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Original Research

Spatiotemporal Evolution of Habitat Quality in Typical Resource- Depleted Cities in China Based on Land Use Changes

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Abstract

Assessing and analyzing the spatial and temporal evolution of urban land use and habitat quality is important for the ecological transformation, habitat conservation, and ecological development of resource-depleted cities. The InVEST model and ArcGIS 10.5 were used to analyze the characteristics of land use transition, the temporal and spatial evolution of habitat quality, and the distribution of hot and cold spots in typical resource-depleted cities in central China from 1990 to 2020, with a view to providing a reference for ecological environmental protection of such cities. The results show the following: (1) During the study period, a decrease in cultivated land and forested land and an increase in construction land were the main reasons for the decline in habitat quality in the study area; thus, attention should be paid to protecting cultivated land and preventing forested land degradation. (2) In terms of the temporal gradient, the overall habitat quality in the region showed a declining trend, habitat degradation characteristics showed a spread from urban city and county areas as the core to the surrounding areas. (3) In terms of spatial distribution, habitat quality in the area shows a pattern of "high in the north and low in the middle".

Keywords: InVEST, habitat quality, land use change, Jiaozuo

Introduction

Resource-based cities, as a special type of city, are the proof of an era, and their development process has obvious stage characteristics. Currently, 262 cities of different levels in China have been identified as resource-based cities. Resource-based cities have made important contributions to urban development and national construction to some extent. However, due to their own particularities, most resource-based cities are faced with resource exhaustion. At present, 69 cities in China are identified as resource-exhausted cities; therefore, it is necessary to study land use change and habitat quality in such cities. Yu et al. [1] analyzed the relationship between land use change and food, energy and water in Shizuishan City, China, it is found that the rapid transformation of resource-depleted cities is to achieve a balance among the economy, society, and ecology. Wang et al. [2] used the residual intelligent module network classification method to classify the land use types in Jiaozuo city from 1993-2020, and used PCA to analyse the driving factors of land use changes,

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the results showed that the spatial-temporal evolution of land use types was affected by policy changes, the level of social development and the adjustment in the economy, industry and agriculture structure. Teng et al. [3] conducted a study on the land use of Wuhai City 2005-2018 on the transformation characteristics of land use and the spatial and temporal evolution of habitat quality, and concluded that land use change is an important cause of habitat quality change. A Hardaker et al. [4] took Wales as the research object and assessed the economic value of ecosystem services under different land use types in Wales. Land use has provided significant ecological and economic benefits. Lars G et al. [5] analyzed the land use change in Ruhr from 2015 to 2020 and found that urban expansion would occupy natural areas, thus affecting the local ecosystem. Therefore, resource-based cities should focus on scientific and reasonable policy formulation in the transition process to promote biodiversity conservation, continuously improve ecological and environmental quality, and help resource-based cities develop sustainably.

Land use change and ecological security are important topics and hot issues in global environmental change research, and the habitat quality of a region is an important reflection of ecosystem service function and health [6-8]. In recent decades, rapid industrial development, localized urban expansion, and intensive agricultural activities have directly affected regional habitat quality and biodiversity [9-10]. As land is an important carrier of ecosystems, understanding its structure and function is key to supporting the future spatial development of cities and solving environmental problems, as well as mitigating regional ecological degradation [11-12]. Therefore, an analysis of the spatial and temporal changes in the habitat quality of different land types can help to restore the ecological background of different historical periods, reveal the evolution patterns of regional ecological and environmental quality, and provide scientific support for ecological restoration [13-14].

In recent years, scholars at home and abroad have carried out much research on habitat quality and proposed various assessment models, mainly the RSEI [15], InVEST [16-17], and GARP models [18], the ecological footprint method [19], and pressure-state response (PSR) [20]. Wang et al. [21] used the InVEST model to assess the habitat quality of Wuhan in 2020, and the results showed that there was significant spatial variation in habitat quality; overall, it was low, with a high degree of degradation. Zhang et al. [22] used the InVEST model to assess the habitat quality of Wenzhou City from 1992 to 2015, revealing the spatial and temporal characteristics of habitat quality under the influence of land use change and socioeconomic and climatic factors. Aneseyee et al. [23] scientifically used the InVEST model to illustrate the main reasons for the decline in habitat quality in the Winik watershed of the Omo-Gibe basin in southern Ethiopia, and proposed conservation strategies in terms of land use. Wang et al. [24] combined DEM data with land use data and applied the InVEST model to assess habitat quality in Wenzhou from 1992 to 2015. Wu et al. [25] used the InVEST model to assess habitat quality in the Altai region from 1995-2018, and elucidated the effects of different landscape conditions on habitat; they proposed four zoning management schemes to clarify local ecological management schemes and conservation measures for ecological control and sustainable management and planning of the city to provide a basis for decision making and scientific support. The results of previous studies show that the InVEST model can provide a scientific assessment of habitat quality, but relatively few studies have been conducted on the characteristics of land use change and spatial and temporal changes in habitat quality during the transformation of resource-depleted cities.

