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Study on the Sustainable Development of an Arid Basin Based on the Coupling Process of Ecosystem Health and Human Wellbeing Under Land Use Change—A Case Study in the Manas River Basin, Xinjiang, China

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Abstract: Due to the differences in the contributions of land use types to ecosystem health and human wellbeing, there is a trade-off and a coordinating relationship between ecosystem health and human wellbeing, which affects the sustainable development of a river basin. To explore the impacts of the responses of ecosystem health and human wellbeing and the combined effects under land use change, this paper, taking the Manas River Basin (MRB) as an example, evaluated the health status of the MRB by the model: Vitality (V), organization (O), resilience (R), and services (S). From a sustainability perspective, an index system of human wellbeing was constructed, which included society and the economy, health and safety, materials and resources, and ecology and the environment. On this basis, the coupling coordination relationship and sustainable development status of the basin was assessed. The results showed that as land use changed, the ecosystem health showed a downward trend, and human wellbeing grew exponentially. The sustainable development index and the coupling coordination degree of the MRB were similar, indicating that the level of balance between ecosystem health and human wellbeing was the key to the sustainable development of the basin, and the overall situation was in a state of moderate imbalance and moderate unsustainability. Therefore, it is necessary to carry out sustainable management of the whole basin.

Keywords: land use change; basin ecosystem health; human wellbeing; sustainable development; Manas River Basin

1. Introduction

In the 1980s, based on the needs of ecosystem sustainable development, the concept of ecosystem health was created and provided a new way of thinking and a new method for regional environmental management [1,2]. Since the 1980s, the connotation of ecosystem health has changed from the initial diagnosis of ecosystem characteristics [3–5] to the integration of the ecosystem services capacity for humans [4,6]. The research methods have ranged from single or comprehensive bioindicators [7,8] to the establishment of a comprehensive indicator system at the system level [9,10]; the research object has previously been from the scale of a single ecosystem [11,12] to a regional/basin scale [13,14].

The focus of research has gradually evolved from the establishment of concepts and the description of phenomena to the exploration of rules and analysis processes, and the research has continued to expand. The regional/landscape scale is the core scale of ecosystem health research, and ecosystem health assessments at the basin scale have become an important direction for development [15]. Basin-scale ecosystem health refers to the ability of an ecosystem to resist natural and man-made disturbances, maintain structural integrity, be self-sustaining and renewing, meet the reasonable needs of people, and serve society [16]. The status of ecosystem health is closely related to human sustainable development [17], and natural ecosystems provide the materials and services needed for human survival, so maintaining ecosystem health is the primary factor in achieving socio-economic sustainable development [18], but worldwide ecosystems are generally compromised by natural and human factors and have degraded functions [19,20]. As a complex natural and socio-economic ecosystem, the basin is strongly influenced by natural factors and human activities, and the health status of the basin is related to the level of regional sustainable development. Therefore, the ecosystem health of the basin urgently requires sustainable policy management.

Land, as a key link connecting human activities and the geographical environment, is the most concrete landscape that shows the relationship between human production activities and the natural environment. Changes in land use patterns, scale, intensity, and usage not only cause changes in the structure and function of the basin ecosystem, but also changes in the materials cycle and energy flow processes between the basin landscapes [21,22], which ultimately triggers changes in the biochemical earth processes in the whole basin, affecting the stability of the basin and the sustainable export capacity of the services; these factors reinforce the close relationship of the land use patterns with ecosystem health. Health indicators can effectively reflect the ecological effects caused by land use change, although it is difficult to accurately measure the degree of influence of the land use patterns on the quality of the ecological environment [23]. At present, concern about the impacts of land use change on ecosystem health has increased, and quantitative research has become the main focus. Based on land use patterns and terrestrial ecosystem health, Chunzi Ma identified the standard health range values for 118 lake water quality indicators in the Dongyang Plains [24]. Xian Cheng analyzed the impacts and contribution rates of different land use modes and economic factors on ecosystem health indicators before and after the rainy season and pointed out that land use intensity was the main driving force of river ecosystem health compared with socio-economic factors [25]. Peng Jian quantitatively analyzed the response of ecosystem health to rural land use change and pointed out that the decrease in forest land and the expansion of construction land made the ecosystem health decline in most areas and noted that there was still a great lack of exploration of the internal correlation between land use modes and ecosystem health [26]. At present, the current research on the time dynamic analysis of the relationship between land use change and ecosystem health is not sufficient. Based on the time scale, building the basin ecosystem health evaluation index system from the perspective of land use could more comprehensively evaluate the ecological effects caused by land use change and more directly analyze the dynamic relationship between land use change and ecosystem health.

Human wellbeing is based on the experiences of the people who believe that there is value in activities and status, including maintenance of the basic material conditions of a high quality of life, health, good social relations, security, and freedom of choice and action [27]. The primary goal of human wellbeing research in the early stage is to supplement the gross domestic product (GDP) economic indicators, while that of human wellbeing research from the perspective of sustainability research is different. Human wellbeing research takes the maintenance and improvement of human wellbeing as the ultimate goal of sustainable development and aims to quantitatively analyze the changes and influencing factors of human wellbeing, especially the impacts of ecosystem services on human wellbeing [28]. Human wellbeing depends on the supply, regulation, support, and cultural services of the ecosystem. Starting in 2005, Millennium Ecosystem Assessment (MA) proposed a relationship between ecosystem services and human wellbeing at the global scale in the Future Earth plan for 2012, which involved studying the relationship between both natural and human-driven

global environmental change and human wellbeing [29]; research on “ecoSERVICES” takes “the impact of changes in ecosystem services on human wellbeing and human response to changes in ecosystem services” as the core of the research, while the research on ecosystem services and human wellbeing has attracted the attention of increasing numbers of scholars [30–33]. Land use is seen as a key factor in changes to human wellbeing and quality of life [34,35]. In recent years, combined with research on land use change, research on the relationship between ecosystem services and human wellbeing has become increasingly rich. The results of this research have shown that with the increase in land use intensity, the economy, crop production, and living standards have all improved; these factors are positively correlated with supply services, but the regulation services have been reduced [36–38]. This research has also pointed out that the changes to human wellbeing and the social responses caused by land use and climate change require more in-depth study [39].

Humans cause various resource-related, ecological, and environmental problems for the ecosystem in the process of maximizing their own wellbeing or changing the structure and function of the ecosystem through land use change, which directly or indirectly affects the ecosystem health. When the disturbances reduce or exceed the regulatory capacity of the system itself, the ecosystem also limits the sustainable growth of human wellbeing by having lower quality ecosystem services. A number of studies have shown that the capacity of ecosystems to produce ecosystem services is declining. A study by Costanza showed that the annual loss of global ecosystem services due to land use change in 1997–2011 reached 4.5–2 billion [40]. MA pointed out that approximately 60% of the tested ecosystem services were weakened and were utilized in an unsustainable way, and the capacity of the ecosystem to sustainably supply ecosystem services was seriously threatened by human activities. However, under the influence of natural and human factors, the mismatch between the declining ecosystem service supply capacity and the increasing social demand has become an important reason for the decline of human wellbeing [41,42]. Ecosystem services are an important representation of the health of an ecosystem. Changes in ecosystem health directly or indirectly affect the output of ecosystem services. Only a healthy ecosystem can continuously provide valuable services for humans in the process of regeneration, which then affects the balance and sustainability of human wellbeing. The complex relationship between ecosystem health and human wellbeing is related to the sustainable development level of the whole basin. If this relationship falls into a vicious cycle, it leads to the unsustainability of the whole basin and eventually threatens the survival and development of humans. However, there is a lack of systematic analysis on the impact of the evolution characteristics of the ecosystem health and human wellbeing and the relationship of coupling and coordination between them on regional sustainable development under human disturbance. From the perspective of sustainability research, it is of great significance to study the interaction between human wellbeing and ecosystem health under land use change.

The Manas River Basin (MRB) is located in the arid inland area of northwestern Xinjiang. It has a typical mountain–oasis–desert structure and an oasis socio-economic system, and the contradiction between the fragility of the ecological environment and the demand for human development is more prominent than in other areas. Since the establishment of the People’s Republic of China, large-scale water and soil development have been carried out in the basin, and the land use patterns have undergone significant changes. In this process, the status and dynamic evolution of the ecosystem health of and human wellbeing in the basin, the coupling coordination relationship between the two, and the change in sustainable development status of the basin under this interaction remain to be studied. This paper explored the sustainable development level of the MRB in recent decades, including (1) the transformation of land use structure, (2) the changes in ecosystem health and human wellbeing and the driving factors of these changes, (3) the dynamic linkage between ecosystem health and human wellbeing, (4) the evolution of sustainable development in the composite system, and (5) the mechanism of interaction among land use, ecosystem health, and human wellbeing.

2. Study Area

The MRB is located in the northwestern part of the Xinjiang Uygur Autonomous Region in the arid region of northwest China. It is on the southern edge of the Junggar Basin and is bordered by the Gurbantunggut Desert in the north. The total area is 24,300 square kilometers, and the main administrative areas include Shihezi city, Manas County, and Shawan County. The area experiences frequent drought due to low levels of rain and high rates of evaporation and has a typical continental climate, with an average annual temperature of 6.6 °C, an average annual precipitation of 110–200 mm, and an annual evaporation of 1500–2000 mm. However, the light and heat resources in the basin are plentiful, and the annual sunshine hours are up to 2550–3110 hours. The terrain slopes from the southeast to the northwest, with the highest elevation at 5242.5 meters and the lowest elevation at 256 meters, which gives the basin an obvious vertical zonal distribution, and there are significant regional differences in the geology, climate, soil, biological community, etc. The basin geomorphology shows a structure that is typical of the mountain-basin system, and the proportion of mountains, oases, and deserts is 1.1:0.96:0.35. From the south to the north, the basin can be divided into three parts: The southern hilly area, the central oasis plains area, and the northern desert area. Manas River, which is the largest river in the basin, runs through these areas (Figure 1).

