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Habitat Quality Effect and Driving Mechanism of Land Use Transitions: A Case Study of Henan Water Source Area of the Middle Route of the South-to-North Water Transfer Project

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Abstract: Accelerating urbanization and industrialization have had substantial impacts on economic and social activities, changed the surface environment of the earth, and affected global climate change and biodiversity. If reasonable and effective management measures are not implemented in time, unchecked urbanization and industrialization will damage the structure and function of the ecosystem, endanger human and biological habitats, and ultimately lead to difficulties in achieving sustainable development. This study investigates the habitat quality effect of land use transition and analyzes the cause and mechanism of such changes from an economic–social–ecological complex system perspective in the Henan Water Source (HWS) area of the Middle Route of the South-to-North Water Transfer Project (MRP). The study comprehensively examines the characteristics of land use transition from 2000 to 2020. The results indicate that the habitat quality of the HWS area of the MRP decreased slowly over the past 20 years, with a more obvious decrease in the past 10 years. Specifically, the proportion of high quality habitat areas is relatively large and stable, and the medium and low quality habitat areas increase significantly. Analyzing the change degree of the proportion of different levels of habitat quality area in each county, revealed that Dengzhou City had the most dramatic change, followed by the Xichuan and Neixiang counties; other counties did not undergo obvious change. The results of habitat quality factor detection by GeoDetector showed that land use transition plays a decisive role in the change of habitat quality. The types of land use with high habitat suitability compared to those with low habitat suitability will inevitably lead to a decrease in habitat quality. Additionally, elevation, slope, landform type, and annual precipitation are important factors affecting the habitat quality in the HWS area of the MRP, indicating that ecological factors determine the background conditions of habitat quality. The gross domestic product (GDP) per capita, the proportion of agricultural output value, grain yield per unit area in economic factors, population density, and urbanization rate in social factors affect the spatial differentiation of habitat quality to a certain extent. Soil type, annual mean temperature, vegetation type, and NDVI index have weak effects on habitat quality, while road network density and slope aspect have no significant effect on habitat quality. The results of this study provide a basis for the improvement of habitat quality, ecosystem protection and restoration, land resource management, and related policies in the HWS area of the MRP. They also provide references for the research and practice of the habitat quality effects of land use transition in other regions.

Keywords: land use transition; habitat quality effect; driving mechanism; the Middle Route of the South-to-North Water Transfer Project (MRP); Henan Water Source (HWS) area

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1. Introduction

The accelerating process of urbanization and industrialization has led to the rapid change of land use patterns in China, and the conflict between the social economic system and natural ecosystem is thus increasing. Since the Reform and Opening Up in 1978, urbanization and industrialization have been promoted extensively in China [1], and great achievements have been made in economic and social development. Moreover, the land use pattern has changed dramatically. Construction utilized substantial amounts of cultivated land from 1997 to 2009, which led to the loss of approximately 8.2 million hm^2 of arable land in China [2], and threatened national food security. Moreover, to ensure food production, the Chinese government has formulated a strict system of farmland occupation and compensation balance, which results in a large number of ecological spaces, such as forestland, grassland, and unused land, being reclaimed for crop production. This practice has made the ecosystem function declining and climate change [3–5]. It is estimated that since 1850, land use/cover change has caused a 145 PgC loss in the global terrestrial ecosystem [6]. Since the beginning of the 21st century, China's ecological and environmental problems have become increasingly prominent. The government has gradually realized the importance of ecosystem protection for maintaining ecosystem functions, protecting biodiversity, and realizing regional sustainable development. The government, therefore, has taken the ecological civilization as an important development strategy to actively promote the improvement and protection of habitat quality and other ecosystem protection and restoration efforts.

Investigating the effect of land use transition on habitat quality has important scientific and practical significance in the current period of China's ecological civilization construction. As a new method in Land Use/Cover Change (LUCC) research, land use transition has been widely investigated by scholars in recent years [7–13]. Land use transition refers to the change in land use patterns over time corresponding to the transition of the economic and social development stage. With the improvement in economic and social development, regional land use pattern conflicts gradually weaken [9], which can effectively reflect the change of the natural environment, and social and economic development process [14]. Since Grainger [15,16] published research on land use transition in forest countries [9], scholars have extensively discussed the concept, connotation, mechanism [17], and methods of land use transition [18] and analyzed the land use transition characteristics of typical regions [19–23] or typical land types (e.g., rural homestead [9,24,25], industrial land [26,27], cultivated land [28–32]). Some scholars have discussed the environmental effect caused by regional land use transition [14,33–36], which has enhanced the theory, methodology, and empirical research of land us e transition. Regarding the environmental effect of land use transition, the change of ecosystem service value or environmental quality index has obtained an increasing amount of attention from scholars. However, the change in habitat quality has received less attention. Habitat quality refers to the ability of an ecosystem to provide suitable survival and development conditions for individuals and populations, which is an important basic condition to determine biodiversity [37]. It can effectively reflect the health degree of ecosystems [38–40], and is an important embodiment of ecosystem function [41,42]. Investigating the effect of land use transition on habitat quality and analyzing the changing trend, can understand the conflict between urban construction and environment, especially the conflict between human development and biodiversity protection. Investigating the driving mechanism of the habitat quality effect, can have a deeper understanding of the causes and mechanism of this conflict, which can provide a decision-making basis for sustainable management of the environment, the maintenance of biodiversity, and the realization of harmonious coexistence between humans and nature in the future.

2. Materials and Methods

2.1. Study Area

The Middle Route of the South-to-North Water Transfer Project (MRP) is an important inter basin water transfer project in China that began on 30 December 2003, and opened on 12 December 2014. It provides water for production, daily life, industry, and agriculture to more than 20 large and medium-sized cities in Henan, Hebei, Beijing, and Tianjin. By December 2020, the MRP had delivered 34.8 billion m^3 of water, and more than 69 million people had directly benefited from the project, which is of great strategic significance to optimizing China's water resources allocation pattern and promoting regional coordinated development. The water source area of the MRP is an important ecological function protection area for water conservation in China. It covers seven prefecture-level cities in Henan, Hubei, and Shaanxi provinces. Xichuan County, Xixia County, Neixiang County, Luanchuan County, Lushi County, and Dengzhou City are in Henan Province. The total administrative area of the six counties (cities) is 17,312 km^2, and the overall geographical location of the six counties is 32°22′′ N–34°23′ N, 110°34′ E–112°20′′ E (Figure 1). This area is the transition zone from the second to third steps of China's terrain. It has various geomorphic types, including mountains, hills, and plains, and is mainly composed of medium and large undulating mountains with medium altitude. There are many rivers in the Henan Water Source (HWS) area of the MRP, and the primary tributaries include Danjiang River, Guanhe River, and Xihe River. Xichuan County is the main distribution area of the Danjiang Reservoir area, which is the water source of the MRP. The research area has important biological habitats, such as Funiu Mountain National Nature Reserve, Baotianman National Nature Reserve, Dinosaur Egg Fossil Group National Nature Reserve, Danjiang Wetland National Nature Reserve, and Xixia Giant Salamander Provincial Nature Reserve, as well as several rare animal and plant resources, such as the endangered species of Chinese merganser, peach blossom jellyfish, etc.

