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A Spatial-Temporal Evolution and Predictive Analysis of the Habitat Quality in Ningxia, China Based on the PLUS Model and InVEST Model

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Abstract: *This study examines the spatio-temporal evolution of habitat quality in Ningxia, China, due to land use change. The research predicts land use changes for 2030 using the PLUS model and assesses habitat quality using the InVEST model. The findings indicate a decrease in grassland, forest, and unused land area from 2000 to 2020, which is expected to continue until 2030. The habitat quality coefficient remained stable during this period, indicating well-controlled habitat degradation. However, the predicted habitat quality coefficient for 2030 is expected to decrease, with areas of low habitat quality expanding. This study supports the need for a shift towards an intensification mode of land use to balance ecological protection and regional economic development in Ningxia.*

Keywords: *Land Uses; Habitat Quality; PLUS Model; InVEST Model; Habitat Quality Forecast*

1. Introduction

Habitat quality, closely related to human beings, reflects the human living environment and is a core indicator of regional biodiversity and natural ecological services. It is crucial for improving the security of the region, nature, ecology, and human beings[1]. In recent years, population growth and rapid economic development have increased the demand for land resources. Overexploitation of natural resources, changes in land use patterns, and functional intensity have damaged the ecosystem, leading to a decline in natural resource value. Studying land use change and evaluating habitat quality can help analyze regional ecological environment changes, develop ecological policies, and promote sustainable land resource development[2].

Ningxia plays a crucial role in China's economic, social development, and ecological security. It has always prioritized comprehensive and systematic management of natural resources, promoting high-quality development. Therefore, simulating and predicting habitat quality in Ningxia is theoretically significant. It can evaluate overall habitat quality, provide a theoretical basis for regional ecological restoration, and promote high-quality development. Analyzing regional habitat quality has a profound impact on protecting the ecological environment and biodiversity. By understanding the basic laws of spatial and temporal changes in habitat quality, internal principles of changes are revealed, and the correlation between habitat quality and landscape distribution is studied, providing a scientific reference and practical considerations for ecological protection and land planning in Ningxia.

In recent years, with the deepening of research on habitat quality mechanisms and the maturation of 3S technology, an increasing number of studies have utilized models to calculate habitat quality. These models include the Maxent (Maximum Entropy) model[3], ARIES (Artificial Intelligence for Ecosystem Services) model[4], SolVES (Social Values for Ecosystem Services) model[5,6], HSI (Habitat Suitability Index) model[7], and InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model[8]. The InVEST[8] model is widely employed in habitat quality assessment due to its ease of manipulation and application, minimal data information requirements, and strong spatial expression level of distribution.Simple analysis of habitat quality change characteristics in a specific region can provide theoretical support for current regional ecological protection, but it is insufficient to support the development of future regional ecological protection strategies and may not meet the needs of regional development. Therefore, an increasing number of studies have been conducted to predict future habitat quality using models. For example, Luan Yongfei et al[9] used InVEST and Cellular Automata-Markov

(CA-Markov) models to analyze, predict, and explore the spatiotemporal evolution path and characteristics of land use in Hohhot, predicting the typical land use evolution model in 2030. Wang Zhuo et al[10] utilized the InVEST model and Patch-generating Land Use Simulation (PLUS) model to analyze the potential impact of Wuhan's urban expansion on terrestrial carbon storage. Unlike previous cellular automata models, the PLUS model is based on raster data and is more convenient for data acquisition. Compared with other models, the PLUS model can better identify the incentives for various types of land use change and simulate patch-level changes for various types of land use[11].Therefore, this paper coupled the InVEST model and the PLUS model to analyze the temporal and spatial evolution characteristics of habitat quality in Ningxia based on the land use change data of Ningxia and forecast the future habitat quality in Ningxia. This aims to evaluate the current state of habitat quality in Ningxia as a whole and provide a basis for regional ecological restoration and the formulation of future ecological protection policies.

2. Material And Methods

2.1 Study Area Overview

Ningxia, located in northwest China, is situated at the convergence of the Yellow River, desert, and loess plateau. The region experiences a temperate continental arid and semi-arid climate, with an average annual water surface evaporation of 1250mm. Summer precipitation is low, with July recording the highest temperature at 24°C. Temperature varies widely, with January being the coldest month at -9°C. Annual rainfall ranges from 150mm to 600mm. Ningxia covers 51,800 square kilometers, representing 0.54% of China's effective land area, with the majority being cultivated dry land. It is bordered by Shaanxi Province to the east, the Inner Mongolia Autonomous Region to the west and north, and Gansu Province to the south, encompassing a total area of 66,400 square kilometers. The terrain slopes from southwest to northeast, with an average altitude of over 1,000 meters. The region can be divided into three major areas: the irrigation area in the north, the arid area in the central part, and the mountainous area in the south. The area exhibits a gradual transition from flowing water topography to wind-eroded terrain from south to north. Hills cover 38.00%, plains 26.80%, mountains 15.80%, and deserts 1.80%.

