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# Evaluation of Coupled Human–Natural System Coordination in Xinjiang and Analysis of Obstacle Factors

**Xinyun Wang [1] and Chuanglin Fang [1,2,*]**

[1] College of Geography and Remote Sensing Sciences, Xinjiang University, Urumqi 830017, China; wangxinyun@stu.xju.edu.cn
[2] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
* Correspondence: fangcl@igsnrr.ac.cn

**Abstract:** The coupling and coordination of humans and natural systems, as the core of geographical research, is an important issue that social development needs to confront and explore. The study of the coupling and coordination of the human–natural system in Xinjiang, as well as the obstacles, is of great significance for its ecological environment and social development. This study establishes a multidimensional index system for the coupling of the human–natural system in Xinjiang. The comprehensive evaluation index and coupling coordination degree of the human–natural system from 2013 to 2020 were calculated, using weighted methods and a coupling coordination evaluation model. The main obstacles to the development of coupling and coordination in Xinjiang were identified, with the aid of a barrier model. The study indicates: (1) the human–natural system composed of ecological environment, urban–rural livability, cultural characteristics, civil harmony, and green development reflects the comprehensive development level of Xinjiang; (2) from 2013 to 2020, the sustainable development of the human–natural system in Xinjiang was good, with an upward trend in the evaluation index; (3) from 2013 to 2020, the level of coupling and coordination of the human–natural system in Xinjiang improved, transitioning from low to high levels; (4) from 2013 to 2020, the main factors impeding the coordinated development of the human–natural system changed. In addition to urban–rural differences and water resource conditions, medical conditions and carbon emissions also became major influencing factors on the coupling and coordination degree of the human–natural system in arid regions. Therefore, the research on the coupling and coordination relationship of the human–natural system and the analysis of obstacles in Xinjiang can provide scientific basis for the high-quality sustainable development and the construction of a beautiful Xinjiang.

**Keywords:** human–natural system; evaluation of coupled coordination; obstacles; Xinjiang

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## 1. Introduction

The United Nations Intergovernmental Panel on Climate Change has released the "Sixth Assessment Report Synthesis: Climate Change 2023" (AR6 Synthesis Report: Climate Change 2023), pointing out that human activities have caused widespread and rapid changes in the atmosphere, oceans, cryosphere, and biosphere. The natural environment faces numerous challenges, such as air pollution [1], ocean warming and acidification [2], shrinking of the cryosphere [3], carbon emissions [4,5], traffic congestion [6], water insecurity [7,8], soil pollution [9,10], ecosystem degradation [11,12], irregularities of urban landscapes [13], and energy shortages [14]. Coordinating the development of population, the economy, society, resources, and the environment in order to ensure sustainable development is currently a very important issue. To protect the sustainability of the Earth's ecosystem, we need to adopt a method of coupled human–natural system evaluation. This would help reduce resource development and consumption [15], strengthen environmental protection measures [16], promote clean industrial processes [17], enhance biodiversity

conservation and restoration [18,19], and reduce greenhouse gas emissions [20]. Only through scientific methods and collective efforts can we achieve a harmonious co-existence between humans and the Earth's ecosystem. In Xinjiang, an important ecological barrier and Economic Zone in China, how to coordinate the relationship between humans and land, comprehensively respond to and solve comprehensive problems such as the fragile ecological environment, pressure on water resources protection, and regional development lag, and realize the protection and governance of systematic, holistic, and collaborative arid areas are major challenges for ecological protection and high-quality development at this stage. Against the background of the "belt and road" construction, how to understand and master the coupling and coordinated development degree of humans and the land system in Xinjiang, and find the reasons that hinder the coordinated development of Xinjiang, is a scientific problem faced by Xinjiang at present.

## 2. Literature Review

The human–natural system is comprehensive, dynamic, and complex. It achieves dynamic equilibrium and coordinated development through the exchange of structural elements, functions, and matter or energy within the system It also promotes adaptive evolution between human society and external natural systems through mutual interactions [21]. The concept of coupling, originating from physics and later introduced to geography, refers to the benign interaction between two or more subsystems within a system, and can be used to characterize complex, non-linear relationships among various subsystems [22]. Coordination refers to the process of coordinating and harmonizing the internal components of the system by adjusting the relationships among them in order to achieve the optimal state of the overall function of the system. Coordination emphasizes harmony, consistency, and integrity within the system and aims to achieve optimization of system objectives by optimizing the allocation of resources and adjusting the operation mechanism. Coupling and coscheduling are comprehensive measures of the coupling effect and coordinated development level among the elements within the system. They not only consider the strength of the interaction between systems, but also evaluate the overall function of the system under this interaction. The core of the coupling coordination model is to construct the interaction mechanism between systems and determine the system boundaries: clarify the research object and divide the system boundaries; construction of index system: select indicators reflecting the characteristics of each system to form a comprehensive evaluation system; perform a coupling degree calculation: use the coupling degree function or similar method in physics to quantify the interaction strength between systems; and coordinate degree evaluation: according to the actual situation of the system, set the coordination degree evaluation criteria to evaluate the coordinated development of the systems. The coupling coordination model is suitable for system research with the following characteristics: multisystem co-existence: the research object contains two or more interrelated and interactive subsystems; data availability: data reflecting the characteristics of each system can be collected to ensure the feasibility of model construction; system dynamics: the state of the system changes with time, requiring dynamic monitoring and evaluation; and optimization requirements: we hope to propose optimization control strategies by analyzing the coupling and coordination relationship between systems. At present, the coupling coordination degree model gradually changes from two research objects [23] to three or four research objects [24], making it widely suitable for human–natural systems research. The coupled and coordinated relationships within the human–natural system represent a complex scientific issue that requires consideration at multiple spatial scales, involves long time series, adapts to multidimensional systems, exhibits significant spatiotemporal heterogeneity, and includes both positive and negative feedback mechanisms [25]. The research topics within human–natural system coupling and coordination include interactions between human activities and a number of issues, such as climate change [26], vegetation change [27,28], water resource security [29], food security [30], and ecological protection [31], as well as other aspects of the natural environment. The research methods primarily include the EKC curve [32], the ecological footprint approach [33], the DPSIR method [34], system

dynamics [35], the coupled coordination model [36], the Human Activity Intensity on Land Surface [37], Ecological Carrying Capacity [38], and Multiscale Geographically Weighted Regression [39]. As shown in Table 1, based on a comparison of the advantages and disadvantages of the above methods, this paper chooses the coupled coordination model, which is simple in structure and easy to operate, to analyze the human–natural system relationship in Xinjiang.

An obstacle degree model can assist in accurately identifying the primary factors impeding the coordinated development of the human–natural system, ensuring the harmonious growth of population, economy, society, resources, and environment. This promotes the sustainable development of natural environments and human socio-economic activities [40]. Research on the coupling and coordination of the human–natural system, gaining a deep understanding of the underlying mechanisms and accurately identifying the obstructive factors, represents a cutting-edge field in Earth system science research [41]. It necessitates a systematic approach, integrating natural and human processes to explore the primary influencing factors. This approach then reveals the interactions and feedback mechanisms between natural environments and socio-economic activities, thereby providing a scientific foundation for promoting sustainable regional economic development. Coupling degree and obstacle degree models are often used in the analysis and evaluation of various complex systems. In this paper, the coupling degree model is used to analyze the interaction between the five subsystems (ecological environment, urban–rural livability, cultural characteristics, civil harmony, and green development) of the Xinjiang human–natural system; At the same time, the obstacle degree model is used to identify the main obstacle factors restricting the sustainable development of the human–natural system in Xinjiang. Through the comprehensive analysis of these two models, we can formulate a more scientific and reasonable regional planning scheme to promote the sustainable development of Xinjiang.

As a strategic location in China's northwest, Xinjiang's unique geography, natural resources, and cultural milieu contribute to its distinctive and complex human–environment dynamics. Researching the coupling of the human–natural system in Xinjiang helps uncover the interaction mechanisms between human activities and the natural environment, offering scientific guidance for the region's economic and social development. With rapid economic growth and rising population, Xinjiang faces numerous ecological and environmental issues, as well as socio-economic challenges. These issues are often closely linked to imbalances in the human–natural relationship. In-depth research into barriers to the coupling of the human–natural system in Xinjiang can reveal the root causes of these issues, offering a scientific foundation for targeted policies and measures. Additionally, studying the coupling of the human–natural system in Xinjiang and its barriers enhances public understanding of this relationship, advancing the adoption and practice of the concept of harmonious co-existence between humans and nature. This is critically important for advancing the construction of an ecological civilization and promoting sustainable social development in Xinjiang and across the nation.

In the current research on the evaluation of human–natural system coupling coordination and obstacle analysis in Xinjiang, there exist some pivotal challenges and deficiencies. These challenges are primarily concentrated in the following aspects:

(1) The deficiencies in the study of sustainability of human–natural systems: presently, research on human–natural systems in Xinjiang often fails to fully integrate human and natural factors, lacking a comprehensive indicator system that closely integrates human factors with those derived from the Earth. This produces problems in completely reflecting the interactions between humans and the environment when assessing the overall development level of Xinjiang. (2) Current research may focus mainly on demographic, economic, social, resource, and environmental aspects, while neglecting other important factors such as culture, history, and policy, which also have a significant impact on human–natural systems. (3) Difficulties in data acquisition: the geographical location and harsh natural conditions of Xinjiang often make it more challenging to obtain high-quality, high-frequency data. This limits the depth and breadth of research and increases the uncertainty of research outcomes.

**Table 1.** Comparison of advantages and disadvantages of human–natural system research methods.

| Method | Advantages | Disadvantages |
| --- | --- | --- |
| EKC Curve | 1. Provides a theoretical framework for the relationship between economic development and environmental quality;<br>2. Provides confidence for policy makers. | 1. Endogenous defects may have a two-way causal relationship;<br>2. Limited data sources and applicability;<br>3. Weak explanatory and predictive power. |
| Ecological Footprint Approach | 1. Intuitive and easy to understand, based on quantification of land area;<br>2. Strong comparability, standardized processing of various resources;<br>3. Easy to operate and apply. | 1. The assessment result is nonabsolute, based on the global average productivity;<br>2. Ignores the diversity of land functions;<br>3. Static analysis method, unable to predict future trends. |
| DPSIR Method | 1. Systematic and comprehensive analysis;<br>2. High flexibility, can be adjusted according to the problem; easy to understand and apply. | 1. Data requirements are high, and it is difficult to obtain and process;<br>2. Strong subjectivity, in definition and quantification;<br>3. Limited scope of application, may not apply to all environmental issues. |
| System Dynamics | 1. Strong system analysis ability and handling of complex relationships;<br>2. Strong dynamic simulation ability and prediction of system changes;<br>3. Policy analysis tools to provide decision support. | 1. Ignores external factors and focus on the internal system;<br>2. Lacks measurement standards for complex environments;<br>3. The analysis process is complex and time-consuming, requiring high professional knowledge and skills. |
| Human Activity Intensity on Land Surface | 1. Quantifies the intensity and distribution of human activities;<br>2. Reveals the impact of human activities on the environment;<br>3. Guides environmental protection and sustainable development. | 1. Data acquisition and processing are difficult;<br>2. The influencing factors are complex and difficult to quantify accurately;<br>3. Regional differences are large, and it is difficult to make unified comparison. |
| Ecological Carrying Capacity | 1. Reflects ecosystem service capacity;<br>2. Guides ecological management and resource utilization;<br>3. Emphasizes sustainable development. | 1. Quantification is difficult and involves multiple complex factors;<br>2. Regional differences are obvious and are difficult to compare uniformly;<br>3. It is difficult to obtain and process relevant data. |
| Multiscale Geographically Weighted Regression | 1. Handles spatial data heterogeneity;<br>2. Has high flexibility, allowing different variables to be estimated at different scales;<br>3. To improve the prediction accuracy, is suitable for regions with large spatial changes. | 1. High computational complexity, requiring long computational time and powerful computing power;<br>2. High demand for data requires high resolution and sufficient samples;<br>3. Model selection and validation are complex and require cross-validation techniques. |
| Coupling Coordination Degree Model | 1. Reflects the relationship between systems and quantifies the degree of coordination;<br>2. From a macro perspective, reveals the interaction between systems;<br>3. Is widely used in economic geography and other fields. | 1. Unable to deeply analyze the internal structure and functions of the subsystem;<br>2. It is difficult to consider complex factors among multiple systems (such as nonlinearity, feedback, time delay). |

To address the aforementioned issues, this study initially defines a human–natural system for the ecological environment, urban–rural livability, cultural characteristics, civil harmony, and green development in Xinjiang. This system encompasses 12 indicator layers, including air, water, plant, basic, environment, medical, input, revenue, society, life, save, and protection. It aims to develop a new evaluation index to assess the comprehensive development of the human–natural system in arid regions. Moreover, to address the issue of indicator fragmentation, the study proposes a human–land integration approach to circumvent shortcomings. Subsequently, the study employs a coupled coordination model to measure the coupled and coordinated development level of the human–natural system. Lastly, it utilizes a barrier model to explore the main obstacles to the coupled and coordinated development of the human–natural system in Xinjiang. This model has been applied in various fields such as meteorology, economics, demography, and natural science, with successful research results and recognition having been achieved [22,40].