Jiaozuo is a typical resource-depleted city in central China and can serve as a successful example of socioeconomic transformation of this type of city. The objectives of this study were (1) to analyze the spatial and temporal evolution of land use change characteristics and habitat quality in the area from 1990 to 2020 using ArcGIS 10.5 technology and InVEST 3.9.2, and to explore the inherent spatial evolution of habitat quality; and (2) to explore the correlation between land use and habitat quality, which can help decision makers reasonably plan and use land to protect the environment and provide a reference for the planning and construction of Jiaozuo Garden City.

Materials and Methods

Study Area

Jiaozuo City is located in northwestern Henan Province (34°49′N-35°29′N, 112°43′E-113°38′E), bordered by the Taihang Mountains to the north and the Yellow River to the south, with a total area of approximately 4,071 km^2; it is under the jurisdiction of six counties (cities) and four districts (including the Demonstration Zone for Urban-Rural Integration) (Fig. 1). Once one of the five major coal bases, Jiaozuo made a significant contribution to national and local economic construction, but the overexploitation of coal had a large impact on the local ecological environment and the city was listed as one of the first resource-depleted cities in China in 2008. In the late 1990s, Jiaozuo began economic restructuring and introduced a series of environmental improvement measures to transform it into an eco-friendly tourist city, and this transformation process epitomizes the development of many resource-depleted cities.

Data Sources

The remote sensing images of Jiaozuo City in this study were obtained from the Geospatial Data

Cloud (https://www.gscloud.cn) with a resolution of 30 m × 30 m, and the administrative district vector data were obtained from the Resource and Environment Science Data Centre of the Chinese Academy of Sciences (http://www. resdc.cn). The study area was classified into 11 land categories according to the Classification of Current Land Use (GB/T 21010-2017): cultivated land, forested land, shrubland, other forested land, grassland, rivers, water ponds, urban land, rural settlements, mining land, and other unused land. Land use/land cover (LULC) types were obtained from remote sensing images during the study, and land use classification data for four periods in 1990, 2000, 2010, and 2020 were obtained using ENVI 5.3 and ArcGIS 10.5.

Land Use Change Analysis

Land use change in this study was mainly analyzed by using a transfer matrix. A transfer matrix is a powerful tool used to quantitatively describe the characteristics, direction, and structure of LULC changes, which can reflect not only the area of land use types at the beginning and end of each studied time period but also the origin and composition of each land type in different periods [26-27]. In this study, the area conversion of each land type in Jiaozuo City over the past 30 years was calculated with the help of ArcGIS 10.5 to obtain a land use transfer matrix from 1990 to 2020. By analyzing the direction and quantity of land type transfer in Jiaozuo in each period, the evolution of habitat quality under land use change can be analyzed more intuitively.

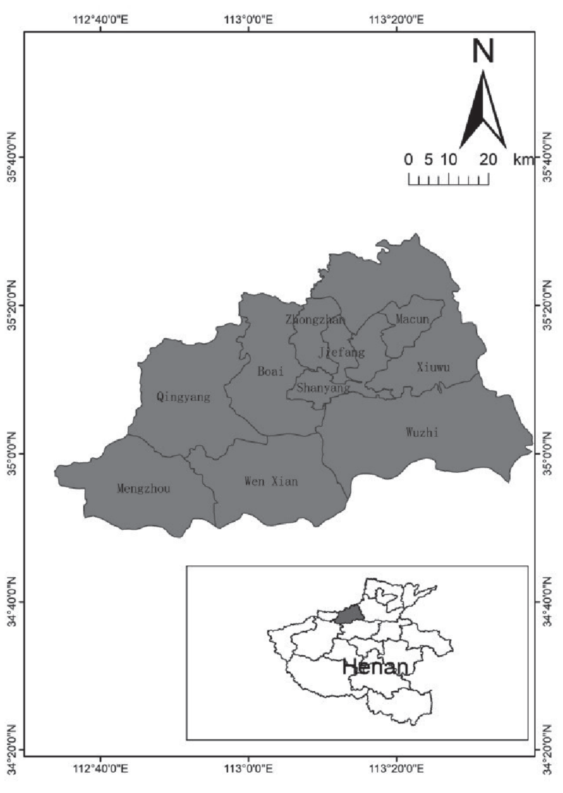

Fig. 1. Location of Jiaozuo City.