By 2022, the region's GDP is projected to reach 506.96 billion yuan, with a 4.00% year-on-year growth rate. Agriculture increased by 40.75 billion yuan, a 4.70% increase; industrial growth value was 244.91 billion yuan, a 6.10% increase; and the service sector increased by 221.23 billion yuan, a 2.10% increase. The proportion of agricultural growth in regional production is 8.00%, industrial growth is 48.30%, and service growth is 43.70%. As of the end of 2022, Ningxia's total permanent population was 7.28 million, a 30,000 increase from the previous year. The total permanent population of townships and towns was 4.83 million, accounting for 66.34% of the total permanent population, an increase of 0.30% from the previous year. In terms of per capita GDP, it was 69,781.00 yuan, a 3.50% increase.

2.2 Data Sources

The study utilized land use, socio-economic, climate, and environmental data. Thirteen driving impact factors were selected based on uniformity, quantifiability, systematization, and criticality principles. Land use data for 2000, 2010, and 2020 were obtained from GlobeLand30 with a 30m resolution. Socio-economic data, including population, GDP, roads, and rivers, were sourced from the Chinese Academy of Sciences Resources Environment and Data Center at a 30m spatial resolution. Climate and environmental data, such as temperature, rainfall, and soil species, were provided by Liu Bintao Digital Mountain and Remote Sensing Application Center, Chinese Academy of Sciences, at a 30m resolution. DEM data was acquired from the Geospatial Data Cloud Platform and processed using ArcGIS 10.7 software to ensure consistent valid rows and effective columns. All data were resampled and collected using ArcGIS 10.7 software to achieve a 30m resolution and WGS_1984_World_Mercator coordinate system.

Table 1 shows the specific channel sources of administrative division vector boundary and raster data used in this study. Vector data was converted into raster data to meet the requirements of the PLUS model. TIF format data was standardized to have a consistent number of rows and columns, specifically 19,528 rows by 13,213 columns, to improve prediction accuracy and ensure the accurate running of the PLUS model.

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Table 1: Study area data source

Data type	Data name	Data sources
Land use data	Ningxia's land use classification data for 2000, 2010 and 2020	Globeland30(Global public goods for geographic information)
Socioeconomic factors	POP(Population distribution data)	Resource Environment and Data Center, Chinese Academy of Sciences(http://www.resdc.cn)
	GDP(GDP data)	
	Distance to high-speed	
	Distance to railway	
	Distance to national highway	
	Distance from provincial road	
	Distance from the county office	
Climate and environmental data	soil types	Provided by Liu Bintao, Digital Mountain and Remote Sensing Application Center, Chengdu Institute of Mountain Hazards and Environment, Chinese Academy of Sciences
	Average annual temperature	
	Average annual precipitation	
	Elevation	Geospatial data cloud
	slope	Generated by elevation
	Distance to the river	Resource Environment and Data Center, Chinese Academy of Sciences(http://www.resdc.cn)

2.3 Data Analysis and Processing

2.3.1 Land use transfer matrix

The land use transfer matrix can delineate the composition characteristics of regional land use change, express the distribution direction of land use change led by human activities, and better expose the temporal and spatial evolution process of land use distribution[12], and its expression is:

$$S_{ij} = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & nn \end{bmatrix} \tag{1}$$

Formula: S_{ij} is the area of land converted from class I to class J land, and n is the number of types of land use. Using the integration and intersection tools of ArcGIS combined with Excel software, the data information of land use transformation in two periods from 2000 to 2010 and 2010 to 2020 was calculated to study and analyze the actual status of land use change in Ningxia.

2.3.2 PLUS model

The PLUS model is a land-use change model generated from patches proposed by raster data. The standard model effectively avoids the main problems and shortcomings of the previous CA model in studying the causes of land use change and simulating the spatiotemporal scale patch level change of multiple types of land use types through two types of transformation rule strategies[13].