This study aims to quantify the integrated development index of human–natural system in Xinjiang and explore its coupled coordination characteristics, aiming to identify the primary factors influencing the comprehensive development of the region and to provide a scientific decision-making basis for the sustainable development of Xinjiang by:

(1) Developing a comprehensive human–natural coupled system, encompassing five dimensions: ecological environment, urban and rural livability, cultural features, civil harmony, and green development, in order to analyze the interrelationships among its subsystems.
(2) Analyzing the development trends of the human–natural system in Xinjiang from 2013 to 2020, utilizing the comprehensive evaluation index system.
(3) Utilizing the coupled coordination model to investigate the characteristics of coupling and coordination among various dimensions of the human–natural system in Xinjiang, as well as their temporal and spatial variations.
(4) Identifying the key factors that hinder the coordinated development of the human–natural system in Xinjiang, using the obstacle model. By combining GIS and remote sensing data, this study comprehensively analyzes the development dynamics and changes in coupled coordination, aiming to provide scientific support for sustainable development and regional harmony of Xinjiang, and contributing to the construction of a beautiful China.

## 3. Material and Methods

### *3.1. Research Framework*

This study takes the human–natural system conflict as a starting point, and the harmonious co-existence of humans and nature as theoretical guidance. We construct a comprehensive evaluation index system of the human–natural system in Xinjiang with 12 general and 40 specific indices, including air, water, plant, basic, environment, medical, input, revenue, society, life, save, and protection. First, we calculate the weights of the indices through entropy weighting and hierarchical analysis. We then analyze the comprehensive development mechanism of Xinjiang in terms of ecological environment, urban and rural livability, cultural characteristics, civil harmony, and green development through the weighting and coupling coordinated evaluation model. Second, we use the weighting method and the coupling coordination evaluation model to analyze the comprehensive index changes and coupling coordination changes. Third, we use a GIS spatial statistics method to analyze the regional differences and trends of the human–natural system in Xinjiang. Lastly, we use the obstacle degree model to explore the main influencing factors of coupling coordination during the study period. The results of the study provide a scientific basis for the development of China's arid areas. The research framework of this paper is shown in Figure 1.

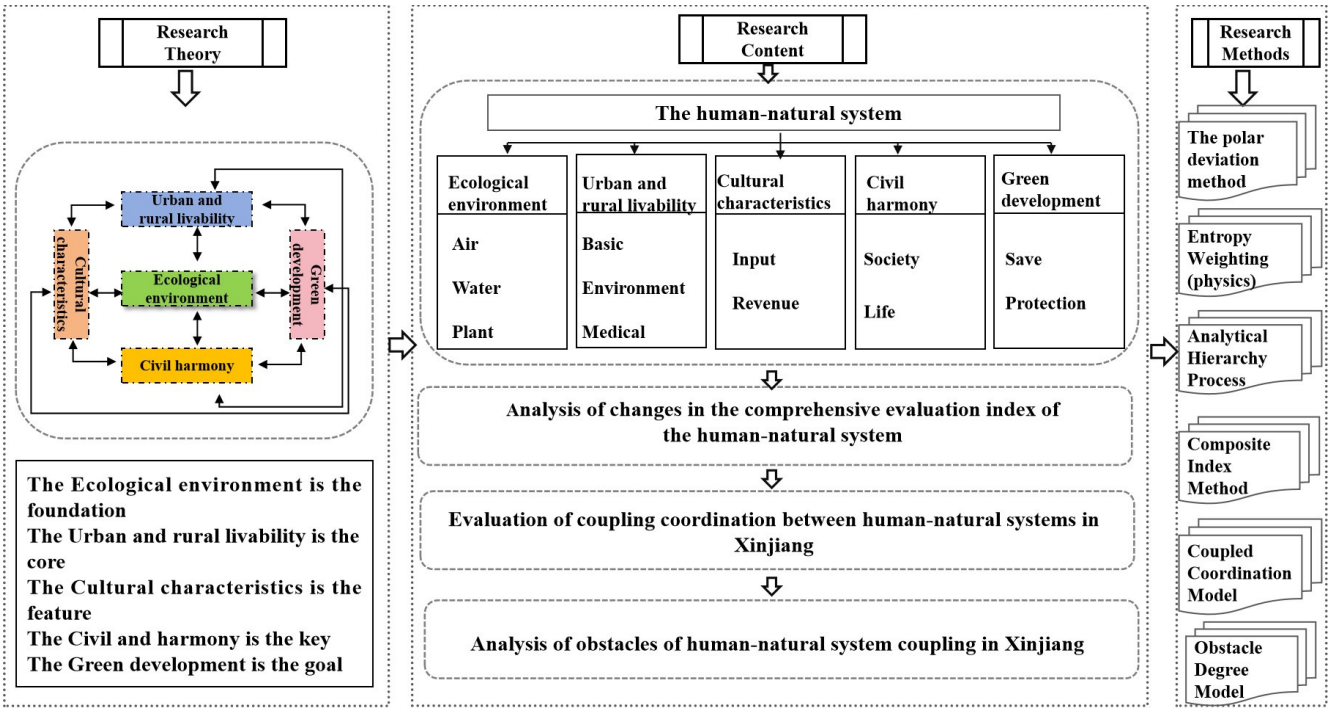



**Figure 1.** Research framework.

### *3.2. Interaction Mechanism*

The coupling mechanism of the human–natural system is the interaction and mutual influence between human activities and the environment. By analyzing this mechanism, we can better understand the impact of human activities on the Earth's environment, put forward corresponding environmental protection measures and policies, and achieve sustainable development. The coupling mechanism mainly includes the impacts of human activities on the environment: resource exploitation and utilization, environmental pollution, and ecological damage, as well as other aspects. For example, large-scale industrial production and energy consumption have led to considerable environmental pollution and resource waste. The environment also impacts human activities. For example, climate change affects agricultural production and the supply of water resources; also, geological disasters pose a threat to human habitation and production. There are adjustment mechanisms within human–natural relations. These are the means by which human beings regulate human–natural relations through the formulation of policies, laws, and planning, so as to reduce negative impacts and promote harmonious development. For example, measures such as energy conservation and emission reduction or the promotion of sustainable development are introduced in order to reduce environmental pollution and the waste of resources.

The human–natural system in Xinjiang is a holistic system, in which the ecological environment is the foundation, urban and rural livability is the core, cultural characteristics are a feature, civil harmony is the key, and green development is the goal. The five subsystems are constructed on the basis of the inseparability of the terms "human" and "natural". The ecological environment subsystem provides space for the development of the other four subsystems, while urban–rural livability, cultural characteristics, civil harmony, and green development provide feedback to the ecological environment from different perspectives.

The ecological environment is the basis for human survival and development, with sunlight, air, and water as the essential elements for life's activities. Only on this basis can material resources for economic activities be provided and requirements for comfort be met. At the same time, the environment has a self-purifying capability, absorbing or assimilating the wastes and energy generated by human activities in a livable environment.

The ecological environment is, therefore, the basic condition for urban and rural livability, while urban and rural livability is the core element of the ecological environment. The ecological environment provides material resources for human cultural activities, and its improvement can promote people's quality of culture and their spiritual civilization. Deterioration of the ecological environment will lead to the distortion of cultural values, the decline of moral standards, and other problems. Therefore, the ecological environment is the basis for the development of cultural characteristics, and cultural characteristics are the embodiment of the idea of the ecological environment. The key to the creation of environmental problems lies in the attitude of human beings toward the environment. It is people's cultural pattern that determines their attitude and behavior on environmental issues; this also forms a good cultural environment. A good ecological environment can provide resources for a harmonious society, and its deterioration will lead to social instability, conflict intensification, and other problems. On the contrary, a harmonious society makes man and nature live in harmony, establishing and protecting the ecological balance. The ecological environment is, therefore, the fundamental root of civilization and harmony. It is only by observing ecological priorities in development and by formulating environmental protection policies that we can make the green hills and mountains constantly bring forth mountains of gold and silver. Only by increasing the development and use of clean energy and taking the road of ecological priority and green development can we create a beautiful Xinjiang where green mountains are always present, green water is always flowing, and the air is always fresh. Therefore, the ecological environment is the foundation of green development, and green development is the ambitious goal of the ecological environment.

People's requirements for their living environment are constantly increasing. To be livable means not only meeting the material needs of people, but also greater spiritual power. Consequently, the livable environment needs strengthening of the cultural construction. The cultural values of the living environment must mean that people's care is sustainable, with a cultural atmosphere arising from the environment. The livable environment is, therefore, the core carrier of human features, and human features are the connotation of a livable environment. Harmonious and stable living conditions are the inevitable requirement of a livable environment. For people to live and work in peace and contentment is the greatest form of harmony. A comfortable environment not only helps to ensure the basic needs of the residents, but also improves their quality of life, as well as strengthening their sense of integration and of belonging to society. It also helps to form good social order and a stable social structure. A livable environment is, therefore, the core condition for civil harmony; and civil harmony is the key requirement for a livable environment. On the basis of producing a good living environment, the concept of green sustainable development has gradually become an important goal to be pursued by people. Therefore, a livable environment is the core aim of green development, and green development is the key goal of a livable environment. Culture is an important pillar of social order and is of great significance to the construction of a harmonious society. The promotion of a harmonious society is conducive to the creation of a good cultural atmosphere. Promotion of green development can improve the harmonious coexistence of humans and nature, alongside the development of ecological science and technology. The establishment of a harmonious society helps develop a system to promote the green behavior of humankind, taking the route toward low-carbon transformation. A harmonious society is, therefore, a key step in green development, and green development is the goal of a harmonious society.

In Xinjiang, the ecological environment system, urban and rural livability system, cultural characteristics system, civil harmony system, and the green development system all interact with each other through the flow of elements between the systems. This influences the development stability of the human–natural system, determining the state of sustainable development of the arid zone, which can be characterized by coupling coordination (Figure 2).