MRB is located in the economic belt on the northern slope of Tianshan Mountain, which is an important agricultural and industrial production base in Xinjiang. There are also significant differences in the population, economy, and society from high mountains to desert. Due to differences in resource allocation, the mountain areas, oases, and deserts have differing economic uses. The southern high mountain area is covered with snow all the year round, and the modern glaciers are very active. The mountain is the main source of water for all rivers in the basin. The middle and low mountainous areas are the forest areas and year-round pastures. In the low mountainous areas, due to overgrazing and artificial reclamation, the degradation of the vegetation is serious, resulting in soil erosion. Because of the poor soil in the whole mountain area, agriculture is only distributed in the flat and wide valley and the valley between the mountains. The population here is sparse and mainly comprises ethnic minorities; the economy is depressed. The central plains area is the largest oasis farming area in Xinjiang and the fourth largest irrigated area in China. It is also the economic and industrial center of the basin. The Shihezi urban areas, Shawan urban areas, and Manas urban areas are all distributed in this region. Higher daily and annual temperature differences are beneficial to photosynthetic activity and sugar accumulation in crops, especially in high sugar content crops like melons, fruit and sugar beets, and the cotton fiber grown in this area is long and has good color, making the region an important production base for grain, oil, sugar, and cotton in Xinjiang. The population of the area accounts for 76.65% of the population of the whole basin, and the economic output accounts for 85.11% of the GDP of the basin. However, salinization is more serious in the middle and upper parts of the basin's alluvial and diluvial plain. The transition zone between the desert and cultivated land in the north has basically disappeared due to the expansion of the oasis. The oasis and sand dunes in the Mosuo Bay area are interspersed, and rainfall is scarce, limiting the development of agriculture.

The arid basin ecosystem is more sensitive to human activities. The rapid growth of population and the increasing urbanization and industrialization in recent decades have caused oasis expansion and structural changes in the basin. The impacts of human activities on the ecosystem require further study. The strategy for coordinating the relationship between resource exploitation and resource protection and human wellbeing and ecosystem health remains a difficult problem for the development of arid basins.

Figure 1. Geographic location, Digital Elevation Model (DEM), and landscape overview of the Manas River Basin (MRB).

3. Materials and Methods

3.1. Data Sources

The land use data from 1989–2016 were obtained through the interpretation of remote sensing data. The remote sensing image data came from the US Geological Survey, China Geospatial Data Cloud, and the Global Land Cover Facility of University of Maryland. Landsat images with a spatial resolution of 30 m were selected from August to September of the study years, including Landsat 5 Thematic Mapper (TM) images from 1989, 1996, 2006, and 2011; Landsat 7 Enhanced Thematic Mapper (ETM) images from 2000 and 2003; and Landsat 8 Operational Land Imager (OLI) images from 2016. Seven images differed by about 1 month, but the vegetation had similar growth states, which ensured the comparability of the results. Moreover, the selected images contained less than 2% cloud cover, which is adequate for land use interpretation and ecological environment quality index calculation. The meteorological data, including the monthly average temperature, total monthly precipitation, and total monthly solar radiation, came from the National Meteorological Administration (<http://data.cma.cn>) and the local meteorological bureau. The soil attribute data were from the Soil Survey Office of the Xinjiang Uygur Autonomous Region. The 30 m Digital Elevation Model (DEM) data, slope and slope length data, and national net primary productivity (NPP) of vegetation data were from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (<http://www.resdc.cn>). The agricultural, population, and socio-economic data were from the 1990–2017 “Shihezi Statistical Yearbook”, the “Shawan County Historical Data Collection”, the “Manas County Historical Data Collection”, and the “Xinjiang Statistical Yearbook”.

3.2. Methods

3.2.1. Land Use Change: Interpretation of Remote Sensing Data and Land use Intensity

Remote Sensing Interpretation

Remote sensing interpretation is the most effective way to obtain large-scale land use data. The remote sensing images for 1989, 1996, 2000, 2003, 2006, 2011, and 2016 were separately pre-processed through splicing, cutting, radiometric calibration, and atmospheric correction by ENVI5.1. According to the land use/land cover remote sensing classification system of China and the research needs, the remote sensing images were interpreted by supervised classification and visual correction, and the land use types were divided into forest land, grassland, cultivated land, water area, construction land, glacier, and desert. Next, we used the high-resolution data provided by Google Earth combined with the field observation data and experience to test the accuracy. The kappa coefficient showed that except for the accuracy of 76.63% in 1989 that resulted from a quality issue with the remote sensing images, the accuracies of other years were higher than 80%, which effectively met the research needs.

Land use Intensity

Land use intensity mainly refers to the degree of influence of human activities on land. Brown and Vivas proposed the use intensity coefficient of each land use type according to the amount of energy and material used by each land use types per unit area [43], which has been shown to be an effective indicator to represent the human pressure on the land. Land use intensity can be calculated as follows:

$$LUI = \sum \%LU_i \times LDI_i \quad (1)$$

where $\%LU_i$ refers to the proportion of the i -th land use type, LDI_i is the i -th land use intensity coefficient, and LUI is the total land use intensity (Table 1).

Table 1. Coefficients of different land use intensities.

Item	Forest Land	Grassland	Cultivated Land	Water Area	Construction Land	Glacier	Desert
LDI	1	3.41	7	1	8.43	1	1

3.2.2. Ecosystem Health: Index System Construction and Index Calculation

In recent years, based on land use characteristics, the VORS model, which was expanded from Costanza's classic VOR evaluation mode, was more commonly used in research on the regional health assessments related to land use. Compared to other regional ecosystem health assessment models, such as the subsystems, the press–state–response framework, and the reliability–resilience–vulnerability framework, etc., the VORS model has fewer indexes and takes ecosystem services into account, which provides an effective quantitative research method for evaluating the ecological effects caused by land use [26,44–46]. The VORS model was used to evaluate the ecosystem health of the MRB. The calculation formula is as follows:

$$H = \frac{1}{4} V * O * R * S \quad (2)$$

Vitality

Ecosystem activity refers to the level of system metabolism and primary productivity, which is usually expressed as the net primary productivity (NPP) of the vegetation [45,47]. The CASA model, which is based on photosynthetic effective radiation and light energy utilization, has become a well-established model for NPP estimation [48]. The calculation method is as follows:

$$NPP = SOL * FPAR * 0.5 * T_1 * T_2 * W * \varepsilon_{\max} \quad (3)$$

where SOL is the total solar radiation, FPAP is the absorption ratio of the photosynthetically active radiation, 0.5 is the ratio of the solar effective radiation absorbed by vegetation to the total solar radiation, T1 and T2 are the temperature stress factors, W is the water stress coefficient, and $\varepsilon_{\max}$ is the maximum light energy utilization rate. NPP was calculated by using envi5.1 under the software module v1.0 of vegetation net primary productivity developed by Wenquan Zhu, and the calculation method for each parameter follows the method of Zhu [49,50].

Elasticity

Ecosystem elasticity has two meanings: One is the ability of an ecosystem to resist external interference, and the other is the ability of the ecosystem to regenerate after being disturbed through a self-regulation mechanism [26]. The resistance and resilience of different land use types to interference are significantly different. In general, resistance and resilience are negatively correlated. The stronger the resistance of a land use type, the more difficult it is for the ecosystem (which means that there is more complex structure) to recover to the original level once it has been damaged. Peng Jian [26] defined ecosystem elasticity in terms of resistance and resilience. According to whether the external interference exceeds the self-regulation ability of the system, the weight of the system resistance and resilience is determined, and the expert scoring method is used to assign the resistance and resilience of the different land use types. The results are shown in Table 2.

$$E = 0.3 * \text{Resil} + 0.7 * \text{Resist} \quad (4)$$

Table 2. Coefficients of resilience and resistance of different land use types.

Item	Forest Land	Grassland	Cultivated Land	Water Area	Construction Land	Glacier	Desert
Resilience	0.5	0.8	0.4	0.7	0.2	0.1	1
Resistance	1	0.7	0.5	0.8	0.3	0.1	0.2

Organization

Ecosystem organization refers to the stability of its structure, which is generally expressed by the landscape pattern index. Landscape heterogeneity and connectivity are commonly used indicators to reflect the stability of the structure of a system, and they have the same importance [45]. In addition, the water area is an important landscape type in the basin due to the mountain–oases–deserts system structure in arid areas, and the connectivity of water areas also affects the organizational state of the basin to a certain extent. Based on the description of the characteristics of the type, shape, quantity, and internal connection degree of the landscape patches in the basin, the organization level of the basin is characterized from the three aspects of landscape heterogeneity, the degree of landscape connectivity, and the degree of important landscape type connectivity. Using FRAGSTATS software for calculation, and the weight setting of each index follows those of Frondoni et al. and are listed as follows:

$$O = 0.35 * LH + 0.35 * LC + 0.33 * CC \quad (5)$$

$$= 0.25 * SHDI + 0.1 * AWMPFD + 0.25 * FN1 + 0.1 * CONT + 0.2 * FN2 + 0.1 * CONNECT \quad (6)$$

where O is the ecosystem organization, LH is the landscape heterogeneity, LC is the landscape connectivity, CC is the water connectivity, AWMPFD is an indicator of the area-weighted average patch fractal dimension, FN1 is the landscape fragmentation index, SHDI is Shannon's diversity Index, CONT is the landscape contagion index, FN2 is the water fragmentation index, and CONNECT is the water connection index.

Services

The quality and sustainability of ecosystem services are important criteria for measuring ecosystem health [26]. There are great differences in the abilities and types of services provided by different land use types. Costanza et al. calculated the average service value of different ecosystems [51]. For reference, based on the knowledge of hundreds of ecological experts in China, Gaodi Xie adjusted the average values twice and established an equivalent factor table of the ecosystem service values per unit area in China [52]. The equivalence factor method is more intuitive and easier to use and has lower data demands. It is especially suitable for the assessment of the value of ecosystem services at regional and global scales [53,54]. Based on the study of Xie, this study used the ratio of the average NPP per unit area of each land use type in the MRB to the average value of the national unit area as the regulating factor to build a unit equivalence factor table for the basin.