(1)LEAS land use expansion analysis strategy

After extracting and processing the external expansion data information of land use in phase II, the development probability of each type of land use was calculated by random forest standard algorithm, and the contribution rate research and analysis was carried out according to the driving impact factors of land use external expansion. Among them, the random forest classification standard algorithm, the operation processing equation is:

$$P_{i,k}^{d}(x) = \frac{\sum_{n=1}^{M} I(h_n(x)=d)}{M} \tag{2}$$

In the above calculation equation: the value of d is 0 or 1, 1 means that other land types are converted to land class k, and 0 means that any other land use exchange that does not include land type k in it; $I(h_n(x) = d)$ is the instruction mathematical function of the strategy tree; $h_n(x)$ is the prediction type of the nth strategy tree; $P_{i,k}^{d}(x)$ is the probability of an increase in class k land-use species at the basic unit of distribution space.

(2)CARS is based on a CA model of multi-class random plaque seeds

The CA Standard Model is a real-world scenario-driven land-use simulation model. It uses adaptation coefficients, neighborhood effects, and development probabilities to ensure that total land use meets future demand at a macro scale. The neighborhood weight, an important indicator in land use simulation, ranges from 0 to 1. A higher value indicates a stronger expansion capacity for the land type, calculated based on the expansion area proportion of each land use type. The land use transfer matrix, shown in Table 2, indicates whether different land types can be converted to each other. The model can also establish prohibited development zones based on land policies and restrictions, such as ecological redlines, permanent basic farmland redlines, and urban development boundaries. Additionally, 13 driving factors, including terrain, elevation, slope, roads, and rivers, were selected for the CARS module simulation to obtain land use data for 2010 and 2020. This data was used to simulate the land use in Ningxia for 2030 while ensuring accuracy.

Table 2: Limit the transition matrix

land-use type	cultivated land	woodland	grass	Water body	use of land in construction	unused land
cultivated land	1	0	1	1	0	0
woodland	1	1	0	0	0	1
grass	1	1	1	1	1	1
Water body	1	1	1	1	0	1
use of land in construction	1	0	1	1	1	0
unused land	1	1	0	0	1	1

Under the constraints of various land use development probabilities, plaques are automatically formed according to the automatic formation of random seeds and the gradual reduction of limit values. The equation is:

$$OP_{i,\ k}^{d=1,\ t} = P_{i,\ k}^{d} \times \Omega_{i,\ k}^{t} \times D_{k}^{t} \tag{3}$$

In the above equation: where : is the comprehensive probability of the transformation of the space unit i to the earth class k at t time; the suitability probability of the development of the land type towards k at the space unit I; Indicates the impact of future demand on ground type k; The neighborhood effect representing unit i is the proportion of the land-use component of land class k in the next neighborhood. Among them, the neighborhood weight parameters are shown in Table 3, and the neighborhood weight values of the land use types in this paper are obtained by calculating various types of land expansion in Ningxia and trial and error and debugging according to the accuracy of the simulation[14].

Table 3: Neighborhood weight reference

Type of land use	cultivated land	woodland	grass	Water body	use of land in construction	unused land
Domain weights	0.7	0.4	0.3	0.2	0.9	1

2.3.3 InVEST model

The InVEST model is a comprehensive evaluation model, and this article utilizes the "Habitat Quality" function application module to assess the impact of land use change on habitat quality in Ningxia. Before running the habitat quality standard model, it is necessary to preprocess the layer data and input three types of data. This study selects cultivated land, construction land, and unused land as the threat impact sources based on the real development situation of the analysis area[15] and assigns proportional weights and maximum impact distances (Table 4). Habitat suitability ranges from 0 to 1, and each factor has different sensitivity. Land use types not suitable for the habitat are assigned a value of 0, while the sensitivity of the habitat to the threat factor is assigned a value of 1. Based on relevant references and research, the suitability and sensitivity of the habitat are determined (Table 5), with a k value of 0.05.

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Table 4: Threat feed attribute table

Threat factors	Maximum impact distance/km	Weight	Spatial decay type
cultivated land	2	0.6	Linear
use of land in construction	5	1	Index
unused land	4	0.5	Linear

Table 5: Table of sensitivity to land-use type threat sources

Type of land use	Habitat suitability	Stress factors		
		cultivated land	use of land in construction	unused land
cultivated land	0.4	0	0.7	0.4
woodland	1	0.6	0.8	0.2
grass	0.9	0.4	0.7	0.6
Water body	0.7	0.6	0.8	0.2
use of land in construction	0	0	0	0.1
unused land	0	0	0	0

3. Result

3.1 Analysis of spatiotemporal evolution characteristics of land use from 2000 to 2020

A 20-year analysis of land use change in Ningxia from 2000 to 2020 was conducted in 10-year intervals. China's land use classification system utilizes a three-level classification system, with the first level encompassing six categories, including arable land, forest land, construction land, and unused land based on land resources and their characteristic attributes. Using ArcGIS 10.7, the land use types in Ningxia were classified into these six categories, and the reclassification tool was employed to analyze the land use changes in Ningxia over the 20-year period. The land use distribution status of each stage was depicted in Figure 1.