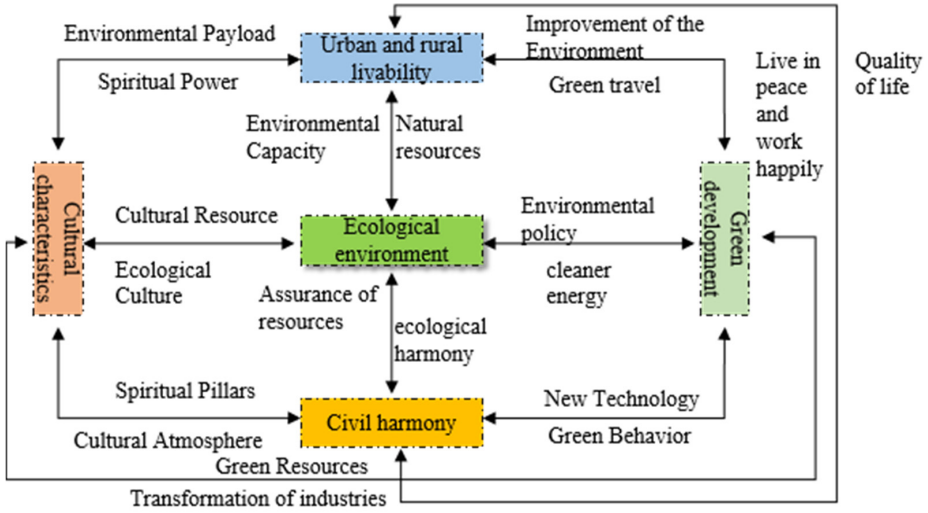



**Figure 2.** Mechanism diagram of the human–natural system in Xinjiang.

### *3.3. Overview of the Study Area and Data Sources*

The Xinjiang Uyghur Autonomous Region, referred to as Xinjiang, is located near the northwest border of China, with Urumqi as its capital. It is the largest provincial administrative region in China, accounting for one sixth of China's total land area. Xinjiang is located in the hinterland of Eurasia, deep inland, surrounded by mountains, and with little oceanic airflow, thus forming a distinct temperate continental climate. The temperature difference is large, with moderate sunshine (annually 2500–3500 h). Precipitation is low, and the climate is dry. Xinjiang's annual average precipitation is about 150 mm, but it varies greatly from place to place. The temperature in southern Xinjiang is higher than in the north, and the precipitation in northern Xinjiang is higher than in the south (Figure 3).

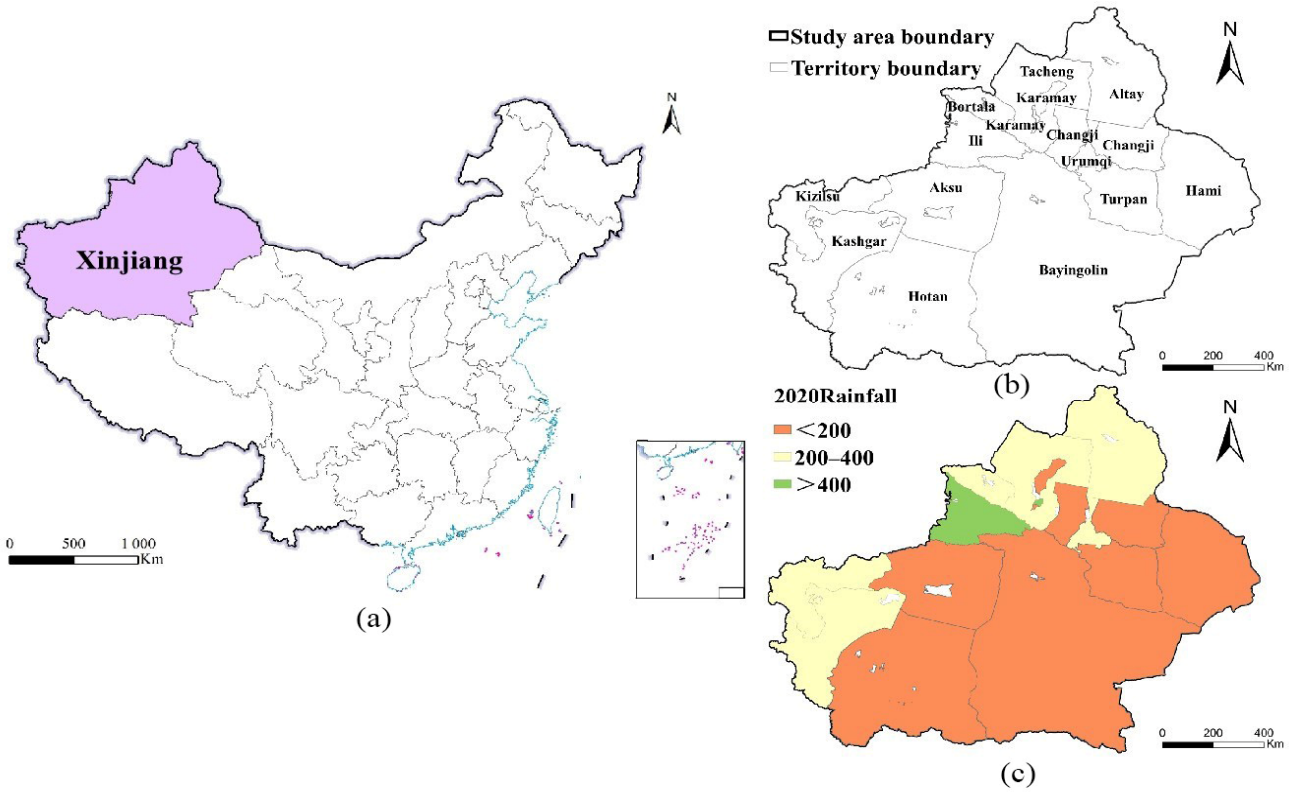



**Figure 3.** (**a**) Schematic diagram of Xinjiang's location; (**b**) overview and territorial divisions; and (**c**) precipitation distribution map.

The research data for this article are sourced from the "Xinjiang Statistical Yearbook (2014–2021)", "Xinjiang National Economic and Social Development Statistical Bulletin (2013–2020)", "Xinjiang Water Resources Bulletin (2013–2020)", "Xinjiang's 70 Years of Splendor", "Xinjiang's 40 Years of Reform and Opening Up", and relevant materials from the statistical yearbooks and bulletins of various prefectures in Xinjiang. The carbon emissions data are sourced from the China Carbon Accounting Database (https://www.ceads.net.cn/, accessed on 1 January 2023), with individual missing data calculated using linear interpolation.

### *3.4. Construction of the Indicator System*

Before constructing a comprehensive evaluation index system for the human–natural system in Xinjiang, the first task is to clarify the evaluation goal. The setting of this goal needs to be closely centered on the harmonious development of human and nature, and secondly through the literature analysis method, drawing on the research experience of scholars on the coupling of regional human–natural systems and the establishment of a regional comprehensive indicator system [21,29]. Combined with the natural attributes of arid zones, the indicators are selected through expert consulting method and the frequency analysis method, ensuring that the selected indicators can comprehensively and accurately reflect the actual development in various dimensions, following the principles of science, system, operation, and representativeness. The selection of indicators is based on the principles of scientificity, systematicity, operability, and representativeness to ensure that the selected indicators can comprehensively and accurately reflect the actual situation of each dimension. Due to the characteristics of the human–land system data, such as the variety of types, formats, and standards, human–land system big data in Xinjiang generally have the problems of a low degree of data integration, difficulty in matching the scales of natural and socio-economic data, and difficulty in meeting the demand for data quality. The indicator system is amended by deleting irrational indicators and adding or replacing some of the indicators, and then the perfected indicator system is fed back to the relevant experts and scholars. Then, the improved indicator system was fed back to relevant experts and scholars, and, after the validity and reliability analysis and repeated discussions and modifications, a more perfect indicator system of the human–land system in Xinjiang was finally determined, as shown in Figure 4. A comprehensive evaluation index system was constructed from five dimensions: ecological environment, urban and rural livability, cultural characteristics, civil harmony, and green development, and 40 elements of the indicator system were derived (Table 2). After standardizing the indicator data by extreme deviation, the weights of the indicators were determined by the information quotient method and the expert scoring method.

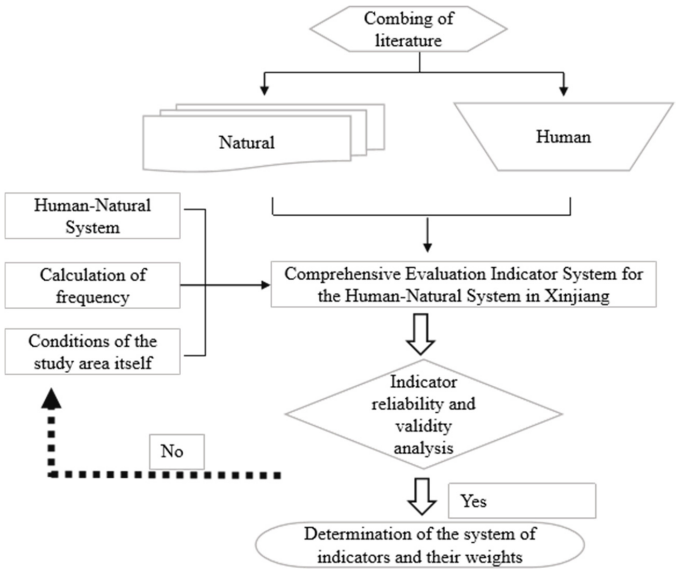



**Figure 4.** Indicator selection process diagram.

**Table 2.** Indicator system and its weights.

| Subsystem | Dimension | Number | Specific Indicators | Property | Objective | Subjectivity | Weight | Rank |
|---|---|---|---|---|---|---|---|---|
| Ecological environment | Air | A1 | Proportion of good days with air quality better than Π-level | + | 0.20 | 0.11 | 0.16 | 9 |
| | | A2 | PM10 concentration | − | 0.11 | 0.11 | 0.11 | 27 |
| | | A3 | SO2 concentration | − | 0.07 | 0.11 | 0.09 | 35 |
| | Water | A4 | Water resources development and use Rate | + | 0.18 | 0.17 | 0.17 | 3 |
| | | A5 | Per capita water resources | + | 0.15 | 0.17 | 0.16 | 8 |
| | Plant | A6 | Per capita ecological space area | + | 0.11 | 0.17 | 0.14 | 15 |
| | | A7 | Per capita forest area | + | 0.10 | 0.08 | 0.09 | 34 |
| | | A8 | Per capita grass area | + | 0.09 | 0.08 | 0.08 | 37 |
| Urban and rural livability | Basic | B1 | Per capita building area | + | 0.14 | 0.10 | 0.12 | 23 |
| | | B2 | Per capita road area | + | 0.13 | 0.05 | 0.09 | 33 |
| | | B3 | total household water used by residents | + | 0.16 | 0.18 | 0.17 | 4 |
| | Environment | B4 | Per capita park green space area | + | 0.08 | 0.07 | 0.08 | 38 |
| | | B5 | Total of municipal household garbage | + | 0.10 | 0.13 | 0.12 | 21 |
| | | B6 | total sewage discharge | + | 0.11 | 0.13 | 0.12 | 20 |
| | Medical | B7 | Number of beds per 10,000 people | + | 0.14 | 0.17 | 0.16 | 11 |
| | | B8 | Number of doctors per 10,000 people | + | 0.13 | 0.17 | 0.15 | 13 |
| Cultural characteristics | Input | C1 | Fixed investment in culture, sports and recreation | + | 0.05 | 0.26 | 0.16 | 7 |
| | | C2 | Number of employed workers in culture, sports and recreation | + | 0.11 | 0.13 | 0.12 | 22 |
| | | C3 | Number of travel agencies | + | 0.18 | 0.05 | 0.12 | 24 |
| | | C4 | Number of star-rated hotels | + | 0.16 | 0.05 | 0.11 | 29 |
| | Revenue | C5 | Consumption index of recreational, educational and cultural goods and services for the population | + | 0.17 | 0.20 | 0.18 | 1 |
| | | C6 | Number of Class A scenic spots | + | 0.08 | 0.12 | 0.10 | 31 |
| | | C7 | Number of inbound tourists | + | 0.19 | 0.07 | 0.13 | 17 |
| | | C8 | Domestic tourism income | + | 0.07 | 0.12 | 0.10 | 32 |
| Civil harmony | Society | D1 | Inbound tourism revenue | + | 0.05 | 0.05 | 0.05 | 40 |
| | | D2 | Import and export volume of foreign trade | + | 0.11 | 0.17 | 0.14 | 16 |
| | | D3 | Number of high school graduates | + | 0.18 | 0.13 | 0.15 | 12 |
| | | D4 | Number of students in school per 10,000 people | + | 0.16 | 0.15 | 0.16 | 10 |
| | Life | D5 | Urban–rural income ratio | − | 0.17 | 0.20 | 0.18 | 2 |
| | | D6 | Consumer price index of residents (last year = 100) | + | 0.08 | 0.07 | 0.07 | 39 |
| | | D7 | Participation rate of medical insurance for urban and rural residents | + | 0.19 | 0.14 | 0.17 | 6 |
| | | D8 | Urban registered unemployment rate | − | 0.07 | 0.10 | 0.09 | 36 |
| Green development | Save | E1 | Energy consumption per 10,000 yuan of GDP | − | 0.07 | 0.13 | 0.10 | 30 |
| | | E2 | Water consumption of 10,000 yuan of GDP | − | 0.10 | 0.13 | 0.11 | 25 |
| | | E3 | proportion of the secondary and tertiary industry | + | 0.12 | 0.13 | 0.12 | 19 |
| | | E4 | Tertiary industry increased value | + | 0.12 | 0.13 | 0.12 | 18 |
| | Protection | E5 | Carbon dioxide emissions | − | 0.09 | 0.20 | 0.15 | 14 |
| | | E6 | afforestation area | + | 0.13 | 0.10 | 0.11 | 26 |
| | | E7 | Harmless treatment total of municipal household garbage | + | 0.10 | 0.12 | 0.11 | 28 |
| | | E8 | Total ecological water consumption | + | 0.26 | 0.08 | 0.17 | 5 |

### *3.5. Research Methodology*

#### 3.5.1. Data Standardization Treatment

The polar deviation method was used to standardize the indicators and eliminate effects of scale:

$$A_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} (i = 1, 2, 3, \ldots m; j = 1, 2, 3, \ldots n)(Positive\ indicator) \quad (1)$$

$$A_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} (i = 1, 2, 3, \ldots m; j = 1, 2, 3, \ldots n)(Negative\ indicator) \quad (2)$$

where $X_{ij}$ is the original data, and $A_{ij}$ is the normalized data.

