land

Article

Agroecological Efficiency Evaluation Based on Multi-Source Remote Sensing Data in a Typical County of the Tibetan Plateau

Qizhi Wang [1], Maofang Gao [1,*] and Huijie Zhang [2]

[1] Key Laboratory of Agricultural Remote Sensing, Ministry of Agriculture and Rural Affairs, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, China; wangqizhi@caas.cn

[2] Agricultural Information Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China; zhanghuijie@caas.cn

* Correspondence: gaomaofang@caas.cn

Abstract: Evaluating agricultural ecology can help us to understand regional environmental status and contribute to the sustainable development of agricultural ecosystems. Furthermore, the results of eco-environmental assessment can provide data support for policy-making and agricultural production. The application of multi-source remote-sensing technology has the advantages of being fast, accurate and wide ranging. It can reveal the status of regional ecological environments, and is of great significance to monitoring their quality. In this paper, an agroecological efficiency evaluation model was constructed by combining remote sensing data and ecological index (EI). Multi-source remote-sensing data were used to obtain the evaluation index. Indicators collected from satellites, such as biological richness, vegetation cover, water network density, land stress, and pollution load, were used to quantitatively evaluate the agroecological efficiency of Rangtang County in the Tibetan Plateau. The results showed that the EI of Rangtang County increased from 61.77 to 65.10 during 2000–2020, which means that the eco-environmental quality of this area was good, and it has shown an obviously improving trend over the past 20 years. Rangtang County has converted more than 30 km^{2}of grassland into woodland over the past 20 years. Climate change and human activities have had combined effects on the ecological environment of this area. The change in ecological environment quality is greatly affected by human disturbance. Policymakers should continue setting up nature reserves and should implement the policy of returning farmland to forests. Unreasonable grazing and rational allocation of land resources are still critical points of concern for future ecological environment construction. EI, combined with remote sensing and statistical data, is proven to be able to reasonably represent changes in ecological environment in Rangtang County, thus providing more possibilities for ecological evaluation on the Tibetan Plateau, and even the whole world.

Keywords: agricultural sustainability; agroecological efficiency; ecological balance; EI; Rangtang County; remote sensing

check for updates

Citation: Wang, Q.; Gao, M.; Zhang, H. Agroecological Efficiency Evaluation Based on Multi-Source Remote Sensing Data in a Typical County of the Tibetan Plateau. *Land* **2022**, *11*, 561. https://doi.org/10.3390/land11040561

Academic Editor: Francisco Manzano Agugliaro

Received: 28 February 2022
Accepted: 8 April 2022
Published: 10 April 2022

1. Introduction

Agroecology describes the natural and social environment that human beings depend on in the process of utilizing biological resources to form agricultural products [1,2]. Agricultural ecosystems have made a great contribution to the survival of human beings and the development of social economy [3]. In recent years, the intervention, destruction, and disordered exploitation of agricultural resources by human subjective behavior has led to a series of serious ecological and environmental issues, which affect the quality of human life, and the stability as well as recovery ability of agricultural ecology in residential areas [4,5]. Comprehensive and clear assessment can effectively track the changing trends in agricultural ecology on different time scales, and can meet ecological monitoring needs on global or regional spatial scales [6]. It can also reveal the internal relations of various indicators in the agricultural ecosystem, thereby providing quantitative data support for producers cultivating crops and managers making policies [7,8].

Since the development of multi-dimensional the evaluation of agroecological performance, researchers have made many achievements and revealed some problems at the same time. Scholars have carried out agroecological assessment on all continents, creating and updating evaluation systems, methods, and indicators. Their research results summarize past environmental changes, guide current crop-planting patterns, and predict future ecological trends [9–11]. However, due to its rich connotation, multiple sources, complex mechanisms, scale difference, and temporal and spatial variation, agroecological evaluation is still difficult in terms of administrative management and scientific research [12–14]. In 2006, in order to standardize the process of ecological evaluation, the former State Administration of Environmental Protection of the People's Republic of China issued the Technical Criterion for Ecosystem Status Evaluation (Trial) (HJ/T192-2006), which put forward the ecological environment index, and used it as the basis for regional ecological environment assessment. Later, the revised Technical Criterion for Ecosystem Status Evaluation (HJ 192-2015) was issued in 2015, which defines the Ecological Index(EI) [15]. EI is used to reflect the overall state of a regional ecological environment. The index system includes a biological richness index, vegetation-cover index, water-network-density index, land-stress index, pollution-load index, and an environmental restriction index. These five sub-indices reflect the richness of organisms in the evaluated area, the height of vegetation cover, the amount of water, the stress intensity, and the pressure from pollutants, respectively. The environmental restriction index is a restrictive index, which refers to the restriction and regulation of the ecological environment according to the serious ecological damage of human settlements, production and life safety, and environmental pollution in the region.

Remote-sensing technology is showing its unique advantages in the field of agroecological efficiency evaluation. In cases with a long timespan, large space range, complex ground conditions, and other factors that make it difficult to obtain data, the satellite-borne remote-sensing platform has excellent and stable performance [16]. Compared with traditional monitoring methods, the rapid development of remote-sensing technology is playing a more important role. Remote-sensing technology can quickly provide rich resources and environmental information, and its accuracy has been greatly improved [17]. The combination of remote-sensing technology and geographic information systems can provide real-time and dynamic spatiotemporal change information for ecological environment research and regulation, and can provide new means for regional ecological evaluation and analysis [18]. In research on ecological evaluations based on remote sensing, scholars have achieved fruitful results in various aspects. The research focus has developed from natural factors to the interaction between nature and human activities. In addition, the research focus has developed from a piece of single remote-sensing information for ecological environment monitoring into a comprehensive analysis of a variety of remote sensing and human information [19]. Integrating satellite remote-sensing data with social statistics into ecological assessment models will also help to explore the driving forces, promoting the improvement of the ecological environment, and implementing the construction of ecological civilization in action.

Rangtang, a typical county of the Tibetan Plateau chosen as the study area, is a region which is sensitive to social and economic development and global climate change due to its fragile ecological environment [20]. Forest and grassland degradation, lake atrophy, and agricultural production environment degradation have begun to restrict the sustainable development of economy and society in Rangtang County. In the past, there were limited quantitative studies on its ecological environment. The government releases data on local socio-economic fundamentals every year, but ignores the underlying links between these indicators and ecological factors. Therefore, it is necessary to make use of multi-source remote-sensing data to carry out agroecological evaluation in Rangtang County.

Therefore, we used multi-source remote-sensing data and the ecological index (EI) in the revised Technical Criterion for Ecosystem Status Evaluation (HJ 192-2015) to build an agroecological performance evaluation model which is suitable for Rangtang County. We created an ecological evaluation system that included biological richness, vegetation cover, water network density, land pressure, and pollution load. For the first time, we applied an ecological assessment model coupled with satellite remote-sensing data to the key region, the Tibetan Plateau. Combining this with local socio-economic data, we quantitatively evaluated the agricultural ecological efficiency of Rangtang County every five years from 2000 to 2020. After identifying the values and trends of the ecological indices and each sub-index for the past 20 years, we analyzed the causes and influencing factors of said changes, aiming to provide a basis for the rational use of land resources and the rational planning of the ecosystem in the Tibetan Plateau.

2. Material

2.1. Study Area

Rangtang County, Aba City, in Sichuan Province, in the eastern part of the Tibetan Plateau, along with Nanmoqie National Wetland Nature Reserve, was selected as the study area. It is located in the upper reaches of the Dadu River, with geographic coordinates of 31°298′–32°41′ N, 100°31′–101°294′ E, as shown in Figure 1. The county covers an area of 6863 square kilometers, with a population of 43,177. The geotectonic strata span three geological units, and belong to the Mesozoic fold belt. It is mostly Triassic marl intercalated with glutenite, occasionally intercalated with volcanic rock and limestone marine strata, located in the Xianshuihe seismic zone. Rangtang County has a plateau monsoon climate, with an average elevation of 3285 m. The climate has obvious vertical zoning. The south is wet, and the north is dry. There is no obvious difference in the four seasons. The annual temperature range is small, and the daily range is large [20]. The main landform types are middle mountains, high mountains, high plains, hilly plateaus, and glacial landforms. Its surface is mostly covered with alpine meadows. The agriculture is mostly cattle and sheep grazing, with less arable land, such that the ecological stability is weak. It is an ideal research area for multi-dimensional performance evaluations of agricultural ecology.

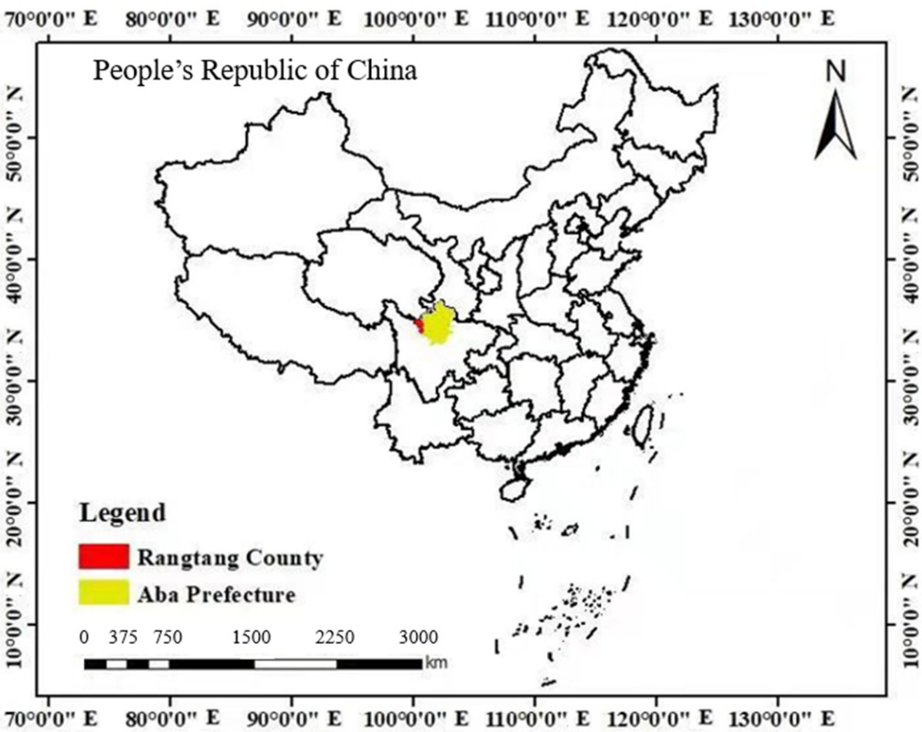

Figure 1. Location of the Study area, Rangtang County, Aba Prefecture, People's Republic of China.