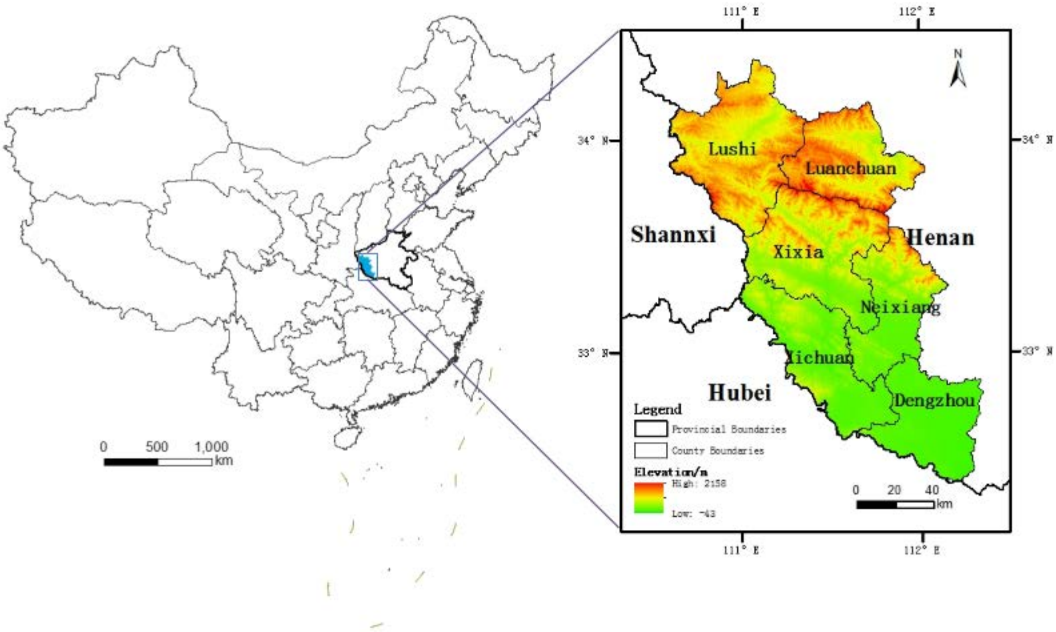

Figure 1. Location of Henan Water Source area of the Middle Route of the South-to-North Water Transfer Project.

2.2. Data Sources

The analysis of this study is mainly based on the data of land use, Digital Elevation Model (DEM), administrative boundaries, environmental properties, and economy and society. The sources of the involved data are specified as follows. (1) Land use data derived from the global 30 m land cover data (http://www.globallandcover.com/, 14

January 2021) of National Geomatics Center of China was obtained from 2000, 2010, and 2020 to represent before, during, and after the implementation of the first phase of the MRP. The land use types were divided into seven categories: Cultivated land, forest land, grassland, construction land, wetland, water area, and other land. (2) DEM data were derived from Geospatial Data Cloud platform with a spatial resolution of 30 m. (3) The vector data of administrative boundaries, highways, and railways were derived from the National Catalogue Service for Geographic Information (https://www.webmap.cn/, 26 January 2021). (4) Landform, vegetation, soil type, temperature, precipitation, and NDVI data were derived from the Resource and Environment Science and Data Center of the Chinese Academy of Science (https://www.resdc.cn/, 23 February 2021). (5) Economic and social data, namely, per capita GDP, population density, urbanization rate, grain output per unit area, etc., were derived from the *Luoyang Statistical Yearbook*, *Nanyang Statistical Yearbook*, *Sanmenxia Statistical Yearbook*, statistical bulletin of national economic and social development, and government work reports of each county. Some missing data were calculated and obtained using the moving average method. All the above data were transformed to the same coordinate system by projection (WGS_1984_UTM_ Zone_49n) and cut according to the administrative boundary of the study area.

2.3. Methods

In this study, the land use transfer matrix was used to study the characteristics of land use transition in the HWS area of the MRP. Then, the InVEST model was used to analyze the changes in habitat quality and degradation degree of the study area. Finally, the GeoDetector model was used to analyze the driving factors and mechanisms of regional habitat quality (Figure 2).

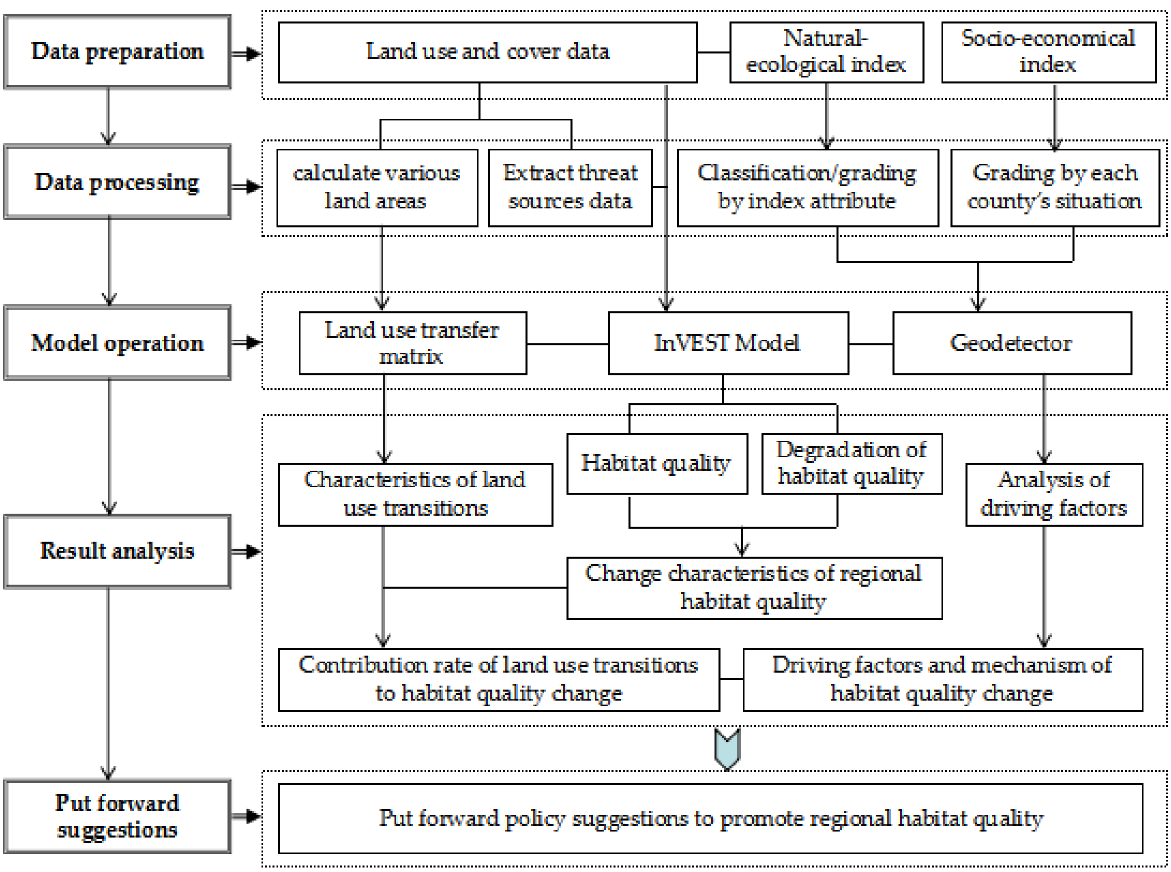

Figure 2. Research logic and process of this study.

2.3.1. Land Use Transfer Matrix

The land use transfer matrix reflects the conversion between different land use types in different periods of a certain region. This matrix can quantitively characterize the change in regional land use [14]. The land use transfer matrix is shown in Equation (1).

$$A_{ij}=\begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ A_{n1} & A_{n2} & \cdots & A_{nn} \end{bmatrix} \quad (1)$$

where A is the area of land type, i and j are the land types before and after the transfer, respectively, n is the number of land types, and A_{ij} is the transfer area from land type i to land type j. Each row represents the flow direction information from land type i to other land types, and each column represents the source information from other land types to land type j.

2.3.2. Habitat Quality Module of the InVEST Model

The Habitat Quality module of the InVEST model can calculate the regional habitat quality index, and its spatial distribution by analyzing the land use cover map and the threat factors. Habitat quality index is a comprehensive index to evaluate the habitat suitability and degradation degree of land use type [43], and is calculated using Equation (2).

$$Q_{xj}= H_j\left[1-\left(\frac{D_{xj}^z}{D_{xj}^z+K^z}\right)\right] \quad (2)$$

where Q_{xj} is the habitat quality index of grid unit x of land use type j; H_j is the habitat suitability score of land use type j, with a range of 0–1; z is the scale constant, generally 2.5; K is the semisaturation constant, which was 0.5 in this study; and D_{xj} is the habitat degradation index, which indicates the degradation degree of habitat under stress.

$$D_{xj}= \sum_{r=1}^{R}\sum_{y=1}^{Y_r}\left(\frac{\omega_r}{\sum_{r=1}^{R}\omega_r}\right)r_y i_{rxy}\beta_x S_{jr} \quad (3)$$

where R is the number of stress factors, Y_r is the total number of grid cells of stress factors, ω_r is the weight, r_y is the number of stress factors on the grid cell, β_x is the accessibility level of grid x, S_{jr} is the sensitivity of land use type j to stress factors, and the value range is 0–1, and i_{rxy} is the influence distance of stress factors, which can be divided into linear and exponential decline.

$$i_{rxy}= 1-\left(\frac{d_{xy}}{d_{r\ \max}}\right),\ \text{if linear} \quad (4)$$

$$i_{rxy} = \exp\left(-\left(\frac{2.99}{d_{r\ \max}}\right)d_{xy}\right),\ \text{if exponential} \quad (5)$$

Based on previous studies [44–48], the InVEST model user's guide [43], and the reality of HWS area, this study constructed an evaluation table of habitat threat factors and threat degree (as shown in Table 1) and the sensitivity of land use types to the threat factors (Table 2).