#### 3.5.2. Calculation of Weights

The size of the indicator weight responds to its role in the evaluation system and is a relative value. Determining the weights is, therefore, particularly important.

There are two commonly used methods to determine the weights: the subjective assignment method (hierarchical analysis method, expert assignment method, empirical assignment method, etc.) and the objective assignment method (coefficient of variation method, mean square deviation method, entropy weight method, complex correlation coefficient method, etc.). In this study, both subjective and objective methods were selected.

The combination of subjective and objective methods can organically integrate the advantages of each weighting method and overcome the shortcomings of the single weighting method to a certain extent. Through the comprehensive use of subjective and objective methods to determine the weight of science and technology evaluation index, it not only reflects the experience information of decision makers, but also reflects the information of actual science and technology data, making the comprehensive evaluation results more reasonable and objective. This method can reflect the degree of subjectivity and objectivity at the same time, which can not only reflect the wishes of decision makers, but also avoid the subjective randomness of evaluation results and improve the rationality and objectivity of weight determination.

Therefore, the entropy weight method and expert scoring method have been used to measure and evaluate the development level of Xinjiang.

(1) Information entropy method:

$$H_j = -\frac{1}{lnn} \sum_{j=1}^{m} P_{ij} ln P_{ij} \quad (3)$$

$$w_j = \frac{1 - H_j}{n - \sum_{j=1}^{m} H_j} \quad (4)$$

(2) Yaahp software (yaahpV10.3Setup) was utilized to implement the Analytic Hierarchy Process (AHP).

(3) The average of the weights derived from information entropy and the analytic hierarchy process was calculated.

#### 3.5.3. Calculation of Indices

$$U = \sum_{n=1}^{j} A_{ij} W_{Aj} \quad (5)$$

3.5.4. Coupling Coordination Model

(1) Coupling degree calculation:

$$C_n = n \times \left\{ (U_1 \times U_2 \times U_3 \times \ldots \times U_n) / \left[ \prod (U_i + U_j) \right] \right\}^{\frac{1}{n}} \quad (6)$$

In this paper, five subsystems are involved, so $n$ = 5, and the organizing formula gives:

$$C = 5 \times \frac{\sqrt[5]{A \times B \times C \times D \times E}}{A + B + C + D + E} \quad (7)$$

(2) Calculation of the degree of coordination:

$$D = \sqrt{C \times T} \quad (8)$$

$$T = \alpha \times A + \beta \times B + \gamma \times C + \delta \times D + \varepsilon \times E \quad (9)$$

(Note: $T$ is the comprehensive evaluation index of Xinjiang, based on reference to relevant literature, plus expert scoring; the coefficients of $\alpha$–$\varepsilon$ are 0.2).

3.5.5. Obstacle Degree Model

$$O_j = \frac{F_j I_j}{\sum_{j=1}^{n} F_j I_j} \quad (10)$$

$$I_j = 1 - f(U_j), j = 1, \cdots, n \quad (11)$$

where the factor contribution degree ($F_j$) is the degree of contribution of subsystem $j$ to the comprehensive system, i.e., the weight of this subsystem; the indicator deviation degree ($I_j$) is the gap between the actual development index of subsystem $j$ and the ideal development index; and the obstacle degree ($O_j$) is the degree of constraint of subsystem $j$ to the comprehensive system.

## 4. Results and Analysis

### *4.1. Analysis of Changes in the Comprehensive Evaluation Index of the Human–Natural System*

4.1.1. Time Variation Analysis

Figure 5 shows the trends of changes in Xinjiang's ecological environment, urban and rural livability, cultural characteristics, civil harmony, and green development, as well as the comprehensive development index from 2013 to 2020. Figure 5a shows that the indices of ecological environment (EE), urban and rural livability (UR), cultural characteristics (CC), civil harmony (CH), and green development (GD) all showed a fluctuating upward trend from 2013 to 2020, with varying degrees of increase. Specifically, the EE showed a "*W*+*V*" trend, with troughs appearing in 2014, 2016, and 2018. The lowest value was 0.21 in 2014, and the highest was 0.74 in 2020. The urban and rural livability followed a "*W*" trend, showing troughs in 2014 and 2017, with the lowest value being 0.24 in 2014 and the highest value being 0.61 in 2020. The rise of CC was 0.34, showing an "*M*" trend, with a trough appearing in 2018. The lowest value was 0.21 in 2013, and the highest was 0.61 in 2019. In the early stages, from 2013 to 2017, there was a rapid increase, almost showing a straight upward trend. The rise of CH was 0.43, revealing a "*V*" trend. A trough appeared in 2015, with the lowest value being 0.08 and the highest value being 0.76. In the middle and later stages (2015–2020), there was a rapid rise, with an increase of 0.68. The GD index increased by 0.37, showing an "*M*" type change trend, with peaks appearing in 2015 and 2018, with a maximum value of 0.81 in 2018 and a minimum value of 0.18 in 2013. As shown in Figure 5b, between 2013 and 2020, the overall comprehensive evaluation index of the human–natural system in Xinjiang showed a general upward trend. More specifically, from 2013 to 2014 it showed a downward trend, with a small decrease from 0.29 to 0.27. From 2014 to 2019, it showed a continuous upward trend, with a large increase from 0.27

to 0.64. In 2019–2020, it showed a constant trend, with the general shape of an inverted "*N*"-type change, reaching a minimum value of 0.27 in 2014 and a maximum value of 0.64 in 2019 and 2020.

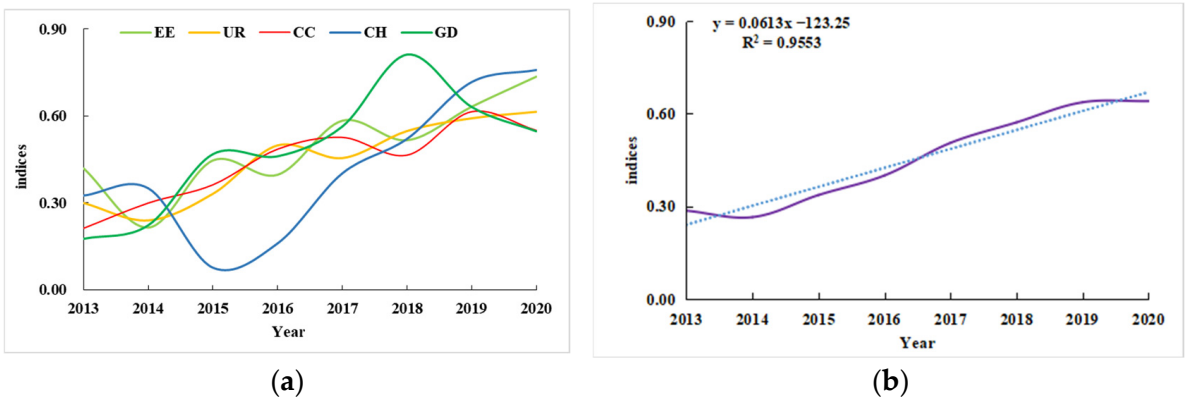



**Figure 5.** (**a**) Xinjiang five subsystem development index from 2013 to 2020; (**b**) Xinjiang comprehensive development indexfrom 2013 to 2020.

#### 4.1.2. Spatial Variation Analysis

Figure 6 illustrates the variations in EE, UR, CC, CH, GD, and the comprehensive development (CD) index among different regions in Xinjiang from 2013 to 2020. It can be seen from the change chart of the comprehensive evaluation index in Figure 6a that, in 2020, the comprehensive development indices of other regions except Changji and Tacheng reached the maximum. It can be seen from Table 3 that, from 2013 to 2020, the CD in Xinjiang increased, including Urumqi (0.31), Karamay (0.17), Turpan (0.41), Hami (0.32), Changji (0.13), Yili (0.35), Tacheng (0.15), Altay (0.20), Bortala (0.31), Bayingolin (0.36), Aksu (0.28), Kizilsu (0.33), Kashgar (0.23), and Hotan (0.38). It can be seen from the change chart of EE in Figure 6b that, in 2020, the eco-environmental indices of other regions reached the maximum, except in Urumqi.

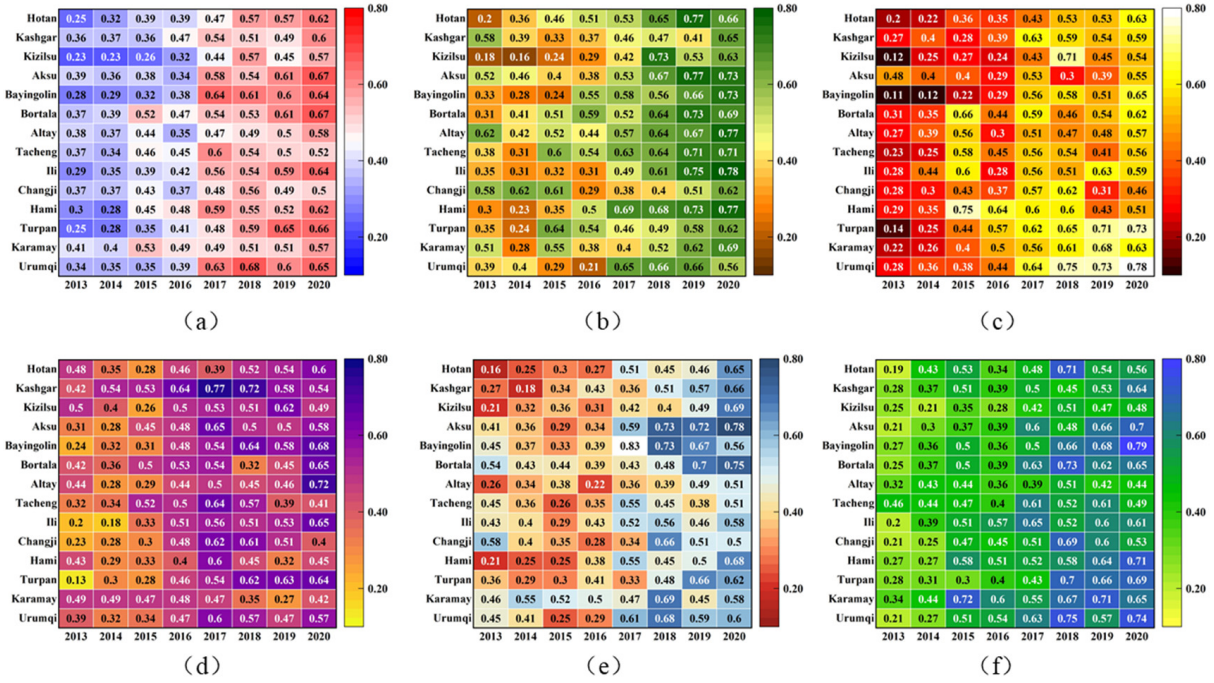



**Figure 6.** Index of Various Regions in Xinjiang from 2013 to 2020. (**a**) CD; (**b**) EE; (**c**) UR; (**d**) CC; (**e**) CH; (**f**) GD.