2.2. Data and Processing

The data collected in this study include socio-economic data of Rangtang County and remote-sensing image data used to obtain ecological environment evaluation indicators.

2.2.1. Socio-Economic Data

The socio-economic data were obtained from the Rangtang County Yearbooks from the past 20 years, involving 6 categories, and a total of 15 items [21]. These items are natural population growth rate, food production, meat production, milk production, livestock inventory, livestock production, total power of agricultural machinery, annual electricity consumption in rural areas, total agricultural income, total forestry income, total animal husbandry income, per capita disposable income of rural residents, per capita gross domestic product, gross agricultural output value, and water resources' quantity.

The data are sorted year-by-year, and individual missing data are completed by interpolation.

2.2.2. Landsat Data

Landsat data are used to obtain land use type and water density in Rangtang County. In order to better reflect the distribution characteristics of the species in Rangtang County, the data months were selected to be as similar as possible in summer, with higher vegetation coverage. Some images are unusable due to large cloud cover, so images of adjacent years are used instead. The Landsat data collection is shown as Table 1.

Table 1. Landsat data collection table.

Sensors	Year	WRS Path and Row	Date
L7	2000	P131R38	26 August 1999
		P132R37	1 August 1999
		P132R38	1 August 1999
	2005	P131R38	11 September 2005
		P132R37	15 September 2004
		P132R38	15 September 2004
	2010	P131R38	11 August 2011
		P132R37	15 August 2010
		P132R38	15 August 2010
L8	2015	P131R38	30 October 2014
		P132R37	22 September 2015
		P132R38	22 September 2015
	2020	P131R38	25 August 2019
		P132R37	16 August 2019
		P132R38	16 August 2019

The remote sensing images of representative years in the study area were preprocessed to obtain the remote sensing images of corresponding years in the study area. Its data preprocessing was mainly carried out through the following three steps: first, sensors in the process of data acquisition will cause image distortion or the effects of distortion. In order to eliminate these effects, a radiation calibration of remote sensing image processing is needed. Landsat7 appeared in the 2003 ETM + airborne scan line corrector (SLC) fault, therefore the lead to the resulting image to obtain the data stripe is missing. Therefore, the Landsat7 data in 2005 and 2010 were striped before radiometric calibration. Secondly, the sensor will be interfered by water vapor, oxygen, carbon dioxide, and so on, when scanning and acquiring the reflectance of ground objects. It is necessary to reduce these interferences by means of atmospheric correction to obtain more accurate reflectance. Finally, Landsat data covering the whole Rangtang county involve three images. In order to obtain remote sensing images of rangtang County, it is necessary to mosaic the images processed in the first two steps, then overlay the administrative division data of Rangtang County, and cut the mosaic images to obtain remote sensing images representing the year of the study area.

2.2.3. MODIS Data

The normalized difference vegetation index (NDVI) can directly reflect the surface vegetation coverage. The terra and aqua combined moderate resolution imaging spectroradiometer (MODIS) vegetation index (MOD13A2) is a terrestrial level three standard raster data product [22]. It has a 16-day temporal resolution.

Since the data have been corrected for atmospheric, radiation, and geometric accuracy, interference from clouds, the atmosphere, and solar altitude angles have been removed, which effectively reduces noise in the NDVI data.

The means of monthly maximum NDVI from May to September in 2000, 2005, 2010, 2015, and 2020 were obtained, and were used for the analysis of vegetation-cover change characteristics and the evaluation of the ecological environment in Rangtang County.

2.2.4. DEM Data

The slope data were calculated from the global digital elevation model from the Shuttle Radar Topography Mission (SRTM, https://srtm.csi.cgiar.org/, accessed on 30 November 2018), which was launched by NASA. This V4.1 version of the data was obtained by the International Center for Tropical Agriculture using interpolation algorithms, and has a spatial resolution of 30 m.

3. Methodology

3.1. Ecological Index (EI)

The EI is based on the comprehensive weighted indices of biological richness, vegetation cover, water network density, land stress, pollution load, and environmental restriction to obtain the ecological environment of the study area. The weights of each evaluation index are shown as Table 2, and the definitions are listed in Section 3.2. They were extracted from the revised HJ 192-2015.

Table 2. The weight of each indicator of the ecological environment evaluation method.

Index	Weight
Biological Richness	0.35
Vegetation Cover	0.25
Water Network Density	0.15
Land Stress	0.15
Pollution Load	0.1
Environmental Restriction	Binding Index

According to the weight of each evaluation index in the table, the calculation method of the ecological environment condition is as follows:

$$\mathrm{EI} = 0.35 * BRI + 0.25 * VCI + 0.15 * WNDI + 0.15 * (100 - LSI) + 0.10 * (100 - PLI) + ERI \quad (1)$$

In the formula, *BRI* is the Biological Richness Index; *VCI* is the vegetation-cover index; *WNDI* is the water-network-density index; *LSI* is the land-stress index; *PLI* is the pollution-load index; and *ERI* is the environmental restriction index. The total EI ranges from 0 to 100. A higher value represents better ecological environment quality.

The flow chart of the overall methods is shown in Figure 2.

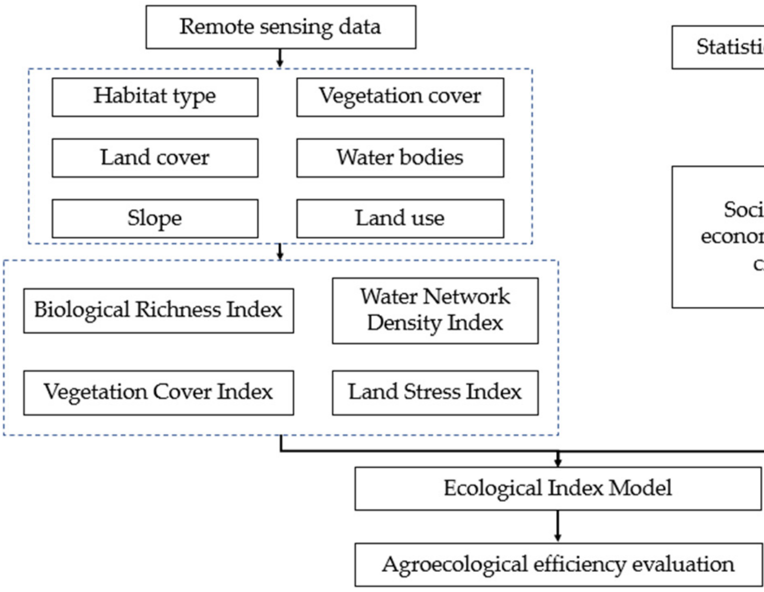

Figure 2. Flowchart of Rangtang County agroecological efficiency evaluation.

3.2. EI model Construction

3.2.1. Biological Richness Index

This index evaluates the abundances and shortages of organisms in the region, and comprehensively represents the habitat quality and biodiversity of organisms.

$$Biological\ Richness\ Index = (BI + HQ)/2 \tag{2}$$

In the formula, *BI* means biodiversity index which is defined in the National Environmental Protection Standard of the People's Republic of China HJ623–2011 Regional Biodiversity Assessment Standard. *HQ* is the habitat-quality index. Habitat quality is a weighted assignment of land cover types to evaluate the quality of biological habitat. It determines the number of organisms per unit area. When there are no dynamic, updated data on biodiversity index, the change in biological richness index is equal to the change in habitat-quality index. According to the Rangtang County Yearbook, *BI* has not experienced an obvious change in recent years. Thus, the change of biological richness index is only relative to *HQ*.

The sub-weights of each habitat type in the habitat-quality index are shown in Table 3. A higher value represents better biological richness.

$$\begin{aligned} Habitat\ Quality\ Index = {} & A_{bio} * (0.35 * woodland + 0.21 * grassland + 0.28 * wetland \\ & + 0.11 * arableland + 0.04 * constructionland + 0.01 * unusedland)/totalarea \end{aligned} \tag{3}$$

The area of each land type was extracted from remote sensing data. In the formula, A_{bio} means normalization constant of habitat-quality index, which is 511.26.

3.2.2. Vegetation-Cover Index

The index evaluates the coverage degree of regional vegetation.

$$Vegetation\ Cover\ Index = A_{veg} * \sum_1^n Pi/n \tag{4}$$

In the formula, *Pi* is the mean of monthly maximum NDVI from May to September in one year. It has been calculated in the years 2000, 2005, 2010, 2015, and 2020. *n* refers to the number of area pixels. A_{veg} means normalization constant of vegetation-cover index, which is 0.012.

A higher vegetation -cover index value represents better vegetation cover.

Table 3. The weight of each habitat type in the habitat-quality index.

Land Type	Weights	Sub-Type	Sub-Weights
Woodland	0.35	Woodland exists	0.60
		Shrub-land	0.25
		Sparse woodland	0.15
Grassland	0.21	High coverage	0.60
		Mid coverage	0.30
		Low coverage	0.10
Wetland	0.28	River	0.10
		Lake	0.30
		Tidal flat wetland	0.50
		Permanent glacier	0.10
Arable land	0.11	Paddy field	0.60
		Dry field	0.40
Construction land	0.04	Town	0.30
		Rural settlement	0.40
		Other construction land	0.30
Unused land	0.01	Sand	0.20
		Saline soil	0.30
		Bare land	0.20
		Bare rock	0.20
		Other unused land	0.10

3.2.3. Water-Network-Density Index

This index evaluates the water richness in the region, which is expressed by the total length of rivers per unit area, the water area, and the amount of water resources in the evaluation region. When the calculated water network density index is greater than 100, the value is 100.

$$\text{Water Network Density Index} = \left(A_{veg} * RL + A_{lak} * WA + A_{res} * WRQ\right)/3 * area \quad (5)$$

In the formula, A_{riv} is the normalization constant of river length, which is 84.37. RL refers to the river length. A_{lak} is the normalization constant of water area, which is 591.79. WA refers to the water area. A_{res} is the normalization constant of quantity of water resources, which is 86.39. WRQ refers to the quantity water resources. A higher value represents better water network density.