Due to the existence of service flow, we must consider the spatial proximity effect between ecosystems, or the interaction between different ecosystems. It is generally believed that the human-dominated areas will have negative effects on the surrounding natural ecosystems [44], such as through urban sewage pollution in rivers. Wetland and forest ecosystems have strong service capacities, which has a positive impact on the surrounding ecosystem; for example, the pollination of forest land may improve the productivity of farmland [55]. In this regard, Marulli and Mallarach (2005) proposed a matrix of spatial proximity effect coefficients between the different ecosystems (between 0–1) [56]. Peng Kang modified this matrix based on expert scores [45], as shown in Table 3. The METLAB2018b was applied to complete the calculation, and calculation method of ecosystem service value is as follows:

$$ESV = \left(\sum_{i=1}^n \left(A_i * \frac{b_i}{B_i} * X_i \right) \right) \times \left(1 + \sum_{j=1}^m \frac{SNE_j}{100} \right) \quad (7)$$

where ESV refers to the ecosystem services, A_i represents the i area of land use type b_i , B_i is the average NPP of the i land use in the MRB and the nation, X_i is the i land use service equivalent factor, n is the number of land use types, $n = 7$, m is the number of adjacent grids, $m = 4$, and SNE_j is the spatial proximity effect coefficient of the j grid.

Table 3. Spatial proximity effect coefficients of each land use type.

Item	Forest Land	Grassland	Cultivated Land	Water Area	Construction Land	Glacier	Desert
SNEs	5	3	4	5	3	3	3
SNEd	4	2	−2	4	−4	−4	−4

SNEs refer to the spatial proximity effect of the same type of land use, and SNEd refers to the spatial proximity effect of different types of land use.

3.2.3. Human Wellbeing: Construction of the Indicator System and Index Calculation

The wellbeing composite index, which effectively measures changes in ecosystem services and health, is a very necessary indicator for measuring sustainable human development. Society and the economy, health and safety, and materials and resources are fundamental and important concerns for assessing human wellbeing [27,37,42,57]. Economic growth, social stability, adequate materials, and physical and mental health are undoubtedly the components of human wellbeing. Many scholars have carried out extensive evaluation and research on human wellbeing from such relevant aspects, but it is rare to incorporate ecological and environmental wellbeing into the human wellbeing evaluation system. The ecological environment is closely related to the quality of human life, and it is also the junction between ecosystem health and human wellbeing. As the ecological environment deteriorates, its impact on humans becomes increasingly obvious. Therefore, this study combined the ecological

environment with society and the economy, health and safety, material and resources to build a human wellbeing evaluation system, as shown in Table 4. The calculation formula is as follows:

$$W = \sum_{i=1}^n \alpha_i Z_i \quad (8)$$

where α_i is the weight of the i index, which is determined by the mean value of the subjective method (expert consultation method) and objective method (entropy weight method), and Z_i is the standardized value of the i index. All the indicators were treated as positive; that is, the higher the value was, the higher the level of wellbeing was (Table 4).

Table 4. Index system of human wellbeing.

Target Arrangement	Factor Arrangement	Indicator Arrangement	Selection Criteria	Weights
Human wellbeing	Health and safety	Mortality	Reflecting the physical health of the residents	0.0287
		Average life expectancy		0.0474
		Proportion of expenditure on education, entertainment and science and technology	Reflecting the psychological and mental health of the residents	0.0334
		Number of criminal offenses per year	Reflecting the personal security of residents from the aspects of social security and medical security	0.0340
		Number of traffic accidents per year		0.0318
		Beds per thousand people		0.0368
	Material and resources	Per capita supply of agricultural products	Reflecting the supply level of residents' material demand from the supply of industrial and agricultural products and housing area	0.0367
		Per capita supply of industrial products		0.0392
		Per capita housing construction area		0.0328
		Per capita renewable water resources on the surface	Reflecting resource supply capacity from per capita share of water, energy, cultivated land and forest resources	0.0358
		Per capita forest area		0.0505
		Per capita cultivated land area		0.0401
		Energy supply capacity		0.0522
	Society and economy	Number of annual divorces	Reflecting the degree of family harmony	0.0261
		Urbanization rate	Reflecting the degree of urbanization	0.0276
		Disposable income of urban residents	Reflecting the level of economic development in terms of economic quantity, consumption structure and industrial structure	0.0509
		Per capita net income of farmers and herdsmen		0.0444
		Engel coefficient		0.0497
		Per capita GDP		0.0490
		Proportion of added value of tertiary industry in GDP		0.0290
	Ecology and environment	Equivalent pollution load of water body	Reflecting environmental quality in terms of water, soil and air pollution, heat, dryness, humidity, and greenness	0.0281
		Agricultural film pollution of soil		0.0296
		Air quality index		0.0272
		Remote sensing ecological index		0.0318
		Free from natural disasters	Reflecting the degree of ecological security in terms of natural disaster, soil erosion and salinization	0.0511
		Free from soil erosion		0.0218
		Free from soil salinization		0.0342

Note: The data of the indicators come from government statistical data, except for the three indicators: "Equivalent pollution load on water bodies", "Ecological environment quality", "Soil and water conservation".

Equivalent Pollution Load on Water Bodies

The equivalent pollution load is an evaluation index that is frequently used in pollution assessments. The index mainly reflects the potential pollution levels from the pollution sources. Due to the lack of water quality monitoring data during the research period, the water pollution situation in the study area was estimated with the equivalent pollution load method. The total nitrogen (TN) and total phosphorus (TP) from planting, aquaculture and rural life were selected as the evaluation factors. The calculation formula is as follows:

$$P_i = \sum_i^2 \sum_j^3 \frac{C_{ij}}{C_o} \quad (9)$$

where P_i is the equivalent emission of i pollutants (m^3), C_{ij} is the amount of the i pollutant released by the j pollution source ($\text{t}\cdot\text{a}^{-1}$), and C_o is the value concentration of the pollutant according to the standard series of GB3838-2002 III (TN is 1 mg/L and TP is 0.2 mg/L).

Amount of pollutants released by the planting industry = cultivated land area * pollutant loss coefficient.

Amount of pollutants released by the aquaculture industry = quantity of livestock and poultry * excretion coefficient * loss rate.

Amount of pollutants released in rural areas = coefficient of production and discharge of pollutants in urban domestic sewage * 0.4 + coefficient of production and discharge of faecal pollutants.

The loss coefficient of the cultivated land pollutants is the average value for Xinjiang. The livestock and poultry types include cattle, sheep, pigs, and poultry, which have excretion coefficients that are derived from the parameters for the northwestern region in the Manual of Source and Sewage Discharge Coefficient of Livestock and Poultry Breeding. The loss rate is the average value for Xinjiang, which is 15%; the scale of the livestock and poultry and the treatment utilization rate are based on the national first-time pollution source survey data. The coefficient of the production and discharge of urban domestic sewage and fecal pollutants come from the "Sewage Discharge Coefficient from domestic sources and Instructions for Use".

Ecological Environment Quality: Remote Sensing Ecological Index

The remote sensing ecological index (RSEI) is a new type of ecological index obtained through remote sensing, as proposed by Xu Hanqiu, and is based on natural factors coupled with the greenness index, wetness index, dryness index, and heat index, and can quickly monitor and evaluate regional ecological environment quality. Greenness, wetness, dryness, and heat are the most direct and sensitive environmental factors that humans perceive in their ecological environment. These factors can effectively characterize the quality of the ecological environment and are often used to evaluate ecosystems [58,59]; see citations for the specific calculation references [60]. The ENVI5.1 was applied to complete the calculation, and calculation method of RSEI is as follows:

$$\text{RSEI} = f(G, W, T, D) = f(\text{NDVI}, \text{Wet}, \text{LST}, \text{NDBSI}) \quad (10)$$

where G is greenness, W is wetness, T is heat, D is dryness, NDVI is vegetation index, Wet is the wetness component, LST is the surface temperature, and NDBSI is the building and bare soil index.

Soil and Water Conservation

Statistical modelling of soil erosion has become an important approach to soil erosion research. Among these models, the US soil loss experience model (USLE) that was released by the US Department of Agriculture in 1997 is the most convenient and widely used soil erosion model. Based on the characteristics of the unique geomorphological types in China, the modified soil loss equation (RUSLE) has been widely used in the estimation of soil erosion. This study used the RUSLE to assess the potential soil water erosion in the study area for long periods of time [61] to reflect the soil retention

capacity of the basin. The ArcMAP 10 was applied to complete the calculation, and calculation method is as follows:

$$A = R * K * LS * C * P \quad (11)$$

where A is the potential soil water erosion amount ($t \cdot ha^{-1} \cdot a^{-1}$); R is the rainfall erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1}$); K is the soil erodibility factor ($t \cdot ha^{-1} \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$); LS is the slope and slope length factor; C is the vegetation coverage factor; and P is the engineering measure factor.

3.2.4. Sustainable Development Model

When considering the ecosystem health and human wellbeing as a human–land composite system, it is especially important to analyze the sustainable development levels of the composite system to understand the contradictory state of the human and geographical environments and to formulate sustainable development policies for the basin. The sustainable development of the basin composite system is affected by the development status of the subsystem and the level of coupling and coordination between them. Therefore, with reference to the human development index equation, the sustainable development equation of the ecosystem health–human wellbeing composite system of the basin was constructed as follows:

$$HWSDI = (H * W * D)^{\frac{1}{3}} \quad (12)$$

where $HWSDI$ is the sustainable development index of the ecosystem health–human wellbeing composite system, and H , W , D are the ecosystem health, human wellbeing, and the coupling and coordination degree of the two factors, respectively.