**Table 3.** Changes in development indices in Xinjiang from 2013 to 2020.

| Name | CD | EE | UR | CC | CH | GD |
|---|---|---|---|---|---|---|
| Urumqi | 0.31 | 0.17 | 0.50 | 0.18 | 0.15 | 0.54 |
| Karamay | 0.17 | 0.17 | 0.40 | −0.07 | 0.11 | 0.31 |
| Turpan | 0.41 | 0.27 | 0.59 | 0.51 | 0.25 | 0.41 |
| Hami | 0.32 | 0.47 | 0.22 | 0.02 | 0.46 | 0.44 |
| Changji | 0.13 | 0.04 | 0.18 | 0.17 | −0.08 | 0.32 |
| Ili | 0.35 | 0.43 | 0.31 | 0.45 | 0.15 | 0.41 |
| Tacheng | 0.15 | 0.33 | 0.33 | 0.09 | 0.06 | 0.03 |
| Altay | 0.20 | 0.15 | 0.30 | 0.27 | 0.25 | 0.12 |
| Bortala | 0.31 | 0.38 | 0.31 | 0.23 | 0.21 | 0.40 |
| Bayingolin | 0.36 | 0.41 | 0.54 | 0.44 | 0.11 | 0.52 |
| Aksu | 0.28 | 0.21 | 0.07 | 0.27 | 0.37 | 0.49 |
| Kizilsu | 0.33 | 0.45 | 0.42 | −0.01 | 0.48 | 0.23 |
| Kashgar | 0.23 | 0.07 | 0.31 | 0.13 | 0.39 | 0.36 |
| Hotan | 0.38 | 0.46 | 0.43 | 0.12 | 0.50 | 0.37 |

From 2013 to 2020, the EE in Xinjiang has increased, with increases in Urumqi (0.17), Karamay (0.17), Turpan (0.27), Hami (0.47), Changji (0.04), Yili (0.43), Tacheng (0.33), Altay (0.15), Bortala (0.38), Bayingolin (0.41), Aksu (0.21), Kizilsu (0.45), Kashgar (0.07), and Hotan (0.46) (Table 3). It can be seen from the change chart of UR in Figure 6c that, in 2020, except for Karamay, Hami, Yili, and Kizilsu, the UR in other regions reached the maximum. From 2013 to 2020, the UR has increased in Urumqi (0.50), Karamay (0.40), Turpan (0.59), Hami (0.22), Changji (0.18), Yili (0.31), Tacheng (0.33), Altay (0.30), Bortala (0.31), Bayingolin (0.54), Aksu (0.07), Kizilsu (0.42), Kashgar (0.31), and Hotan (0.43) (Table 3). As can be seen from Figure 6d, some regions and states reached the maximum value from 2017 to 2018, and then decreased slightly. From 2013 to 2020, the CC in all regions of Xinjiang, except Karamay and Kizilsu, increased in Urumqi (0.18), Karamay (−0.07), Turpan (0.51), Hami (0.02), Changji (0.17), Yili (0.45), Tacheng (0.33), Altay (0.30), Bortala (0.31), Bayingolin (0.54), Aksu (0.07), Kizilsu (0.42), Kashgar (0.31), and Hotan (0.43) (Table 3). As can be seen from Figure 6e, Bayingolin reached the maximum in 2017, Changji and Karamay reached the maximum in 2018, and other regions reached the maximum in 2020. From 2013 to 2020, except for Changji, the CH of other regions in Xinjiang showed an increasing trend, with increases in Urumqi (0.15), Karamay (0.11), Turpan (0.25), Hami (0.46), Changji (−0.08), Yili (0.15), Tacheng (0.06), Altay (0.25), Bortala (0.21), Bayingolin (0.11), Aksu (0.37), Kizilsu (0.48), Kashgar (0.39), and Hotan (0.50) (Table 2). As can be seen from Figure 6f, except for Karamay, the maximum values in other regions occurred between 2018, 2019, and 2020. From 2013 to 2020, the GD in Xinjiang showed an increasing trend, with increases in Urumqi (0.54), Karamay (0.31), Turpan (0.41), Hami (0.44), Changji (0.32), Yili (0.41), Tacheng (0.03), Altay (0.12), Bortala (0.40), Bayingolin (0.52), Aksu (0.49), Kizilsu (0.23), Kashgar (0.36), and Hotan (0.37) (Table 3). Taking 2017 as the dividing line, the development index of each subsystem has changed significantly (Table 3).

**Table 4.** Coupling coordination level divisions.

| The Category of Coupled Coordination | CCD | The Coupled Coordination Sub-Class | CCD | Level |
|---|---|---|---|---|
| Region of dissonant recession | 0.000–0.399 | Extreme dysfunctional decline | 0.000–0.999 | 10 |
| | | Severe dysfunctional decline | 0.100–0.199 | 9 |
| | | Moderate dysfunctional decline | 0.200–0.299 | 8 |
| | | Mild dysfunctional decline | 0.300–0.399 | 7 |

**Table 4.** *Cont.*

| The Category of Coupled Coordination | CCD | The Coupled Coordination Sub-Class | CCD | Level |
|---|---|---|---|---|
| Overdeveloped zone | 0.400–0.599 | Recessional coordination | 0.400–0.499 | 6 |
| | | Barely coordinated | 0.500–0.599 | 5 |
| Coordinated development zone | 0.600–0.999 | Primary coordination | 0.600–0.699 | 4 |
| | | Moderate coordination | 0.700–0.799 | 3 |
| | | Good coordination | 0.800–0.899 | 2 |
| | | High coordination | 0.900–0.999 | 1 |

### *4.2. Evaluation of Coupling Coordination between Human–Natural Systems in Xinjiang*

#### 4.2.1. Temporal Trends in Coupled Human–Natural System Coordination Levels in Xingjiang

Figure 7a illustrates significant changes in the types of coupling and coordination (Table 4) of the human–natural system in various regions of Xinjiang from 2013 to 2020, and shows notable differences. Imbalance and decline occurred primarily in 2013. Barely coupled coordination was mainly observed between 2013 and 2016. Primary coupled coordination was distributed between 2013 and 2019. Intermediate coupled coordination mainly occurred between 2017 and 2020, and good coupled coordination was mainly observed in 2018, 2019, and 2020. Figure 7b illustrates the coupling and coordination levels of the human–natural system in Xinjiang. These are mainly concentrated in three levels: barely coupled coordination, primary coupled coordination, and intermediate coupled coordination. The region of imbalance and decline (RC) is distributed in Turpan, Kizilsu, Bayingonlin, and Hotan. With the exception of Karamay, barely coupled coordination (BC) is distributed in other prefectures. The distribution of primary coupled coordination (PC) and intermediate coupled coordination (MC) is spread across various prefectures in Xinjiang. Good coupled coordination (GC) is mainly found in Kizilsu, Turpan, Bayingonlin, Urumqi, Bortala, and Aksu. The distribution of different levels of coupling and coordination is relatively even throughout Xinjiang, encompassing regions in East Xinjiang, North Xinjiang, and South Xinjiang.

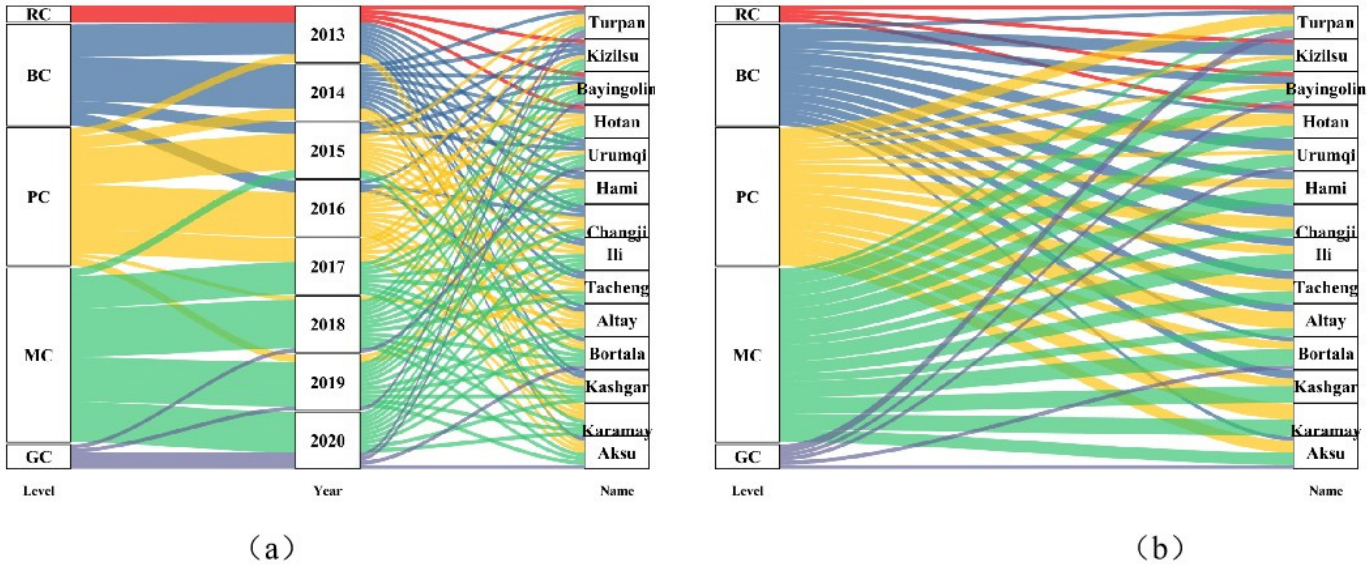



**Figure 7.** (**a**) Time interval of coupling coordination level concentration; (**b**) Regional agglomeration of main coupling coordination levels in Xinjiang.

4.2.2. Spatial Changes in the Coupled Human–Natural System Coordination Levels in Xinjiang

Figure 8 demonstrates a clear spatial shift in the level of coupling coordination between the human and land systems in Xinjiang from 2013 to 2020. In 2013, Kizilsu, Hotan, Bayingonlin, and Turpan were situated in the coupling imbalance zone, which is predominantly located in southern Xinjiang. Aksu and Karamay exhibited primary coupling coordination, while the remaining areas demonstrated only minimal coupling coordination. Notably, Urumqi and Bayingonlin demonstrated good levels of coordination, while in 2015, the entire Xinjiang region showed varying degrees of coupling and coordination, with Bortala and Karamay having intermediate levels, and Kizilsu and Bayingonlin in southern Xinjiang showing minimal levels. It is clear that significant progress has been made in improving coordination across the region. By 2018, all regions except for Altay had achieved intermediate or higher levels of coupling and coordination. In 2020, all regions in Xinjiang showed an increase in coupling coordination levels except for Aksu, with Bortala, Turpan, Bayingonlin having good coordination and the remaining areas having intermediate coordination.