The highest elevation in Rangtang County is more than 5000 m above sea level, and at the top of this, the mountain is covered with snow all year round. To obtain river length and water area by remote- sensing methods, it is necessary to eliminate the disturbance of snow. Therefore, the water index model with a better extraction effect is used.

This model takes Landsat images as the data source, and builds the water index WI2020 of six visible bands and near-infrared bands on the Google Earth Engine platform. This model applies a linear operation on four bands, and its expression is [23]:

$$\text{WI2020} = (3 * b3 - b2 + 2 * b4 - 5 * b5)/(3 * b3 + b2 + 2 * b4 + 5 * b5) \quad (6)$$

In the formula, $b2$, $b3$, $b4$, and $b5$ represent the reflectance of the blue band, green band, red band, and near-infrared band, respectively. This index is a good way to distinguish between snow and water on the plateau, which can extract water bodies more accurately. According to the statistical yearbook data, the ratio of the amount of water resources and the annual average water resource amount in Rangtang County in each year is less than 1.4. Therefore, the equilibrium amount of water resources used in calculation is the actual value of each year.

3.2.4. Land-Stress Index

This index evaluates the degree of stress on the land quality in the region, which is represented by the area of soil and water loss, land desertification, land development, and other stress types per unit area in the evaluation region. As a professional industrial standard promulgated by the Ministry of Water Resources, People's Republic of China, the standards for classification and gradation of soil erosion defines soil erosion-type zoning, and stipulates the quantitative calculation method of soil erosion intensity.

Overall, three indices, land-cover type, slope and coverage of non-cultivated forest and grass, were used to determine the classification of soil erosion, as shown in Table 4.

Table 4. Classification index of soil erosion.

Vegetation Coverage/%	Slope					
	<5°	**5–8°**	**8–15°**	**15–25°**	**25–35°**	**>35°**
<30	micro	mild	moderate	severe	extremely severe	drastic
30–45	micro	mild	moderate	moderate	severe	extremely severe
45–60	micro	mild	mild	moderate	moderate	severe
60–75	micro	mild	mild	mild	moderate	moderate
>75	micro	micro	micro	micro	micro	micro

When the land in use is a residential area, water area, or unused land, the degree of soil erosion is micro slight.

Considering the small agricultural land and non-vegetated areas in Rangtang County, the coverage of non-cultivated forest and grass can be approximately equal to the fractional vegetation coverage (*FVC*). *FVC* refers to the proportion of the vertical projection area of vegetation on the ground to the total area [24]. The pixel dichotomy model based on remote-sensing *NDVI* can be used to estimate FVC at a regional scale.

$$FVC = (NDVI - NDVI_{soil})/(NDVI_{veg} - NDVI_{soil}) \tag{7}$$

The $NDVI_{soil}$ is the *NDVI* value for areas that are completely bare soil or free of vegetation, and can be approximately considered as the minimum value of the *NDVI* in the region. The $NDVI_{veg}$ represents the *NDVI* value of pure vegetation pixels completely covered by vegetation, and can be approximately considered as the maximum value of the *NDVI* in the region. *NDVI* is the real value in each grid. The pixel dichotomy model assumes that the surface of a pixel is composed of vegetation cover and bare soil cover. The vegetation spectral information is also obtained by the spectral linear weighting of the two components. The *FVC* value in the pixel can be obtained by calculating the linear relationship of the real *NDVI* value.

The land-stress index decentralization weight is shown in Table 5.

$$\text{Land Stress Index} = A_{ero} * (0.4 * SEA + 0.2 * MEA + 0.2 * CLA + 0.2 * OLA)/\text{total area} \tag{8}$$

Table 5. The weight of Land-Stress Index.

Type	Weights
Severe erosion	0.4
Moderate erosion	0.2
Construction land	0.2
Other land stress	0.2

In the formula, A_{ero} is the normalization constant of land-stress index, which is 236.04. *SEA* refers to severe erosion area. *MEA* refers to moderate erosion area. *CLA* refers to construction land area. *OLA* refers to other land-stress area.

When the land-stress index is greater than 100, the value is 100. A higher value represents higher land stress.

3.2.5. Pollution-Load Index

The environmental pollution pressure within the evaluation area of the index is expressed by the pollution load per unit area of the evaluation area. When the pollution load index is less than 0, the value is 0.

Considering that the pillar industries of Rangtang County are planting and animal husbandry, the annual gross output value accounts for more than half of the gross national product. There is less industrial pollution in Rangtang County, and they have shown no significant change over the years. Therefore, the variation in the pollution-load index over five years was ignored, and its value was set as 0.

3.2.6. Environmental Restriction Index

This index is a binding indicator, which refers to the occurrence of serious impacts on the production and life of human settlements in the region.

According to the environmental emergency response plan, the final ecological environment level will be reduced by one if all levels of environmental emergencies caused by human factors occur in the evaluation area. The ecological environment cannot be rated as excellent or good in cases of major or extreme environmental events. If there are environmental pollution or ecological destruction incidents reported by environmental protection authorities or national media, or there are illegal cases of ecological environments reported by environmental protection authorities or listed for supervision in the evaluation area, or it is included in the restricted approval area, the ecological environment level shall be reduced by one level.

Since no such environmental restriction events occurred in Rangtang County during the period of 2000 to 2020, the final ecological environment grade was evaluated according to the calculated value of the EI.

3.3. Selection of Evaluation Unit

The selection of appropriate evaluation units is of great significance to the presentation of ecological environment evaluation results in Rangtang County. At present, the commonly used ecological environment assessment units include administrative unit, watershed unit, and grid unit. In this paper, remote sensing images were used to extract the ecological environment evaluation factors of Rangtang County, so that the evaluation results could be spatialized instead of a numerical value, which could reflect the spatial distribution and difference of the ecological environment in Rangtang County. Therefore, in order to better present the spatial distribution of each sub-index, the grid unit is selected as the evaluation unit in this paper. Considering the remote sensing image resolution and the area of Rangtang County, 500 m $\times$ 500 m was finally determined as the evaluation unit of this study, that is, Rangtang County was divided into a uniform grid 500 m $\times$ 500 m, and then the evaluation index data in each grid were counted to realize the spatial expression of regional ecological environment quality. The fishnet was used to make grid data layers covering the whole of Rangtang County, as shown in Figure 3 below.

3.4. Evaluation of EI Changes

3.4.1. Classification of Ecological Environment

According to the EI, the ecological environment is divided into five levels, namely excellent, good, fair, poor, and bad, as shown in Table 6.

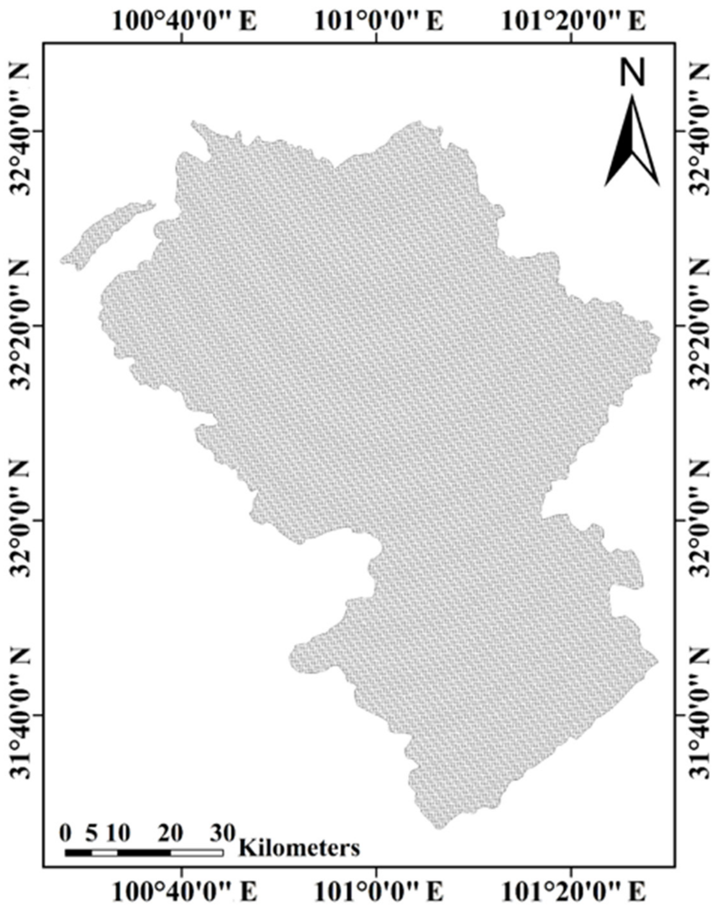

Figure 3. The fishnet of Rangtang County.

Table 6. Classification of EI based on ecological quality.

Level	Index	Description
Excellent	EI ≥ 75	The vegetation coverage is high, the biodiversity is rich, and the ecosystem is stable.
Good	55 ≤ EI < 75	The vegetation coverage is relatively high, the biodiversity is relatively rich, and it is suitable for human life.
Fair	35 ≤ EI < 55	The vegetation coverage is moderate, and the biodiversity is average. It is more suitable for human life, but there are restrictive factors that are not suitable for human life.
Poor	20 ≤ EI < 35	Vegetation coverage is poor, there is severe drought and less rainfall, fewer species, there are obvious factors that restrict human life.
Bad	EI < 20	The conditions are poor and human life is severely restricted.

3.4.2. Analysis of the Change in Ecological Environment

According to the change in the ecological index and the benchmark value, the ecological environment quality change is divided into four levels, that is, no obvious change, slight change, obvious change, and significant change. The method for evaluating the change in each sub-index refers to the degree of change in the ecological environment, as shown in Table 7.

