arid and semi-arid regions (Figure 1), facing significant challenges in water resources. The Yellow River Basin serves as a crucial water source for the region. However, years of excessive extraction and improper usage have resulted in reduced water flow and declining water quality in the Yellow River. Moreover, the impact of climate change has led to irregular rainfall patterns and exacerbating drought conditions. In regions like Ningxia and Xinjiang, where rivers are scarce, strict water conservation measures are essential to meet the demands of daily life and agriculture. To address water scarcity, the government has implemented various measures, including water resource allocation and transfer projects, integrated water management, and the promotion of water-saving technologies.

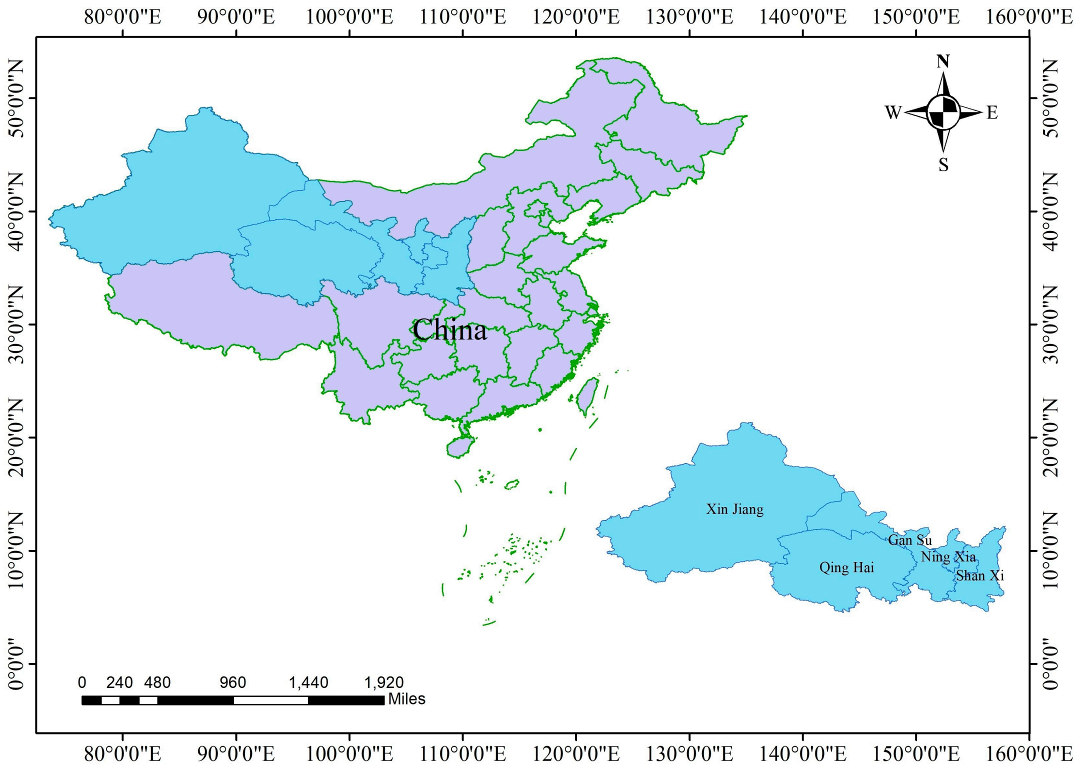

Figure 1. Overview map of the five northwestern provinces in China.

The five northwestern provinces have made remarkable progress in economic development, benefiting from government support and open policies that have provided new opportunities for industrial upgrading and growth. These provinces are actively developing their respective advantageous industries, fostering economic diversification. Shaanxi Province relies on its rich historical and cultural resources, actively promoting cultural tourism. Gansu Province has boosted economic growth through infrastructure development and the expansion of emerging industries. Qinghai Province is focused on developing green energy, tourism, and modern agriculture to build eco-friendly and livable cities. In Ningxia and Xinjiang, the emphasis lies on energy, metallurgy, and chemical industries, while also increasing efforts to alleviate poverty and improve residents' income. However, striking a balance between economic development and resource conservation remains a challenge. The government needs to take effective measures to ensure the sustainability of economic growth while protecting the environment and people's well-being.

The five northwestern provinces possess unique natural landscapes and are significant ecological conservation areas in China. However, due to excessive exploitation and improper utilization, some regions are facing threats to their ecological environment. In grassland areas, overgrazing and grassland degradation have led to soil erosion and desertification, disrupting the ecological balance. Desertification is also becoming increasingly severe, with desert areas expanding and posing serious threats to neighboring regions. The government has recognized the urgency of ecological conservation and has implemented various measures, such as afforestation, returning farmland to forests and grasslands, and desertification control, to restore and protect the ecological environment.

In conclusion, as an essential geographic region in China, the five northwestern provinces face numerous challenges and opportunities. The government needs to increase investment and policy support to promote regional coordinated development, sustainable economic growth, and environmental protection. Strengthening international cooperation and learning from international best practices are of vital significance for solving the region's significant issues.

2.2. Coordinated Evaluation Index System for Coupling of Five Northwestern Provinces in China

In the process of constructing the index system, the indicators we choose follow the sustainable development strategy and the people-oriented principle and build a scientific evaluation index system. The principles for constructing the evaluation index system for the coupling coordination of water resources, socio-economic factors, and ecological environment in the five northwestern provinces are as follows.

Systematic Principle: The evaluation index system should comprehensively consider various factors such as water resources, socio-economic aspects, and the ecological environment, forming a systematic evaluation framework to ensure mutual interactions and coordination among these factors [19]. Scientific Principle: The selection and design of indicators should be based on scientific theories and empirical research, ensuring the accuracy and reliability of the indicators. This will provide scientific interpretability and comparability of the evaluation results [20–22].

Operability Principle: The evaluation indicators should be feasible for measurement and calculation in practical applications, facilitating assessment and comparison in real-world scenarios. Balancing Principle: The selection of indicators should strike a balance among different factors, avoiding excessive emphasis on one aspect at the expense of others [23]. This approach achieves the coordinated development of water resources, socio-economic factors, and the ecological environment. Sustainability Principle: The evaluation index system should consider the requirements of long-term sustainable development, ensuring that the evaluation results can reflect the system's evolution and changes. This guides decisions and management toward sustainability. Applicability Principle: The index system should be adjusted and optimized based on the actual conditions of the five northwestern provinces, adapting to the characteristics and needs of different regions, thus enhancing the applicability and effectiveness of the evaluation [24].