The analysis revealed that the landscape substrate in Ningxia is predominantly composed of grassland and cultivated land, followed by unused land and forest land, with water area and construction land constituting a relatively smaller proportion. Cultivated land is distributed throughout Ningxia, densely concentrated in the south and north. Forest land is mainly found in the southern part of Ningxia, particularly in the southern part of Guyuan City, where the landscape patches are distributed in a north-south direction. Grasslands are concentrated in central and eastern Ningxia, while water areas are primarily distributed in a linear pattern. Construction land has undergone significant changes driven by urbanization development. Unused land is mainly located in Zhongwei City, particularly due to its proximity to the southeastern edge of the Tengger Desert, located 18 kilometers west of Zhongwei City.

The study also conducted the transfer matrix operation of Ningxia's land use using Excel, SPSS, and other data analysis software to analyze the data information between the actual development status and land use types in different years.

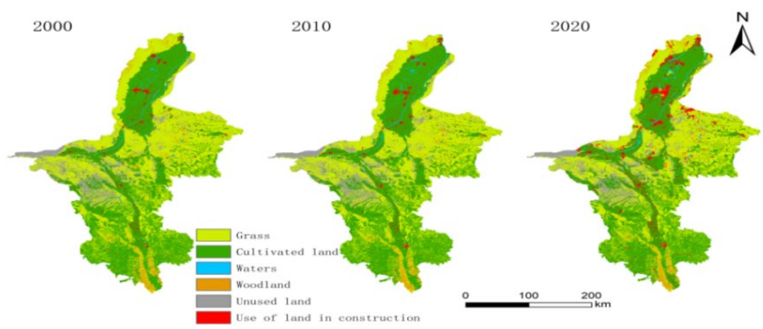

Figure 1: Map of land use distribution in Ningxia from 2000 to 2020

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3.1.1 Land use change, 2000-2010

In the land use effective area distribution in Ningxia from 2000 to 2010, grassland and cultivated land accounted for the majority of the effective area proportion. There was minimal transformation of rivers, but the overall effective area of grassland showed a decreasing trend. This was attributed to the low dependence of grassland vegetation cover on soil, leading to strong transformation treatment capacity, exceeding that of forest land, arable land, water bodies, and other land use types. The growth of construction land is increasing, although at a slower rate. During this decade, forest land, water bodies, and unused land decreased by 111.94km2, 12.11km2, and 12.00km2, respectively, while construction land, grassland, and arable land increased by 95.21km2, 15.45km2, and 25.38km2. Table 6 indicates that 117.53km2 of forest land was converted into cultivated land, 315.91km2 of water bodies were transformed into arable land, and 163.07km2 of arable land was converted into construction land. The conversion of unused land is infrequent due to the lengthy time required for conversion and the minimal change produced in a short period.

Table 6: Land-use change conversion matrix, 2000-2010

Area (km^2)	2010 type						
2000 type	grass	cultivated land	use of land in construction	woodland	Water body	unused land	total
grass	36251.68	16.11	8.95	0	14.67	0	36291.40
cultivated land	0.42	34131.82	163.07	0.04	349.14	0.01	34644.50
use of land in construction	1.35	79.70	1176.81	0.51	2.65	0.28	1261.30
woodland	1.03	117.53	1.08	2058.63	0.83	0	2179.12
Water body	48.20	315.91	5.05	8.00	348.84	2.29	728.29
unused land	4.17	8.81	1.56	0	0.05	6721.67	6736.26
total	36306.86	34669.88	1356.52	2067.18	716.19	6724.26	81840.88

3.1.2 Land use change, 2010-2020

In the distribution of land use types in Ningxia from 2010 to 2020 (Table 7), there was a decrease in grassland, forest land, and unused land by 2452.36km2, 38.66km2, and 320.82km2, respectively. This reduction is attributed to Ningxia's development planning, which emphasizes the promotion of investment in constructing key natural ecological safety barriers in the western region and implementing a comprehensive strategy for natural ecological and socio-economic improvement and progress. Simultaneously, to ensure total food production and food security and shape effective ecological functions, the area of unused land has been continuously reduced and fully developed, reflecting Ningxia's gradual high-speed development. Additionally, due to urbanization and rapid economic growth, the area of construction land in Ningxia has significantly increased by 2484.74km2. The land use area of water bodies and cultivated land has also increased, albeit to a lesser extent compared to construction land.