InVEST Model for Habitat Assessment

The InVEST model was developed jointly by Stanford University, the Nature Conservancy, and the World Wildlife Fund to assess ecosystem services [20]. In this study, the habitat quality module of InVEST 3.9.2 software was adopted to assess the habitat quality of Jiaozuo City. In this model, the LULC raster dataset was used as the basis for assessing habitat quality and habitat degradation in Jiaozuo, combining the sensitivity of threat factors and maximum impact distances and weights. Habitat quality values range from 0 to 1, with higher values representing better habitat quality in the region. The specific calculation formulae are detailed in [28], and the parameters set in the model, including the sensitivity of threat factors (Table 1), maximum impact distance and weight, and attenuation type (Table 2), mainly refer to research on the habitat quality module of the InVEST model by relevant scholars at home and abroad [29-31] and the InVEST 3.2 user's manual, combined with relevant experts' recommendations for assigning values.

Spatial Autocorrelation and Hotspot Analysis

Spatial autocorrelation analysis of habitat quality determines the degree of spatial differences in habitat quality between an area and its surrounding units and their significance [32-33]. Global autocorrelation of habitat quality can measure the distribution characteristics between spatial elements across the study area and is assessed using the Moran index with a threshold value of [-1,1]. The nature and degree of autocorrelation are reflected by positive or negative values and the magnitude of the value [9, 34], where [-1, 0) indicates a negative correlation, i.e., the habitat quality of the area is spatially different from the neighboring areas, (0, 1] indicates a positive correlation, i.e., areas with higher or lower habitat quality are spatially clustered, and 0 indicates a random distribution [35]. In this study, the spatial autocorrelation tool in ArcGIS 10.5 was used to analyze the spatial clustering

Table 1. Threat factors.

Threat factors	Maximum impact distance (km)	Weight	Decay type
Cultivated land	5	0.5	Linear
Urban land	9	0.9	Exponential
Rural settlements	6	0.7	Exponential
Mining land	7	0.7	Exponential
Other unused land	4	0.3	Linear

Table 2. Sensitivity of habitat types to threat factors.

Land-use type	Habitat suitability	Cultivated land	Urban land	Rural settlements	Mining land	Other unused land
Cultivated land	0.5	0	0.7	0.6	0.5	0.5
Forested land	1	0.8	0.7	0.6	0.6	0.4
Shrubland	0.9	0.6	0.8	0.7	0.7	0.3
Other forested land	0.7	0.8	0.8	0.6	0.6	0.4
Grassland	0.8	0.6	0.7	0.6	0.6	0.5
Rivers	0.9	0.6	0.8	0.7	0.8	0.4
Water Ponds	0.7	0.6	0.6	0.7	0.6	0.4
Urban land	0	0	0	0	0	0
Rural settlements	0	0	0	0	0	0
Mining land	0	0	0	0	0	0
Other unused land	0.4	0.5	0.6	0.5	0.6	0

and distribution characteristics of habitats in Jiaozuo City using global Moran's I as the statistic.

Habitat quality hot (cold) spot analysis reflects whether there is a statistical clustering of high-value areas (hot spots) and low-value areas (cold spots) in the spatial distribution of habitat quality [36], which to some extent can be considered a reflection of relatively better or worse habitat quality in the region. In this study, the hot spot analysis tool in ArcGIS was applied to analyze the clustering status of habitat quality of Jiaozuo City in terms of local spatial distribution using the Getis-Ord Gi* statistical index [37-38].

Results and Discussion

Analysis of Land Use Change in Jiaozuo City

Looking at the proportion of area of each land use type in Jiaozuo (Fig. 2 and Table 3), the main land use type is cultivated land, followed by forestland and construction land; from 1990 to 2020, the areas of cultivated land, forestland, grassland, and water showed a decreasing trend, with decreases of 5.00, 9.10, 10.10, and 37.15%, respectively. In contrast, the areas of construction land, mining land and unused land gradually increased during the same period, with increases of 45.19, 451.35 and 175%, respectively.