Table 7. Classification of changes in ecological environment.

Level	Change Value
No obvious change	$\lvert\Delta EI\rvert < 1$
Slight change	$1 \leq \lvert\Delta EI\rvert < 3$
Obvious change	$3 \leq \lvert\Delta EI\rvert < 8$
Significant change	$\lvert\Delta EI\rvert \geq 8$

If the eco-environmental status index presents the characteristics of fluctuating changes, the regional eco-environment is sensitive. According to the range of fluctuation in the ecological environment quality, the changes in the ecological environment are divided into stable, fluctuating, large fluctuation, and severe fluctuation, as shown in Table 8.

Table 8. Classification of fluctuations in ecological environment.

Level	Change Value
Stable	$\lvert\Delta EI\rvert < 1$
Fluctuating	$1 \leq \lvert\Delta EI\rvert < 3$
Large fluctuation	$3 \leq \lvert\Delta EI\rvert < 8$
Severe fluctuation	$\lvert\Delta EI\rvert \geq 8$

4. Results and Analysis

4.1. Sub-Indices' Results and Analysis

4.1.1. Land Use Type

The slope of Rangtang County is extracted from DEM data, as shown in Figure 4. Land use types are extracted from remote sensing images, as shown in Figure 5 and Table 9.

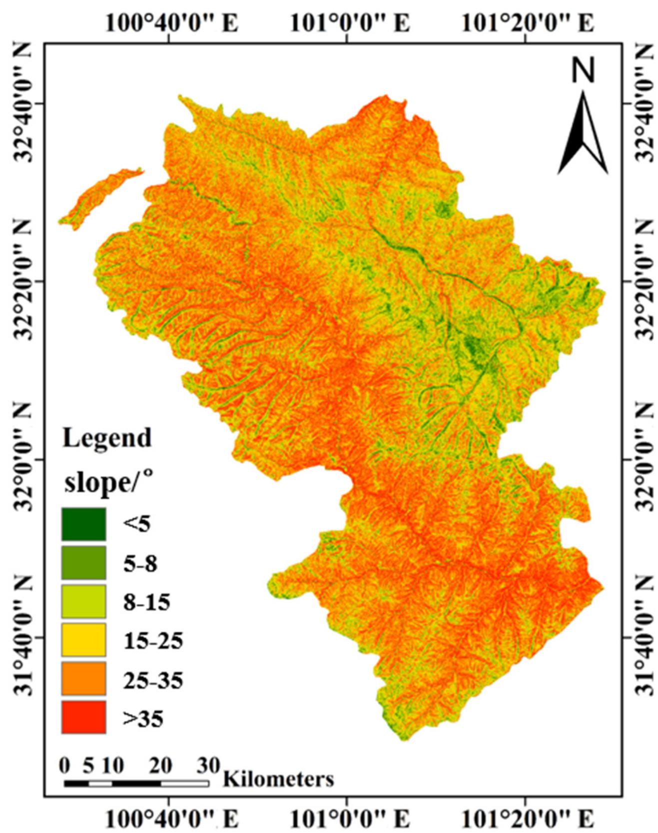

Figure 4. The slope of Rangtang County.

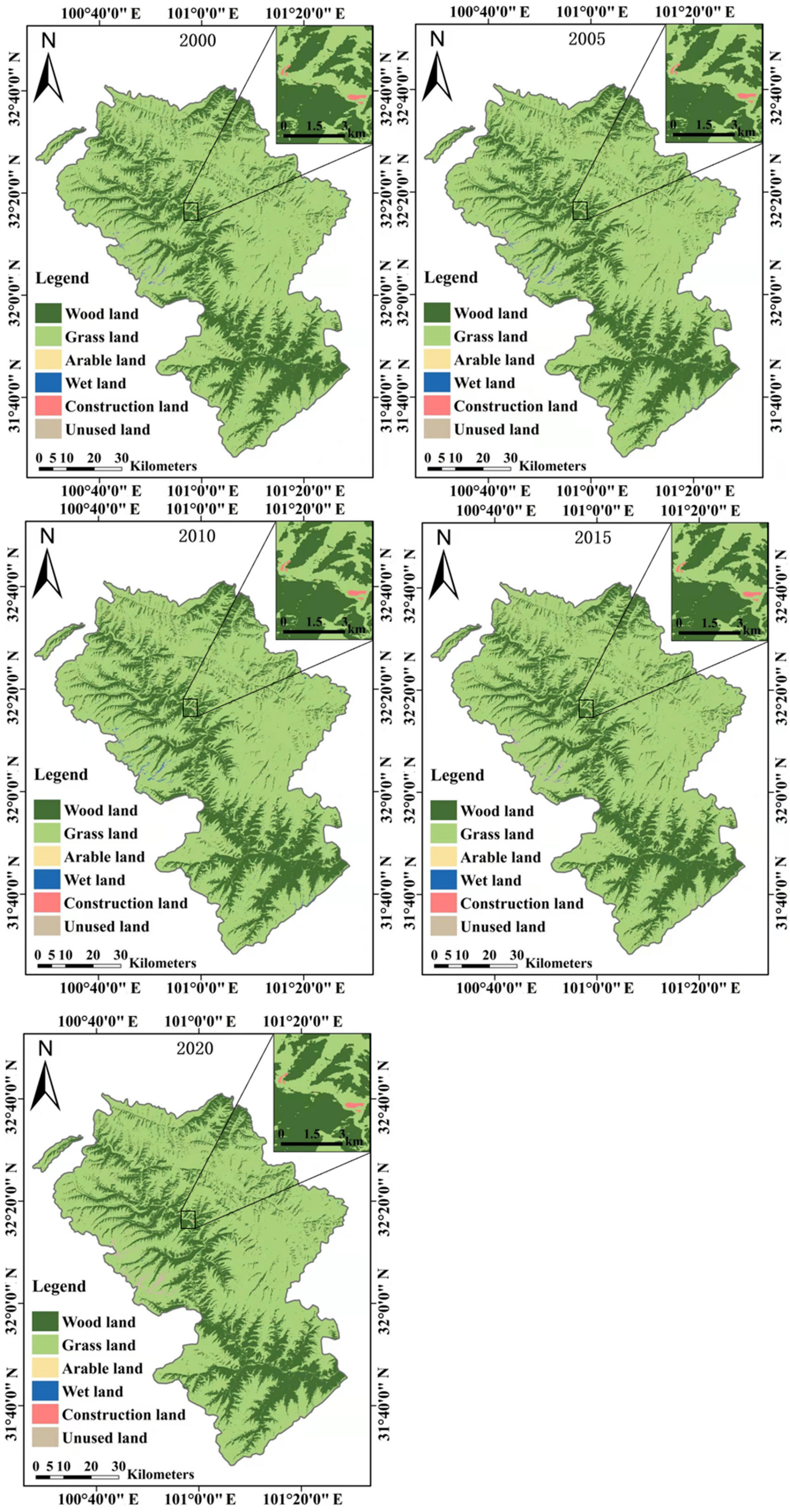

Figure 5. Land use type of Rangtang County.

Table 9. The area of each land type in Rangtang County.

Year	Category	Land Use Type					
		Woodland	Grassland	Arable Land	Wet Land	Construction Land	Unused Land
2000	Area/km^2	1896.66	4766.88	1.14	11.64	0.23	19.39
	Proportion/%	28.3295	71.2006	0.0170	0.1739	0.0035	0.2896
2005	Area/km^2	1899.51	4757.44	1.47	19.03	0.26	19.13
	Proportion/%	28.3721	71.0596	0.0219	0.2843	0.0039	0.2858
2010	Area/km^2	1900.41	4761.02	0.78	21.87	0.26	12.51
	Proportion/%	28.3855	71.1130	0.0117	0.3266	0.0039	0.1868
2015	Area/km^2	1926.40	4724.98	0.40	19.07	0.26	25.73
	Proportion/%	28.7737	70.5746	0.0059	0.2848	0.0039	0.3844
2020	Area/km^2	1917.17	4717.35	0.31	22.77	0.26	38.08
	Proportion/%	28.6217	70.4608	0.0047	0.3401	0.0039	0.5688

The land use in Rangtang county is divided into six types: woodland, grassland, arable land, wet land, construction land, and unused land. Woodland and grassland were the main land use types, accounting for more than 99% of the total, while the remaining four land use types accounted for less than 1% of the total.

4.1.2. Biological Richness

In order to identify the biological richness of the study site, overlay the land use classification results of each year with the grid 500 m × 500 m, and then calculate the biological richness index in each grid, according to the Equation (3) above. The biological richness of Rangtang County is shown in Figures 6 and 7.

The average biological richness index in Rangtang County was 57.03 in 2000, 57.34 in 2005, 58.22 in 2010, 60.31 in 2015, and 60.97 in 2020. The index is higher in green areas, middle in yellow, and lower in red. Since 2000, as time went by, most of the middle area changed from red to green, and the biological abundance of the whole county showed an upward trend. In general, the index of Rangtang county increased by 3, and the ecological environment quality was improved.

4.1.3. Vegetation Cover

According to Equation (4), the vegetation cover in Rangtang County was calculated as shown in Figures 8 and 9.

The average vegetation cover index in Rangtang County was 78.16 in 2000, 78.90 in 2005, 80.18 in 2010, 81.41 in 2015, and 82.39 in 2020. In the high elevations of the west, there are large red areas with less vegetation cover. In general, the vegetation cover index of Rangtang county increased by more than 3, showing an obvious upward trend. The higher the vegetation coverage, the better the ecological environment quality of the region.

4.1.4. Water Density

The water density is extracted according to Formulas (5) and (6), as shown in Figures 10 and 11.