The coupling coordination degree between the ecosystem health and human wellbeing was analyzed with the dynamic coupling model [62] as follows:

$$\begin{aligned} C &= \{[M(W) \times M(H)] / [M(W) + M(H)]^2\}^{\frac{1}{2}} \\ T &= \alpha M(W) + \beta M(H) \\ D &= \sqrt{C \times T} \end{aligned} \quad (13)$$

where $M(W)$ and $M(H)$ are the ecosystem health subsystems and human wellbeing subsystem; C represents the coupling degree of the two, T represents the harmonic index, and α and β are undetermined coefficients, which respectively represent the proportion in the harmonic index of ecosystem health and human wellbeing. In this paper, $\alpha = \beta = 0.5$, and D is the coupling coordination degree between ecosystem health and human wellbeing.

According to the system evolution theory in Bertalanffy's general system theory [63], the dynamic evolution of the composite system was further analyzed. Then, the evolution equation of the system is in the following form:

$$\begin{aligned} W &= \frac{dM(W)}{dt} = \alpha_1 M(W) + \alpha_2 M(H) \\ H &= \frac{dM(H)}{dt} = \beta_1 M(W) + \beta_2 M(H) \end{aligned} \quad (14)$$

where W and H are the evolutionary state of the ecosystem health and human wellbeing under the influence of internal and external factors, respectively, and they influence each other. The change in any subsystem will lead to the change of the whole system. The evolution speed of the two subsystems is as follows:

$$\begin{aligned} V_W &= \frac{dW}{dt} \\ V_H &= \frac{dH}{dt} \end{aligned} \quad (15)$$

where the sustainable development index $HWSDI$ is combined with the change in speed V_W and V_H to diagnose the risk level of regional ecosystem sustainable development. The judging thresholds of the states of coupling coordination and sustainable development refer to previous research results (Table 5) [62,64].

Table 5. Coordination status and sustainable development alarm of the basin.

D	Coupling Coordination State	HWSDI	Sustainable Development Status	Speed of System Change	System Succession Direction	Warning Degree
$0.8 < D \leq 1.0$	Great coordination	$0.8 < HWSDI \leq 1.0$	High sustainability	$VW > 0$ and $VH > 0$	Positive succession	No warning
				$VW < 0$ or $VH < 0$	Regressive succession	Light warning
$0.7 < D \leq 0.8$	Good coordination	$0.7 < HWSDI \leq 0.8$	Relatively high sustainability	$VW > 0$ and $VH > 0$	Positive succession	No warning
				$VW < 0$ or $VH < 0$	Regressive succession	Light warning
$0.5 < D \leq 0.7$	Basic coordination	$0.5 < HWSDI \leq 0.7$	Basic sustainability	$VW > 0$ and $VH > 0$	Positive succession	Light warning
				$VW < 0$ or $VH < 0$	Regressive succession	Medium warning
$0.4 < D \leq 0.5$	Moderate maladjustment	$0.4 < HWSDI \leq 0.5$	Moderate unsustainability	$VW > 0$ and $VH > 0$	Positive succession	Medium warning
				$VW < 0$ or $VH < 0$	Regressive succession	Serious warning
$0.3 < D \leq 0.4$	Serious maladjustment	$0.3 < HWSDI \leq 0.4$	Serious unsustainability	$VW > 0$ and $VH > 0$	Positive succession	Serious warning
				$VW < 0$ or $VH < 0$	Regressive succession	Critical warning
$0 < D \leq 0.3$	Extremely serious maladjustment	$0 < HWSDI \leq 0.3$	Extremely serious unsustainability	$VW > 0$ and $VH > 0$	Positive succession	Critical warning
				$VW < 0$ or $VH < 0$	Regressive succession	Critical warning

4. Results

4.1. Land Use and Intensity Change

Because it is located in the inland arid area and has a typical mountain-basin structure, the MRB makes grassland and desert constitute the basement of land use and cover in the basin. The proportions of grassland and desert in the total area of the basin are 38.12% and 28.38%, respectively. Although the MRB has existed for three or four thousand years, it was inhabited by nomadic group for most of its history, which had low populations and were less culturally and economically developed. Until 1949, after the founding of the People's Republic of China, the Party Central Committee issued the instruction of "cultivating and guarding the border" and designated the MRB as a key area for development and management. From 1952, comprehensive surveying was carried out, and the goals of irrigation-centered farmlands and water conservancy construction were established, and the treatment was carried out in phases. By 1985, a certain number of the water conservancy facilities were built, which promoted the great development of the industry and agriculture. After decades of water and soil development and construction, the areas of cultivated land rose linearly. During the study period, the area of cultivated land increased from 3343.30 hm² in 1989 to 6427.7 hm² in 2016, with a growth rate of 87.11%. The increase in the cultivated land mainly came from the reclamation of the grassland and bare land, which resulted in a decrease of 15.54% and 23.28% in the grassland and desert areas, respectively. After 2011, the area of cultivated land exceeded the desert area. At present, the basin has become the largest agricultural area in Xinjiang, and agriculture and animal husbandry have become the main industries in the region. With the rapid increase in the cultivated land area, the process of oasis development and economic construction has greatly accelerated. The construction land in the river basin has grown rapidly, with an increase of 134.92% from 1989 to 1996. In contrast, the area of forest land decreased rapidly. Due to a large number of timber cuttings and no corresponding planting, the area of forest land decreased by 339.44 hm² from 1989 to 2016, which was a decrease of 34.59%. The highest altitude of the southern mountainous area is 5242.5 m, which is covered by snow throughout the year. Except for the increase in temperature in 1996, which resulted in the increase

in glacier melting and the reduction of the glacier area, there was no significant change in the other years. The area of the rivers and lakes was approximately 175.17 hm², which did not show any obvious fluctuations (Figure 2).

The construction land and the cultivated land are the most strongly coupled land types in the human–land system. The intensity coefficients of these land use types are 8.43 and 7.00, respectively, which were much higher than those of other land use types. With the continuous growth of the areas of these two land use types, the land use intensity of the basin showed a continuous upward trend (Figure 3) from 2.99 to 3.76, which was an increase of 25.75%. The overall pattern, social economy, and ecological environment of the basin also change significantly with the change of land use intensity.

Figure 2. Land use area change of the MRB from 1989 to 2016

Figure 3. Changing trend of the land use intensity in the MRB from 1989 to 2016.

4.2. Changes in the Basin Ecosystem Health and Drivers

The NPP is affected by various factors, such as the temperature, precipitation, radiation, and normalized vegetation index (NDVI). The change in the NPP value reflects the comprehensive trend of the climate and vegetation in the basin. Based on the differences in the vegetation coverage, the NPP followed the trend where cultivated land > forest land > construction land > grassland > desert > waters. During the study period, the NPP in the basin showed a fluctuating upward trend affected by the comprehensive influence of the change in land area, basin climate, and vegetation growth state. The NPP value of the basin increased from 212.90 g c/m² in 1989 to 389.27 g c/m² in 2016, which was

consistent with the trend of the overall increase in temperature, precipitation, and vegetation coverage in recent years.

From 1989 to 2016, the elasticity showed a continuous downward trend. As mentioned before, the elasticity of the river basin was affected by the resilience and resistance of land use types, especially the latter. The change in the elasticity of the basin depended on the transformation mode and amount of land use types. The elasticity coefficients of the forest land (0.85) and grassland (0.73) were relatively high, while those of the cultivated land (0.47) and construction land (0.27) were relatively low. To meet the needs of social and economic development, forest land was cut down in large areas or was converted along with grassland into cultivated land or construction land, which reduced the resistance and recovery ability of the basin to external interference.

Overall, the basin organization showed a downward trend and improved in 2011–2016. The organization state was a measure of the stability of the basin structure. The landscape pattern index reflected the diversity, vulnerability, and connectivity of the organization of the basin. The diversity index showed an overall growth trend. With the intervention of human activities, the degree of fragmentation of the basin patches increased, mainly due to the scattered distribution of the arable land in the early stages of reclamation, which destroyed the integrity of the original grassland and desert and increased the landscape heterogeneity. After 2011, the diversity index decreased, indicating that the patches tended to be evenly distributed in the landscape. To some extent, the area-weighted average patch fractal dimension also reflects the impact of human activities on the landscape pattern. The increase in the man-made landscapes, such as cultivated land and construction land, made the edge of patches more regular and the fractal dimension lower. The contagion index reflects the aggregation degree or spreading trend of different patch types. The index first decreased and then increased before and after 2003, indicating that the fragmentation degree was high from 1989 to 2003. With the increasing degree of dominance of the cultivated land, the cultivated land aggregated patches into a larger area, forming good connectivity between the patches, and enhancing the agglomeration.

During the study period, the ecosystem services showed a fluctuating and decreasing trend, which was consistent with the change trend of the overall health status of the basin (Figure 4). In 1996 and 2006, there were two minimum break points. The driving factor analysis showed that the main factors affecting the health status of the basin in 1989–1996 were organization (−31.81%) and services (−41.34%); the fragmentation of the structure and the decrease in the area of forest land and grassland with high service coefficients were the main reasons for the decline in the health of the basin. Second, the rainstorm and flood in 1996 destroyed a large number of farmlands and roads, which to a certain extent destroyed the organizational stability of the basin and the service capacity of the vegetation (Table 6). In 2006, the service level again dropped to the lowest point. In addition to the replacement of the land with high ecosystem service capacity by land with relatively low service capacity, the precipitation decreased by approximately 18.03% and the temperature increased by approximately 15.65% compared with the average level from 1989–2003. Due to the arid climate conditions, the proportion of NPP per unit area of forest land and grassland, which depended on rainfall supply, decreased by 24.13% and 12.10%, respectively, and the service level of the other land types was also affected to varying degrees, which significantly reduced the overall service capacity of the basin.

Figure 4. Changing trend of the health index in the MRB from 1989 to 2016.