Table 7: Land-use change conversion matrix, 2010-2020

Area (km^2)	2020 type						
2010 type	grass	cultivated land	use of land in construction	woodland	Water body	unused land	total
grass	32249.77	2367.96	769.93	391.82	57.41	469.97	36306.86
cultivated land	993.86	31624.63	1651.21	36.65	262.77	100.75	34669.88
use of land in construction	15.37	139.75	1194.96	0.09	4.70	1.65	1356.52
woodland	346.56	70.01	34.60	1598.56	6.76	10.70	2067.18
Water body	16.82	141.71	10.07	0.27	538.12	9.20	716.19
unused land	232.12	495.72	180.48	1.13	3.64	5811.17	6724.26
total	33854.49	34839.78	3841.25	2028.52	873.39	6403.45	81840.88

During these 20 years, the overall land use area in Ningxia did not change much, and the changes were mainly manifested in the conversion between various types of land,as shown in figure 2, among which:

(1) The degree of change in unused land area is small, mainly because Ningxia has more unusable land area, among which land conversion is not suitable in mountainous areas and protected areas;

(2) The area of cultivated land is growing, mainly because Ningxia is located in the upper reaches of the Yellow River, is an important agricultural and energy production base in western China, and is also an important province for the state to implement the strategy of large-scale development of the western region, the ecological environment is fragile, the reserve resources of cultivated land are insufficient, and the regional development is unbalanced, so in the "Outline of the 14th Five-Year Plan for National Economic and Social Development of the People's Republic of China and the Long-range Goals for 2035", it is pointed out that the comprehensive protection of cultivated land, especially basic farmland, should be strengthened. Strictly control and manage the cultivated land consumed by non-

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agricultural investment and construction, and increase the intensity of supplementary cultivated land;

(3) The continuous expansion of construction land is mainly because Ningxia has promoted the development of tourism and increased infrastructure construction.

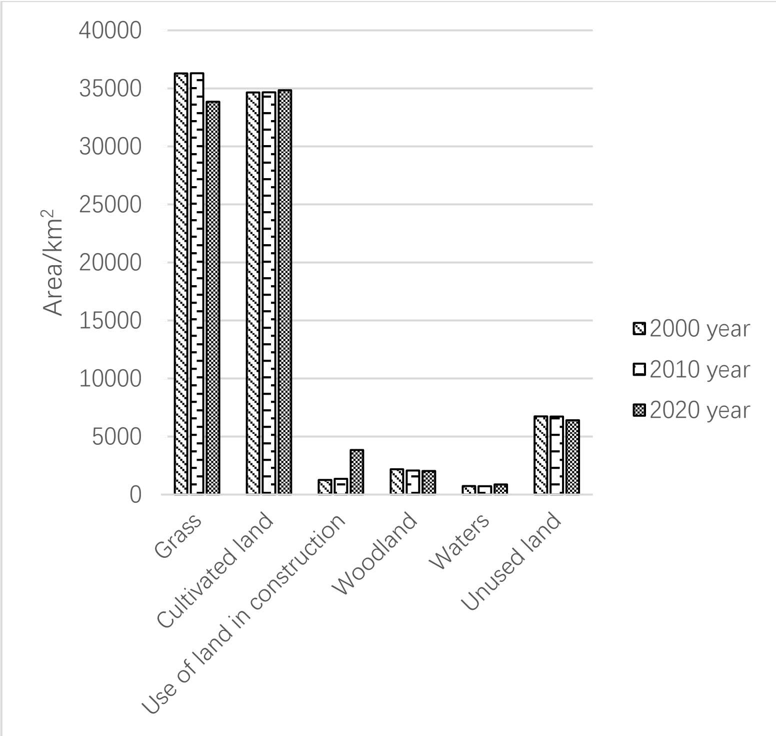

Figure 2: Map of land use change in Ningxia, 2000-2020

3.2 Simulation projections of land use change in 2030

According to the PLUS model, using Ningxia's 2000 land use data to predict land use in 2010, by calculating the Kappa coefficient and the real land use data information in 2010 for comparative analysis, the Kappa coefficient value is 0.98, that is, 97.65%, the Overall Accuracy value is 0.99, that is, 98.50%, and the FoM coefficient value is 0.011.