The water density index ranges from 0 to 100. The darker the color is, the denser the water is. The large area of 0 value is the reason that the land surface of Rangtang County is mostly covered with vegetation. And that is why there is no water body in the grid. The average water density index was 12.44 in 2000, 12.58 in 2005, 13.37 in 2010, 15.03 in 2015, and 16.42 in 2020. The water distribution in Rangtang county is concentrated, mostly in Duke River and its tributaries. This is related to the topographic and geomorphic characteristics of Rangtang County. The index through the river valley is larger than that of the alpine meadow. In general, the water density index of Rangtang County increased by more than 3, that is, the distribution of water resources became obviously better.

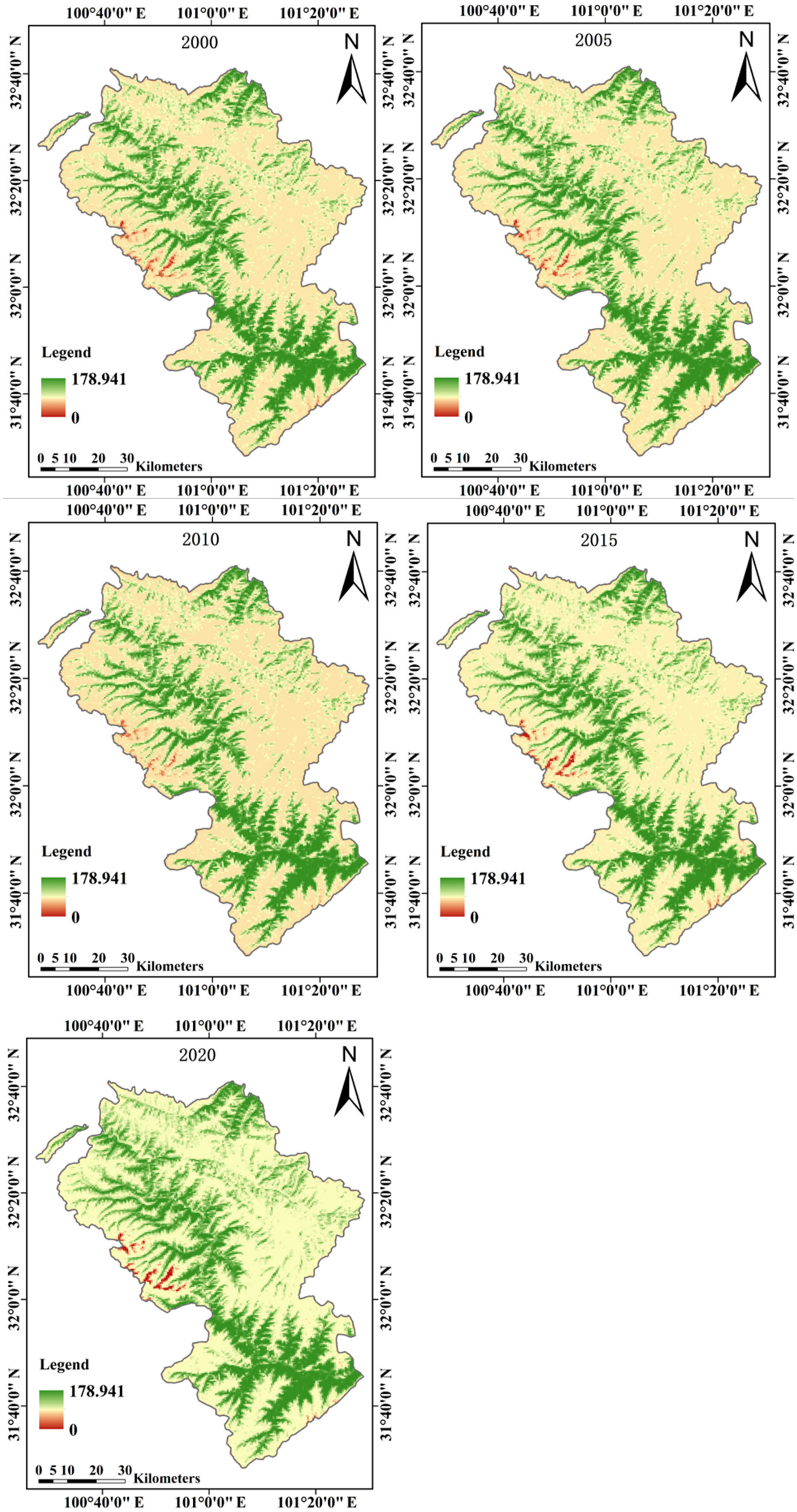

Figure 6. Biological richness index of Rangtang County.

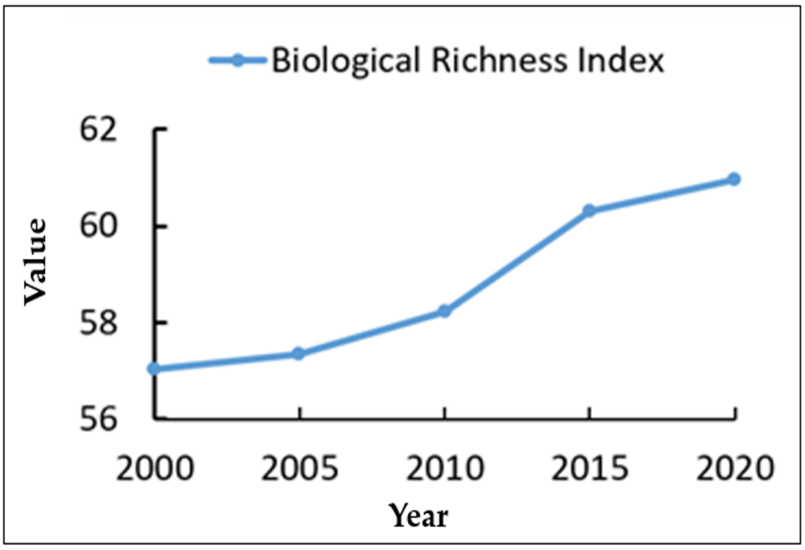

Figure 7. The change of biological richness index in Rangtang County.

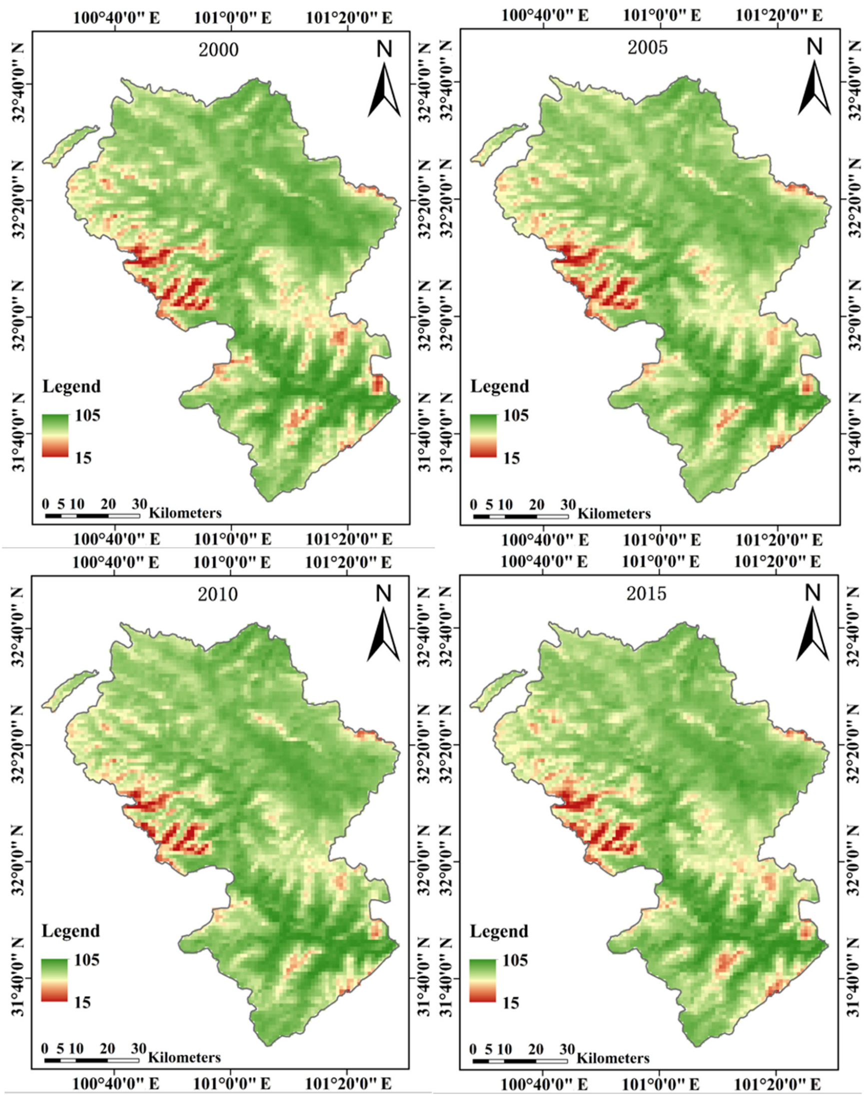

Figure 8. *Cont.*

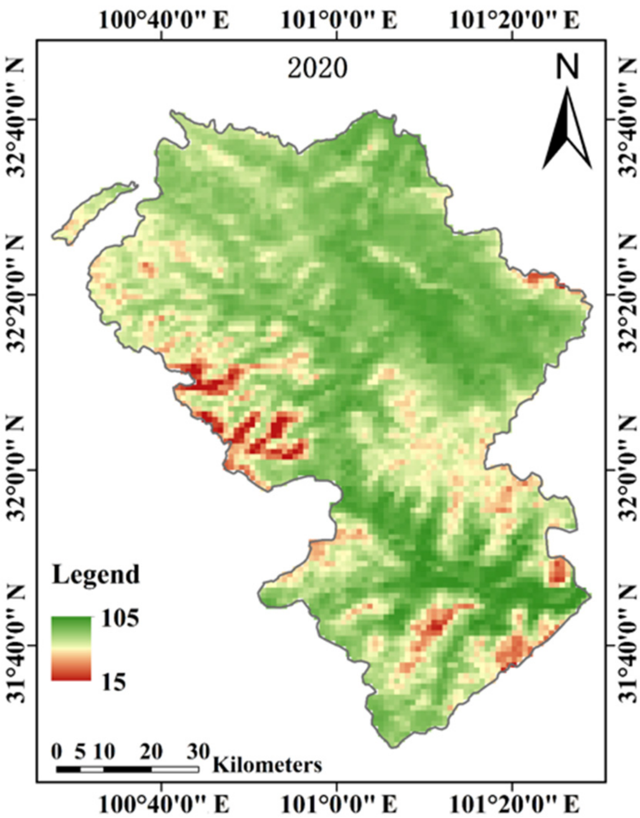

Figure 8. Vegetation cover index of Rangtang County.