Table 6. Changes in the landscape index of the MRB from 1989 to 2016.

Year	SHDI	AWMPFD	FN1	CONTAG	FN2	COHESION
1989	1.3772	1.2881	0.2268	0.5466	0.1134	0.9976
1996	1.3900	1.2823	0.2604	0.5284	0.1345	0.9933
2000	1.4033	1.2771	0.2801	0.5102	0.1473	0.9917
2003	1.4041	1.2735	0.3026	0.5156	0.1532	0.9911
2006	1.4128	1.2684	0.3105	0.5289	0.1687	0.9891
2011	1.4208	1.2612	0.2904	0.5431	0.1748	0.9885
2016	1.4133	1.2547	0.2868	0.5631	0.1742	0.9888

4.3. Changes and Drivers of Human Wellbeing

The health and safety aspects of wellbeing first showed a decreasing trend and then increased; the lowest value appeared in 2000, which was mainly due to the increase of mortality and traffic accidents by 33.18% and 214.02%, respectively, while the number of beds decreased by 19.73%. After 2000, with the development of the economy and society, the living standards were improved, medical and health services had developed rapidly, and medical treatment had been largely guaranteed. The per capita life expectancy increased by approximately 4.61 years from 2000 to 2016. At the same time, the strengthening of traffic controls and the improvement of the overall quality of citizens led to a significant decline in the traffic accidents. The proportion of education, entertainment, and science and technology expenditures and the crime rate showed opposite changes. To a certain extent, these trends reflected the increasingly positive impacts of education on people.

The health of the ecological environment showed a fluctuating downward trend, with the index decreasing by 53.79% from 0.145 in 1989 to 0.067 in 2016. The water and soil pollution continued to increase. The remote sensing ecological index improved yearly due to the increases in temperature, precipitation, and vegetation coverage. The soil salinization decreased overall, but in recent years, it has deteriorated due to the occurrence of local secondary salinization. The amount of atmospheric respirable particles and the number of natural disasters has also increased yearly since 2003.

At the beginning and end of the research period, the speed of social and economic development was remarkable. The wellbeing index increased by 0.057 from 1989 to 1996, mainly benefiting from the increase in economic income. In particular, the per capita net income of the farmers and herdsmen increased from 920.97 yuan to 3028.67 yuan, which was an increase of approximately 2.3 times, and the per capita disposable income of the urban residents increased by 1.7 times, which was less than that of the farmers and herdsmen. As cultivated land was reclaimed, the traditional grazing agriculture

was gradually shifted to planting agriculture, which was more beneficial for improving the economic benefits for farmers and herdsmen. Due to the contributions of the urbanization rate, Engel coefficient, and the proportion of the tertiary industry in 2011–2016, the society and economic wellbeing index increased by 0.1. After decades of economic construction, the total economic volume had been greatly improved and has increased. Currently, the improvement of wellbeing is mainly reflected in the optimization of the economic structure. With the rapid growth of the social economy, the rapid development of social economy played a major driving role in the improvement of human wellbeing at this stage. From 1996 to 2011, social and economic development was relatively flat.

The change trend of the wellbeing index of the materials and resources and human general wellbeing was also relatively consistent. Except for the decline in 2000–2003, the material and resource wellbeing showed an overall upward trend. The growth rate was slower before 2000, and the index increased from 0.066 to 0.093, which was an increase of 40.91%. After 2003, the material resources achieved rapid growth. In 2016, the index reached 0.211, which represented an increase of 112.99%.

The analysis of the driving factors showed that the main factors causing the changes in wellbeing in 1989–2000 were from the perspectives of the ecological environment and social economy (Table 7). With the development of the basin, the economic benefits increased significantly, and the per capita GDP increased from 14.1377 million yuan to 64.2796 million yuan, but this development damaged the ecological environment; with the improvement of ecological environment in 1996–2000, human welfare had been improved. The decline in human wellbeing in 2000–2003 was mainly caused by the reduction in the health of the ecological environment and the loss of material resources, especially the reduction in the most important water and forest resources in the arid basin, which will undoubtedly lead to declines in human wellbeing. Although health and safety had grown, the unilateral improvements were not adequate to improve the overall human wellbeing. The change in wellbeing in 2006–2016 was mainly caused by the improvement of the material resources and social economy (Figure 5). During this stage, the industrial development was rapid, the supply of industrial and agricultural products was more sufficient, the consumption of residents was more diverse, the housing construction areas and comprehensive energy consumption were also greatly increased, and the economic structure was constantly optimized during the total economic growth.

Table 7. Contribution degree of the driving factors in the MRB at each stage.

Item	Index	1989–1996	1996–2000	2000–2003	2003–2006	2006–2011	2011–2016
Health	R	−11.11	−17.53	−18.78	−17.05	−19.91	−52.32
	O	−31.82	−18.34	−37.01	−11.26	19.55	−6.67
	V	−15.73	43.3	1.92	−21.47	47.8	39.47
	S	−41.34	20.83	−42.29	−50.22	12.74	−1.54
Wellbeing	HS	−16.02	2.51	40.55	23.66	13.06	0.30
	EE	−28.64	49.23	−29.10	24.49	−12.29	−20.03
	MR	14.13	13.37	−24.49	37.61	42.38	32.58
	SE	41.22	34.89	5.85	14.24	32.26	47.09

Note: HS, EE, MR, and SE refer to health and safety, ecology and environment, materials and resources, and society and economy.

Figure 5. Changing trend of human wellbeing in the MRB from 1989 to 2016.

The calculation formula for the contribution of a driving factor is as follows:

$$G = \frac{Z_{jk} - Z_{ik}}{\sum_{k=1}^n |Z_{jk} - Z_{ik}|} \times 100\% \quad (16)$$

where G is the contribution rate of index k to total system variation in j during period i , j is the next adjacent time to the i time point, and Z_{jk} and Z_{ik} are the normalized values of index k at time points j and i .

4.4. Dynamic Evolution of the Coupling Coordination Relationship and Basin Sustainable Development

In the above sections, we analyzed the dynamic changes in the ecosystem health and human wellbeing in the study period over 28 years, but the two systems were not independent of each other but rather have complex interactions. To explore the coupling dynamics of ecosystem health and human wellbeing under land use change, the interactions between the two systems were analyzed according to the dynamic coupling coordination model and the nonlinear fitting results of the two subsystems (Figure 6, Table 8). On this basis, the dynamic evolution process of the sustainable development of the basin was analyzed. Figure 7 reflected the evolution trend of the dynamic coupling coordination degree and the sustainable development index between the ecosystem health and human wellbeing in the MRB from 1989 to 2016. It could be found that the changes of coupling coordination degree and sustainable development index were fluctuating in the research period and had a similar change trend with each other. The coupling coordination degree was between 0.4–0.5 except 1989 and 2006; the sustainable development index was less than 0.4 in 2003–2009, which was in a serious unsustainable level. The composite system of ecosystem health and human wellbeing only reached the basic coordination and sustainability in 1989, and generally the basin during the research period was moderately misaligned and unsustainable. According to Table 8, the evolution speed of the ecosystem health was negative from 1989 to 2006, making the composite system in reverse succession. The sustainable development of the system throughout the research period was within the scope of the moderate–high risk levels, so it was necessary to carry out sustainable management of the whole basin.

Figure 6. Development trends and nonlinear fitting of the ecosystem health and human wellbeing.

Figure 7. Changing trends of the coupling coordination degree and sustainable development index in the MRB from 1989 to 2016.

Table 8. Coupling coordination degree, sustainable development index, and development speed of ecosystem health–human wellbeing composite system.

Year	D	HWSDI	V _H	V _W
1989	0.5043	0.5072	-0.0481	0.0083
1996	0.4375	0.4002	-0.0313	0.0102
2000	0.4740	0.4574	-0.0217	0.0114
2003	0.4358	0.3976	-0.0145	0.0124
2006	0.3851	0.3236	-0.0073	0.0135
2011	0.4650	0.4431	0.0047	0.0155
2016	0.4837	0.4732	0.0167	0.0179

5. Discussion

5.1. Ecosystem Health Assessment Model: Ecosystem Services and Ecosystem Health

Currently, the VOR health assessment model that Costanza created based on the characteristics of the ecosystem has been improved and deepened. By incorporating the ecosystem services, the VORS evaluation model has become more common in assessments of ecosystem health on a regional scale and has been demonstrated to be applicable [26,44–46]. Based on the following four points of consideration, the ecosystem services should be the appropriate basis for the ecosystem health assessment of the basin. First, the early expression of ecosystem health connotations should emphasize the “disease-free” nature, “stability”, and “recovery ability” of the ecosystem, without considering the functional state of ecosystem. The ecosystem health assessment should not only evaluate the integrity and stability of

the internal structure and process of the system, but also consider the ability of the target system to exert ecological functions on a larger spatiotemporal scale, while the ecosystem services are a direct expression of the functional status of the ecosystem. Second, the basin ecosystem includes a natural subsystem, social subsystem, and economic subsystem, and the health assessments should include the socioeconomic level of the region. Third, since humans have positive or negative impacts on ecosystem health when seeking ecosystem services, from the perspective of the coupling between humanity and nature, ecosystem services are important indicators of ecosystem health [65]. Fourth, the ecosystem health standards depend on the degree to which the ecosystems meet the expectations of the target object; for example, in terms of farmland itself, contents of heavy metals is only its own property, but when these heavy metals enter the human body or other objects related to human interests through the food chain and cause harm to human health due to excessively high concentrations, the farmland should be deemed unhealthy for food production. In summary, Rapport et al. pointed out that ecosystem health should include two aspects: The ability to meet the reasonable requirements of humans and the ability of the ecosystem itself to persist and regenerate [66]. In addition, ecosystem health assessments are affected by scale, and macro-scale basin health assessments focus more on the spatial patterns among ecosystems and on the ecosystem service capabilities [15]. The output level of ecosystem services reflects the integrity and complexity of the structure and function of basin landscapes. Therefore, the basin scale is most suitable scale for combined assessments of services and health.