2.3.3. GeoDetector

GeoDetector is a statistical method used to detect spatial differentiation and reveal the driving factors behind it [49,50]. GeoDetector has been applied in many fields of natural and social sciences. The factor detection tool can detect the extent to which the independent variable x explains the spatial differentiation of dependent variable y. The calculation formula of q value is as follows (Equation (6)):

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST}$$
$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2,\ SST = N\sigma^2 \tag{6}$$

where h (h = 1, 2, . . . , l) is the stratification of dependent variable y or independent variable x, i.e., classification or partition; N_h and N are the unit numbers of layer h and the whole region, respectively; σ_h^2 and σ^2 are the variances of layer h and region Y, respectively; SSW and SST are the sum of variances within the layer and the total variances of the whole region, respectively; $q \in [0, 1]$, where the larger the value, the stronger the explanatory power of independent variable x to dependent variable y, and vice versa.

Table 1. Habitat threat factors and threat degree.

Threat Factors	Farthest Threat Distance (km)	Threat Degree	Declining Type
Cultivated land	4	0.5	linear
Construction land	8	1.0	exponential
Main traffic arteries	6	0.9	linear
Bare land	5	0.8	linear

Table 2. Sensitivity of land use types to the threat factors.

Land Use Types	Habitat Suitability	Cultivated Land	Construction Land	Main Traffic Arteries	Bare Land
Cultivated land	0.4	0	0.8	0.6	0.4
Forest land	1.0	0.6	0.7	0.8	0.3
Grassland	0.8	0.8	0.6	0.5	0.4
Wetland	0.7	0.7	0.6	0.6	0.2
Water area	0.6	0.5	0.4	0.4	0.2
Construction land	0	0	0	0	0
Other land	0.2	0.5	0.7	0.2	0

3. Results

3.1. Land Use Transitions

3.1.1. Changes in Land Types and Degree of Change

From 2000 to 2020, a total land area of 1522.66 km^2 changed, accounting for 8.9% of the research area. The change in the first 10 years was more intense with 921.08 km^2 of land changing, and slowed down in the past 10 years, during which the altered area was 814.86 km^2. All types of land changed by varying degrees (Figure 3).

Overall, the land types with greater changes were cultivated land, construction land, and water area. A new land type of "other land," mainly bare land, appeared in the study area from 2010 to 2020. During the study period, cultivated land, grassland, and forest land were the most reduced land types, while construction land, cultivated land, and forest land were the most increased land types (Table 3).

3.1.2. Drastic Changes in Construction Land and Cultivated Land

During the study period, the land types with the largest change area were cultivated land and construction land (Table 4), with a net decrease of 437.74 km^2 in cultivated land and a net increase of 301.88 km^2 in construction land. (1) A large area of cultivated land was converted into construction land and water areas. From 2000 to 2010, 159.09 km^2 of cultivated land was converted into construction land, accounting for 17.27% of the total changed area, and 107.52 km^2 of cultivated land was converted into water areas, accounting for 11.67% of the total changed area. From 2010 to 2020, the area of cultivated land occupied by construction reached 263.60 km^2, accounting for 32.35% of cultivated land reduction. During this period, the area of cultivated land converted into water areas decreased slightly, reaching 103.42 km^2 and accounting for 12.70% of cultivated land reduction. (2) The cultivated land occupied by construction was obvious in the southeast plain. Owing to the flat terrain and rapid economic development, the cultivated land occupied by construction was primarily distributed in the southeast plain area (Figure 4), including most areas of Dengzhou City, the south of Neixiang County, and the southeast of Xichuan County. This particular land type was mainly scattered in the surrounding areas of the original urban and rural construction land with low altitudes and was relatively concentrated around the county town. (3) The area of forest land converted to cultivated land was larger than the total area cultivated land returned to forest land. From 2000 to 2010, 150.87 km^2 of forest land was converted into cultivated land, while 128.38 km^2 of cultivated land was converted into forest land in the same period. From 2010 to 2020, the conversion area of forest land to cultivated land was 5.07 km^2 larger than the conversion area of cultivated land to forest land.

3.1.3. Water Area

The water area of the study area increased by 274.38 km^2, with a growth rate of 155.12%, of which 121.18 km^2 increased in the first 10 years, and 153.20 km^2 increased in the second 10 years. This reflects the long-term efforts of the water source area to ensure water quality and quantity. To increase the sustainable water supply capacity of the MRP, Danjiangkou Reservoir implemented the dam heightening project in 2002 and passed the acceptance in 2013. The dam height increased from 162 m to 176.6 m, the normal water level increased from 157 m to 170 m, and the reservoir capacity increased from 17.45 billion m^3 to 29.05 billion m^3. A large number of farmland and villages around the reservoir area had been inundated. Among them, Xichuan County has an inundated area of 137 km^2 with about 150,000 people resettled. From 2000 to 2010, 79.96% of the total amount of water area transferred from cultivated land, followed by wetland (11.56%), grassland (5.58%), and forest land (2.60%), and the proportion of construction land which transitioned to water was relatively small. From 2010 to 2020, the area of cultivated land converted to water areas decreased slightly, accounting for 64.56% of the total converted water area. The proportion of forest land and grassland converted to water area increased significantly to 17.87% and 12.86%, respectively, and the proportion of wetland converted to water area decreased to 3.16%.

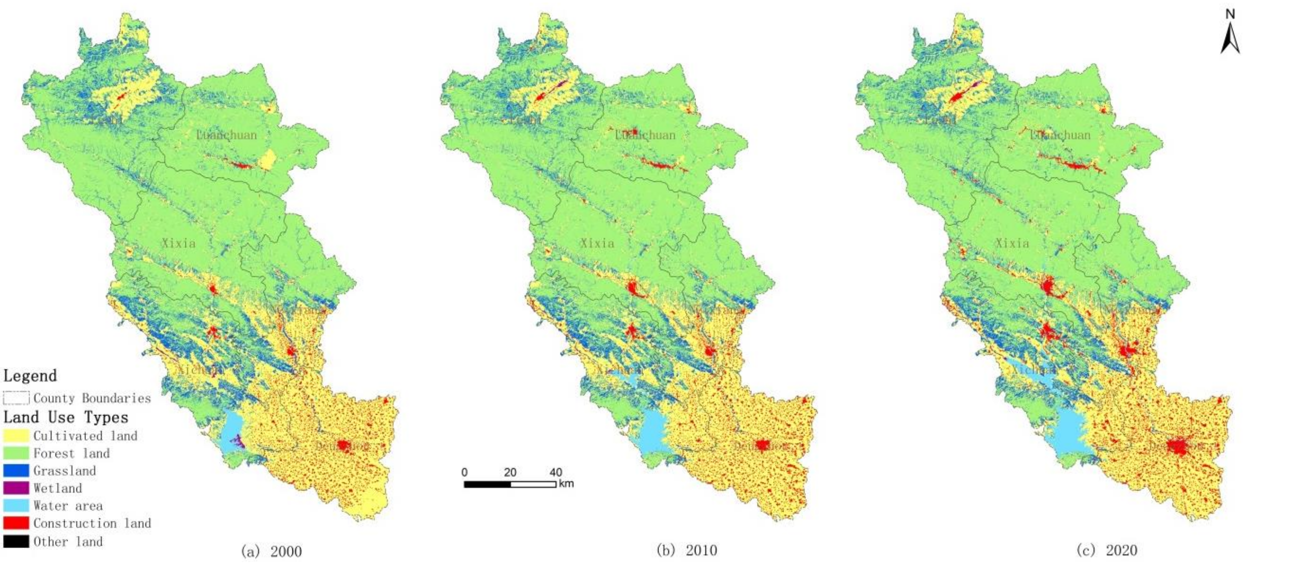

Figure 3. Land use maps in 2000, 2010, and 2020.