Participatory Principle: During the construction of the evaluation index system, the opinions and suggestions of various stakeholders should be fully considered, enhancing the participatory and democratic nature of the evaluation.

The principles for constructing the evaluation index system for coupling coordination encompass a comprehensive approach that balances relationships among different factors. The aim is to objectively and comprehensively reflect the status and development trends of water resources, socio-economic factors, and the ecological environment in the five northwestern provinces [25–28].

The evaluation framework of this study consists primarily of three criterion layers and sixteen indicator layers (Figure 2). These criterion layers encompass the water resources system, the socio-economic system, and the ecological environment system. Each of these systems incorporates relevant indicators, aiming to ensure the accuracy of the assessment for the coupling coordination of water resources, society, and ecology in the five northwestern provinces of China. The water resources system comprises six indicators: Per Capita Water Resource Quantity, Proportion of Groundwater Supply, Water Resource Development and Utilization Rate, Per Capita Domestic Water Consumption, Water Consumption per Ten Thousand Yuan of Industrial Value Added, and Effective Irrigation Water Use Coefficient for Farmland. The socio-economic system includes five indicators: Per Capita GDP, Water Consumption per Ten Thousand Yuan of GDP, Per Capita Industrial Output Value, Natural Population Growth Rate, and Per Capita Urban Road Area. The ecological environment system encompasses five indicators: Urban Green Coverage Rate, Proportion of Ecological Water Use, Wastewater Treatment Rate, Annual COD Emissions, and Proportion of Rivers with Water Quality Class III or Higher. These three criterion layers and sixteen indicator layers are interrelated, collectively forming the evaluation index system for the water resources, socio-economic, and ecological systems in the five northwestern provinces.

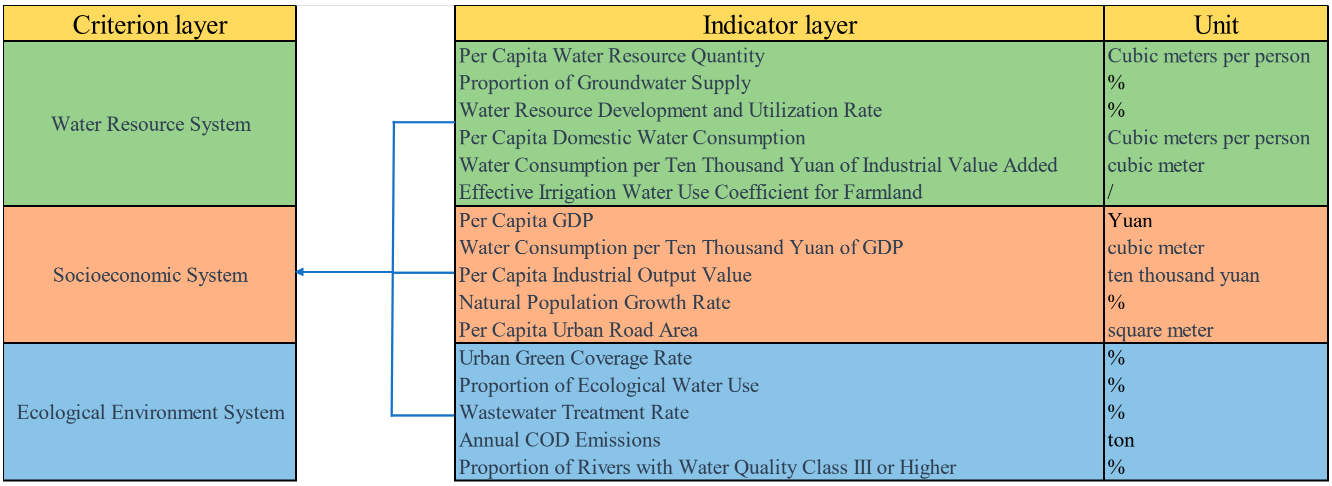

Figure 2. Evaluation framework for coupling coordination of water resources, socio-economic factors, and ecological systems in the five northwestern provinces.

2.3. The Weighting Method

$$x_{\mathrm{ij}} = \left(x_{\mathrm{ij}} - \overline{X_j}\right)/S_j$$

In the formula, x_{ij} is the original value of the evaluation index; $\overline{X_j}$ is the mean value of item j; and S_j is the standard deviation of indicator j.

Improved coefficient of variation (ICV):

$$V_i = \frac{\sigma_i}{\bar{i}}$$

$$w_i = \frac{w_i - c_i}{\sum_{i=1}^{n} w_i - c_i},\ i = 1, 2, \ldots, n$$

In the formula, $\bar{i}$ and σ_i represent the mean and standard deviation of the indicator. i_k and j_k represent the Eth sample values of indicators i and j, respectively, while $\bar{j}$ represents the average value of indicator j.

2.4. Three-Subsystem Comprehensive Evaluation Method

$$R_{WR} = \sum_{j=1}^{m} W_{ij} \times X_{ij}$$

$$R_{ES} = \sum_{j=1}^{m} W_{ij} \times X_{ij}$$

$$R_{EE} = \sum_{j=1}^{m} W_{ij} \times X_{ij}$$

$$T = a \times R_{WR} + b \times R_{ES} + c \times R_{EE}$$

In the formula, R_{WR}, R_{ES}, and R_{EE} are the comprehensive evaluation indices of water resources, the economic society, and the ecological environment system, respectively; T is the comprehensive evaluation index of the three systems; and a, b, and c are the weights of each system, a = b = c = 1/3.

2.5. Evaluation Method of Coupling Coordination Degree

$$C = 3 \times \left\{ \frac{R_{ES} \times R_{EE} \times R_{WR}}{(R_{ES} + R_{EE} + R_{WR})^3} \right\}^{1/3}$$

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

In the formula, C is the coupling degree and D is the coupling coordination degree.