Ecosystem services and ecosystem health are mutually causal [44]. As the core and main driving factors of ecosystem health in the basin, the quality and quantity of services directly affect the results of the health status evaluation. Meanwhile, the changes in the service demands also affect the ecosystem health status through changes in the system structure and the ecological process of human activities. On the other hand, ecosystem health follows the premise of service output; only when a system is stable, sustainable, structurally complete, and capable of adapting and regenerating can it continuously provide services. Therefore, there is a close relationship between ecosystem services and the ability of an ecosystem to be self-sustaining. As we all know, if the external interference exceeds the self-regulation ability of a system, the ecosystem will deteriorate and even lead to an ecological crisis. The deteriorated system cannot regenerate due to the damage to its structure, which also damages the ecological service functions. For example, eutrophication of rivers as a result of excessive nutrient elements destroys the balance of the normal nutrient cycle, changes the physical and chemical properties of the river, causes the death of fish, and even reduces the biodiversity; it also reduces the river water purification, supply of aquatic products, aesthetic appreciation, and other service functions. The decline in the ability of river ecosystem support services to maintain nutrient cycling and biodiversity is the main cause of declining river health, while deteriorating rivers have reduced output capacity of supply services, regulatory services, and cultural services. Therefore, health and ecosystem services are interactive and positively correlated. Integrating the basin service supply capacity into the basin health assessment system can better reflect the quantitative research on ecosystem services and basin health driven by the social economy.

5.2. Construction of Human Wellbeing Index System: Society and Economic Wellbeing and Ecology and Environment Wellbeing

Based on the perspective of sustainability research and combined with the Millennium Ecosystem Assessment framework for human wellbeing, this paper constructed an indicator system for human wellbeing in the MRB from four aspects, including health and safety, materials and resources, society and the economy, and ecology and the environment, which aimed to comprehensively assess the dynamic changes in human wellbeing under the changing health status of the basin and to explore the key factors that restrict and lead the growth of wellbeing. Societal and economic wellbeing and ecology and the health of the environment are considered to be the dominant and limiting factors affecting the growth of human wellbeing. During the study period, the two showed opposite trends.

With the implementation of many policies such as Western (Region) Development, the economic belt on the northern slope of Tianshan Mountain, and the “one belt and one road” system, the economy of the MRB has been developing, and the ecosystem disturbances have become stronger, which has made the response of the ecological environment to economic and social development increasingly obvious. Many studies in the MRB also pointed out that with the development of social economy, the material resources were continuously rich, which better meet the production and living needs of the residents in the basin, but the ecological environment has been seriously damaged [37,38], and has a serious negative impact on the health and safety of the basin, which had been tending to deteriorate [67–70]. In the early stages of economic development, this development may be at the cost of certain ecological damage, but economic growth at the cost of environmental damage over a long period cannot achieve sustainable growth of human wellbeing. Research results at home and abroad show that there is a strong positive correlation between the level of national or regional prosperity and the wellbeing of the people. The “Easterlin Paradox” also notes that under the critical point of approximately \$15,000, the increase in per capita income significantly improves human wellbeing, but above this critical point, the improvement is very limited, and the pursuit of economic growth brings negative effects such as noise, carbon emissions, and environmental degradation, which make people unhappy [71]. From the perspective of sustainability research economic development is only a method for achieving sustainable development goals, and human wellbeing is the core of these goals [40,57].

Under the current land use mode, which is dominated by economic growth, the areas of cultivated land and construction land are increasing. The large increase in cultivated land has increased supply services and improved economic and material needs, but it has also greatly increased the water consumption of the farmlands. Despite the adoption of water-saving irrigation measures, the large expansion of cultivated land has still increased the agricultural irrigation in the study area by 1.87 times from 1989 to 2016. The increase in agricultural water not only causes the serious over-exploitation of groundwater and the use of ecological water, but also leads to secondary salinization. At the same time, agricultural non-point source pollution also causes serious water pollution. The expansion of construction land will promote economic development and cause numerous environmental problems, such as water, air, and noise pollution as well as other types of urban pollution. Land use change led by urbanization is regarded as the main driving force for the loss of ecosystem services and the increase in ecological crises [72]. Therefore, the ecological and environmental effects caused by the expansion of cultivated land and construction land that promote economic development were also the main reasons for the decline in ecological environmental quality during the study period. Ecosystem health is based on ecological protection, which emphasizes the sustainability of the ecological environment. Given the adverse impacts of the damage to the ecological environment on the health of basin ecosystems, the trade-off and coordination of social economic development and ecological environmental protection are the primary issues to be considered in the process of regional sustainable development. The key to solving this contradiction lies in a comprehensive and deep understanding of wellbeing. That is, to define human wellbeing from the perspective of sustainable development, maybe it refers to the state of human satisfaction with the current and future material and spiritual needs, without harming the interests of next generation, which emphasizes the protection for resources and environment. Under the goal of improving human wellbeing, we should not blindly pursue economic growth, but should weigh the advantages and disadvantages and develop in a systematic and coordinated way to avoid short board effect. That is, the potential wellbeing of the ecological environment should be included in the assessment of human wellbeing, and the resource exploitation and protection problems should be properly handled. The development should be carried out along with protection, and protection should be emphasized during exploitation. When humans have a comprehensive understanding of wellbeing and pay more attention to the long-term effects and sustainability of wellbeing, the ecosystem health and human wellbeing will become balanced, and human activities will be guided by emphasizing both factors.

5.3. Sustainable Development of the Coupling System: Relationship of and use of Ecosystem Health and Human Wellbeing

Land use change is widely considered a key factor causing changes in the global environmental and human wellbeing [34,35,73], which can reflect the degree of tension in the human–land relationship to a certain extent. The resource and environmental effects triggered by land use and land cover are reflected in the impacts on climate change, soil degradation, water cycle, biodiversity, and ecological service functions and therefore affect the human living environment, human health, and survival. The different nature of land use determines the difference in the methods and intensities of its impacts on ecosystem health and human wellbeing. Overall, with the refinement of land use, the increase in intensity, and the expansion in scale, the health level of the basin showed a fluctuating decrease and the wellbeing increased exponentially.

Ecosystem services are the key factor connecting land use, ecosystem health, and human wellbeing. On the basin scale, to meet the needs of various wellbeing based on economic growth, humans ask for all kinds of services from the ecosystem by changing the land use pattern. While the change in the way, usage, intensity, and scale of land use will lead to changes in vitality, organization, elasticity, and service of the basin through altering the basin structure, functions, and material-energy flow processes, thereby affecting the health status of ecosystems and ultimately affecting the sustainability of human wellbeing for the ability to damage service output. Therefore, the health of basin ecosystems is the basis and premise for the sustainable development of human wellbeing and regions, and the ultimate goal of sustainable development is to improve human wellbeing; more specifically, sustainable development aims to meet the material and spiritual needs of current and future generations [74]. Healthy ecosystems can provide more comprehensive and higher quality services, and humans can obtain more balanced and sustainable benefits, which main ecosystem health factor of concern for humans.

The change in the wellbeing-oriented changes in the demand for ecosystem services changes the ecosystem ecological process through human activities, which affects the state of ecosystem health. Therefore, the core issue affecting the health status of the basin is the trade-off and coordination of the various types of wellbeing, especially the wellbeing about the socioeconomic and ecological environment. The relationship between the health and wellbeing of an ecosystem is not linear but is complex. The increasing process of human wellbeing is the coupled development process of the coordination and interactive stress between all levels of wellbeing and ecosystem health. The coupling coordination relationship and the sustainable development level of the coupling system depends on the natural attributes of the basin and the stage of human development. To a certain extent, the natural environment limits the overall level of ecosystem health and human wellbeing. For the MRB, which has a typical mountain–oasis–desert structure, there are great differences in the ecosystem health and human wellbeing in the upper, middle, and lower reaches of the basin, as well as their coupling coordination relationship and sustainability level. The stage of human development determines the degree of human disturbance to the ecosystem and the speed and quality of the improvement of wellbeing. In the research period, the coupling coordination degree of the composite system was very closely related to the evolution of the sustainable development index, which indicated that the interaction between the two subsystems, namely the degree of agreement in the human–land relationship, was the key to the sustainable development of the basin. However, the overall sustainability of the MRB was poor, mainly because the development of the ecosystem health and human wellbeing were not balanced. From 1989 to 2016, the ecosystem health and human wellbeing in the basin showed the opposite change trend, indicating that the human wellbeing had grown in an extensive manner and at the cost of ecosystem health damage. In turn, the decline of ecosystem health level in the river basin would limit the speed and quality of wellbeing improvement by reducing the output capacity of ecosystem services. The deterioration of the ecological environment, which inhibited the growth of wellbeing for most of the study period, was a direct manifestation of the decrease in regulation service capacity after the health of the ecosystem was destroyed, or it was a natural negative feedback on human activities. At this stage, the land use in the MRB tended to shift to the cultivated land and construction land and had not paid

enough attention to the health status of the ecosystem, mainly because of the insufficient recognition of the long-term impacts of ecosystem health on the increase in human wellbeing. Therefore, the coordinated development of basin health and wellbeing should be the focus of basin managers in the formulation of sustainable development planning for the basin.