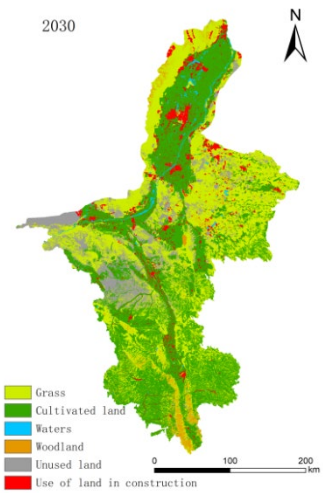

Figure 3: Land use map of Ningxia in 2030

The analysis shows that the closer the Kappa parameter is to 1, the better the uniformity, and the closer the simulated land use data and the real land use data information. When the Kappa parameter is greater than or equal to 75%, the final result of the simulation is good and highly reliable. Therefore, the 2020 coefficient can be used to predict and analyze the land use situation in Ningxia in 2030.

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The land use type of Ningxia in 2030 predicted by the simulation, as shown in Figure 3, is generally highly accurate in the final simulation results obtained by sampling and collecting data at 10-year intervals under natural variation. In the land use change in 2030, the grassland and forest land areas in Ningxia are 31734.40km2 and 1905.76km2 respectively, which is still decreasing compared with 2000, which may be related to Ningxia's recent planning. The cultivated land area is 35144.47km2, which is generally increasing, which may be due to the increase in the total population growth and the total demand for food; the area of construction land is 4194.07km2, which also shows an increasing trend, because Ningxia's development makes full use of the management policy of the large-scale development of the western region and the material resource advantages of Ningxia region to actively promote investment and construction along the Yellow City Belt in Ningxia; the area of unused land has increased compared with 2000, to 7961.70km2, which may be due to the large area of unusable land in Ningxia, and land transformation is not suitable in mountainous areas and protected areas . However, the results of the simulations are in line with the overall trend of land use.

3.3 Spatial-temporal evolution and simulation prediction of habitat quality in Ningxia

3.3.1 Analysis of habitat quality characteristics, 2000-2020

Based on the InVEST model, the spatial distribution of habitat quality from 2000 to 2020 in Ningxia was calculated by entering the land use raster data, threat factor data and threat source data required for model modeling, and the value of habitat quality was continuously changed between 0-1 on the raster map, and the closer the value was to 1, the better the habitat quality and the more conducive to maintaining biodiversity. In order to visualize the distribution of habitat quality, the natural breakpoint method was used in ArcGIS 10.7 to classify the three stages of habitat degradation in Ningxia into four levels: basically unchanged [0-0.008]; mild degeneration (0.008-0.04]; moderate degradation (0.04-0.07]; Highly degraded (above 0.07).

The InVEST model was used to evaluate habitat changes in Ningxia from 2000 to 2020. The spatial evolution map of habitat quality in Ningxia from 2000 to 2020 (Figure 4) shows that the overall spatial pattern of habitat quality in Ningxia Phase III is not obvious. The spatial difference of habitat quality in the south is not significant, while in the north, it is more pronounced. The area with the highest habitat quality index is mainly distributed in the south of Guyuan City, and the area with higher habitat quality is mainly distributed in Wuzhong City. Wuzhong City is located in the middle and upper reaches of the Yellow River and is a core area of Ningxia's development along the Yellow City belt. It is also a key area for ecological protection and high-quality development in the Yellow River Basin, with a high level of biodiversity, resulting in good habitat quality. Conversely, areas with low habitat quality were mainly distributed in the north of Zhongwei City and Guyuan City in southwest Ningxia, due to the large distribution of arable land resources and significant human activity, resulting in low biodiversity. The statistical analysis of temporal changes indicated that the habitat quality was relatively stable, with average values of the habitat quality coefficient in 2000, 2010, and 2020 being 0.45, 0.45, and 0.44, respectively. The standard deviation of the habitat quality coefficient increased from 0.26 to 0.27, showing relatively stable habitat quality in the distribution space（ Table 8). Spatial statistical analysis of the habitat degradation level revealed that the average effective values for 2000, 2010, and 2020 were 0.02, 0.02, and 0.02, and the maximum effective values for the habitat degradation level were all 0.03（ Table 9). These results indicate that the intensity of habitat degradation was controlled within a certain range.