Table 3. Land use transfer matrix (unit: km^2).

2000	2020							Reduction
	Grassland	Cultivated Land	Construction Land	Forest Land	Wetland	Water Area	Other Land	
Grassland	1461.63	64.77	20.28	173.44	0.80	37.74	2.74	299.76
Cultivated land	47.48	4286.88	376.26	140.25	12.56	213.35	1.70	791.60
Construction land	2.58	111.71	481.20	0.66	0.05	1.92	0.59	117.51
Forest land	72.50	171.71	21.75	9146.06	0.19	15.24	1.71	283.09
Wetland	0.54	1.11	0.01	0.10	1.68	17.53	0.00	19.29
Water area	1.61	4.56	1.09	2.79	1.36	165.47	0.00	11.41
Increase	124.72	353.86	419.39	317.23	14.95	285.79	6.73	
Change	−175.05	−437.74	301.88	34.13	−4.34	274.38	6.73	

Table 4. Changes of land use structure.

Land Use Type	2000		2010		2020	
	Area/km^2	%	Area/km^2	%	Area/km^2	%
Grassland	1761.39	10.32	1614.21	9.46	1586.35	9.30
Cultivated land	5078.48	29.76	4901.65	28.72	4640.74	27.19
Construction land	598.71	3.51	715.48	4.19	900.59	5.28
Forestland	9429.16	55.25	9517.76	55.77	9463.29	55.45
Wetland	20.96	0.12	18.41	0.11	16.62	0.10
Water area	176.88	1.04	298.06	1.75	451.26	2.64
Other land	0.00	0.00	0.00	0.00	6.73	0.04

3.1.4. Ecological Land

The area of forest land, grassland, wetland, and water area with strong ecological functions in the study area was relatively large. In 2000, the area of the four land types was 11,388.39 km^2, accounting for 66.73% of the total research area, increasing by 60.06 km^2 in 2010, accounting for 67.09%. In 2020, the ecological land area continued to increase to 11,517.51 km^2, accounting for 69.07%. Among them, forest land initially increased rapidly then decreased slowly, grassland and wetland decreased continuously, and water area increased continuously and rapidly. This phenomenon fully reflects that many engineering measures, and ecological protection and restoration strategies were implemented to ensure the regional water supply capacity.

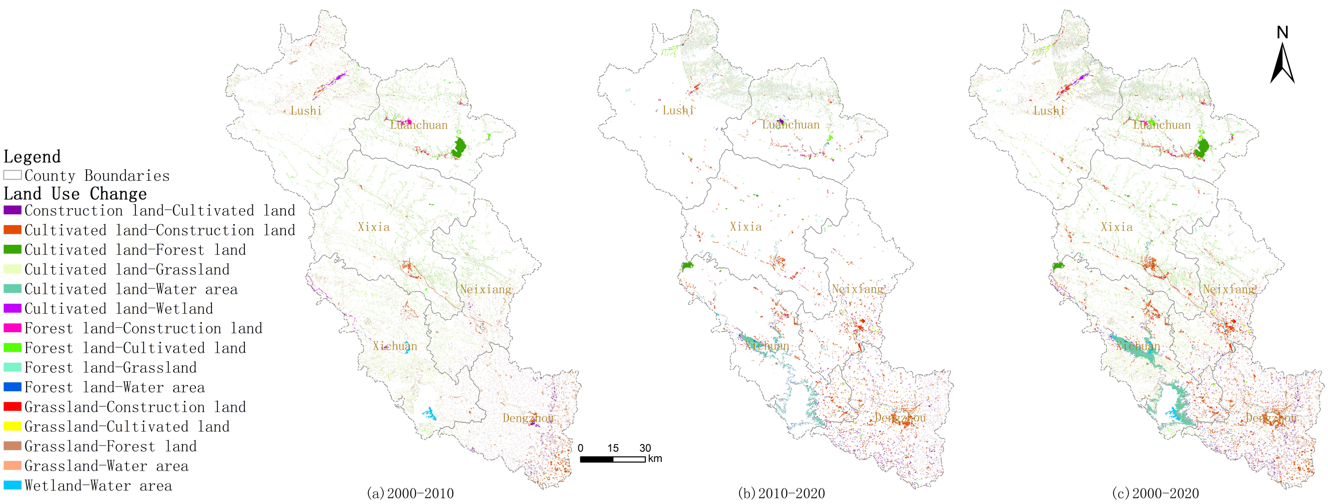

Figure 4. Spatial distribution of land use transitions.

3.1.5. Land Use Changes in Different Counties

By analyzing the change of land use types in each county (Table 5), it can be concluded that: The land use change in Xichuan County was the most severe, followed by Dengzhou City. The most obvious land types in Xichuan County were cultivated land and water area, of which cultivated land reduced by 244.66 km^2 over the past 20 years, with the proportion reducing by 8.70%, and the decrease between 2020 and 2010 was 30.16 km^2 more than that between 2010 and 2000. The water area increased from 5.53% of the total land in 2000 to 14.03% in 2020. The increase in water area between 2020 and 2010 was 12.54 km^2 more than that between 2010 and 2000. The most substantially changed land types in Dengzhou City were cultivated land and construction land, of which cultivated land decreased by 100.43 km^2 over 20 years and the construction land area increased by 98.07 km^2. The change range of land use in other counties was not significant, and the change proportions of different land types were all within 2.1%.

Table 5. Land use changes of each county (unit: km^2).

County	Year	Grassland	Cultivated Land	Construction Land	Forestland	Wetland	Water Area	Other Land
Lushi	2000	545.22	499.01	8.66	2598.88	0.00	5.03	0.00
	2010	495.89	489.43	22.84	2636.99	7.30	4.35	0.00
	2020	493.79	486.61	35.73	2627.94	7.99	4.73	0.00
Luanchuan	2000	137.39	185.87	15.94	2130.46	0.00	1.35	0.00
	2010	113.71	167.78	34.66	2152.64	0.76	1.48	0.00
	2020	113.50	168.13	49.09	2134.21	0.74	3.24	2.11
Xixia	2000	218.62	452.49	28.32	2743.72	0.00	4.56	0.00
	2010	201.70	458.53	48.54	2730.33	0.00	8.63	0.00
	2020	204.64	426.18	79.10	2725.24	0.00	12.55	0.00
Xichuan	2000	548.44	1197.63	81.73	810.69	19.85	155.58	0.00
	2010	506.39	1090.38	92.50	845.45	10.34	268.87	0.00
	2020	492.14	952.97	126.13	837.91	7.88	394.69	2.21
Neixiang	2000	285.57	781.75	105.81	1127.89	0.56	3.53	0.00
	2010	273.17	776.07	116.48	1132.96	0.00	6.44	0.00
	2020	262.92	745.57	154.22	1122.57	0.00	14.42	2.41
Dengzhou	2000	25.77	1960.55	358.17	15.70	0.55	6.80	0.00
	2010	23.01	1918.30	400.39	17.55	0.00	8.27	0.00
	2020	19.03	1860.12	456.24	13.56	0.00	18.58	0.00

3.2. Changes of Habitat Quality

The grid data of cultivated land, construction land, and bare land in 2000, 2010, and 2020 were extracted by ArcGIS 10.6, and the buffer area was set for the vector data of main traffic arteries in each period of the study area. After overlaying the land use maps, the corresponding grid data were extracted; then, the land use maps, various threat source data, habitat threat factors and threat degree, and the sensitivity evaluation table were input into the Habitat Quality module of InVEST 3.9.0. Subsequently, habitat quality distribution maps of the study area in 2000, 2010, and 2020 were obtained and divided into high, medium-high, medium, medium-low, and low grades using the equidistant method (Figure 5).

3.2.1. Overall Habitat Quality

From 2000 to 2020, the mean habitat quality value of the whole region decreased from 0.756 in 2000 to 0.755 in 2010, and then decreased to 0.750 in 2020, with a total converted area of 1520.81 km^2. The area of habitat quality improved was 709.83 km^2, and the area of habitat quality degraded was 810.98 km^2 (Figure 6). Overall, low and medium grade increasing and medium-low and medium-high grade decreasing trends were observed.