6. Conclusions

This paper explored the development trends of ecosystem health and human wellbeing and the coupling coordination relationship between these factors under land use change in the 28 years from 1989 to 2016. On this basis, the sustainable development status of the basin was diagnosed. Dynamic research based on the time scale can more clearly reflect the development and evolution processes of land use, ecosystem health and human wellbeing, which makes each process comparable, identifies the driving factors, and helps to reveal the effectiveness of the phased management in the basin. Based on the characteristics of land use, the evaluation model of the basin ecosystem health enriched the research on the internal relationship between the land use change and ecosystem health. From the perspective of the sustainability of human wellbeing, a more comprehensive indicator system of human wellbeing was constructed. In general, the land use in the shifted towards the improvement of economic wellbeing. The cultivated land and construction land increased, and the forest land and grassland continued to decline, which has led to exponential growth in wellbeing and will lead to a fluctuating decline in ecosystem health in the future. A comprehensive and deep understanding of human wellbeing that includes the importance of ecological environmental protection during the development of basin resources can alleviate, to a certain extent, the contradiction between ecosystem health and human wellbeing. The coupling coordination degree and the sustainable development index based on the sustainable development model reflect the evolution process of the dynamic coupling between ecosystem health and human wellbeing and the evolution of sustainable development in this process. The results showed that the basin was in a state of moderate imbalance and moderate unsustainability, and that the sustainable development was at the risk level of moderate-high risk. In this paper, the coupling effect of ecosystem health and human wellbeing on the sustainable development of the basin under land use change was preliminarily explored, which laid a theoretical foundation for the sustainable development of the basin, but there were still many deficiencies. For instance, the spatial differences were not considered, and the research will be strengthened in the future.

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References

1. Costanza, R. Toward an operational definition of ecosystem health. In *Ecosystem Health: New Goals for Environmental Management*; Island Press: Washington, DC, USA, 1992.
2. Guidotti, T. Perspective on the health of urban ecosystems. *Ecosyst. Health* **1995**, *1*, 141–149.
3. Karr, J.R.; Fausch, K.D.; Angermeier, P.L.; Yant, P.R.; Schlosser, I.J. *Assessing Biological Integrity in Running Water: A Method and Its Rationale*; Illinois Natural History Survey: Champaign, IL, USA, 1986.
4. Rapport, D.J. What constitute ecosystem health. *Perspect. Biol. Med.* **1989**, *33*, 120–132. [[CrossRef](#)]
5. Schaeffer, D.J.; Henricks, E.E.; Kerster, H.W. Ecosystem Health: Measuring ecosystem health. *Environ. Manag.* **1988**, *12*, 445–455. [[CrossRef](#)]
6. Mageau, M.T.; Costanza, R.; Ulanowicz, R.E. The development and initial testing of a quantitative assessment of ecosystem health. *Ecosyst. Health* **1995**, *1*, 201–213.

7. Hilty, J.; Merenlender, A. Faunal indicator taxa selection for monitoring ecosystem health. *Biol. Conserv.* **2000**, *92*, 185–197. [\[CrossRef\]](#)
8. Tang, T.; Cai, Q.; Liu, J. River ecosystem health and its assessment. *Chin. J. Appl. Ecol.* **2002**, *13*, 1191–1194.
9. Hzbavi, Z.; Keesstra, S.D.; Nunes, J.P.; Baartman, J.E.M.; Gholamalifard, M.; Sadeghi, S.H. Health comparative comprehensive assessment of watersheds with different climates. *Ecol. Indic.* **2018**, *93*, 781–790. [\[CrossRef\]](#)
10. Luo, Z.; Zuo, Q.; Shao, Q. A new framework for assessing river ecosystem health with consideration of human service demand. *Sci. Total Environ.* **2018**, *640–641*, 442–453. [\[CrossRef\]](#)
11. Kerr, S.R.; Dickey, L.M. Measuring the health of aquatic ecosystems. In *Contaminant Effects on Fisheries*; Cairns, V.W., Hodson, P.V., Nriagu, J.O., Eds.; Wiley and Sons: New York, NY, USA, 1984.
12. Xu, F.L.; Jorgensen, S.E.; Tao, S. Ecological indicators for assessing freshwater ecosystem health. *Ecol. Model.* **1999**, *116*, 77–106. [\[CrossRef\]](#)
13. Seyed, H.S.; Zeina, H. Spatiotemporal variation of watershed health propensity through reliability-resilience-vulnerability based drought index (case study: Shazand Watershed in Iran). *Sci. Total Environ.* **2017**, *587–588*, 168–176.
14. Meng, L.; Huang, J.; Dong, J. Assessment of rural ecosystem health and type classification in Jiangsu province, China. *Sci. Total Environ.* **2018**, *615*, 1218–1228. [\[CrossRef\]](#) [\[PubMed\]](#)
15. Peng, J.; Wang, Y.; Wu, J.; Zhang, Y. Regional Ecosystem Health Assessment—Research Methods and Progress. *Acta Ecol. Sin.* **2007**, *27*, 4877–4886. (In Chinese) [\[CrossRef\]](#)
16. Rapport, D.J. Defining ecosystem health. In *Ecosystem Health*; Rapport, D.J., Gaudet, C.L., Costanza, R., Epstein, P.R., Levins, R., Eds.; Blackwell Science Inc.: Malden, MA, USA, 1998; pp. 18–33.
17. Wolf, K.L.; Blahna, D.J.; Brinkley, W.; Romolini, M. Environmental stewardship footprint research: Linking human agency and ecosystem health in the Puget Sound region. *Urban Ecosyst.* **2013**, *16*, 13–32. [\[CrossRef\]](#)
18. Rapport, D.J.; Maffi, L. Eco-cultural health, global health, and sustainability. *Ecol. Res.* **2011**, *26*, 1039–1049. [\[CrossRef\]](#)
19. Tolba, M.K.; El-Kholy, O.A. *The World Environment 1972-1992: Two Decades of Challenge*; Chapman & Hall: London, UK, 1992.
20. Li, Z.; Xu, D.; Guo, X. Remote Sensing of Ecosystem Health: Opportunities, Challenges, and Future Perspectives. *Sensors* **2014**, *14*, 21117–21139. [\[CrossRef\]](#)
21. Nainggolan, D.; Termansen, M.; Reed, M.S.; Cebollero, E.D.; Hubacek, K. Farmer typology, future scenarios and the implications for ecosystem service provision: A case study from south-eastern Spain. *Reg. Environ. Chang.* **2013**, *13*, 601–614. [\[CrossRef\]](#)
22. Torres, R.; Gasparri, N.I.; Blendinger, P.G.; Grau, H.R. Land-use and land-cover effects on regional biodiversity distribution in a subtropical dry forest: A hierarchical integrative multi-taxa study. *Reg. Environ. Chang.* **2014**, *14*, 1549–1561. [\[CrossRef\]](#)
23. Zhang, K.; Li, Y.; Huang, G.; You, L.; Jin, S. Modeling for regional ecosystem sustainable development under uncertainty—A case study of Dongying, China. *Sci. Total Environ.* **2015**, *533*, 462–475. [\[CrossRef\]](#)
24. Ma, C.Z.; Huo, S.L.; Sun, W.C.; Xi, B.D.; He, Z.S.; Su, J.; Zhang, J.T. Establishment of physico-chemical variables and Chl a criteria based on land-use patterns and terrestrial ecosystem health. *Ecol. Eng.* **2016**, *97*, 355–362. [\[CrossRef\]](#)
25. Cheng, X.; Chen, L.; Sun, R.; Kong, P. Land use changes and socio-economic development strongly deteriorate river ecosystem health in one of the largest basins in China. *Sci. Total Environ.* **2018**, *616–617*. [\[CrossRef\]](#)
26. Peng, J.; Liu, Y.; Li, T.; Wu, J. Regional ecosystem health response to rural land use change: A case study in Lijiang City, China. *Ecol. Indic.* **2017**, *72*, 399–410. [\[CrossRef\]](#)
27. Millennium Ecosystem Assessment (MA). *Ecosystems and Human Well-being. Synthesis*; Island Press: Washington, DC, USA, 2005.
28. Huang, G.L.; Jiang, Y.Q.; Liu, Z.F.; Nie, M.; Liu, Y.; Li, J.W.; Bao, Y.Y.; Wang, Y.H.; Wu, J.G. Advances in human well-being research: A sustainability science perspective. *Acta Ecol. Sin.* **2016**, *36*, 7519–7527.
29. Wu, S.; Zhao, Y.; Tang, Q.; Zhang, J.; Gao, J.; Liang, T. Land surface pattern study under the framework of Future Earth. *Prog. Geogr.* **2015**, *34*, 10–17. (In Chinese)
30. Costanza, R.; Fisher, B.; Ali, S.; Beer, C.; Bond, L.; Boumans, R.; Danigelis, N.L.; Dickinson, J.; Elliott, C.; Farley, J.; et al. Quality of life: An approach integrating opportunities, human needs, and subjective well-being. *Ecol. Econ.* **2007**, *61*, 267–276. [\[CrossRef\]](#)