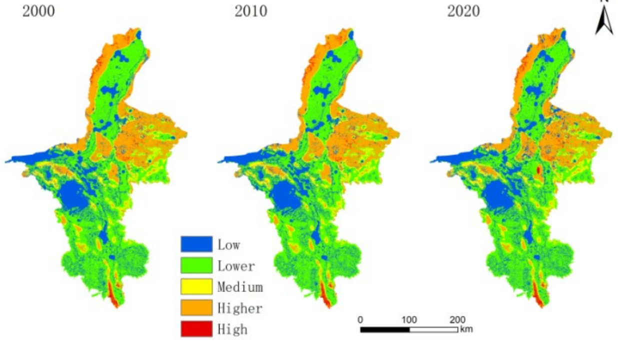

Figure 4: Distribution map of habitat quality in Ningxia, 2000-2020

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Table 8: Spatial statistics of habitat quality in Ningxia

Year	Statistical parameters of habitat quality			
	Minimum	Maximum	Average value	Standard deviation
2000	0	1	0.45	0.26
2010	0	1	0.45	0.26
2020	0	1	0.44	0.27

In 2000-2020, the area with low-grade habitat quality showed an increasing trend, and in 2020, the area with low-grade habitat quality increased by 52.26% compared with 2000; The area of low-grade habitat decreased first, then increased, and the area of medium-grade habitat decreased, accounting for 8.84% , 8.81% , 8.26% of the total number of grids in that year The area of high-grade habitat showed a decreasing trend, with the proportion of raster decreased from 21.74% in 2000 to 20.24% in 2020. The area of high-grade habitat showed an increasing trend, the proportion of grids increased from 0.95% in 2000 to 0.99% in 2020 (Table 10). From 2000 to 2020, China was in a period of rapid development, over-exploiting land resources, and then turning to high-level development, always adhering to the path of ecological and environmental protection development, and actively implementing natural ecological protection management policies such as returning farmland to forest and grassland.

Table 9: Spatial statistics on habitat degradation in Ningxia

Year	Statistical parameters for habitat degradation			
	Minimum	Maximum	Average value	Standard deviation
2000	0	0.3561	0.02	0.03
2010	0	0.3662	0.02	0.03
2020	0	0.3666	0.02	0.03

In 2000-2020, the area with low-grade habitat quality showed an increasing trend, and in 2020, the area with low-grade habitat quality increased by 52.26% compared with 2000; The area of low-grade habitat decreased first, then increased, and the area of medium-grade habitat decreased, accounting for 8.84% , 8.81% , 8.26% of the total number of grids in that year The area of high-grade habitat showed a decreasing trend, with the proportion of raster decreased from 21.74% in 2000 to 20.24% in 2020. The area of high-grade habitat showed an increasing trend, the proportion of grids increased from 0.95% in 2000 to 0.99% in 2020 (Table 10). From 2000 to 2020, China was in a period of rapid development, over-exploiting land resources, and then turning to high-level development, always adhering to the path of ecological and environmental protection development, and actively implementing natural ecological protection management policies such as returning farmland to forest and grassland.

Table 10: Proportion of habitat quality change in Ningxia

Habitat quality level	2000 year		2010 year		2020 year	
	Number of rasters	Percentage/%	Number of rasters	Percentage/%	Number of rasters	Percentage/%
Low	19546562	21.49	19519378	21.46	21397875	23.53
Lower	42717345	46.97	42778591	47.04	42720468	46.97
Medium	8043969	8.84	8010097	8.81	7516559	8.26
Higher	19773638	21.74	19772785	21.74	18410419	20.24
High	866778	0.95	867441	0.95	902971	0.99

The magnitude of the habitat degradation factor indicates the level of influence of the raster by the threat impact factor, and the larger the habitat degradation factor, the greater the disturbance and the greater the degree of degradation.

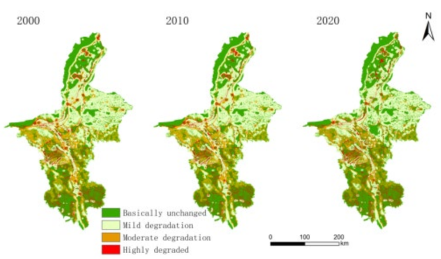

Figure 5: Distribution map of habitat degradation in Ningxia, 2000-2020

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Table 11: Proportion of habitat degradation change in Ningxia

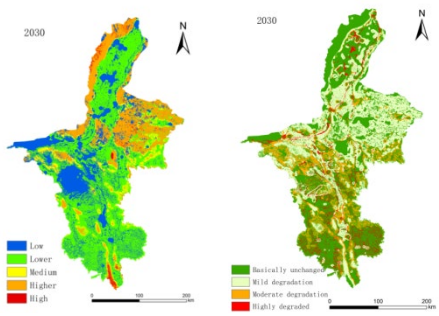
Habitat degradation level	2000 year		2010 year		2020 year	
	Number of rasters	Percentage/%	Number of rasters	Percentage/%	Number of rasters	Percentage/%
Basically unchanged	38352517	42.17	39477627	43.41	40602737	44.64
Mild degeneration	32751522	36.01	32264926	35.48	31778329	34.94
Moderate degradation	13328602	14.66	12895337	14.18	12462072	13.70
Highly degraded	6515651	7.16	6310403	6.94	6105154	6.71