Among them, the medium-low habitat quality area reduction was the largest converted area, with a decrease of 473.74 km^2, and the low habitat quality area increased the most, by 308.61 km^2 (Table 6).

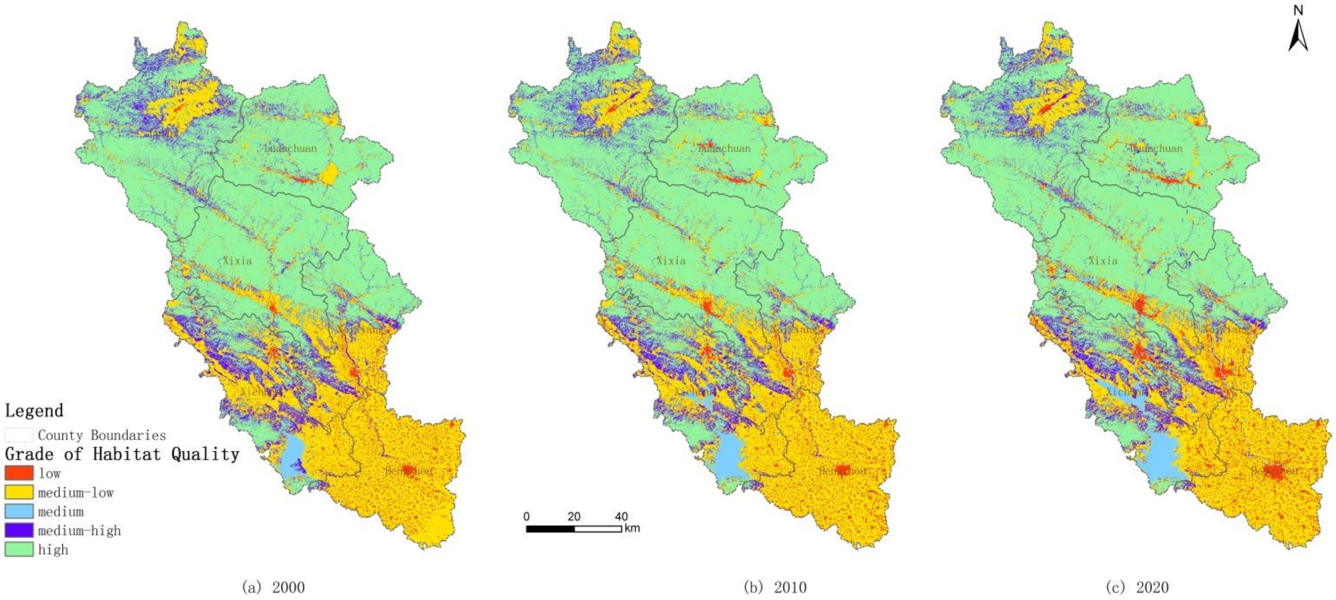

Figure 5. Spatio-temporal patterns of habitat quality.

3.2.2. High Quality Habitat Areas

The proportion of high quality habitat area continued to be about 55% during the study period. High quality habitat areas were mainly distributed in the northern and central regions, including most areas of Xixia County, Luanchuan County, Lushi County, and some areas of Xichuan County and Neixiang County. In 2000, the high quality habitat area was 9429.27 km^2, which increased to 9517.76 km^2 in 2010, and then decreased to 9463.29 km^2 in 2020. Overall, the areas of high quality habitat only changed less than 1% in the past 20 years.

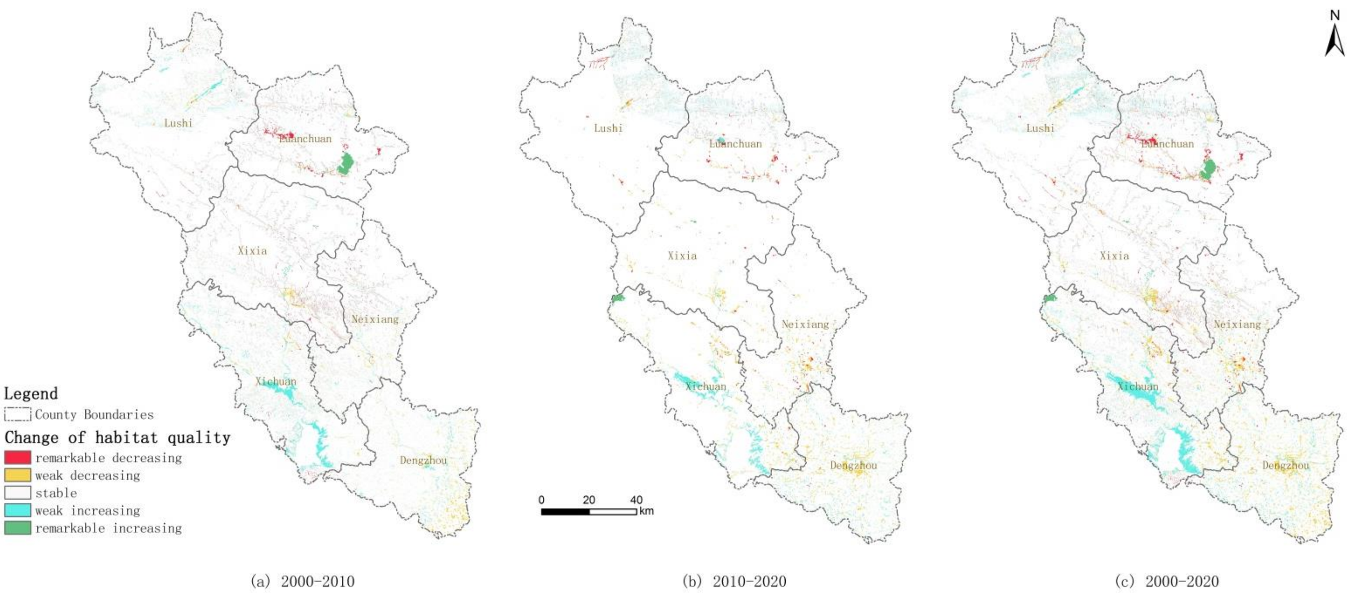

Figure 6. Spatial distribution of the changes of habitat quality.

Table 6. Spatial transfer matrix of habitat quality in the study area (unit: km^2).

2000	2020					Reduction
	Low	Medium-Low	Medium	Medium-High	High	
Low	481.79	111.71	1.92	2.63	0.66	116.92
Medium-low	377.97	4286.88	213.35	60.04	140.25	791.60
Medium	1.09	4.56	165.47	2.97	2.79	11.41
Medium-high	23.02	65.88	55.28	1464.55	173.52	317.69
High	23.46	171.71	15.24	72.79	9146.08	283.19
Increase	425.53	353.86	285.79	138.42	317.21	
Change	308.61	−437.74	274.38	−179.27	34.02	

3.2.3. Medium and Low Quality Habitat Areas

In 2000, the medium quality habitat area was 176.88 km^2, accounting for 1.04%. In 2010, the ratio increased to 1.75%, an increase of 121.18 km^2, with a growth rate of 68.51%. In 2020, the proportion was 2.64%, and the growth rate was 51.40%, with a total increase of 274.38 km^2 in 20 years. The low quality habitat area increased by 51.55% in the past 20 years, and the proportion increased from 3.51% in 2000 to 5.32% in 2020, mainly distributed in Neixiang County and Dengzhou City.

3.2.4. Changes of Habitat Quality in Different Counties

The change of habitat quality in Xichuan County was the most severe, followed by Dengzhou City and Neixiang County. Of all the counties in the study area, the mean habitat quality value only increased in Xichuan County (by 0.009 in 20 years) and decreased in other counties. Among them, the mean habitat quality value in Dengzhou City decreased the most, from 0.345 in 2000 to 0.328 in 2020, a decrease of 0.017 in 20 years. Neixiang County and Xixia County had the second largest decreases in mean habitat quality of 0.011 and 0.010, respectively; Luanchuan County and Lushi County exhibited decreases of 0.008 and 0.003, respectively.

The change of habitat quality in Xichuan County showed that the area of medium-low grade decreased significantly, which decreased by 244.665 km^2 in 20 years, while the area of medium grade increased rapidly, which increased by 239.11 km^2. In Dengzhou City and Neixiang County, the area of low quality habitat area both increased, while the proportion of medium-low grade area both decreased. The change range of Dengzhou City was larger than Neixiang County. The variation in the changes of habitat quality in other counties were not very significant and were all less than 1.2% (Table 7).