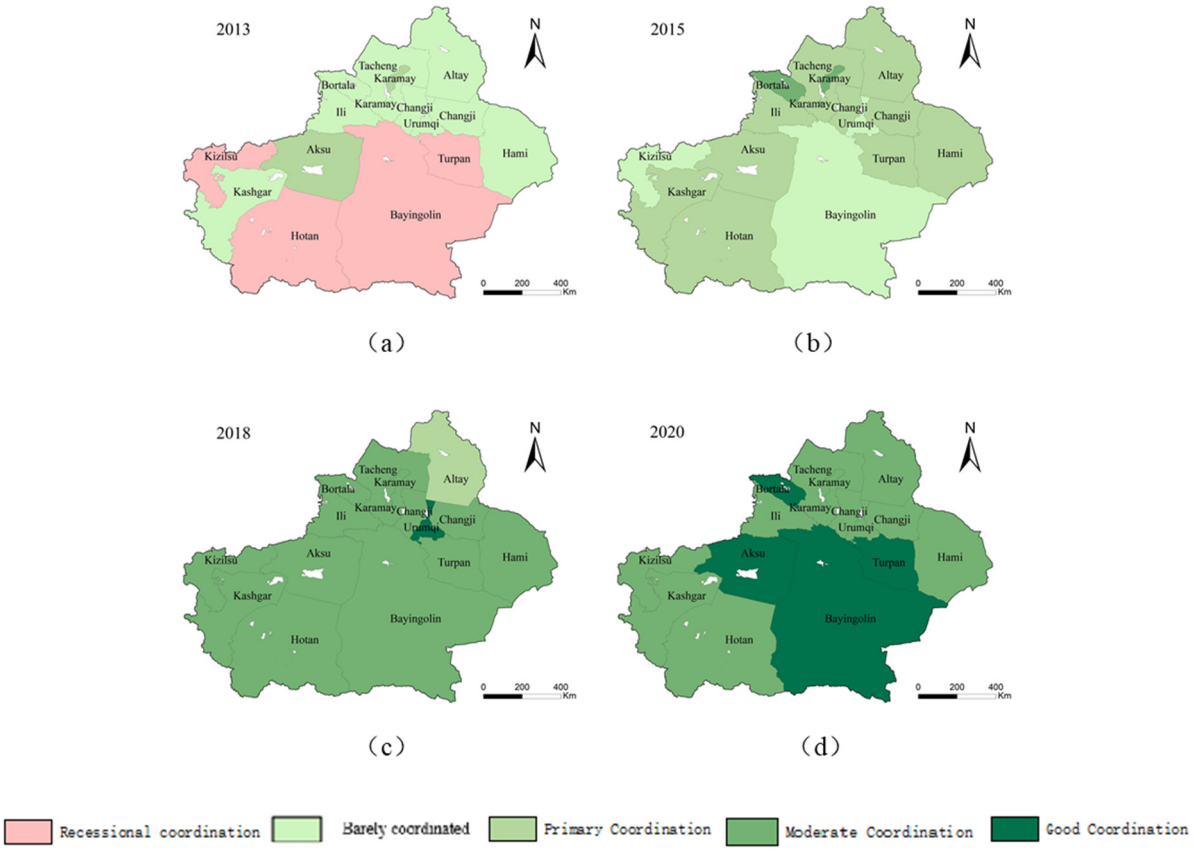



**Figure 8.** Spatial evolution of coupling coordination types in Xinjiang human–natural system. (**a**) 2013; (**b**) 2015; (**c**) 2018; (**d**) 2020.

The coupling level patterns in 2013 and 2015 indicated that the North Xinjiang region had better coupling coordination than the South Xinjiang region. In 2018, all prefectures showed an increase in the coupling level, except for Bortala, Karamay, and Altay. The coupling coordination level exhibited a consistent spatial pattern. In 2020, while Urumqi experienced a decrease in coupling level, other regions saw an increase. This spatial pattern revealed a higher coupling level in the middle than on the two sides. Compared to 2013, there was a significant increase in coupling across all regions in 2020.

The human–land system in Xinjiang has exhibited an upward trend in coupling and coordination over four time nodes (2013, 2015, 2018, 2020), as shown in Figure 9. Notably, from 2013 to 2015 (Figure 9a), the coupling coordination increased. Hotan, Bortala, and

Turpan had significantly faster growth rates, with values of 0.14, 0.13, and 0.13, respectively. In contrast, Urumqi and Aksu had the slowest growth rate, at 0.01. It is worth noting that, from 2015 to 2018 (Figure 9b), the coupling coordination degree of the human–land system in Xinjiang exhibited a remarkable upward trend, with a growth rate that surpassed that of 2013 to 2015. Kizilsu, Urumqi, and Bayingonlin experienced faster growth, with values of 0.24, 0.24, and 0.21 respectively, while Bortala showed a decline, with a decline rate of 0.01. From 2018 to 2020 (Figure 9c), the coupling coordination both increased and decreased. Bortala and Akesu showed a significant increase, at rates of 0.11 and 0.1, respectively, while Karamay, Changji, Tacheng, and Urumqi decreased by 0.06, 0.02, 0.02, and 0.01, respectively. From 2013 to 2020, Figure 8d demonstrates a clear and consistent upward trend in the coupling coordination degree of the human–land system in Xinjiang. It is worth noting that Turpan, Bayingonlin, and Hotan have shown particularly impressive growth rates of 0.33, 0.32, and 0.31, respectively.

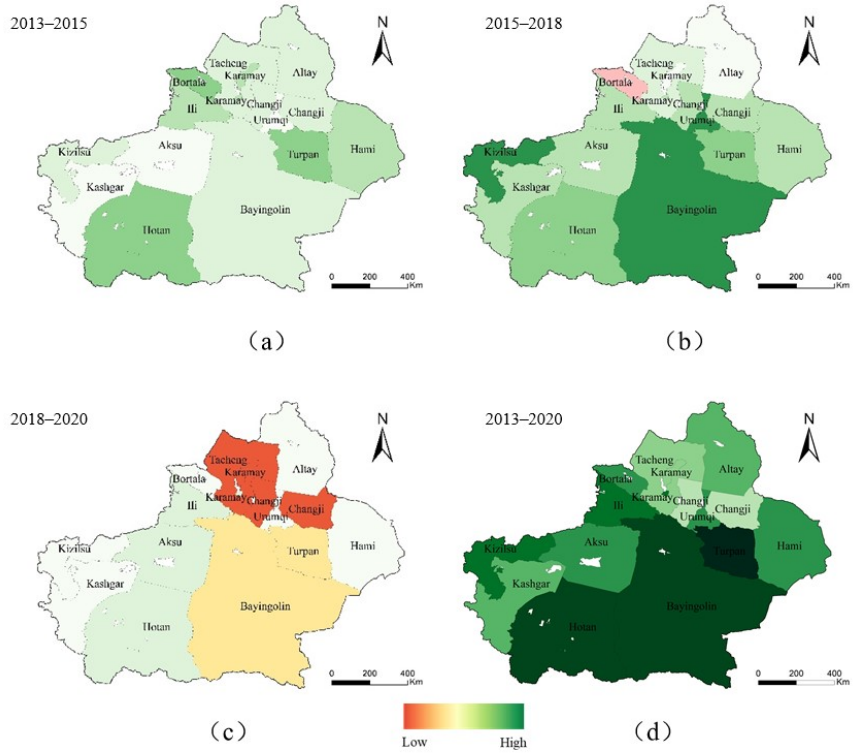



**Figure 9.** Spatial change of coupled coordination of the human–natural system in Xinjiang. (**a**) 2013–2015; (**b**) 2015–2018; (**c**) 2018–2020; (**d**) 2013–2020.

Figure 10 demonstrates a clear spatial increase in the coupling coordination level of Xinjiang's human–land system. The level remained stable from 2013 to 2015 (Figure 10a), with primary coupling coordination increasing and barely coordinated coupling decreasing. Hami, Changji, Ili, Tacheng, Altay, Bortala, and Kashgar confidently progressed from BC to PC. Figure 10b clearly shows that, from 2015 to 2018, the transformation of coupling coordination level was mainly from primary to intermediate. Turpan, Hami, Changji, Ili, Tacheng, Kashgar, and Hotan have successfully transitioned from primary coupling coordination to intermediate coupling coordination. Additionally, Kizilsu, Kashgar, Hotan, and Turpan have made the successful transition from BC to intermediate coupling coordination. From 2018 to 2020, the level remained unchanged in Urumqi, Karamay, Hami, Changji, Ili, Tacheng, Kizilsu, Kashgar, and Hotan, as shown in Figure 10c. Figure 10d shows a clear increase in the level of coupling coordination in several prefectures between 2013 and 2020. The shift has been from forced coupling coordination to intermediate coupling coordination, which is a positive development. Notably, Urumqi, Hami, Changji, Ili, Tacheng, Altay, and Kashgar have all experienced this improvement. Karamay, Turpan, Bayingonlin, Bortala,

Aksu, Kizilsu, and Hotan have all successfully transitioned to higher levels of development.

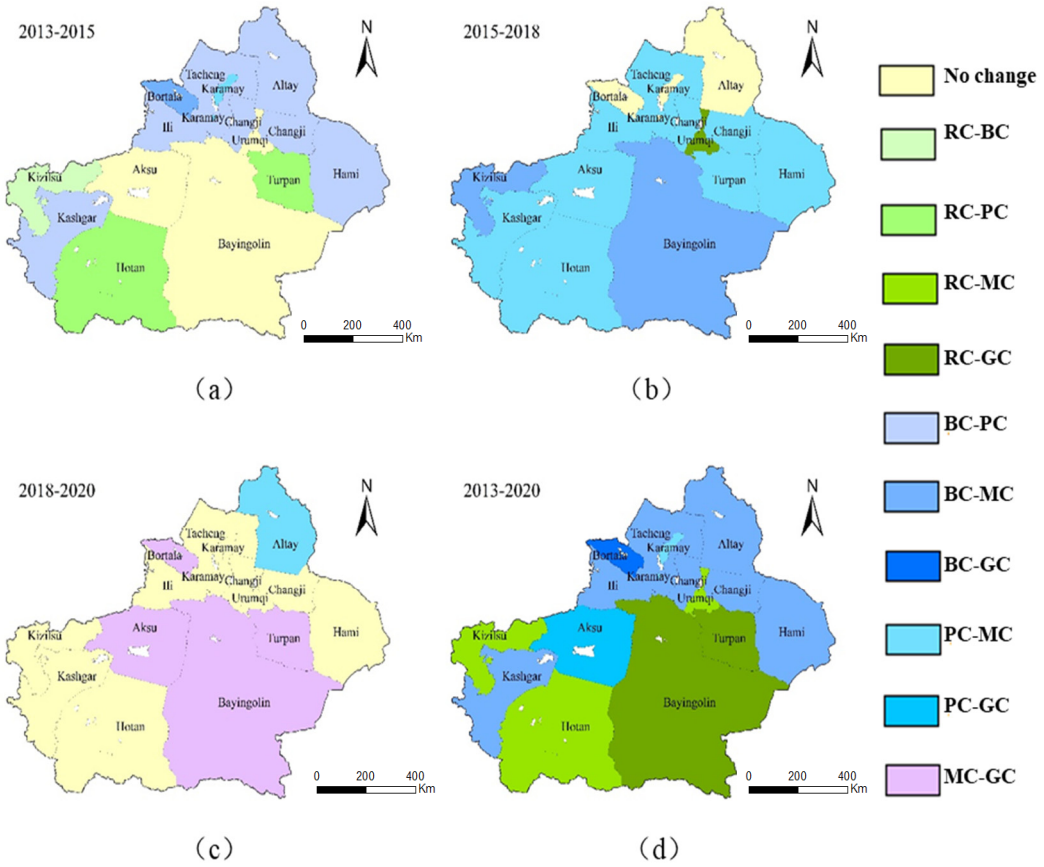



**Figure 10.** Spatial changes in the coupling coordination level of Xinjiang. (**a**) 2013–2015; (**b**) 2015–2018; (**c**) 2018–2020; (**d**) 2013–2020.

### *4.3. Analysis of Obstacles*

This section analyzes obstacles to coupling and coordination of the human–natural system in Xinjiang. Formulas (10) and (11) are used to determine obstructing factors at the subsystem and indicator levels.