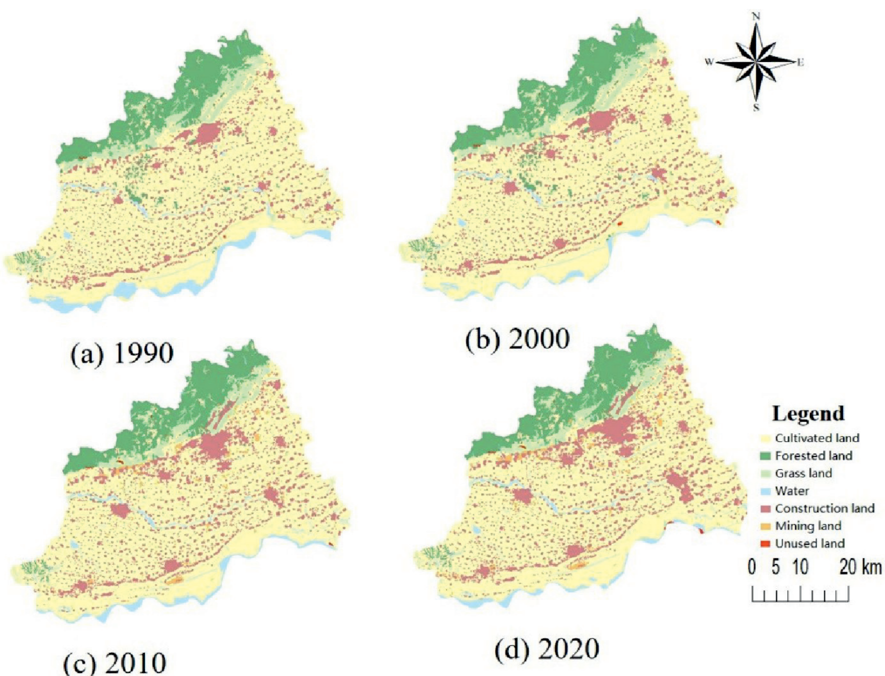

Fig. 2. Land use distribution and changes in the Jiaozuo region.

Table 3. Proportion of land use types in Jiaozuo in each period (%).

Year \ Type	Cultivated land	Forested land	Grass land	Water	Construction land	Mining land	Unused land
1990	65.82	13.19	4.85	4.71	11.02	0.37	0.04
2000	66.65	13.18	4.89	2.48	12.32	0.40	0.08
2010	63.76	12.13	4.28	3.26	14.92	1.57	0.08
2020	62.53	11.99	4.36	2.96	16.00	2.04	0.11

Table 4. Land use type transfer matrix (km^2).

Year	Land-use type	Cultivated land	Forested land	Grass land	Water	Construction land	Mining land	Unused land
1990-2000	Cultivated land	2590.05	4.51	1.31	8.24	63.05	2.41	0.74
	Forested land	2.70	527.76	3.73	0.11	0.33	1.50	4.03
	Grass land	1.70	1.60	193.02	4.56	0.29	6.07	1.04
	Water	97.74	0.11	4.55	91.69	0.11	1.50	0.90
	Construction land	10.94	0.29	0.08	6.30	435.67	9.62	0
	Mining land	0.65	6.16	4.63	3.00	0.57	13.74	0
	Unused land	9.92	2.34	3.28	0	0	0	1.38
2000-2010	Cultivated land	2440.50	36.34	16.13	14.09	69.52	9.42	1.16
	Forested land	1.67	489.32	1.15	0.05	0.25	0	0.01
	Grass land	0.86	0.81	170.80	0.01	0.92	0.07	0.004
	Water	43.40	1.59	1.01	85.06	0.49	0.35	0.26
	Construction land	172.55	4.27	2.29	1.08	424.11	1.02	0
	Mining land	45.34	2.52	5.28	0.36	4.75	5.46	0
	Unused land	0	0.01	1.63	0	0	0	1.64
2010-2020	Cultivated land	2468.06	2.62	2.53	31.49	23.29	4.23	0.67
	Forested land	2.52	479.35	2.83	0.31	0.23	0.13	0.03
	Grass land	3.78	3.45	166.06	2.35	0.55	0.15	0.14
	Water	24.37	0.32	0.51	94.19	0.12	0.02	0.002
	Construction land	57.58	0.27	0.99	0.47	580.60	8.22	0
	Mining land	29.81	0.50	0.41	0.33	0.52	51.05	0
	Unused land	0.24	0.06	0.12	1.75	0	0	2.43
1990-2020	Cultivated land	2311.54	36.93	17.97	89.25	68.47	8.40	0.49
	Forested land	4.33	476.70	4.06	0.26	0.20	0.008	0.03
	Grass land	4.67	6.38	161.70	2.74	0.85	0.12	0.03
	Water	22.59	1.29	1.48	93.49	0.51	0.36	0
	Construction land	261.15	4.66	3.42	2.79	373.15	2.96	0
	Mining land	64.90	2.94	6.49	1.15	3.96	3.18	0
	Unused land	1.01	0.13	1.60	0.99	0	0	0.89