Classification of the CCI Index

The evaluation method we constructed comprehensively considers the interaction among the selected indicators. When calculating the weight of the indicators, we consider the comprehensive weight value of objective and subjective weights so as to consider the integrity of the overall structure of the evaluation system. After considering the multifaceted factors of water resources, socioeconomic development, and ecological environment in the five northwestern provinces of China, these regions can be categorized into six levels to depict the overall degree of coordination. The first level, “Maladjustment”, encompasses areas such as Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang, characterized by scarce water resources, low socioeconomic development, and a fragile ecological environment, posing significant challenges to coordination. The subsequent level, “Borderline disorder”, pertains to regions with limited socioeconomic development, despite facing water scarcity and gradual ecological degradation. Following this is the “Primary coordination” level, covering areas where water resources are relatively limited, but socioeconomic development is gradually improving and ecological environment protection is swiftly advancing. Progressing to the “Intermediate coordination” level, these areas exhibit efficient water resource utilization, ongoing socioeconomic development, and continuous enhancement of the ecological environment. The “Advanced coordination” level includes a few regions marked by abundant water resources, high socioeconomic prosperity, and excellent ecological conditions, showcasing a trend of balanced development. Finally, the top tier is “Quality coordination”, encompassing regions with abundant water resources, highly developed socioeconomic status, and a favorable ecological environment. This multi-tiered classification system offers a nuanced reference for assessing and managing the water-resource, socioeconomic, and ecological coordination of the five northwestern provinces, guiding the formulation and implementation of sustainable development strategies. The classification criteria of this study are presented in Figure 3.

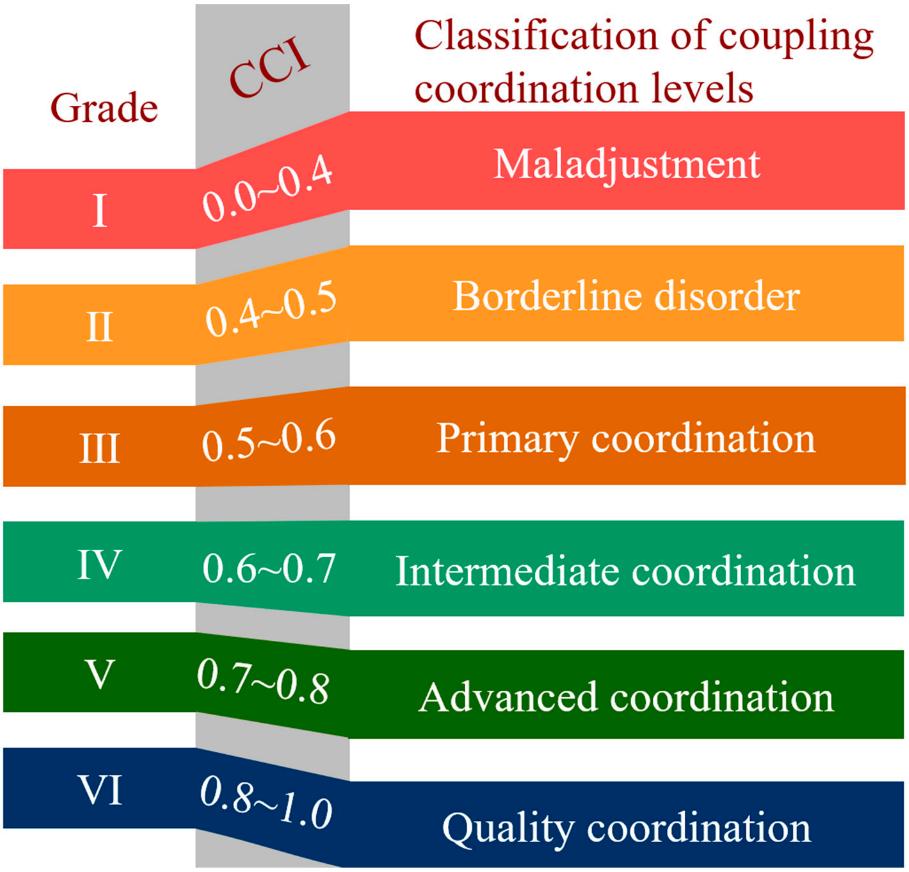

Figure 3. Classification criteria chart for the five northwestern provinces.

2.6. Coupling Coordination Degree Obstacle Factor Analysis

This study introduced the obstacle degree model, analyzed the obstacle factors of each index in the evaluation system, determined the main obstacles affecting the health of the water cycle, and formulated targeted improvement measures. The specific steps of obstacle factor analysis are as follows.

(1) Calculate the contribution degree F_j of the j evaluation indicator:

$$F_j = w_i^* \times w_i$$

In the formula, w_i^* represents the weight value of the corresponding criterion layer for the indicator.

(2) Calculate I_j, which represents the deviation degree.

$$I_j = 1 - x_{ij}$$

(3) Calculate P_j, which represents the obstacle degree of each evaluation index.

$$P_j = \frac{F_j I_j}{\sum_{j=1}^{n} F_j I_j}$$

3. Results

3.1. Coupling Coordination Results

3.1.1. Weight Calculation Results of the Evaluation Index System for Water Resources, Socio-Economic Factors, and Ecological Environment

Within the criteria layer, the highest-weighted criterion is the ecological environment system, with a weight value of 0.4856, while the weight values for the water resources system and the socioeconomic system are approximately equal, at 0.2492 and 0.2652, respectively. Within the indicator layer, the highest-weighted indicator is the proportion of rivers with water quality above Class III in the ecological environment system, with a weight value of 0.16617. Following this is the effective utilization coefficient of irrigation water in the water resources system, with a weight value of 0.15460. The indicator with the lowest weight value is the per capita water resources in the water resources system. The weight distribution diagram of the evaluation indicator system is shown in Figure 4.

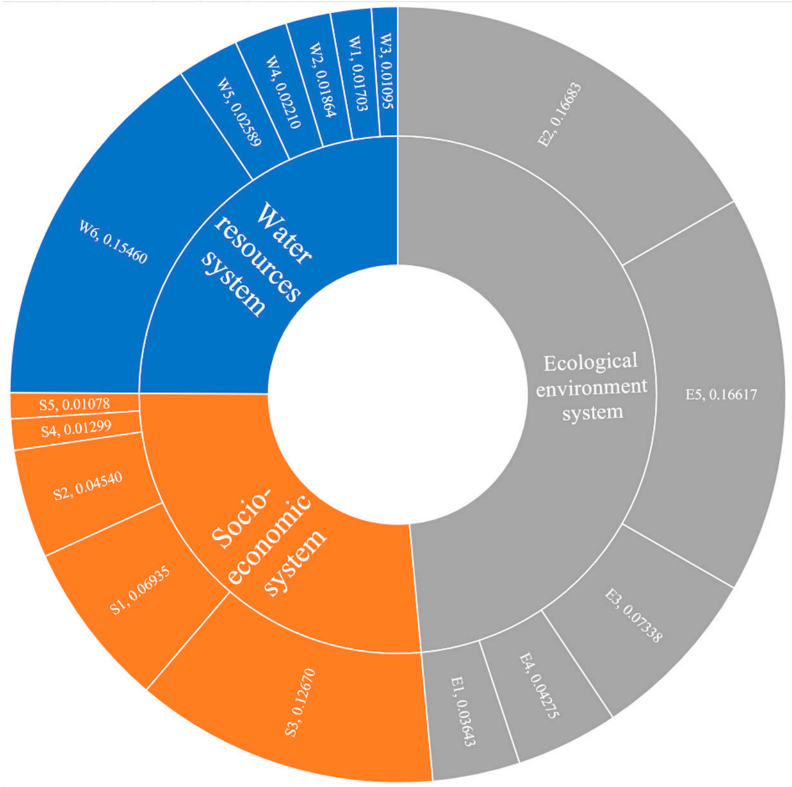

Figure 4. Weight distribution diagram of the evaluation indicator system.