#### 4.3.1. Detailed Analysis of the Subsystem Obstacles

The obstacle degree model ranks the influence system together with factors of the coupling and coordination of the human–natural system in Xinjiang. It identifies the systems and factors with outstanding sustainable development potential. The five subsystems are ranked based on the average obstacle degree value (Table 5). The research period from 2013 to 2020 showed varying degrees of obstruction in each subsystem of the human–natural system in Xinjiang, affecting the degree of coupling and coordination. This evidence highlights the need for further analysis and action. Civilization, harmony, CC, and livable cities are closely related and have high obstacle degrees. They are mutually restrictive and have a significant impact on the construction of a beautiful Xinjiang. It is important to prioritize these factors in order to achieve the desired outcome with any confidence. Xinjiang's human–natural system shows a relatively low degree of coupling and coordination, hindering GD and ecological preservation.

Figure 11a demonstrates the stable obstacle levels of the EE subsystem and the urban–rural livable subsystem from 2013 to 2020. The EE subsystem obstacle level decreased from 16% in 2013 to 15% in 2020, while the urban–rural livable subsystem obstacle level increased from 20% in 2013 to 21% in 2020. Additionally, the CC subsystem and the GD subsystem both experienced an increase in obstacle level from 22% and 23% in 2013 to 25% in 2020,

respectively. However, the obstacle level of the CH subsystem decreased significantly from 19% in 2013 to 13% in 2020. The CH subsystem's constraining effect on the coupling and coordinated development of the human–natural system in Xinjiang is weakening, while the cultural characteristic and GD subsystems' constraints are increasing. The constraints of EE and livability in urban and rural areas have remained unchanged. Figure 11b–e demonstrate the obstacle levels of various regions in Xinjiang for the years 2013, 2015, 2018, and 2020. It is evident that, in 2013, the majority of regions in Xinjiang had low barrier levels for the EE, CC, and CH subsystems. Among the evaluated regions, Kizilsu, Karamay, Changji, and Altay were identified as having the highest barrier levels in the EE, urban and rural livability, CC, and CH subsystems, respectively. Additionally, Changji was found to have the highest barrier level in the GD subsystem. In 2015 and 2018, obstacles to several subsystems increased significantly in various regions, including the EE, CH, and GD subsystems. However, there was a decrease in obstacles to the urban–rural livability and GD subsystems, resulting in a gradual narrowing of the gap between systems. In 2020, barriers to the regional EE subsystem, the urban and rural livable subsystem, and the GD subsystem were reduced. Additionally, barriers to the CC and CH subsystems increased. Turpan faces the largest barriers in its EE subsystem, while Hami faces them in its urban and rural livable subsystem. Karamay's largest barriers are related to its human characteristics subsystem, Bayingonlin's to its civilization harmonious subsystem, and Altay's to its GD subsystem.

**Table 5.** Subsystem correlation degree.

| Subsystem | OD | Order |
|---|---|---|
| Ecological environment | 18.62 | 5 |
| Urban–rural livability | 20.55 | 3 |
| Cultural characteristics | 21.01 | 2 |
| Civil harmony | 21.02 | 1 |
| Green development | 18.79 | 4 |

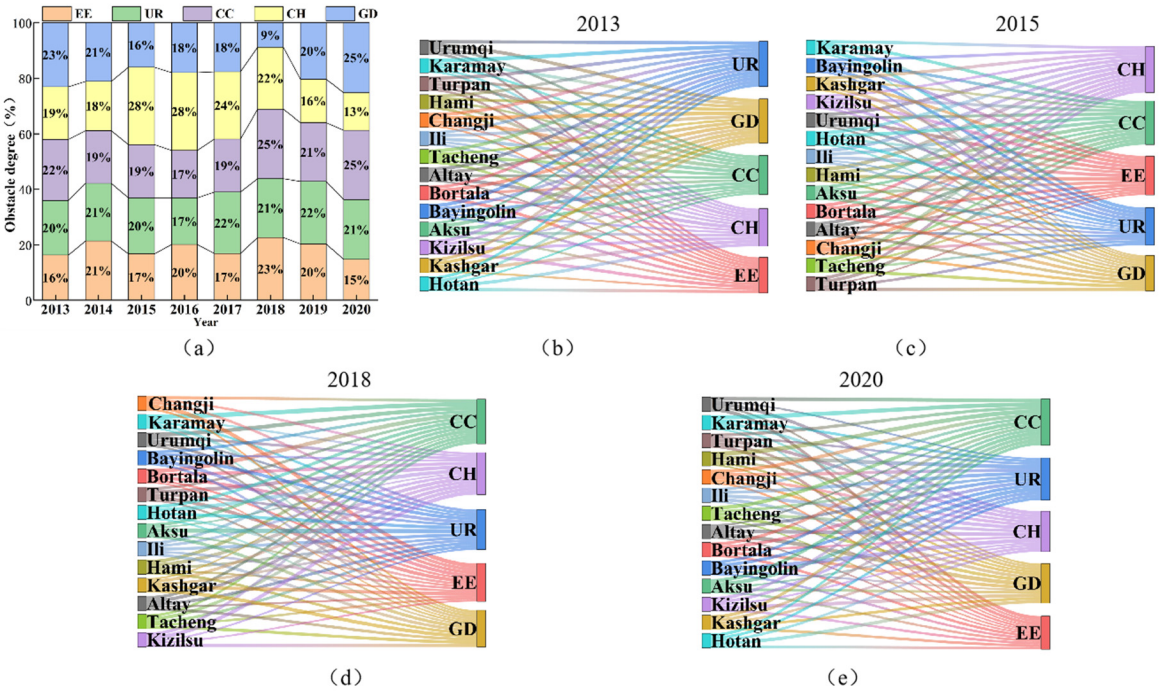



**Figure 11.** Analysis of obstacle factors in various subsystems from 2013 to 2020. (**a**) Change of subsystem obstacle degree from 2013 to 2020; (**b**) change of obstacle degree in various regions of Xinjiang in 2013; (**c**) change of obstacle degree in various regions of Xinjiang in 2015; (**d**) change of obstacle degree in various regions of Xinjiang in 2018; (**e**) change of obstacle degree in various regions of Xinjiang in 2020.

4.3.2. Analysis of the Main Indicator Obstacles

Table 6 presents the top ten obstacles to the coordinated development of the human–natural system in Xinjiang. The factors in 2013 primarily originated from the CH, urban–rural livability, and CC subsystems. The six most significant indicators (ranked in order) are: C5—the consumption index for recreational, educational, and cultural goods and services; A4—the ratio of surface water to groundwater; B3—residential water consumption; E8—ecological water consumption; D5—the income ratio of urban and rural residents; and D7—the medical insurance coverage rate for urban and rural residents. In 2013, coordinated development of the human–natural system in Xinjiang was hindered by the income and water use structures of its urban and rural residents, as evidenced by the layers of criteria representing cultural benefits, water resource conditions, basic needs, environmental protection, and living harmony.

**Table 6.** Obstacle degrees of the index layer of the human–natural system in Xinjiang.

| Order | 2013 | | 2015 | | 2018 | | 2020 | |
|---|---|---|---|---|---|---|---|---|
| | **Obstacle Factors** | **OD** | **Obstacle Factors** | **OD** | **Obstacle Factors** | **OD** | **Obstacle Factors** | **OD** |
| 1 | C5 | 3.76 | D5 | 3.77 | C5 | 3.8 | C5 | 3.93 |
| 2 | A4 | 3.55 | E8 | 3.58 | D5 | 3.78 | A5 | 3.41 |
| 3 | B3 | 3.55 | A4 | 3.55 | A4 | 3.47 | E8 | 3.37 |
| 4 | E8 | 3.54 | B3 | 3.53 | B3 | 3.44 | D5 | 3.27 |
| 5 | D5 | 3.51 | D7 | 3.46 | A1 | 3.35 | B7 | 3.25 |
| 6 | D7 | 3.41 | C5 | 3.45 | B7 | 3.31 | E5 | 3.19 |
| 7 | C1 | 3.23 | D4 | 3.21 | C1 | 3.26 | A1 | 3.14 |
| 8 | D4 | 3.21 | C1 | 3.20 | A5 | 3.23 | A4 | 3.12 |
| 9 | B7 | 3.17 | D3 | 3.17 | D4 | 3.15 | D3 | 3.12 |
| 10 | D3 | 3.12 | B7 | 3.05 | E8 | 3.07 | B7 | 3.03 |

Similarly, in 2015, the CH, urban–rural livability, and CC subsystems were identified as the top ten impediments. The six indicators (ranked in order) are: D5—the income ratio of urban and rural residents; E8—ecological water consumption; A4—the ratio of surface water to groundwater; B3—residential water consumption; D7—the medical insurance coverage rate for urban and rural residents; and C5—the consumption index for recreational, educational, and cultural goods and services. These disparities were evaluated based on criteria layers that represent living harmony, environmental protection, water resource conditions, basic needs, and cultural benefits. The living disparities between urban and rural residents in Xinjiang, as well as the issue of water resources, were significant factors hindering the coordinated development of the human–natural system in 2015.

In 2018, the main obstacles were related to EE, CH, urban–rural livability, and CC. The six indicators (in order of importance) are: C5—the consumption index for recreational, educational, and cultural goods and services; D5—the income ratio of urban and rural residents; A4—the ratio of surface water to groundwater; B3—residential water consumption; A1—the proportion of days with air quality better than level II; and B7—the number of hospital beds per 10,000 people. Cultural benefits, living harmony, water resource conditions, basic needs, air quality, and medical conditions are the layers of criteria that are represented here. It is worth noting that two indicators from the EE subsystem are included among these criteria layers. Water use structures, income and expenditure of urban and rural residents, and air quality are identified as major factors impeding the coupled development of the human–natural system. The top ten impediments in 2020 primarily stem from the subsystems of EE, GD, and CH. The six indicators, in order of importance, are: the consumption index for residential entertainment, education, and cultural goods and services (C5); the per capita amount of water resources (A5); the ecological water consumption (E8); the income ratio between urban and rural residents (D5); the number of hospital beds per 10,000 people (B7); and the carbon dioxide emissions (E5). The indicators

reflect cultural benefits, income ratio between urban and rural residents, water resources, medical and health conditions, and environmental protection. The primary factors impeding the coordinated development of human–natural system coupling in Xinjiang are the income ratio between urban and rural residents, water resources, medical conditions, and carbon emissions.

## 5. Discussion

This article has examined the interrelationships in Xinjiang among EE, urban–rural livability, CC, CH, and GD, based on theories of sustainable development, human–environment harmony, and systems theory. The text establishes an evaluation index system for comprehensive development in Xinjiang that includes multiple elements, information flows, and relationships. It systematically analyses the coupling mechanisms of the urban–rural human–natural system, underpinned by the concept of human–environment harmonious development. The evaluation index is established without separating the subsystems, building on previous research. The article thoroughly analyzes the development trend of the comprehensive evaluation index and the spatiotemporal changes in CCD. It identifies the factors that hinder sustainable development in arid regions. The results clearly indicate that the index system accurately reflects the level of comprehensive regional development. The framework of this indexing system can be directly applied to other regions with minor modifications, in accordance with the actual development conditions of the research area. The models and methods employed in this study are scientifically sound and have been extensively utilized in research on the correlation between human activities and EEs.

### *5.1. Discussion on the Results of the Comprehensive Evaluation Index*

In summary, the comprehensive evaluation index of the human–natural system in Xinjiang shows a fluctuating upward trend, maintaining overall stability and good performance. This indicates that sustainable development construction in Xinjiang has been quite effective. During the study period, the trends in ecological environment, urban and rural livability, CC, CH, GD, and the comprehensive development indices varied across regions in Xinjiang, in line with expected regional differences. Xinjiang is located in the economically underdeveloped northwestern region of China, with its own economic development lagging behind that of the southeast coastal regions. At the same time, its internal economic structure, resource endowment, geographical location, and historical culture vary significantly, leading to differences in the comprehensive evaluation index. Taking 2017 as a dividing line, there were obvious changes in the development indices of various subsystems. The 19th National Congress was convened in 2017, proposing the construction of a beautiful China, indicating that the Party's policy reform system and the implementation of various environmental protection and ecological construction policies have achieved significant results. In recent years, with the intensification of ecological protection efforts in Xinjiang, the development index of the EE subsystem has gradually rebounded. The comprehensive development of the human–natural system in Xinjiang is expected to be further improved.