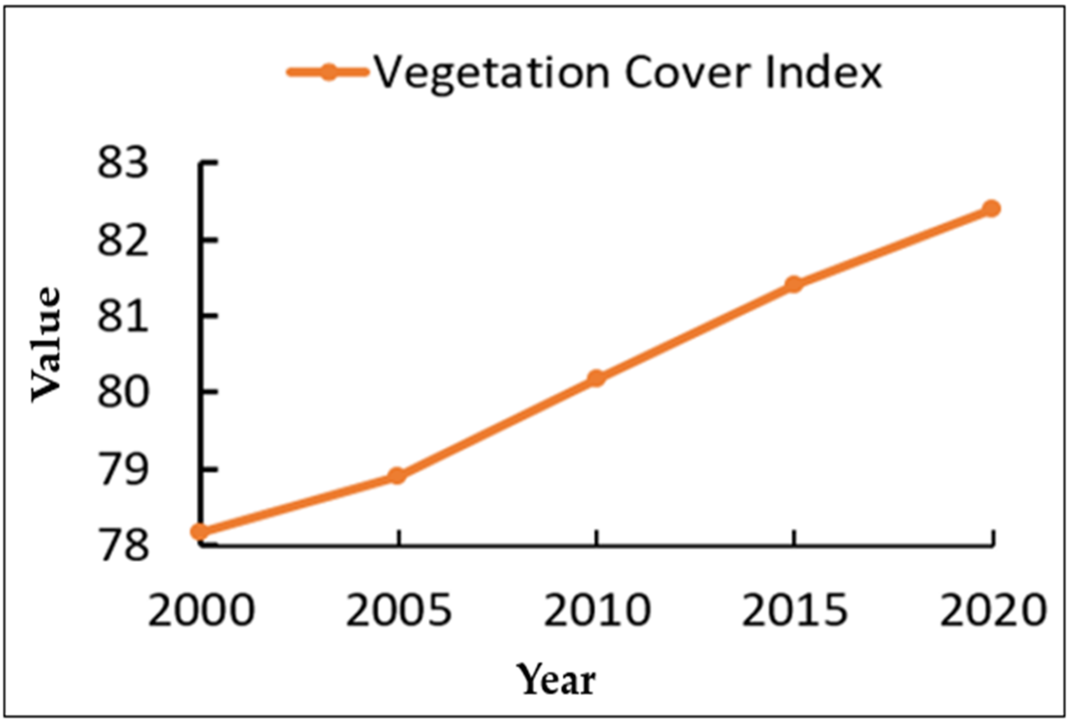

Figure 9. The change of vegetation cover index in Rangtang County.

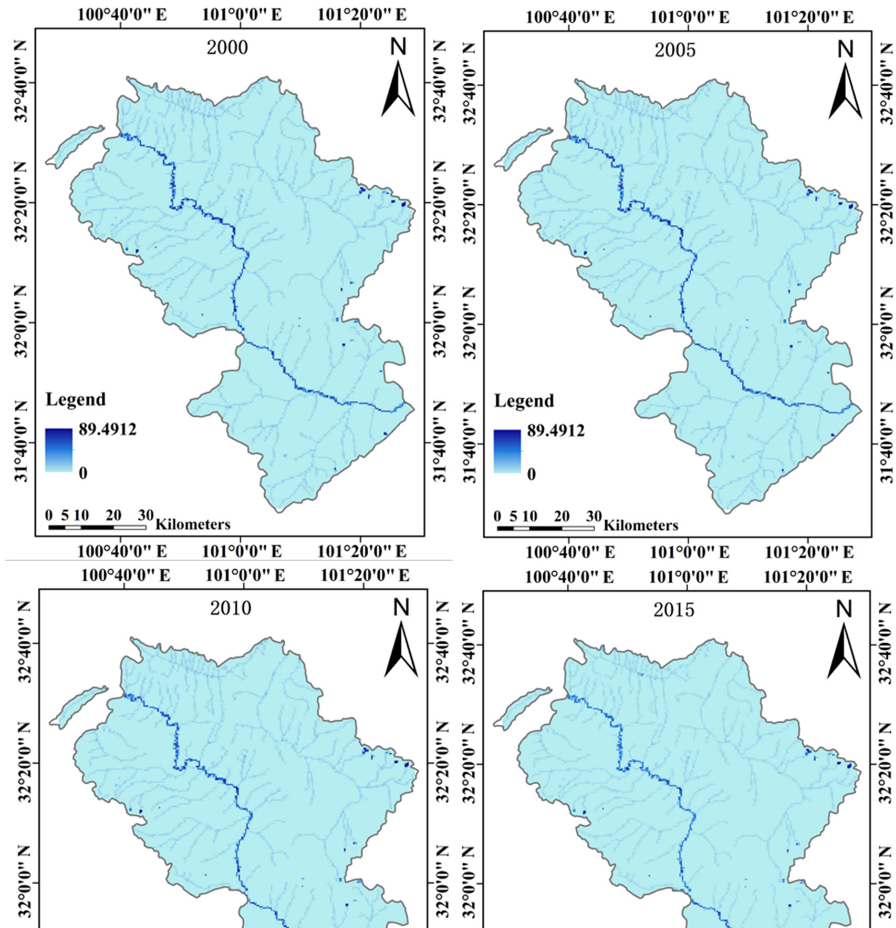

Figure 10. Water density index of Rangtang County.

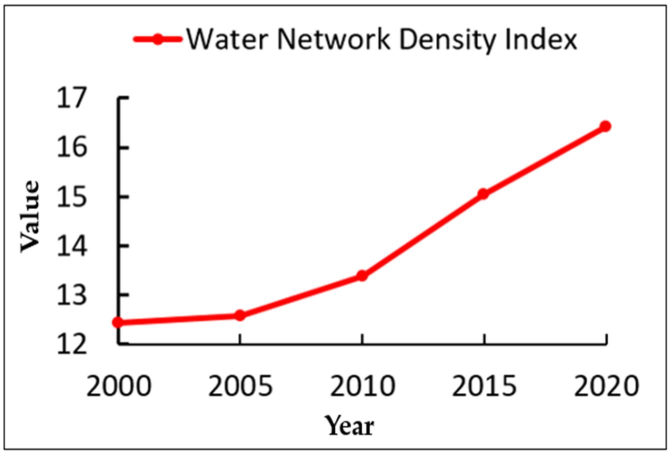

Figure 11. The change of water density index in Rangtang County.

4.1.5. Land Stress

The land erosion values of Rangtang County are shown in Figures 12 and 13.

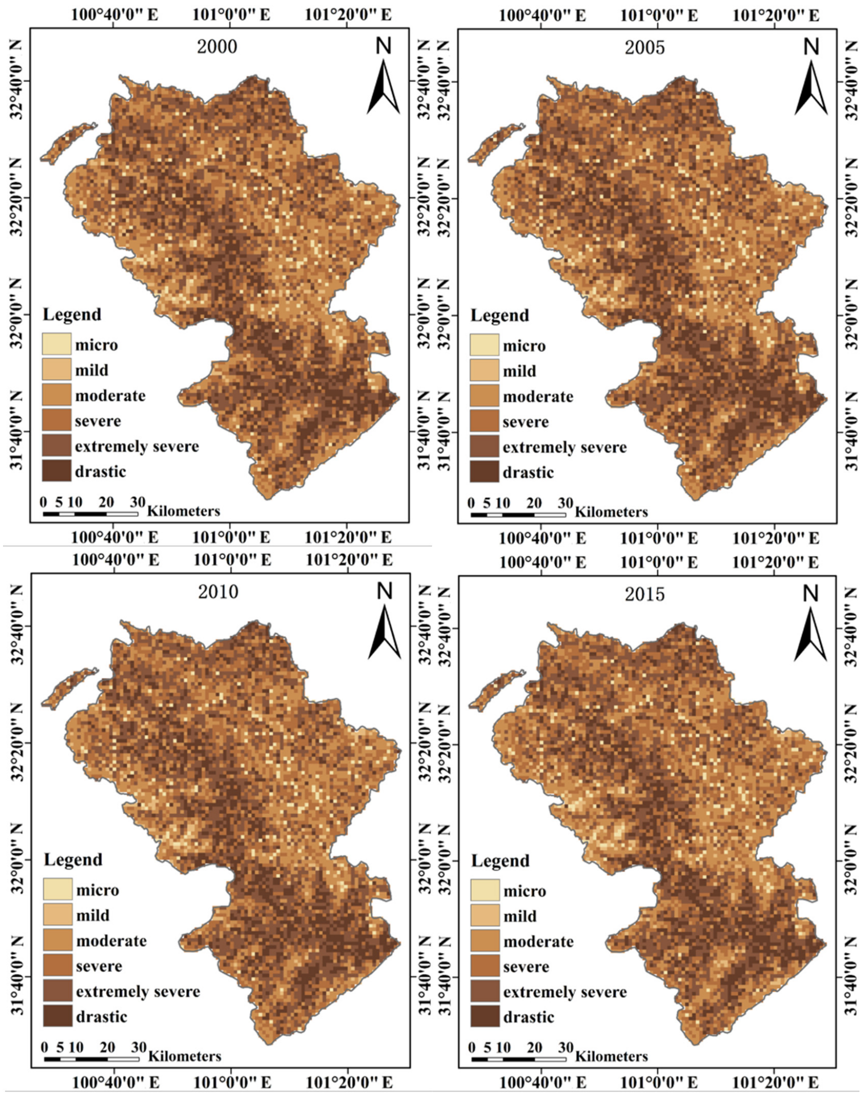

Figure 12. *Cont.*

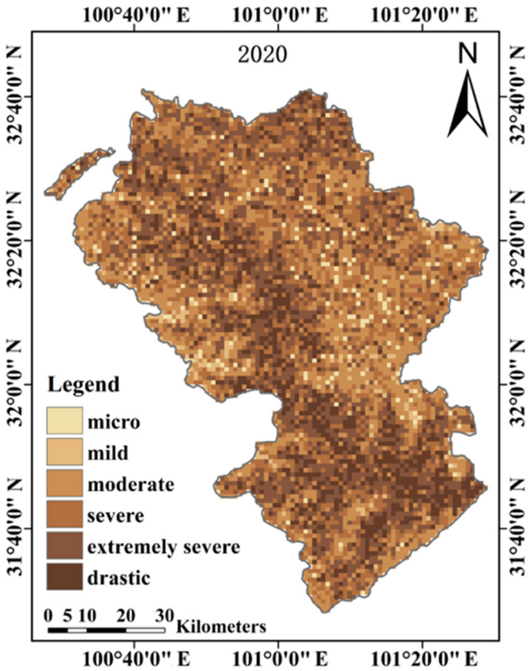

Figure 12. Land stress index of Rangtang County.