3.1.2. CCI Temporal and Spatial Change Analysis

This study first conducts a comprehensive evaluation of water resources, the ecological environment, and socio-economic aspects in the five provinces and regions of northwestern China. The evaluation results indicate that, overall, the comprehensive evaluation scores of water resources, ecological environment, and socio-economic aspects in these five provinces and regions have been gradually improving.

Spatial analysis reveals that Xinjiang and Qinghai have higher scores in ecological environment and water resources, but lower scores in socio-economic aspects. This is primarily due to their significant industrial development, which has a considerable impact on their socio-economic indicators, while human activities have had a relatively lower negative impact on their ecological environment. On the other hand, Shaanxi, Gansu, and Ningxia have higher socio-economic scores, largely attributed to the substantial influence of human activities on their ecological environment.

In terms of the temporal aspect, the comprehensive scores for these five provinces and regions were relatively low before 2015. However, after 2015, with the introduction of various national policies, there has been a significant enhancement in the scores for all three criteria in these areas. The comprehensive evaluation results are depicted in Figure 5.

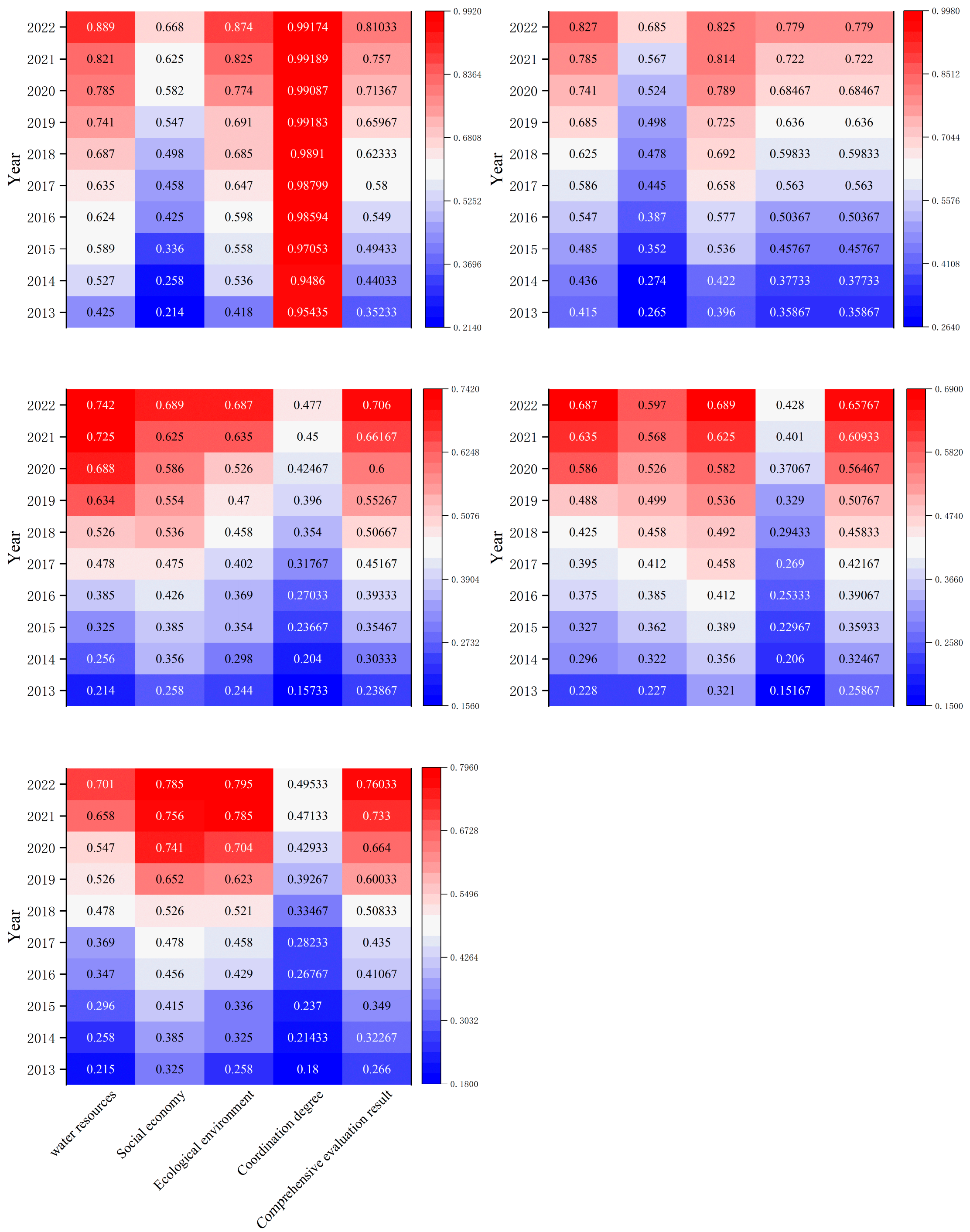

Figure 5. Evaluation results at the criterion level.

Based on the evaluation results at the criterion level and the corresponding calculation of coupling degrees, this study comprehensively analyzes the coupling coordination of water resources, socio-economic aspects, and the ecological environment in the five provinces and regions of northwestern China. In order to clearly depict the temporal and spatial variations of coupling coordination among these provinces and regions, this study employs ArcGIS maps (Figure 6) and bubble charts (Figure 7) to vividly illustrate the changing trends over time and space.