Spatially (Figure 5), from 2000 to 2020, the high degree of habitat degradation in Ningxia was distributed in Zhongwei City and some counties and districts of Guyuan City. The habitat degradation degree in Wuzhong City is almost zero, because Wuzhong City is located in the middle and upper reaches of the Yellow River, which is a key area of the Yellow River Basin Ecological Protection and High-quality Development Pilot Area, and the natural ecological restoration and adjustment system is better than that of other regions. Areas with moderately degraded habitat quality are basically distributed in Zhongwei City, mainly because there is more unused land and relatively little impact from human activities. From the time analysis (Table 11), from 2000 to 2020, the area of the basin where the habitat quality of Ningxia was basically unchanged was as high as 44.64% in 2020. The area of watershed with mild, moderate and highly degraded habitat quality shows a decreasing trend.

3.3.2 Simulation projections of habitat quality in 2030

Based on the simulated land use data in 2030, the InVEST model was used to calculate the actual habitat quality in Ningxia in 2030. Spatially, the overall habitat quality and habitat degradation in Ningxia in 2030 basically continued the previous trend, and the low habitat quality was basically distributed in Zhongwei City, which may be due to the fact that human activities accounted for the vast majority. The areas with the highest habitat quality index were mainly distributed in the southern part of Guyuan City, and the areas with higher habitat quality were mainly distributed in Wuzhong City (Figure 6a). The places with high habitat degradation in Ningxia are still mainly distributed in some counties and districts of Zhongwei City and Guyuan City. The habitat degradation in Wuzhong City is almost zero (Figure 6b).

In terms of time, the average average habitat quality of Ningxia was 0.4237, a decrease of 0.0294 compared with 0.4531 in 2020. Low habitat quality accounted for 25.02% of the number of rasters in that year, an increase of 1.49% over 2020; Secondly, lower, medium, higher and higher habitats accounted for 46.76%, 7.90%, 19.33% and 0.99% of the raster number in that year, respectively, which showed a downward trend compared with 2020. The average average habitat degradation in Ningxia was 0.02, a decrease of 0.01 compared with 0.02 in 2020. The number of rasters was basically unchanged for 47.14% of the rasters in that year, an increase of 2.49% over 2020; Secondly, mild, moderate and high degradation accounted for 33.97%, 12.92% and 5.97% of the grid number in that year, respectively, which also showed a downward trend compared with 2020.



(a) *(b)*

Figure 6: Schematic map of habitat quality distribution and degradation distribution in Ningxia in 2030

4. Conclusion and Discussion

This study focuses on land use changes in Ningxia from 2000 to 2020, and predicts the land use data for 2030 using the PLUS model. The InVEST model is also used to analyze the habitat quality and distribution changes during the same periods. The findings are as follows:

(1)Grassland and cultivated land occupy the largest areas in Ningxia, while forest land, water bodies, and unused land are relatively smaller. The grassland area has decreased, mainly converting into construction land and arable land. Construction land has expanded significantly, while the water body area has shown overall growth. From 2000 to 2020, grassland was mainly transformed into construction land, decreasing from 36291.40km2 to 33854.49km2. Construction land increased from 1261.30km2 to 3841.25km2. Cultivated land and water body areas increased steadily. Habitat quality was generally high in the northeast and low in the southwest.

(2)The simulated area of forest land and grassland in Ningxia in 2030 is expected to continue declining, while construction land will further expand to 4194.07km2. The average habitat quality in 2030 is predicted to decrease to 0.42 from 0.45 in 2020, with an increase in low habitat quality compared to 2020.

(3)There is a clear correlation between habitat quality and land use type change in Ningxia. Economic development and land use changes have led to habitat degradation. However, the implementation of ecological protection measures has eased the degradation rate.

The PLUS and InVEST models provide an effective method for habitat evaluation, but they have limitations. They only consider the effect of threat sources within the study area on the habitat, and there is no standard calculation method for the establishment of the coefficient of the model. Future research should consider various factors to improve the accuracy of simulation results and provide guidance for ecological environmental protection and high-quality development in Ningxia.

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