31. Santos-Martin, F.; Martin-Lopez, B.; Garcia-Llorente, M.; Aguado, M.; Benayas, J.; Montes, C. Unraveling the relationships between ecosystems and human wellbeing in Spain. *PLoS ONE* **2013**, *8*, e73249. [\[CrossRef\]](#)
32. Bennett, E.M.; Cramer, W.; Begossi, A.; Cundill, G.; Díaz, S.; Egoh, B.N.; Geijzendorffer, I.R.; Krug, C.B.; Lavorel, S.; Lazos, E.; et al. Linking biodiversity, ecosystem services, and human well-being: Three challenges for designing research for sustainability. *Curr. Opin. Environ. Sustain.* **2015**, *14*, 76–85. [\[CrossRef\]](#)
33. Horcea-Milcu, A.I.; Leventon, J.; Hanspach, J.; Fischer, J. Disaggregated contributions of ecosystem services to human well-being: A case study from Eastern Europe. *Reg. Environ. Chang.* **2016**, *16*, 1779–1791. [\[CrossRef\]](#)
34. Vitousek, P.M.; Mooney, H.A.; Lubchenco, J.; Melillo, J.M. Human domination of Earth's ecosystems. *Science* **1997**, *277*, 494–499. [\[CrossRef\]](#)
35. Turner II, B.L.; Lambin, E.F.; Reenberg, A. Land Change Science Special Feature: The emergence of land change science for global environmental change and sustainability. *Proc. Natl. Acad. Sci. USA* **2007**, *52*, 20666–20671. [\[CrossRef\]](#)
36. Xu, Y.; Tang, H.; Wang, B.; Chen, J. Effects of land-use intensity on ecosystem services and human well-being: A case study in Huailai County, China. *Environ. Earth Sci.* **2016**, *75*, 416. [\[CrossRef\]](#)
37. Wang, X.; Dong, X.; Liu, H.; Wei, H.; Fan, W.; Lu, N.; Xu, Z.; Ren, J.; Xing, K. Linking land use change, ecosystem services and human well-being: A case study of the Manas River Basin of Xinjiang, China. *Ecosyst. Serv.* **2017**, *27*, 113–123. [\[CrossRef\]](#)
38. Xu, Z.; Wei, H.; Fan, W.; Wang, X.; Zhang, P.; Ren, J.; Lu, N.; Gao, Z.; Dong, X.; Kong, W. Relationships between ecosystem services and human well-being changes based on carbon flow—A case study of the Manas River Basin, Xinjiang, China. *Eco. System. Serv.* **2019**, *37*, 100934. [\[CrossRef\]](#)
39. Li, Z.; Deng, X.; Huang, J.; Zhang, R.; Huang, J. Critical Studies on Integrating Land-Use Induced Effects on Climate Regulation Services into Impact Assessment for Human Well-Being. *Adv. Meteorol.* **2013**, *14*, 1–14. [\[CrossRef\]](#)
40. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the global value of ecosystem services. *Global Environ. Chang.* **2014**, *26*, 152–158. [\[CrossRef\]](#)
41. Wei, H.J.; Fan, W.F.; Wang, X.C.; Lu, N.C.; Dong, X.B.; Zhao, Y.N.; Ya, X.J.; Zhao, Y.F. Integrating supply and social demand in ecosystem services assessment: A review. *Ecosyst. Syst. Serv.* **2017**, *25*, 15–27. [\[CrossRef\]](#)
42. Wei, H.; Liu, H.; Xu, Z.; Ren, J.; Lu, N.; Fan, W.; Zhang, P.; Dong, X. Linking ecosystem services supply, social demand and human well-being in a typical mountain–oasis–desert area, Xinjiang, China. *Ecosyst. Serv.* **2018**, *31*, 44–57. [\[CrossRef\]](#)
43. Brown, M.T.; Vivas, M.B. Landscape development intensity index. *Environ. Monit. Assess* **2005**, *101*, 289–309. [\[CrossRef\]](#)
44. Peng, J.; Liu, Y.; Wu, J.; Lv, H.; Hu, X. Linking ecosystem services and landscape patterns to assess urban ecosystem health: A case study in Shenzhen City, China. *Landsc. Urban Plan.* **2015**, *143*, 56–68. [\[CrossRef\]](#)
45. Kang, P.; Chen, W.; Hou, Y.; Li, Y. Linking ecosystem services and ecosystem health to ecological risk assessment: A case study of the Beijing-Tianjin-Hebei urban agglomeration. *Sci. Total Environ.* **2018**, *636*, 1442–1454. [\[CrossRef\]](#)
46. Yan, Y.; Zhao, C.; Wang, C.; Shan, P.; Zhang, Y.; Wu, G. Ecosystem health assessment of the Liao River Basin upstream region based on ecosystem services. *Acta. Ecol. Sin.* **2016**, *36*, 294–300. [\[CrossRef\]](#)
47. Tian, G.; Qiao, Z. Assessing the impact of the urbanization process on net primary productivity in China in 1989–2000. *Environ. Pollut.* **2014**, *184*, 320–326. [\[CrossRef\]](#) [\[PubMed\]](#)
48. Potter, C.S.; Raderson, J.T.; Field, C.; Matson, P.A. Terrestrial ecosystem production: A process model based on global satellite and surface data. *Glob. Biogeochem. Cycles* **1993**, *7*, 811–841. [\[CrossRef\]](#)
49. Zhu, W.; Pan, Y.; He, H.; Yu, D.; Hu, H. Simulation of maximum light use efficiency for some typical vegetation types in China. *Chin. Sci. Bull.* **2006**, *51*, 457–463. [\[CrossRef\]](#)
50. Zhu, W. *Remote Sensing Estimation of Net Primary Productivity of Terrestrial Vegetation in China and Its Relationship with Climate Change*; Beijing Normal University: Beijing, China, 2005. (In Chinese)
51. Costanza, R.; D'Arge, R.; Groot, R.D.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [\[CrossRef\]](#)
52. Xie, G.D.; Yan, L.; Lu, C.X.; Xiao, Y.; Chen, C. A method of ecosystem service value based on expert knowledge. *J. Nat. Resour.* **2008**, *23*, 911–920. (In Chinese)

53. Costanza, R.; Kubiszewski, I.; Giovannini, E.; Lovins, H.; McGlade, J.; Pickett, K.E.; Ragnarsdottir, K.V.; Roberts, D.; De Vogli, R.; Wilkinson, R. Development: Time to leave GDP behind. *Nature* **2014**, *505*, 283–285. [[CrossRef](#)]
54. Wang, W.; Guo, H.; Chuai, X.; Dai, C.; Lai, L.; Zhang, M. The impact of land use change on the temporospatial variations of ecosystem services value in China and an optimized land use solution. *Environ. Sci. Policy* **2014**, *44*, 62–72. [[CrossRef](#)]
55. Ricketts, T.H. Tropical forest fragments enhance pollinator activity in nearby coffee crops. *Conserv. Biol.* **2004**, *18*, 1262–1271. [[CrossRef](#)]
56. Marulli, J.; Mallarach, J.M. A GIS methodology for assessing ecological connectivity: Application to the Barcelona Metropolitan Area. *Landsc. Urban Plan.* **2005**, *71*, 243–262. [[CrossRef](#)]
57. Smith, L.M.; Case, J.L.; Smith, H.M.; Harwell, L.C.; Summers, J.K. Relating ecosystem services to domains of human well-being: Foundation for a U.S. index. *Ecol. Indic.* **2013**, *28*, 79–90. [[CrossRef](#)]
58. Nichol, J. Remote sensing of urban heat islands by day and night. *Photogramm. Eng. Remote Sens.* **2005**, *71*, 613–621.
59. Gupta, K.; Kumar, P.; Pathan, S.K.; Sharma, K.P. Urban Neighborhood Green Index-A measure of green spaces in urban areas. *Landsc. Urban Plan.* **2012**, *105*, 325–335. [[CrossRef](#)]
60. Xu, H.Q. Remote Sensing Evaluation Index of Regional Ecological Environment Change. *China Environ. Sci.* **2013**, *33*, 889–897. (In Chinese)
61. Wischmeier, W.H.; Smith, D.D. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. Agriculture Handbook No. 537; USDA: Washington, DC, USA, 1978.
62. Li, J.; Dai, Y.; Zhao, W.; Fan, C.; Luo, W.; Xiong, Y.; Zhang, Y.; Tang, L. Study on the spatiotemporal characteristics of the interaction coupling between urbanization system and ecosystem and the early warning of coordinated development—A Case Study of Hunan Province. *Yangtze River Basin Resour. Environ.* **2019**, *28*, 1590–1602. (In Chinese)
63. Bretze, A. Clean coal technologies: A status report. *Electr. World* **1992**, *2*, 37–42.
64. Li, X.; Liu, Y.; Song, T. Measurement of Human Green Development Index. *Chin. Soc. Sci.* **2014**, *6*, 69–95. (In Chinese)
65. Rapport, D.J. Ecosystem services and management options as blanket indicators of ecosystem health. *J. Aquat. Ecosyst. Health* **1995**, *4*, 97–105. [[CrossRef](#)]
66. Rapport, D.J.; Böhm, G.; Buckingham, D.; Cairns, J.; Costanza, R.; Karr, J.R.; De Kruijff, H.A.M.; Levins, R.; McMichael, A.J.; Nielsen, N.O.; et al. Ecosystem health: The concept, the ISEH, and the important tasks ahead. *Ecosyst. Health* **1999**, *5*, 82–90. [[CrossRef](#)]
67. Liang, E.; Zhang, J. Ecological security analysis of landscape pattern change in Manas River Basin of Xinjiang. *Soil Water Conserv. Res.* **2016**, *3*, 170–175. (In Chinese)
68. Feng, Y.; Luo, G.; Yin, C.; Zhou, D.; Lu, L.; Xu, W.; Dai, L. Land use change and ecological security evaluation of inland river basin in Arid Area—Taking Manas River Basin in Xinjiang as an example. *J. Nat. Res.* **2009**, *11*, 1921–1932. (In Chinese)
69. Ling, H.; Xu, M.; Shi, W.; Zhang, Q. Evaluation of oasis ecological security in Manas River Basin, Xinjiang. *J. Appl. Ecol.* **2009**, *9*, 2219–2224. (In Chinese)
70. Zhang, Y.; Wang, M.; Dong, X. Emergy analysis and sustainability assessment of ecological economic system in Manas County, Xinjiang. *Ecol. Econ.* **2009**, *29–32*, 99. (In Chinese)
71. Easterlin, R.A. Explaining happiness. *Proc. Natl. Acad. Sci. USA* **2003**, *100*, 11176–11183. [[CrossRef](#)]
72. Rees, W.; Wackernagel, M. *Urban Ecological Footprints: Why Cities Cannot be Sustainable and Why They are A Key to Sustainability*; Urban Ecology; Springer: Berlin, Germany, 2008.
73. Fischer, J.; Lindenmayer, D.B. Landscape modification and habitat fragmentation: A synthesis. *Glob. Ecol. Biogeogr.* **2007**, *16*, 265–280. [[CrossRef](#)]
74. Yan, J.; Guo, X.; Yang, W.; Qian, G.; Niu, J.; Liang, C.; Zhang, Q.; Li, A. What is sustainability science? *J. Appl. Ecol.* **2014**, *25*, 1–11. (In Chinese)