To gain a comprehensive understanding of the structural characteristics of land use changes in Jiaozuo City during the study period, a land use transfer matrix was constructed (Table 4). It can be seen in Table 4 that from 1990 to 2000, the land use shift was mainly an increase of 33.52 km^2 in construction land and a decrease of 90.51 km^2 in water area. The largest area transferred from water area to cropland was 97.74 km^2, followed by 63.05 km^2 of cropland to construction land, while the rest of the land use changed relatively little. From 2000 to 2010, the largest area of construction land was transferred from cultivated land, 172.55 km^2, followed by 69.52 and 36.34 km^2 from construction land and forestland to cultivated land, respectively. The area of cultivated land transferred to water was one category of land that decreased in area; cultivated land was mainly converted to construction land and water, with 172.55 and 43.40 km^2, respectively. Forestland was mainly converted to cultivated land and construction land, with 36.34 and 4.27 km^2, respectively. Grassland was converted to cultivated land, with the largest area of 16.13 km^2. Construction land increased between 2010 and 2020 by 42.82 km^2 and cultivated land decreased by 53.41 km^2; the rest of the land types changed relatively little. In general, the land use changes in Jiaozuo City during the study period mainly involved the conversion of cultivated land and forest and grassland to construction land, while the rest of the land use types did not change much.

Analysis of Habitat Quality

The InVEST model was used to analyze the spatial and temporal changes in habitat quality in Jiaozuo from 1990 to 2020 (Fig. 3), and ArcGIS was used to classify the habitat quality indices in the study area into five classes. As shown in Fig. 3, higher habitat quality areas are mainly located in Xiuwu, Boai, and the northern part of Qingyang, which are mainly woodlands and water, are less affected by human activities, and are rich in biodiversity. High habitat quality areas are mainly located in Xiuwu, Boai, Qingyang, and the northern part of Zhongzhan District, Mengzhou, Wuzhi, and the southern part of Wenxian, which are relatively rich in biodiversity. Average habitat quality areas are mainly located in Jiefang and the southern part of Wenxian. Areas with average and below average habitat quality are mainly located in Jiefang, Zhongzhan, Macun, Shanyang, Qingyang, Mengzhou, Boai, Wuzhi, and the majority of Wenxian, which mostly consist of cultivated land and urban construction land, where there are high intensity human activities. The constant expansion of land for construction has led to the expansion of low habitat quality areas around towns. In the northern mountainous areas with high habitat quality, the gradual improvement of basic transportation facilities and the continuous development of tourism have had a certain impact on areas with high habitat quality, but the degree of change is weaker compared to that for urban construction land.

As shown in Table 5, the mean values of the habitat quality index were 0.4914, 0.4776, 0.4521, and 0.4394 in 1990, 2000, 2010, and 2020, respectively, indicating that the overall habitat quality of Jiaozuo City decreased during the study period. The standard deviation of the habitat quality index increased from 0.2364 in 1990 to 0.2547 in 2020, and from 0.2364 in 1990 to 0.2547 in 2020, indicating an increase in the degree of variation