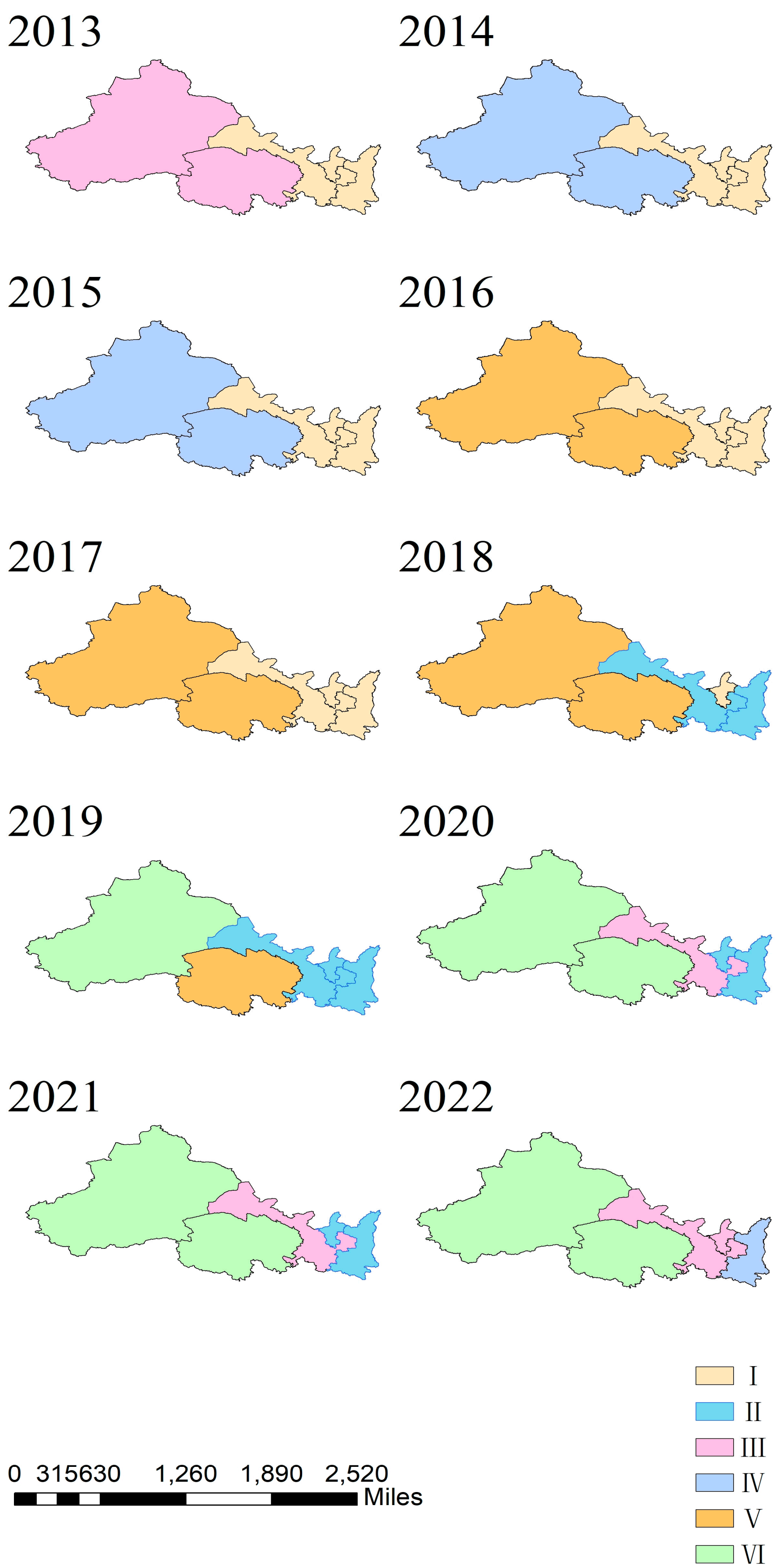

Figure 6. GIS map of the coupling coordination results.

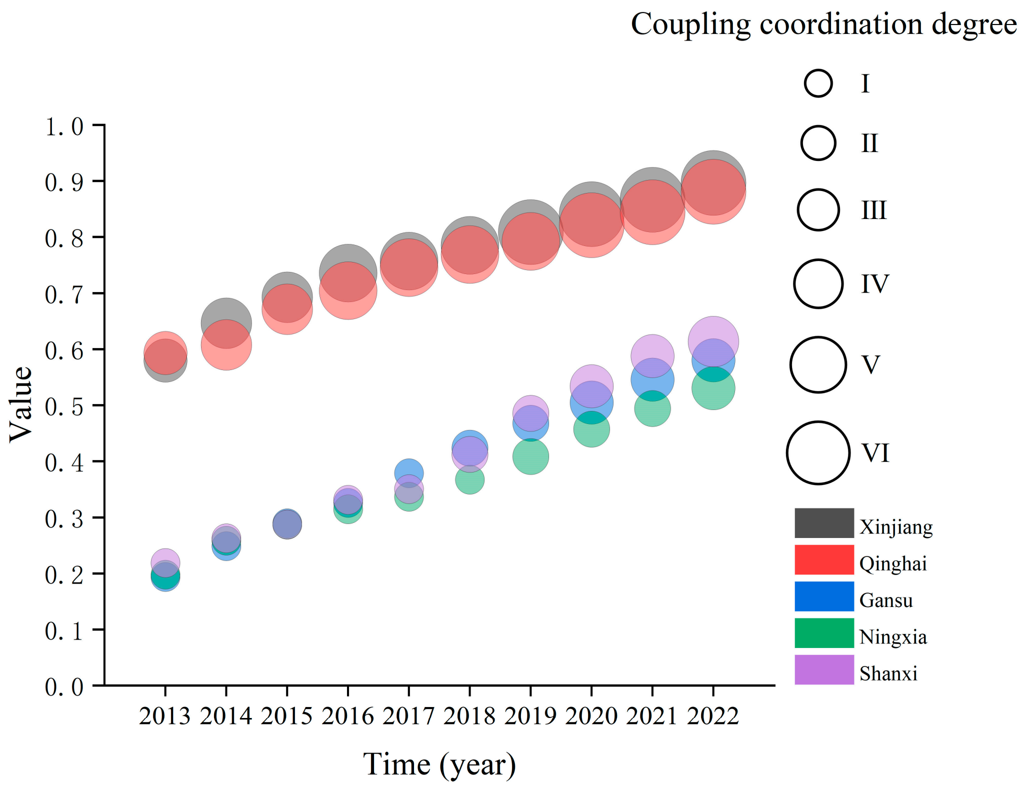

Figure 7. Bubble chart of the coupling coordination results.