Table 7. Changes of habitat quality area in different grades of counties (unit: km^2).

County	Year	low	Medium-Low	Medium	Medium-High	High
Lushi	2000–2010	14.19	−9.58	−0.68	−41.92	38.00
	2010–2020	12.89	−2.82	0.38	−1.40	−9.05
Luanchuan	2000–2010	18.71	−18.10	0.13	−22.92	22.18
	2010–2020	16.54	0.36	1.76	−0.23	−18.43
Xixia	2000–2010	20.21	6.04	4.07	−7.93	−13.39
	2010–2020	30.57	−32.35	3.93	−6.06	−5.08
Xichuan	2000–2010	10.77	−107.25	113.28	−51.55	34.75
	2010–2020	35.84	−137.41	125.82	−16.72	−7.54
Neixiang	2000–2010	10.66	−5.68	2.90	−12.96	5.07
	2010–2020	40.17	−30.35	11.01	−10.31	−10.57
Dengzhou	2000–2010	42.21	−42.24	1.48	−3.31	1.86
	2010–2020	55.85	−58.19	10.31	−3.99	−3.99

3.2.5. Degree of Habitat Degradation

The obtained grid map of habitat quality degradation degree was reclassified using the equidistant method and divided into five categories: Weak, medium-weak, medium, medium-strong, and strong (Figure 7). The habitat quality degradation grades in the study area were mainly medium-weak, weak, and medium degradation. Overall, the degree of habitat degradation in the study area was reduced. The highest habitat degradation value was 0.200 in 2000, which increased slowly to 0.201 in 2010, and then decreased to 0.155 in 2020. In terms of spatial distribution, the areas with strong habitat quality degradation were mainly concentrated in the central and eastern low altitude regions, and the areas with medium-strong degradation were mainly concentrated in Dengzhou City and Xichuan County, for which, a significant increasing trend over the past 10 years was observed. Meanwhile, the areas with weak degradation were mainly concentrated in the south of Lushi County and Luanchuan County and the east of Xixia County. The medium-strong and medium-weak degradation areas showed an increasing trend, and the weak degradation area showed a decreasing trend, especially in the past 10 years.

3.3. Habitat Quality Effect of Land Use Transitions

3.3.1. Driving Factors of Habitat Quality Change

The spatial differentiation of regional habitat quality is restricted by different factors, such as ecological factors that affect the natural background conditions of the biological habitat environment; economic factors that determine the strength of regional economic development, reflecting the manner and degree of human interference with the biological habitat environment; and social factors that reflect human concern and awareness of habitat quality, as well as the protection and management ability. Based on the natural endowment characteristics of the study area, such as mountainous, undulating, a subtropical to the temperate transition zone, and a monsoon continental humid and semihumid climate, as well as the social and economic development characteristics, such as mountainous counties, relatively regressive economic development, and agricultural production dominance, the driving mechanism of the spatial pattern of habitat quality in 2020, was studied using 16 indicators (Table 8) including elevation, slope, geomorphology type, annual precipitation, vegetation type, land use type, per capita GDP, the proportion of agricultural output value, and urbanization rate.

In ArcGIS 10.6, the elevation, slope, annual precipitation, annual average temperature, and NDVI index of the study area were divided into 9 grades by using the natural breakpoint method, and the aspect, geomorphology type, soil type, vegetation type, and land use type were divided into 9, 10, 9, 8, and 7 categories, respectively, according to their classification standards and combined with the actual situation of the study area. The fishing net creating tool of ArcGIS 10.6 was used to generate 1×1 km grid data (18,297 evaluation units in total) of the study area. The road network density was calculated according to the ratio of the road length in the grid to the grid area and was divided into eight categories using the natural breakpoint method. Economic and social data were identified according to the spatial grid and divided into six categories according to the index values of each county. Based on the grid data of habitat quality and driving factors in the study area, the center point of 1×1 km grid was used as the sampling point (17,647 sampling points in total), the corresponding X and Y attribute values were extracted, and the generated data table was input into the GeoDetector for operation.

The results of factor detection (Figure 8) indicated that land use type was the most influential factor on habitat quality in the study area, with a q value as high as 0.99, followed by elevation, slope, geomorphology type, and annual precipitation, with a q value between 0.4 and 0.6. The q values of per capita GDP, the proportion of agricultural output value, grain yield per unit area, population density, and urbanization rate were all ~0.39, while the q values of soil type, annual mean temperature, vegetation type, and NDVI index were between 0.18 and 0.23, and the q values of road network density and aspect were the lowest. The results of risk detection reveal the suitable range or types of influencing factors of regional high quality habitat and provide a decision-making basis for the protection and restoration of the ecological system. According to the detection results (Table 8), the areas with high quality habitat were mostly distributed in forest land, with altitude >1503 m and slope of 33.48–40.06; additionally, the slope aspect was in the north, and the geomorphology type was dominated by medium altitude and large undulating mountains. The annual precipitation and annual average temperature were 554–591 mm and 12.30–13.40 °C, respectively; the main vegetation types were swamp and grass, the NDVI index was 0.08–0.29, and the road network density was <0.54.

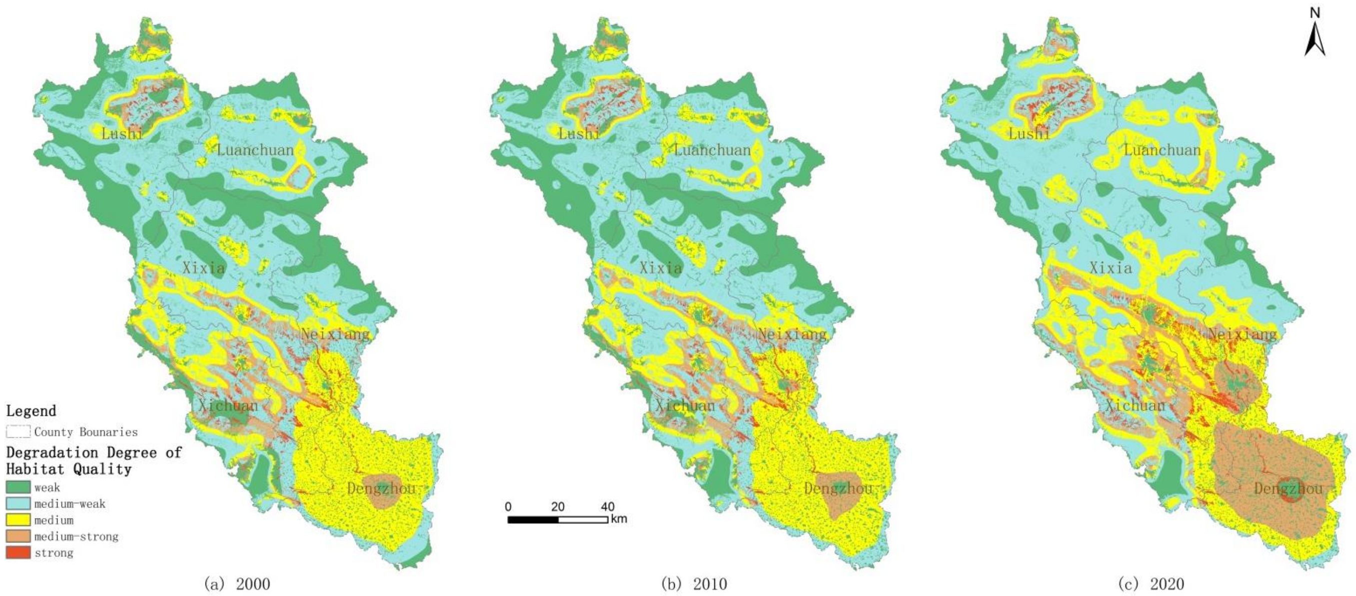

Figure 7. Spatio-temporal distribution of the degradation degree of habitat quality.

Table 8. Driving factors of habitat quality change and dominant range/type.