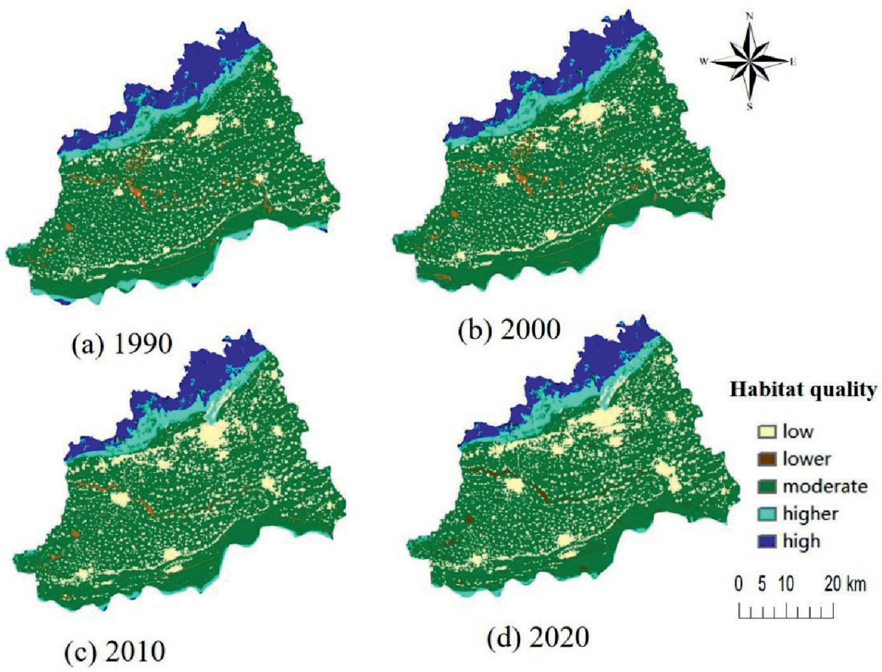

Fig. 3. Spatial distribution of habitat quality grades in Jiaozuo.

Table 5. Spatial statistics of habitat quality in different periods.

Class	1990			2000			2010			2020		
	P	Avg	SD	P	Avg	SD	P	Avg	SD	P	Avg	SD
Low	11.45	0.4914	0.2364	12.79	0.4776	0.2400	16.55	0.4521	0.2508	18.12	0.4394	0.2547
Lower	1.96			2.11			1.19			1.40		
Moderate	69.70			69.82			67.15			65.84		
Higher	6.97			5.85			6.38			6.31		
High	9.93			9.44			8.74			8.34		

in the habitat quality index between neighboring grid cells. The proportion of average habitat quality in Jiaozuo City was the largest over the 30-year period, increasing and then decreasing from 69.70% in 1990 to 69.82% in 2000, then decreasing to 67.15% in 2010 and 65.84% in 2020. However, overall, the proportion of average habitat quality gradually decreased. The proportion of low habitat quality increased from 11.45% in 1990 to 18.12% in 2020 and that of lower habitat quality decreased from 1.96% in 1990 to 1.40% in 2020. The proportion of higher habitat quality tended to decrease gradually overall, from 9.93% in 1990 to 8.34% in 2020; the change in the proportion of higher quality was less than 1%, decreasing from 6.97% in 1990 to 6.31% in 2020. During 2010-2020, the rate of increase of low and lower habitat quality and the rate of decrease of average habitat quality in Jiaozuo slowed compared with those in 2000-2010, and the regional proportion of higher quality also stabilized without major changes, indicating that the habitat quality in Jiaozuo has become relatively stable.

To further analyze the habitat quality in Jiaozuo City over the 30-year study period, we used ArcGIS 10.5 to calculate the area of converted habitat quality classes for four time periods. As shown in Fig. 4 and Table 6, habitat quality in Jiaozuo showed a decreasing trend during the study period, with the area of decreasing habitat quality being larger than the area of increasing habitat quality, but most of the areas did not change in habitat quality. Areas with declining habitat quality were mainly concentrated around urban construction sites, especially in 2000-2010, when the total area reached 307.85 km^2, much higher than the 184.24 and 133.68 km^2 in the other two periods. The highest proportion and the most extensive distribution of habitat quality decreased by 5.55% during the study period, while the low habitat quality area increased by 270.77 km^2, the highest increase among the five habitat classes. The high habitat quality areas are mostly located in the mountainous areas in northern Jiaozuo City, while the low habitat quality areas are mostly located in and around urban construction sites. As Jiaozuo City has continued to implement ecological protection and