In terms of spatial distribution, Xinjiang and Qinghai exhibit relatively higher levels of coupling coordination, while Shaanxi, Gansu, and Ningxia have comparatively lower levels. This disparity can be attributed to the lower impact of human activities on the natural environment in Xinjiang and Qinghai, leading to a milder influence, whereas Shaanxi, Gansu, and Ningxia experience more intensive human activities and consequently exert a higher impact on the natural environment. Despite these variations, the overall differences in coupling coordination across the five provinces and regions are not substantial, as they all demonstrate favorable degrees of coupling coordination.

Regarding the temporal aspect, all five provinces and regions are witnessing positive development over the years. Shaanxi, Gansu, and Ningxia have shown faster rates of improvement, with more pronounced trends. While Xinjiang and Qinghai display slower trends, they are still moving towards positive development trajectories.

3.1.3. Analysis of Factors Hindering Water Resources, Socio-Economic Factors and Ecological Environment in Five Northwestern Provinces of China

This study introduces the obstacle degree model to calculate the primary obstacles affecting the three major factors in five provinces and regions (Figure 8). From the calculated results, it is evident that the obstacle factor with the highest average obstacle degree is the water usage per 10,000 GDP yuan. This is mainly due to the rapid economic development and the fast-growing tourism industry in the five northwestern provinces and regions. The obstacle degrees for urban green coverage rate and water usage per 10,000 industrial values added are the lowest among the six major obstacle degrees, with values of 6.692 and 6.924, respectively. This indicates that urban greening and industrial water control in the five northwestern provinces and regions are well managed. The second-highest obstacle degree is for the ecological water usage ratio, which is 13.758, suggesting that the five provinces and regions should allocate more water for ecological purposes. The obstacle degrees for the proportion of rivers with water quality above Grade III and the effective utilization coefficient of agricultural irrigation water are 8.656 and 10.868, respectively, indicating that the five provinces and regions should optimize agricultural irrigation water usage and increase the proportion of rivers with water quality above Grade III.

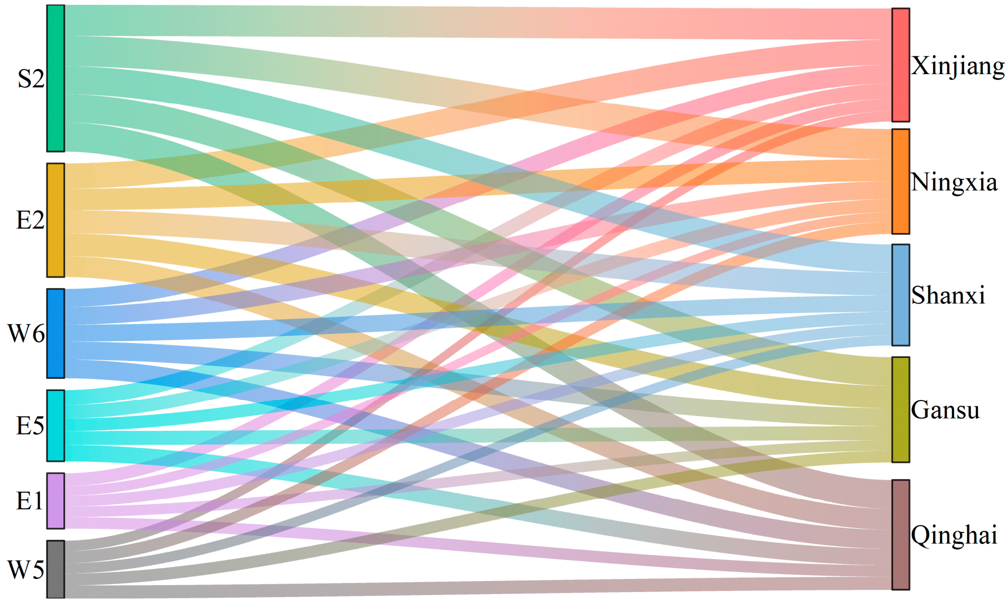

Figure 8. Analysis of primary obstacle factors.

4. Discussion and Policy Suggestion

4.1. Discussion

The comprehensive evaluation and coupled coordinated development study of water–economic–ecological systems in the five northwestern provinces of China holds significant implications for both regional and national sustainable development strategies. This research endeavor delves into the intricate interplay between water resources, economic activities, and ecological well-being, shedding light on the complex dynamics that underlie the region's socio-environmental landscape.

4.1.1. Integrated Resource Management and Sustainability

One of the pivotal insights gleaned from this study pertains to the importance of integrated resource management. By examining the interconnections between water availability, economic growth, and ecological integrity, the research underscores the necessity of adopting a holistic approach to ensure long-term sustainability.

4.1.2. Socio-Economic Implications

The findings of this study have profound socio-economic implications. The northwestern provinces of China have historically been characterized by their water scarcity and vulnerability to climate change impacts. The comprehensive evaluation showcases the potential trade-offs between economic growth and ecological health, emphasizing the need for balanced development strategies. This study thus equips policymakers and stakeholders with valuable insights to formulate effective policies that harmonize economic advancement with environmental preservation.

4.1.3. Policy Formulation and Governance

Effective governance and policy formulation emerge as critical aspects elucidated by this research. The study illuminates the challenges of achieving coupled coordinated development within water–economic–ecological systems. It underscores the necessity of cross-sectoral collaboration and innovative governance mechanisms to tackle the intricate challenges posed by resource scarcity and environmental stressors [17]. The insights garnered from this research can aid in the design of robust policy frameworks that foster sustainable growth while safeguarding ecological resilience.

4.1.4. Adaptation to Changing Conditions

The research also underscores the imperative of adaptive management in the face of changing conditions. With climate change exacerbating water scarcity and altering ecological dynamics, the northwestern provinces must embrace flexibility and resilience in their development paradigms. The study's comprehensive evaluation provides a baseline to monitor changes and adapt strategies accordingly, ensuring that developmental efforts remain aligned with the evolving socio-environmental context.

4.1.5. Knowledge Extension and Global Relevance

While this study focuses on the specific context of the five northwestern provinces of China, its insights reverberate globally. Water scarcity, economic growth, and ecological preservation constitute universal challenges [18]. The methodologies employed and lessons learned from this research can inspire similar assessments in other regions grappling with similar concerns. By disseminating these findings, the study contributes to a broader dialogue on sustainable development strategies across diverse geographical contexts.