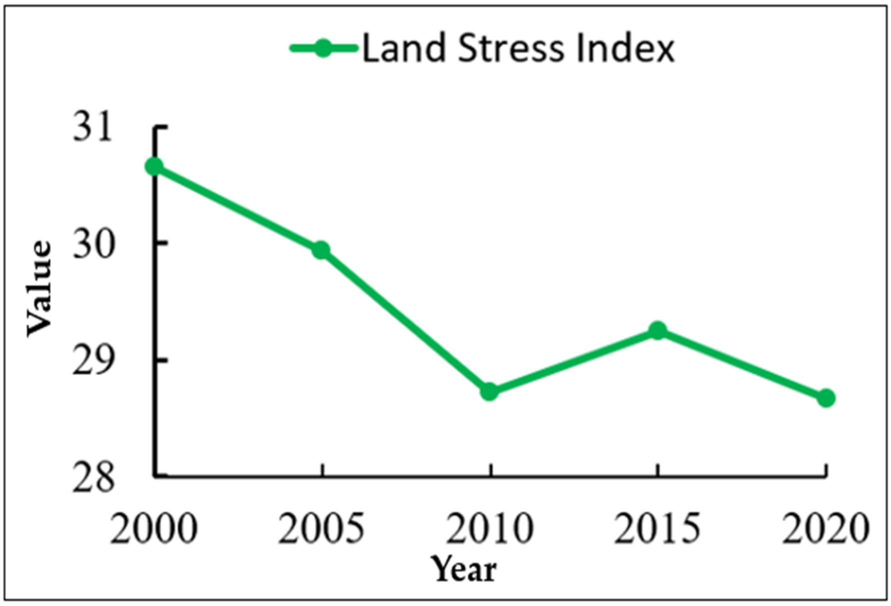

Figure 13. The change of land stress index in Rangtang County.

The mean value of land stress index in Rangtang County was 30.65 in 2000, 29.93 in 2005, 28.72 in 2010, 29.24 in 2015, and 28.67 in 2020. The overall trend is downward. The land stress index was negatively correlated with the ecological environment, indicating that the ecological environment in Rangtang County was slightly improved.

4.2. EI index Results and Analysis

According to the Equation (1), the EI index and its changes in Rangtang County during 2000–2020 can be calculated as shown in the Figure 14 and Tables 10 and 11.

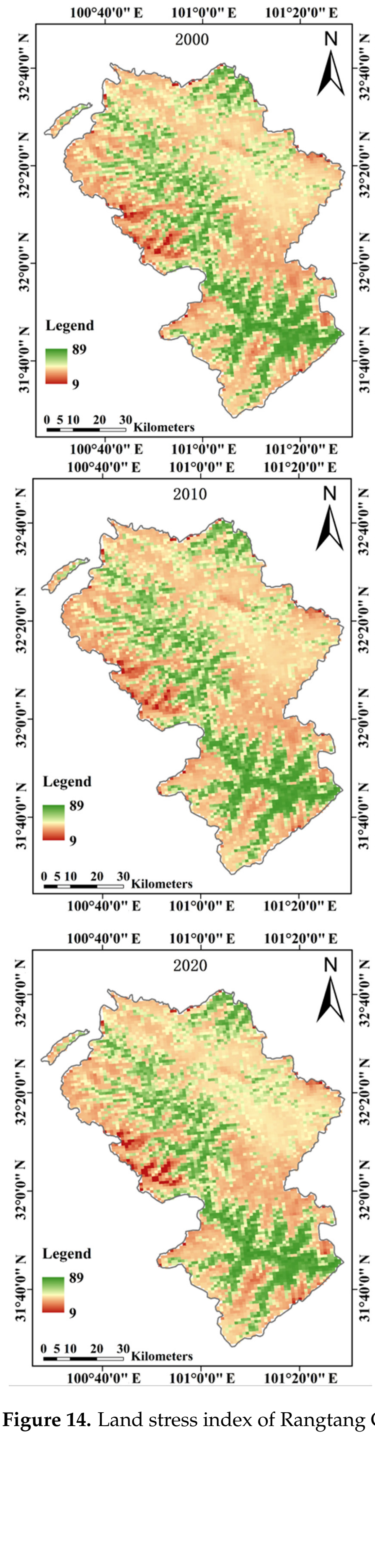

Figure 14. Land stress index of Rangtang County.

Table 10. Value of EI in Rangtang County.

Year	EI
2000	61.77
2005	62.19
2010	63.12
2015	64.33
2020	65.10

Table 11. Change in EI in Rangtang County.

Year Change	EI Change
2000–2005	+0.42
2005–2010	+0.93
2010–2015	+1.21
2015–2020	+0.77
2000–2020	+3.33

In terms of the calculation, the ecological environment index over 20 years in Rangtang County was 61.77, 62.19, 63.12, 64.33, and 65.10. According to the scope of the ecological environment index, the ecological environment is divided into five grades: excellent, good, average, poor, and bad. Since the index over the five years is in the range of 55 to 75, the ecological environment of Rangtang County can be considered good over the period of 20 years. The results show that the vegetation coverage is relatively high, and the biodiversity is relatively rich, which is suitable for human life and residency. The annual evaluation results of the Sichuan Provincial Environmental State Bulletin from 2000 to 2020 show that the ecological environment of Rangtang County is in good condition, which is consistent with the results obtained in this study.

In terms of spatial distribution, there are five grades in Rangtang County: of excellent, good, average, poor and poor ecological environment. Among them, the high-altitude areas, such as the western, northeastern, and southeastern regions, are subject to geographical and climatic factors, and the ecological environment is relatively poor. The regional distribution with higher index is consistent with the distribution of the river basin, which is rich in water resources, higher vegetation coverage, and better ecological environment. The yellow area, which occupies most of the spatial distribution map, is mainly distributed in the eastern region, and becomes lighter year by year, indicating that the ecological environment in most areas of Rangtang County is getting better year by year.

According to the absolute values of comprehensive index changes, the change in the ecological environment is divided into four levels: an absolute value of less than 1 means no obvious change, an absolute value between 1 and 3 means it changes slightly, an absolute value between 3 and 8 means clear changes, and an absolute value greater than or equal to 8 means a significant change. In addition, if the status of the ecological environment changes, it clearly fluctuates. Therefore, over the past 20 years, the ecological environment of Rangtang County has become obviously better, and the rate of increase from 2010 to 2015 was better than that of other relatively stable years. On the whole, the EI shows a slowly rising trend, such that ecological environment of Rangtang County shows a better trend in terms of stability.

5. Discussion

5.1. Impact of Spatiotemporal Change in Land-Use Types on Ecological Environment

The present situation of land use is the result of human transformation, cultivation, and use of land according to its natural characteristics and social needs [25,26]. Changes in land-use type will cause the transformation of material and energy cycles in the region, which will have a significant impact on the regional ecological environment, and produce obvious ecological environmental effects [27]. As can be seen from the land-cover distribution map of Rangtang County, the spatial scale difference is obvious. Therefore, EI values corresponding to different land use types were extracted in order to more clearly explore the driving influence of land use types on ecological environment status as shown in Table 12.

Table 12. EI index of each land type in Rangtang County from 2000 to 2020.

	2000	2005	2010	2015	2020
Woodland	76.49	77.27	77.09	77.83	78.21
Grassland	56.31	56.66	57.99	59.26	60.29
Arable land	55.04	53.86	55.38	57.29	57.40
Wet land	61.43	57.47	60.12	63.42	62.59
Construction land	52.44	54.21	54.14	55.75	57.07
Unused land	28.07	23.90	24.70	31.13	29.93
Average	61.77	62.19	63.12	64.33	65.10

The average EI index of woodland in Rangtang County was the largest, that is, the ecological environment condition of woodland covered area was the best. However, the corresponding value of unused land was low, that is, the ecological environment status of unused land area was poor. Compared with the average EI of the whole county in the same research year, only the EI index of woodland was higher than the average, indicating that woodland plays an important role in the ecological environment of Rangtang County. The improvement of ecological environment in Rangtang county can be attributed to the increase of woodland area and corresponding EI index. There is a close relationship between land use change and ecological environment in Rangtang County.

5.2. Impact of Natural Factors on Ecological Environment

Temperature and precipitation are the main factors affecting regional ecological environment change. Under the background of global climate change, the climate of the Tibetan Plateau presents obvious transitions of warming and wetting. From 2000 to 2020, the annual precipitation and annual average temperature of Rangtang County showed an upward trend. The annual precipitation increased by 50.1 mm, and the annual average temperature increased by 0.9 °C. In general, the ecological environment of Rangtang County developed in a favorable direction throughout the study period, which may be attributed to the humid regional climate caused by the increase in precipitation. The rise in temperature may accelerate the evaporation of soil moisture, which will have a negative impact on the ecological environment. Thus, the ecological risks arising from this cannot be ignored.