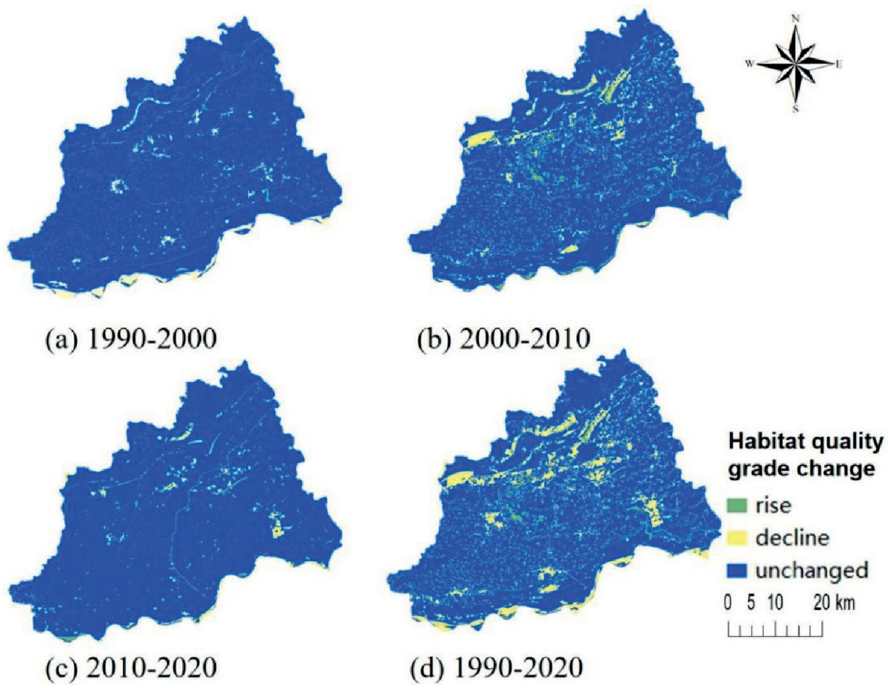

Fig. 4. Habitat quality grade change.

Table 6. Spatial statistics of habitat quality grade in different periods.

Class \ Year	1990-2000	2000-2010	2010-2020	1990-2020
Rise (km^2)	45.35	155.60	38.89	143.49
Unchanged (km^2)	3827.24	3594.23	3884.50	3380.92
Decline (km^2)	184.24	307.85	133.68	532.43

restoration projects for mountains, water, forests, fields, lakes, and grasses in recent years, and has carried out ecological restoration work for abandoned mines, aquatic ecosystem management projects for the Dasha River, and ecological protection for the urban section of the South-North Water Diversion, the local habitat quality has been further improved, and there is a lower risk of overall habitat quality deterioration.

Overall, habitat quality in Jiaozuo City showed a decreasing trend during the study period, with a larger area of decreasing habitat quality than increasing habitat quality in all periods. The decrease in habitat quality was mainly based on the conversion of general quality to lower and lower quality, and the distribution characteristics of degradation showed a radial spread with urban and county areas as the core. The main increase trend was due to the conversion of low and lower quality areas to general quality areas, mainly distributed linearly along the northern mountainous areas and along the Yellow River.

Analysis of Habitat Degradation

The spatial distribution of habitat degradation in Jiaozuo City was obtained by combining the calculation of the InVEST model and the analysis of ArcGIS 10.5 (Fig. 5). As shown in Fig. 4, the areas with higher habitat degradation are mainly concentrated in around the urban areas of cities and counties, in the form of points or strips around Qingyang, Mengzhou, Wuzhi, and the city districts (Jiefang, Macun, Zhongzhan, and Shanyang, including the demonstration zone of urban–rural integration). This is mainly due to the higher intensity of human activities in these areas, which has a greater impact on the surrounding ecological environment, leading to more serious degradation of habitat quality. The areas with low habitat degradation are mainly concentrated in the protected mountainous areas in the north and the watershed in the south, which have a better ecological environment, mostly forested grassland and watershed, and are less affected by human activities, so there is a lower degree of habitat quality degradation.

As shown in Table 7, during 1990-2020, the mean values of habitat degradation in Jiaozuo were 0.0169, 0.0178, 0.0199, and 0.0209, and the maximum value increased from 0.1377 in 1990 to 0.1465 in 2020. The mean and maximum values of habitat degradation showed an increasing trend, indicating that the intensity of habitat degradation was increasing and the degradation was increasing. The trend of habitat quality