Driving Factors			Unit	Range/Type
Ecological factors	Topography	elevation $x1$	m	>1503
		slope $x2$	°	33.48–40.06
		slope aspect $x3$	—	North
	Geomorphology	geomorphology type $x4$	—	Middle elevation relief mountains
	Soil	soil type $x5$	—	Calcareous soil
	Climate	annual precipitation $x6$	mm	554–591
		annual average temperature $x7$	°C	12.30–13.40
	Vegetation	vegetation type $x8$	—	Swamp, grass
		NDVI index $x9$	—	0.08–0.29
	LUCC	land use type $x10$	—	Forestland
Economic factors	GDP	per capita GDP $x11$	Yuan/person	55,716–57,676
	Industry	proportion of agricultural output value $x12$	%	13.49–20.50
		grain yield per unit area $x13$	kg/hm^2	4271–4532
Social factors	Carrying capacity	population density $x14$	Person/km^2	137.78–146.72
	Development degree	urbanization rate $x15$	%	50.00–50.14
		road network density $x16$	km/km^2	<0.54

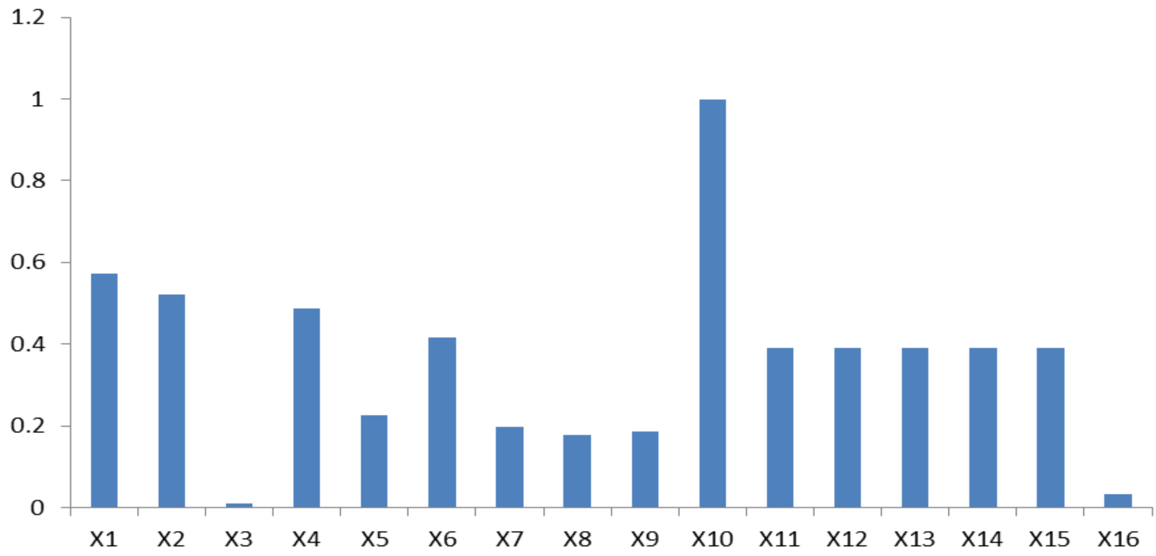

Figure 8. *Q* value of each factor's influence on habitat quality.

It can be concluded that: (1) Land use type determines the regional habitat quality, and its analysis can be used to identify the core driving effect of land use transition on changing habitat quality; (2) ecological factors, such as elevation, slope, geomorphology type, and precipitation constitute the background conditions of biological habitat, which have an important impact on the quality of the habitat; (3) GDP per capita, the proportion of agricultural output value, grain yield per unit area, and population density, and urbanization rate are economic and social factors, respectively, which affect the spatial differentiation of habitat quality to a certain extent; (4) moreover, among the ecological factors, soil type, annual mean temperature, vegetation, type, and NDVI index (Normalized Difference Vegetation Index) have a weak effect on habitat quality, whereas road network density and slope aspect have no significant effect on the habitat quality.

3.3.2. Contribution of Land Use Transition to Habitat Quality Effect

As mentioned in Section 3.3.1, land use type is the core factor that determines the quality of regional habitat. In the process of regional economic and social development, human economic production activities and social management behavior jointly determine the direction and characteristics of land use transition. The economic and social activities in the study area, including agricultural planting, industrial development, and human living, contributed to the expansion of construction land with low habitat suitability in the southern plains and the surrounding areas of low altitude cities and towns, and constantly occupied cultivated land, woodland, and grassland with high habitat suitability. From 2000 to 2020, the total area of land use conversion with decreased habitat suitability (811.69 km^2) was larger than the area of land use conversion with increased habitat suitability (710.99 km^2) (Table 9), which led to a continuous decline of habitat quality in the study area; however, a series of measures have been implemented to curb the continuous degradation of habitat quality. In the past 20 years, to ensure the water supply capacity of the MRP to cities in northern China, the government increased the water area of the study area by increasing dams, and the increased water area mainly came from cultivated land. In the design of this study, the habitat suitability of water area (0.6) was greater than that of cultivated land (0.4); therefore, the habitat quality of Xichuan County, as the core distribution area of the reservoir, showed a gradually increasing trend, which differed from that of other counties.

Table 9. Changes in habitat suitability of different land types in the study area from 2000 to 2020.

Conversion of Land Types with Declining Habitat Suitability	Area/km^2	%	Conversion of Land Types with Improving Habitat Suitability	Area/km^2	%
Cultivated land—Construction land	376.26	46.36	Cultivated land—Water area	213.35	30.01
Forest land—Cultivated land	171.71	21.15	Grassland—Forest land	173.44	24.39
Forest land—Grassland	72.50	8.93	Cultivated land—Forest land	140.25	19.73
Grassland—Cultivated land	64.77	7.98	Construction land—Cultivated land	111.71	15.71
Grassland—Water area	37.74	4.65	Cultivated land—Grassland	47.48	6.68
Forest land—Construction land	21.75	2.68	Cultivated land—Wetland	12.56	1.77
Grassland—Construction land	20.28	2.50	Water area—Forest land	2.79	0.39
Wetland—Water area	17.53	2.16	Construction land—Grassland	2.58	0.36
Forest land—Water area	15.24	1.88	Construction land—Water area	1.92	0.27
Water area—Cultivated land	4.56	0.56	Water area—Grassland	1.61	0.23
Grassland—Other land	2.74	0.34	Water area—Wetland	1.36	0.19
Forest land—Other land	1.71	0.21	Construction land—Forest land	0.66	0.09
Cultivated land—Other land	1.70	0.21	Construction land—Other land	0.59	0.08
Wetland—Cultivated land	1.11	0.14	Wetland—Grassland	0.54	0.08
Water area—Construction land	1.09	0.13	Wetland—Forest land	0.10	0.01
Grassland—Wetland	0.80	0.10	Construction land—Wetland	0.05	0.01
Forest land—Wetland	0.19	0.02			
Total	811.68	100	Total	710.99	100

4. Discussion

4.1. Mechanism of Land Use Transitions Affecting Habitat Quality Change

The essence of land use transition is changing land use form in the process of economic and social development. The fundamental reason for land use transition is because of the change of land use type caused by human economic and social activities on the natural ecosystem. Therefore, it is necessary to analyze the mechanism of land use transition affecting habitat quality change from an economic–social–ecological complex system perspective (Figure 9).

In terms of the natural ecosystem, ecological background factors largely determine the quality of living conditions. For example, lush forests can provide animals with good hiding conditions, and abundant precipitation and suitable temperature can provide them with sufficient food. High altitude and steep mountains are difficult for human activities to reach; therefore, they are less disturbed and suitable for plant and animal habitats and reproduction areas. It can be inferred from the above mentioned detection results that each natural ecological element does not have the same effect on the habitat quality of the study area. First, land use type is the core determinant of habitat quality, indicating the research from land use transition to habitat quality change. Second, the influence of elevation and slope is strong, reflecting the important influence of the degree of human interference on the quality of habitat. Third, the geomorphology type and annual precipitation have an important impact on the spatial differentiation of habitat quality, indicating that these factors largely affect the quality conditions of biological habitats. Fourth, soil type, annual average temperature, vegetation type, and NDVI index have a certain effect on the habitat quality, indicating that they are also important influences on the habitat conditions of organisms. Fifth, the effect of the slope aspect is weak, indicating that the spatial distribution and changes of habitat quality are almost not affected by aspect conditions.