5.3. Impact of Social and Economic Development on Ecological Environment

The ecological stability of the Tibetan Plateau is poor, and it is vulnerable to the influence of human policy and behavior. In recent years, local managers in Rangtang County have also begun to realize the importance of the ecological environment for sustainable development, and have introduced some policies and measures to protect it. Since the end of the last century, Rangtang county has taken the lead in promoting the policy of returning farmland to forest, restoring sloping farmland step-by-step, which easily causes soil erosion in forest vegetation. In the past 20 years, the project of converting farmland to forest in Rangtang county has accumulated an area of more than 800 square kilometers, and has achieved remarkable results in terms of ecological benefits. At the same time, there is a plan to control the amount of livestock land to prevent overgrazing of grassland, which adversely affects vegetation restoration. Nanmoqie Nature Reserve, with a total area of more than 1010 square kilometers, was established in Rangtang County in 2003, and was upgraded to a national nature reserve in 2015. The establishment of reserves with numerous rare wild animals contributes to the health and stability of the plateau ecosystem. Standardized protection and management can provide scientific knowledge for the development and utilization of the ecological environment in the entire Tibetan Plateau region.

5.4. Significance of EI in Remote Sensing and Ecological Findings

The EI evaluation model, coupled with satellite remote-sensing data, was constructed for the first time, which makes the ecological environment evaluation complete and continuous. Through the research in Rangtang County, EI has been proven to have a good performance in ecological evaluation under extreme environments. EI reflects the gradually improved ecological environment in Rangtang County quickly and conveniently, which is consistent with environment reports in recent years. Due to the natural conditions of high altitude and low temperature in the Tibetan Plateau, the assessment of its ecological environment is a difficult, key point in measuring the trend of global ecological change. The successful construction of the EI model in the Tibetan Plateau makes it possible to extend it to different regions of the world. Its application in different areas provides quantitative data support for producers and policy makers.

6. Conclusions

Through the processing and analysis of remote-sensing image data in Rangtang county from 2000 to 2020, the results showed that remote-sensing data can be used as a data source for technical specifications of ecological environment assessment. EI, which is composed of five sub-indices extracted from remote-sensing data, is a good integration of indicators reflecting ecological quality, which can comprehensively reflect the changes in ecological environment quality in Rangtang County. From 2000 to 2020, the EI values in Rangtang County were 61.77, 62.19, 63.12, 64.33, and 65.10, which are good values, consistent with the ecological evaluation conclusion of Sichuan Province. In the past 20 years, the eco-environmental quality of Rangtang County has been improving greatly. On the whole, the vegetation coverage is relatively high, and the biodiversity is relatively rich, which is suitable for human life and residency.

The construction of the EI model proves that the change in ecological environment in Rangtang county is affected by both natural and human factors, and that policy is the main driving force. The establishment of Nanmoqie Nature Reserve, known as "the unique Tibetan Plateau wetland in the world", has not only maintained the stability of the ecological environment in Rangtang County, but has also accumulated scientific knowledge around ecological construction in the Tibetan Plateau region. Rangtang County should adhere to the correct policy of setting up nature reserves and returning farmland to forest, and should maintain the fine state of the ecological environment within the territory continuously. Under the modern layout, while promoting economic and social development, we should follow the natural law, rationally allocate resources, and use of land, and scientifically develop agriculture.

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

Funding: This research was funded by the National Natural Science Foundation of China (41871282) and the China Agriculture Research System Project of Ministry of Finance, Ministry of Agriculture and Rural Affairs (CARS-08-G21).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Huang, J.; Yu, H.; Dai, A.; Wei, Y.; Kang, L. Dry lands Face Potential Threat under 2 °C Global Warming Target. *Nat. Clim. Chang.* **2017**, *7*, 417–422. [CrossRef]
2. Shi, S.; Wei, W.; Yang, D.; Hu, X.; Zhou, J.J.; Zhang, Q. Spatial and Temporal Evolution of Eco-Environmental Quality in the Oasis of Shiyang River Basin Based on RSEDI. *Chin. J. Ecol.* **2018**, *37*, 1152–1163.
3. Wang, S.; Caldwell, C.D.; Kilyanek, S.L.; Smukler, S.M. Using agroecology to stimulate the greening of agriculture in China: A reflection on 15 years of teaching and curriculum development. *Int. J. Agric. Sustain.* **2019**, *17*, 298–311. [CrossRef]
4. Aguilera, E.; Diaz-Gaona, C.; Garcia-Laureano, R.; Reyes-Palomo, C.; Guzmán, G.I.; Ortolani, L.; Sanchez-Rodriguez, M.; Rodriguez-Estevez, V. Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agric. Syst.* **2020**, *181*, 102809. [CrossRef]
5. Pham, L.V.; Smith, C. Drivers of agricultural sustainability in developing countries: A review. *Environ. Syst. Decis.* **2014**, *34*, 326–341. [CrossRef]
6. Trabelsi, M.; Mandart, E.; Grusse, P.; Bord, J. ESSIMAGE: A tool for the assessment of the agroecological performance of agricultural production systems. *Environ. Sci. Pollut. Res.* **2019**, *26*, 9257–9280. [CrossRef]
7. Boeraeve, F.; Dendoncker, N.; Cornélis, J.T.; Degrune, F.; Dufrêne, M. Contribution of agroecological farming systems to the delivery of ecosystem services. *J. Environ. Manag.* **2020**, *260*, 109576. [CrossRef]
8. Aubin, J.; Callier, M.; Rey-Valette, H.; Mathe, S.; Wilfart, A.; Legendre, M.; Slembrouck, J.; Caruso, D.; Chia, E.; Masson, G.; et al. Implementing ecological intensification in fish farming: Definition and principles from contrasting experiences. *Rev. Aquac.* **2019**, *11*, 149–167. [CrossRef]
9. Tan, S.; Shao, J. Land consolidation project layout based on ecological suitability evaluation in hilly areas of Southwest China. *Geogr. Res.* **2018**, *37*, 659–677.
10. Hong, C.Q.; Jin, X.B.; Chen, C.C.; Wang, S.M.; Xiang, X.M.; Yang, X.H.; Gu, Z.M.; Zhou, Y.K. Dynamically monitoring productivity of cultivated land enrolled in land consolidation programs based on fusing multi-source remote sensing data: Methodology and a case study. *Geogr. Res.* **2017**, *36*, 1787–1800.
11. Lv, Y.; Zhang, C.; Ma, J.; Yun, W.; Gao, L.; Li, P. Sustainability Assessment of Smallholder Farmland Systems: Healthy Farmland System Assessment Framework. *Sustainability* **2019**, *11*, 4525. [CrossRef]
12. Siva, M.; Damani, O. Design of Farm Assessment Index (FAI) for a holistic comparison of farming practices: Case of organic and conventional farming systems from two Indian states. *Agroecol. Sustain. Food Syst.* **2018**, *43*, 329–357.
13. Chen, S.; Chen, B.; Fath, B. Ecological risk assessment on the system scale: A review of state-of-the-art models and future perspectives. *Ecol. Model.* **2013**, *250*, 25–33. [CrossRef]
14. Marianne, T.; Jack, H.; Peter, B. Soil ecosystem health and services–Evaluation of ecological indicators susceptible to chemical stressors. *Ecol. Indic.* **2011**, *16*, 67–75.
15. State Administration of Environmental Protection of People's Republic of China. *Technical Criterion for Ecosystem Status Evaluation*; China Environment Publishing Group: Beijing, China, 2015.
16. Ryschawy, J.; Dumont, B.; Therond, O. Review: An integrated graphical tool for analysing impacts and services provided by livestock farming. *Animal* **2019**, *13*, 1760–1772. [CrossRef]
17. Chaparro-Africano, A.M. Toward generating sustainability indicators for agroecological markets. *Agroecol. Sustain. Food Syst.* **2019**, *43*, 40–66. [CrossRef]
18. López-Ridaura, S.; Masera, O.; Astier, M. Evaluating the sustainability of complex socio-environmental systems the MESMIS framework. *Ecol. Indic.* **2002**, *2*, 135–148. [CrossRef]
19. Xu, H. A remote sensing index for assessment of regional ecological changes. *China Environ. Sci.* **2013**, *33*, 889–897.
20. Chai, L.; Tian, L.; Ao, Y.; Wang, X. Effects of human disturbance on vegetation cover change in Qinghai-Tibet Plateau. *Res. Soil Water Conserv.* **2021**, *28*, 382–388.
21. Rangtang County People's Government. *Rangtang County Yearbook 2000–2020*; Sichuan Science and Technology Press: Chengdu, China, 2020.
22. Kamel, D. MOD13A2 MODIS/Terra+Aqua Vegetation Indices 16-Day L3 Global 1km SIN Grid V006 [Data Set]. NASA EOSDIS Land Processes DAAC. Available online: https://doi.org/10.5067/MODIS/MOD13A2.006 (accessed on 30 September 2020).
23. Huang, Y.; Deng, K.; Ren, C.; Yu, Z.; Pan, Y. New water index and its stability study. *Prog. Geophys.* **2020**, *35*, 829–835.
24. Gitelson, A.; Kaufman, Y.; Stark, R.; Rundquist, D. Novel Algorithms for Remote Estimation of Vegetation Fraction. *Remote Sens. Environ.* **2002**, *80*, 76–87.
25. Castellini, C.; Bastianoni, S.; Granai, C.; Bosco, A.D.; Brunetti, M. Sustainability of poultry production using the emergy approach: Comparison of conventional and organic rearing systems. *Agric. Ecosyst. Environ.* **2005**, *114*, 343–350. [CrossRef]
26. Angela, M.; Wayne, L.G. A Regional Multiple Stressor Risk Assessment of the Codorus Creek Watershed Applying the Relative Risk Model. *Hum. Ecol. Risk Assess. Int. J.* **2002**, *8*, 405–428.
27. Odanaka, K.A.; Rehan, S.M. Impact indicators: Effects of land use management on functional trait and phylogenetic diversity of wild bees. *Agric. Ecosyst. Environ.* **2019**, *286*, 106663. [CrossRef]