The rise of EE means that Xinjiang has made remarkable achievements in ecological and environmental protection, and the stability of the ecosystem has been enhanced. This will help maintain biodiversity, protect water conservation functions, and reduce the frequency and impact of natural disasters. With the rise of the ecological environment development index, Xinjiang will pay more attention to ecological restoration and reconstruction. By implementing a series of ecological restoration projects, such as grassland protection, desertification control, wetland restoration, etc., the structure and function of damaged ecosystems can be significantly improved, and the quality of ecological environment can be improved.

The rise of UR will promote the improvement of people's livelihood in Xinjiang. By strengthening infrastructure construction, improving the level of public services, increasing residents' income, and other measures, the quality of life and happiness of residents can be

significantly improved. At the same time, improvement of the ecological environment will also provide residents with a more livable living environment. With the improvement of the livable index of urban and rural areas, Xinjiang will pay more attention to the integration of urban and rural development. By promoting the construction of new urbanization, strengthening the construction of rural infrastructure, improving the level of agricultural modernization, and other measures, we can promote the free flow of urban and rural factors and the balanced allocation of public resources, narrow the gap between urban and rural development, and realize the common prosperity of urban and rural areas.

The rise of CC promotes national unity and social stability. Xinjiang is a multi-ethnic area, and the rise of the development index of cultural characteristics will promote the exchanges and integration among all ethnic groups and enhance national unity and social stability. By implementing a series of livelihood projects and social governance measures, we can narrow the development gap between regions and nations and promote social harmony and stability.

The rise of CH will promote the coordinated development of Xinjiang and its surrounding areas. By strengthening regional cooperation and promoting connectivity and resource sharing, we can promote economic and cultural exchanges and cooperation between Xinjiang and the mainland and Central Asia and form a good pattern of complementary advantages and coordinated development.

The rise of GD will promote the development of green industry in Xinjiang. Green industry is characterized by environmental protection, low-carbon usage, and high efficiency, which meets the requirements of sustainable development. Xinjiang can rely on its rich natural resources and unique location advantages to develop green industries such as ecological agriculture, green energy, and eco-tourism, so as to achieve a win–win situation of economic and ecological benefits. With the improvement of green transformation development index, Xinjiang will pay more attention to the optimization and upgrading of industrial structure. By eliminating backward production capacity, developing high-tech industries and strategic emerging industries, and other measures, we can promote the development of industries in the direction of high-end, intelligent, and green, and improve industrial competitiveness and sustainable development ability.

To sum up, the rise of CD in Xinjiang is of great significance to the sustainable development of Xinjiang. It will not only contribute to the improvement and protection of the ecological environment, the sustainable development of the economy, and the improvement of the people's livelihood, but also promote the coordinated development of the region and promote national unity and social stability. These positive changes will lay a solid foundation for the future development of Xinjiang.

### *5.2. Discussion on the Evaluation of Human–Natural System Coupling*

During the period 2013–2020, there was a pronounced change in the type of coupled human–natural system coordination across various regions in Xinjiang, with significant disparities observed. The period of disharmony and decline was primarily concentrated in 2013, while the period of strained coupled coordination occurred mainly between 2013 and 2016. The period of initial coupled coordination was distributed between 2013 and 2019, followed by a period of moderate coupled coordination predominantly occurring between 2017 and 2020. Finally, the period of GC occurred predominantly in 2018, 2019, and 2020. The levels of coupled human–natural system coordination across various regions in Xinjiang were primarily concentrated in strained coupled coordination, initial coupled coordination, and medium coupled coordination. This suggests that, during the study period, the levels of coupled human–natural system coordination across various regions in Xinjiang were gradually improving. Xinjiang is a relatively underdeveloped region, facing challenges such as water scarcity, fragile EEs, and issues with population and economic development. However, its ecological environment, urban and rural livability, CC, CH, and GD are generally in a relatively balanced state. From 2013 to 2020, there was noticeable spatial variation in the levels of coupled human–natural system coordination

in Xinjiang. The levels showed some fluctuations, but on the whole there was an upward trend, with a shift from low to high. Compared to 2013, there was a very noticeable change in the level of coupling in 2020, with an increase across all regions. This suggests that, although Xinjiang's EE is inherently poor, and its sustainable development has been affected by overdevelopment and unreasonable utilization, improving the comprehensive development index of various subsystems and narrowing their gaps can enhance the level of coupled coordination.

### *5.3. Obstacles and Analysis of Impact Factors*

During the research period from 2013 to 2020, the subsystems in Xinjiang showed varying degrees of obstruction to the coupling and coordination of the human–natural system. Among these, CH, cultural features, and urban–rural livability posed relatively high and consistent obstruction levels to the coupling and coordination of the human–natural system. This suggests that these factors, along with GD and ecological conservation, exert significant influence on the harmonious development of the human–natural system in the context of building a beautiful Xinjiang. Through analysis of the obstruction levels of key indicators, it was observed that the income and expenditure patterns of urban and rural residents in 2013, as well as water resource allocation, were major factors impeding coordinated development. In 2015, disparities in living standards among urban and rural residents and water resource issues were major factors impeding the coordinated development of the human–natural system. In 2018, water resource allocation, income and expenditure patterns among urban and rural residents, and air quality were major factors impeding the coupled development of the human–natural system. By 2020, income and expenditure ratios among urban and rural residents, water resource issues, medical conditions, and carbon emissions were the major obstacles. From 2013 to 2015, the major obstruction factors underwent constant change, yet disparities in urban–rural living standards and water resource allocation persisted as major obstructions over time. From 2013 to 2020, the income gap among urban and rural residents in Xinjiang experienced fluctuations from narrowing to widening, before narrowing again. The income gap among urban and rural residents also showed significant spatial variations, especially between the southern and northern Xinjiang, as well as the eastern part of Xinjiang. Overall, the income gap between urban and rural residents in Xinjiang has narrowed after experiencing fluctuations. However, a certain disparity still exists. The government has taken multiple measures to promote balanced urban–rural development, but further efforts are still required. The primary reason for the high level of water resource barriers is the irrational structure of water resource utilization, which is prominently reflected in the large proportion of agricultural water use, the small proportion of ecological water use, and the rising proportion of residential water use. Second, the reduction in per capita water resources and the increase in per capita water consumption are also important reasons for the high level of barriers in the water resource subsystem. The reasons for the high level of barriers in medical conditions are the remote location of Xinjiang, the relatively underdeveloped economy, the low proportion of medical and health technical personnel, the low proportion of hospital beds, and the lack of advanced medical technology and equipment. The reasons for the high level of barriers in carbon emissions are the implementation of dual-carbon goals, the high proportion of secondary industry in Xinjiang, and the large carbon emissions.

### *5.4. Limitations*

This study has several limitations. First, based on the actual conditions of the research area, we rigorously selected evaluation criteria for the coordinated development of the human–natural system in Xinjiang. However, some criteria were not included due to data gaps. For instance, indicators reflecting CC and GD need to be further enhanced. Furthermore, while existing criteria can to some extent reflect the coupling relationship between humans and the land system in Xinjiang, the spatial effects between the human–natural system may be less clearly discerned due to the limited sample size. Under current

theoretical conditions, finding the optimal development path through simulation research on the coupled and coordinated human–natural system in arid regions and providing a reference for sustainable development will become focuses of the team's future research.

## 6. Conclusions and Responses

### *6.1. Conclusions*

Between 2013 and 2020, the index of Xinjiang shows an inverse "*N*"-type change trend, in which the minimum value is reached in 2014, and the maximum value is reached in 2019; all subsystems show a fluctuating upward trend, with different degrees of increase; during the study period, the comprehensive evaluation index of all regions in Xinjiang has increased, and in 2020, the comprehensive development index of all regions except Changji and Tacheng reached the maximum value; the index of the five subsystems of each prefecture is divided by 2017, with obvious changes. In 2020, except for in Changji and Tacheng, the comprehensive development index of all other regions reached the maximum value; the indices of the five subsystems in each prefecture took 2017 as the dividing line, and the changes were obvious.

During the 2013–2020 period, the changes in the type of coupled human–natural system coordination in Xinjiang's prefectures are extremely obvious, while the differences are also significant. RC is mainly concentrated in 2013, BC is mainly concentrated in 2013–2016, PC is distributed between 2013–2019, MC is mainly in 2017–2020, and GC mainly appears in 2018, 2019, and 2020. The Xinjiang human–natural system coupling coordination grades are mainly concentrated in the three grades of barely coupled coordination, primary coupled coordination, and intermediate coupled coordination in each state. The coupling coordination level in Xinjiang has obvious changes in space, showing a trend of gradual increase from south to north. The level of coupling coordination in Xinjiang shows some fluctuation, but generally shows an upward trend, and the coupling coordination grade generally shifts from low to high.

Between 2013 and 2020, the correlation value of each subsystem to the coupled coordination level of Xinjiang varies, among which the obstacles of CH, CH, and UR livability to the coupled coordination level of the human–natural system of Xinjiang are higher and close to each other, and the obstacles of GD and EE to the coupled coordination level of the human–natural system of Xinjiang are relatively low. Between 2013 and 2020, the main obstacles to the coordinated development of human–natural systems have changed, except for urban–rural differences and water resources, medical conditions, and carbon emissions, which are also known as the main reasons for hindering the coordinated development of human–land systems.

### *6.2. Countermeasures*

The subsystems of CH, cultural features, and urban–rural livability play a significant role in promoting the coupled and coordinated improvement of the human–natural system in Xinjiang, encompassing EE, urban–rural livability, cultural features, CH, and GD. Accelerating the development of these subsystems is beneficial for enhancing the impact of the coupled and coordinated system. It is imperative to actively leverage policy leadership, vigorously narrow the urban–rural gap, promote the development of distinctive culture, expand external exchanges, improve medical standards, and achieve sustainable development. Increasing investment in rural areas and other under-resourced regions will balance resource allocation and narrow the urban–rural gap. It is essential to integrate resources, as well as coordinate efforts across sectors, regions, industries, and departments. Importance should also be attached to incorporating the development of distinctive culture into overall economic and social development planning, as well as infrastructure construction. In advancing the development of the Belt and Road Initiative, we should actively engage in international cooperation and attract foreign investment. We should improve the medical system, strengthen medical teams, and introduce advanced medical technologies.

It is important to establish an ecological protection system and abandon construction approaches that sacrifice the environment. To this end, the government should intensify policy support for achieving dual-carbon goals, formulate corresponding development strategies, and guide resources such as capital and technology toward low-carbon sectors. Due to the relatively weak level of high technology in arid regions, it is imperative to place greater emphasis on the research and development of environmental protection technologies and the efficiency of economic transformation. Emphasis should be placed on developing environmentally friendly low-carbon urban industries, which would serve as a sustainable means to promote coordinated urban development. The government should adjust the structure of water resource utilization, increase ecological water usage, and simultaneously enhance public awareness and development of water resource protection. The aim should be to improve the efficiency of water resource use. However, local governments should flexibly adjust environmental policies in accordance with their own development capabilities and urban differences, avoiding a one-size-fits-all approach.

As China's gateway to the west, Xinjiang should effectively leverage its advantages, enhance inter-city cooperation, and establish an effective platform for inter-regional resource sharing and mutually beneficial cooperation, promoting the integrated development of the core and local areas. Such cooperation should encompass aspects of EE, urban and rural livability, CC, CH, and GD. With a foundation in regional ecological integration, viable approaches should be explored to foster sustainable development in arid regions of China and even other developing countries.

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## Abbreviations

| | |
|---|---|
| BC | Barely coupled coordination |
| CC | Cultural characteristics |
| CD | Comprehensive development |
| CCD | Coupling coordination degree |
| CH | Civil harmony |
| EE | Ecological environment |
| GC | Good coupled coordination |
| GD | Green development |
| HC | High coordination |
| MC | Moderate coordination |
| OD | Obstacle degrees |
| PC | Primary coupled coordination |
| RC | Recessional coordination |
| UR | Urban and rural livability |

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