4.2. Policy Suggestion

In recent years, the five provinces and regions in northwestern China have increasingly emphasized the coordinated development of water resources, socio-economic progress, and ecological environment, alongside their economic growth. To optimize the coupling coordination of water resources, socio-economic aspects, and the ecological environment, formulating corresponding policies becomes particularly crucial. Firstly, the government can enhance water resource management, promote efficient utilization and conservation of water resources, establish a water resource allocation system, and rationally distribute water resources to reduce wastage. Secondly, encouraging industrial structure upgrading and transformation can drive the economy towards green and low-carbon development, lessening pressure on the ecological environment. Additionally, intensifying environmental protection efforts, strictly controlling pollution emissions, advancing ecological restoration projects, and safeguarding the integrity of ecosystems are vital. Concurrently, strengthening research capabilities and fostering interdisciplinary collaboration can provide scientific evidence and technical support for policy formulation. Lastly, establishing a robust monitoring and assessment system to regularly evaluate coupling coordination and adjusting policy measures promptly ensures effective policy implementation and continuous improvement [19]. By implementing comprehensive strategies, the northwestern provinces and regions can achieve synergistic development of water resources, socio-economic aspects, and the ecological environment, ultimately realizing sustainable development goals.

5. Conclusions

In conclusion, the comprehensive evaluation and coupled coordinated development study of water–economic–ecological systems in China's five northwestern provinces significantly enriches our understanding of the intricate relationships shaping regional development. By examining the interdependencies between water, economy, and ecology, the study not only offers valuable insights for regional policymakers but also contributes to the broader discourse on achieving sustainable development within the constraints of a resource-constrained world. The study's emphasis on integrated resource management, socio-economic implications, governance considerations, adaptation strategies, and global relevance positions it as a seminal contribution to the field of sustainable development.

The comprehensive evaluation and coupled coordinated development analysis conducted in this study shed light on the dynamic changes within the water–economic–ecological systems of the five northwestern provinces of China, revealing two key trends:

(1) Positive Development Trend in the Comprehensive Evaluation of Three Subsystems: The comprehensive evaluation of the water, economic, and ecological subsystems demonstrates a positive developmental trajectory over the years. As time progresses, these provinces have exhibited improvements in various aspects of these subsystems. Effective water resource management has strengthened the sustainable supply of water. Additionally, economic growth has led to optimized resource utilization, curbing excessive exploitation of water resources. The comprehensive evaluation of the ecological subsystem indicates positive outcomes in ecosystem restoration and protection efforts, with biodiversity conservation and ecological functionality gradually recovering.

(2) Positive Development Trend in Coupled Coordinated Development Across the Five Provinces: The study also highlights the collaborative and coordinated development trend among the five provinces within their water–economic–ecological systems. Over time, the relationships between water, economy, and ecology in these provinces have become more interconnected. Scientific water resource utilization has provided a solid foundation for economic development while simultaneously emphasizing ecosystem protection to ensure sustainable resource utilization. Economic growth strategies increasingly prioritize eco-friendly development, resulting in a virtuous cycle of economic growth and ecological preservation. This trend of coordinated development contributes to ensuring sustainable water resource utilization, economic prosperity, and ecological health over the long term.

In summary, our study primarily focused on quantitative measures, but we understand the importance of integrating a human perspective into sustainable development research. The comprehensive evaluation and coupled coordinated development analysis of the water–economic–ecological systems in the five northwestern provinces of China highlight the positive achievements in sustainable development within these provinces. This not only offers valuable insights for regional decision-makers but also provides valuable experience for addressing similar challenges on a global scale. Furthermore, this study underscores the importance of comprehensive evaluation and coordinated development in resource-constrained settings, offering valuable lessons for future research endeavors with similar objectives. In future studies, we will consider how to incorporate qualitative analyses to provide a more comprehensive interpretation of sustainable development.

Author Contributions: Conceptualization, J.S. and F.W.; methodology, J.S.; software, H.Y.; validation, F.W., D.S. and Y.R.; formal analysis, J.S.; investigation, F.W.; resources, D.S.; data curation, F.W.; writing—original draft preparation, H.Y.; writing—review and editing, H.Y.; visualization, D.S.; supervision, J.S.; project administration, J.S.; funding acquisition, F.W. All authors have read and agreed to the published version of the manuscript.

Funding: It was jointly supported by the National Natural Science Foundation of China (52279014 and 52109085), the Key Research and Promotion Project of Henan Province (232102320257), and the Key Research and Development Project of Ningxia Hui Autonomous Region (2021BEG02012).

Data Availability Statement: Data will be made available on request.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Zhang, H.; Sun, M.; Zhang, H.; Zhang, L.; Wang, Z. Spatial Distribution and Influencing Factors of Chinese Time-Honored Catering Brands in the Five Northwestern Provinces. *Sustainability* **2021**, *13*, 3755. [CrossRef]
2. Zhang, Z.; Jia, J.; Guo, Y.; Wu, B.; Chen, C. Scenario of carbon dioxide (CO_2) emission peaking and reduction path implication in five northwestern provinces of China by the low emissions analysis platform (LEAP) model. *Front. Energy Res.* **2022**, *10*, 983751. [CrossRef]
3. Wongchuig, S.; Espinoza, J.C.; Condom, T.; Junquas, C.; Sierra, J.P.; Fita, L.; Sörensson, A.; Polcher, J. Changes in the surface and atmospheric water budget due to projected Amazon deforestation: Lessons from a fully coupled model simulation. *J. Hydrol.* **2023**, *625*, 130082. [CrossRef]