In terms of economic systems, humans engage in production and business activities, and not only do they obtain many resources needed for survival from the natural ecosystem and damage the stability of the original ecosystem, but they also change the types of land cover, which have important impacts on the natural environment. The impact of economic activities on the natural ecosystem is spatially manifested as changes in land use patterns, including spatial changes in the structure and distribution and temporal changes in the orientation and degree. In the process of land use transition, due to different habitat suitability, a change of land use type directly leads to a change of habitat suitability—which finally leads to a change of regional habitat quality. Land use types with lower habitat suitability not only affect their own habitat quality, but also negatively affect the habitat quality of the surrounding land use types. For example, the habitat quality of forest land adjacent to construction land is different from that adjacent to grassland, due to different potential threats, although they have the same habitat suitability under the two conditions.

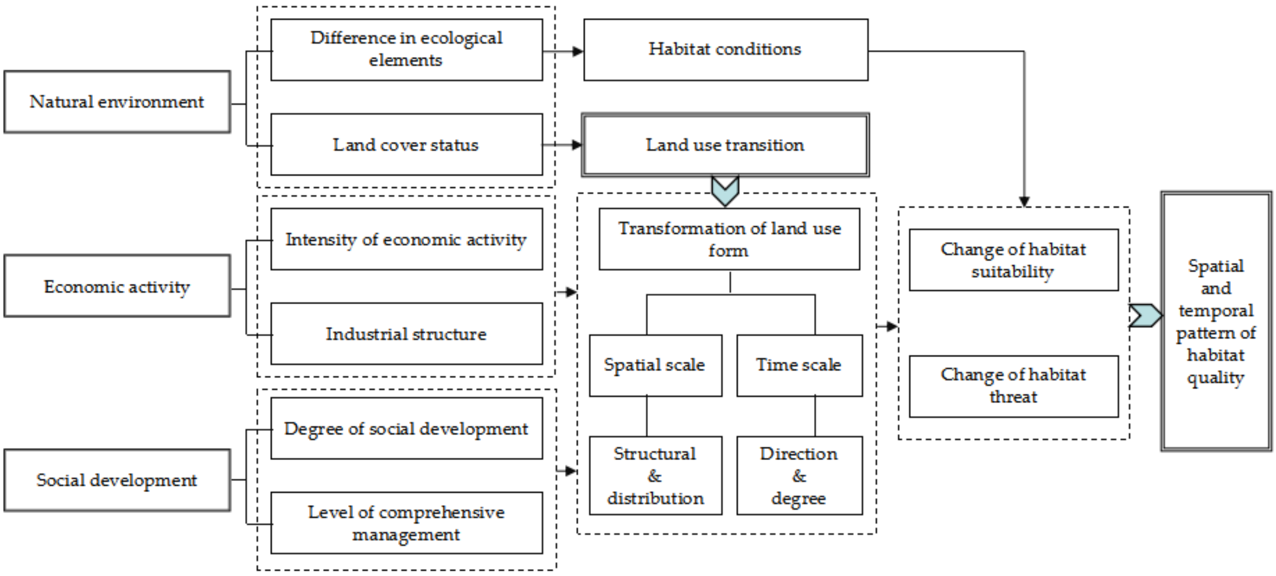

Figure 9. Mechanism of land use transitions affecting habitat quality change.

Regarding the social system, on the one hand, the higher the degree of social development, the more construction land and cultivated land with lower habitat suitability are needed to meet people's demands. Population growth and demand for agricultural products are important factors driving land system changes [51]. On the other hand, the higher the level of social development, the stronger the binding force of people on their own activities and behaviors. As human cognition improves, the concept of sustainable development of the harmonious coexistence between humans and nature will dominate social development, continuously using scientific management methods to minimize the impact of human activities on the natural environment. The degree of disturbance and destruction of habitat quality follows the Environmental Kuznets Curve. When the level of economic and social development is low, the habitat quality shows a trend of deepening with economic development. Then, with the improvement of people's cognitive ability and management level, the degree of disturbance and destruction will gradually decrease, and the habitat quality will gradually improve.

Therefore, to effectively improve habitat quality, we should study the endogenous factors and mechanisms of habitat quality change from an economic–social–ecological complex system perspective. From the above mentioned analysis, the core concept of controlling habitat quality change is to control the change of land cover type, which requires studying the dynamic mechanism of promoting land use change. According to the theory of human–earth system science, the interaction between humans activities and the earth's environment is the main driving force of the evolution of modern earth's surface system. In the coupling process of the human–earth system, the social and economic systems are the main bodies of human activities and the main causes of driving environmental changes [52]. Therefore, adjusting and optimizing the allocation of economic and social system elements and adopting reasonable control and management measures will help establish a coordinated and sustainable relationship between humans and land and realize the coordinated development of natural ecosystems and economic and social systems.

4.2. Suggestions on Improving Regional Habitat Quality

We recommend that the following points should be taken into consideration by policy-makers:

(1) The territorial and spatial planning must be strengthened, and water source areas must be regulated. On the basis of reasonable delineation of the "three areas and three lines," the local government should strictly regulate territorial and spatial use to prevent the extensive use and disorderly expansion of construction land caused by urban expansion; additionally, the government should continue to promote the return of farmland to forest and grassland and reasonably increase the quantity and quality of ecological space, improving the functions of water source area ecosystems, such as carbon sequestration, water conservation, and biodiversity conservation.

(2) Research, monitoring, and evaluation on environmental quality should be continued. An all-round, full-time, and long-period comprehensive monitoring system for the environment of the water source area should be established; research, monitoring, and evaluation should be conducted on water quality, water quantity, climate, vegetation, biodiversity, and other factors; changes of adverse factors affecting habitat quality should be reduced; and positive countermeasures for sudden ecological security incidents should be implemented, including the timely elimination or reduction of the impact.

(3) Environmental protection and restoration should be actively promoted. According to the theory of "landscape, forest, field, lake, and grass" community life, combined with the ecological space planning and control policy of water source areas, the core ecological protection area should be designated in the middle and north areas with high habitat quality, and the occupation and interference of human activities on the ecological space should be reduced in the southeast plain area with significantly declined habitat quality and strong habitat degradation. Based on the degree of ecosystem damage, different artificial support methods, such as conservation, natural restoration, assisted regeneration, and ecological reconstruction, should be adopted to conduct ecological restoration activities [53] in water source areas.

(4) A scientific and effective compensation mechanism for ecological protection should be established. The industrial development of water source areas is limited by the objective of environment protection, which leads to serious losses in local finance and people's income. The principles of clear authority and responsibility, overall coordination, and overall planning should be followed based on scientific research on quantitative accounting of ecological compensation for the MRP, and the authority and responsibility of government departments at all levels of the water source and receiving area should be clarified. The relevant industrial policies and laws, and regulations should be improved to form a long-term ecological compensation operation mechanism.

(5) Feasible paths to achieve green and sustainable development should be explored. Using the theory of "green water and mountains are also golden and silver mountains" as a guide, the government should explore the ecological resource asset accounting of water source areas and realize the ecological product value; actively cultivate and develop ecotourism, green agriculture, a special agricultural products processing industry, and other green industrial systems which rely on the local rich mountain landscape and biological resources; and form an endogenous mechanism for achieving high quality development of the ecology, economy, and society in the water source area.

5. Conclusions

Research on the habitat quality effect of land use transition can effectively reveal changes in the ecosystem under the influence of human activities, facilitate identification of the change characteristics and change trend, and control the change direction. Exploring the driving mechanism of habitat quality change can provide reasonable decision-making and action basis for the effective protection of biological habitats and construction of an ecological security pattern of harmonious coexistence between humans and nature. Using the HWS area of the MRP as an example, this study investigated the habitat quality effect and driving mechanisms of land use transition. Our work can serve as a guide for local governments aiming to effectively control regional land use transition, improve the environment, enhance water conservation capacity, and other ecosystem functions. The research on the driving mechanism of land use transition to habitat quality change from an ecological–economic–social complex system perspective proposed in this study can also further enrich the theory of land use transition and human–land system science and provide a reference for research on human–land system coupling and sustainable development. In future studies, the construction of an ecological security pattern of water source areas under the background of land use transition should be focused on, including identifying important ecological protection sources, strengthening green infrastructure construction, and improving the quality of ecological space, to provide a decision-making reference for the ecological protection and restoration of water source areas. A long-term mechanism to realize the value of ecological products in water source areas should be established under the guidance of the theory of human–earth system science to produce a low carbon, green, and sustainable development model in line with the actual situation of the region.

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