4. Arlos, M.J.; Arnold, V.I.; Bumagat, J.S.; Zhou, J.; Cereno, K.M.; Deas, A.; Dai, K.; Ruecker, N.J.; Munkittrick, K.R. Combining chemical, bioanalytical and predictive tools to assess persistence, seasonality, and sporadic releases of organic micropollutants within the urban water cycle. *Water Res.* **2023**, *244*, 120454. [CrossRef] [PubMed]
5. Nakagawa, T. Numerical modeling on global-scale mantle water cycle and its impact on the sea-level change. *Earth Planet. Sci. Lett.* **2023**, *619*, 118312. [CrossRef]
6. Mohtar, W.H.M.W.; Razali, M.A.M.; Mazlan, M.A.; Rozaini, A.Z.A.; Mooralitharan, S.A.; Hamid, A.A.; Buyong, M.R. Rapid detection of ESKAPE and enteric bacteria using tapered dielectrophoresis and their presence in urban water cycle. *Process. Saf. Environ. Prot.* **2023**, *177*, 427–435. [CrossRef]
7. Zhou, F.; Zhang, W.; Jiang, A.; Peng, H.; Li, L.; Deng, L.; Sun, Y.; Wang, H. Spatial-temporal variation characteristics and coupling coordination of the "water resources—Water environment—Water ecology" carrying capacity in the Three Gorges Reservoir Area. *Ecol. Indic.* **2023**, *154*, 110874. [CrossRef]
8. Grigg, N. Water Resource Engineering: A Discipline or a Specialty and Why It Matters. *J. Hydraul. Eng.* **2023**, *149*, 13583. [CrossRef]
9. Liang, H.; Yu, L. Effects of reservoir system historical evolution on water system landscape patterns: The case of Changshou, China. *Environ. Sci. Pollut. Res. Int.* **2023**, 1–16. [CrossRef]
10. Su, C.; Wang, M.; Xie, X.; Han, Z.; Jiang, J.; Wang, Z.; Xiao, D. Natural and anthropogenic factors regulating fluoride enrichment in groundwater of the Nansi Lake Basin, Northern China. *Sci. Total. Environ.* **2023**, *904*, 166699. [CrossRef]
11. Ma, W.; Lian, J.; Rene, E.R.; Zhang, P.; Liu, X. Enhanced thyroxine removal from micro-polluted drinking water resources in a bio-electrochemical reactor amended with TiO2@GAC particles: Efficiency, mechanism and energy consumption. *Environ. Res.* **2023**, *237*, 116949. [CrossRef]
12. Bhaga, T.D.; Dube, T.; Shekede, M.D.; Shoko, C. Investigating the effectiveness of Landsat-8 OLI and Sentinel-2 MSI satellite data in monitoring the effects of drought on surface water resources in the Western Cape Province, South Africa. *Remote. Sens. Appl. Soc. Environ.* **2023**, *32*, 101037. [CrossRef]
13. Piao, J.; Nam, S.W.; Kim, Y.; Park, E. Enhancing groundwater management using aggregated-data analysis and segmented robust regression: A case study on spatiotemporal changes in water quality. *Sci. Total. Environ.* **2023**, *899*, 165981. [CrossRef] [PubMed]
14. Bresinsky, L.; Kordilla, J.; Hector, T.; Engelhardt, I.; Livshitz, Y.; Sauter, M. Managing climate change impacts on the Western Mountain Aquifer: Implications for Mediterranean karst groundwater resources. *J. Hydrol. X* **2023**, *20*, 100153. [CrossRef]
15. Deng, Y.; Shao, Z.; Dang, C.; Huang, X.; Zhuang, Q. The impact of policies on land cover and ecosystem services dynamics in the Poyang Lake Ecological Economic Zone, China. *Ecol. Indic.* **2023**, *156*, 111169. [CrossRef]
16. Hamdi Aya, A.; Abdulhameed Isam, M.; Mawlood Ibtihal, A. Application of Weap Model for Managing Water Resources in Iraq: A Review. *IOP Conf. Ser. Earth Environ. Sci.* **2023**, *1222*, 012032. [CrossRef]
17. Gidey, E.; Mhangara, P. An Application of Machine-Learning Model for Analyzing the Impact of Land-Use Change on Surface Water Resources in Gauteng Province, South Africa. *Remote. Sens.* **2023**, *15*, 4092. [CrossRef]
18. Meiyan, H.; Peijiang, Z.; Chaoqi, C. Study on coupling of typical elements in surface water and groundwater in the middle reaches of the Yangtze River, China. *J. Hydrol.* **2023**, *626*, 130298. [CrossRef]
19. Bakas, T.; Papadopoulos, C.; Latinopoulos, D.; Kagalou, I.; Akratos, C.; Angelidis, P.; Pliakas, F.-K.; Spiliotis, M. Supporting Participatory Management Planning for Catchment Operationalization with Intuitionistic Fuzzy Sets—A Study in Laspias River, Thrace, Greece. *Water* **2023**, *15*, 2928. [CrossRef]
20. Yoosefdoost, I.; Basirifard, M.; Álvarez-García, J.; Río-Rama, M.d.l.C.d. Increasing Agricultural Resilience through Combined Supply and Demand Management (Case Study: Karaj Reservoir Dam, Iran). *Agronomy* **2022**, *12*, 1997. [CrossRef]
21. Hoffmann, A.A.; Sgrò, C.M. Climate change and evolutionary adaptation. *Nature* **2011**, *470*, 479–485. [CrossRef] [PubMed]
22. Hernández-Bedolla, J.; Solera, A.; Paredes-Arquiola, J.; Pedro-Monzonís, M.; Andreu, J.; Sánchez-Quispe, S.T. The Assessment of Sustainability Indexes and Climate Change Im-pacts on Integrated Water Resource Management. *Water* **2017**, *9*, 13. [CrossRef]
23. Xin, Y.; Zhang, J.; Lu, T.; Wei, Y.; Shen, P. Response of prokaryotic, eukaryotic and algal communities to heavy rainfall in a reservoir supplied with reclaimed water. *J. Environ. Manag.* **2023**, *334*, 117394. [CrossRef] [PubMed]
24. Tang, Y.; Pan, Y.; Zhang, L.; Yi, H.; Gu, Y.; Sun, W. Efficient Monitoring of Total Suspended Matter in Urban Water Based on UAV Multi-spectral Images. *Water Resour. Manag.* **2023**, *37*, 2143–2160. [CrossRef]
25. Lv, C.; Xu, X.; Guo, X.; Feng, J.; Yan, D. Basin water ecological compensation interval accounting based on dual perspectives of supply and consumption: Taking Qingyi River Basin as an example. *J. Clean. Prod.* **2023**, *385*, 135610. [CrossRef]
26. Zhu, H.; Hu, X.-D.; Wu, P.-P.; Chen, W.-M.; Wu, S.-S.; Li, Z.-Q.; Zhu, L.; Xi, Y.-L.; Huang, R. Development and testing of the phytoplankton biological integrity index (P-IBI) in dry and wet seasons for Lake Gehu. *Ecol. Indic.* **2021**, *129*, 107882. [CrossRef]
27. Bu, J.; Li, C.; Wang, X.; Zhang, Y.; Yang, Z. Assessment and prediction of the water ecological carrying capacity in Changzhou city, China. *J. Clean. Prod.* **2020**, *277*, 123988. [CrossRef]
28. Li, J.; Zhao, M.; Han, Y.; Wei, J. Assessment on water cycle health in the Central Plains Urban cluster based on the DSWU NWU SWS NWS A—WCHI model. *Ecol. Indic.* **2023**, *157*. [CrossRef]