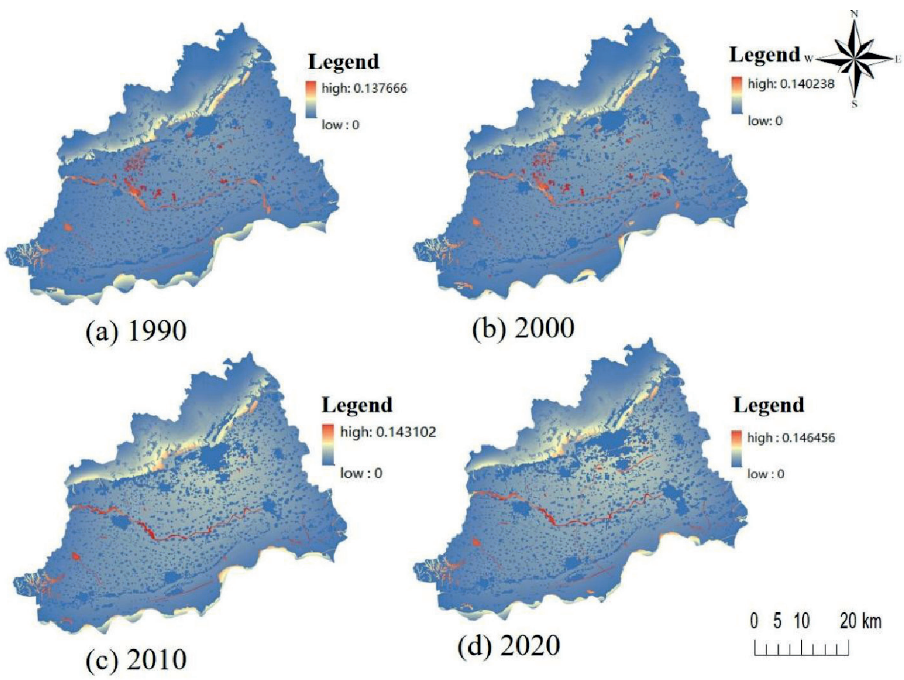

Fig. 5. Spatial distribution of habitat degradation in Jiaozuo.

Table 7. Statistics of habitat degradation.

Year	Statistical parameters of habitat degradation			
	Minimum value	Maximum value	Average	Standard deviation
1990	0	0.1377	0.0169	0.0161
2000	0	0.1402	0.0178	0.0166
2010	0	0.1431	0.0199	0.0155
2020	0	0.1465	0.0209	0.0166

Table 8. Spatial autocorrelation statistics.

Year	Spatial autocorrelation of habitat quality			Spatial autocorrelation of habitat degradation		
	Moran's I	Z-score	P-value	Moran's I	Z-score	P-value
1990	0.3763	36.4276	0.0000	0.2485	20.4229	0.0000
2000	0.2764	32.6861	0.0000	0.2384	29.1226	0.0000
2010	0.2908	34.8317	0.0000	0.1860	23.5876	0.0000
2020	0.5989	40.7587	0.0000	0.4917	38.2810	0.0000

degradation increased significantly. The standard deviation of habitat degradation also showed an overall increasing trend, indicating increasing spatial variation in habitat degradation between raster cells.

Analysis of Habitat Variation and Spatial Distribution Characteristics

To further investigate the spatial correlation of habitat quality changes in Jiaozuo City over three decades, we conducted a global spatial autocorrelation analysis of the spatial distribution of habitat quality and degree of degradation (Table 8). The results show that the global Moran's I for the degree of habitat degradation during 1990-2020 is greater than 0, and the corresponding Z-score is much greater than the threshold value of 1.96, indicating that there was significant spatial autocorrelation in the spatial distribution of habitat quality during the study period and there was spatial clustering of the habitat quality distribution. The global Moran's I values of habitat quality in Jiaozuo City in 1990, 2000, 2010, and 2020 are 0.3763, 0.2764, 0.2908, and 0.5989, respectively, showing a decreasing then increasing trend, indicating that the spatial clustering of habitat quality in the study area had a tendency to aggregate. At the same time, it can be found that the global Moran's I of habitat degradation during 1990-2020 is also greater than 0, and the p-value is 0. The z-score is also much higher than the threshold value of 1.96, indicating the characteristics of spatial agglomeration, but the change trend of Moran's I shows a trend of decreasing and then increasing, indicating spatial agglomeration of habitat degradation during 1990-2020. The spatial clustering of habitat degradation during 1990-2020 shows a trend of first scattering and then concentrating. This is mainly due to the accelerated urbanization and continuous socioeconomic development in the last decade, leading to a tendency for the spatial clustering of habitat degradation in the study area to further concentrate.

Habitat Quality and Habitat Degradation Cold/Hotspot Analysis

The spatial clustering and dispersion of habitat quality and habitat degradation in Jiaozuo City in different years (cold/hot spots) are shown in Figs 6 and 7. The results show that there are obvious cold and hot spots for both habitat quality and habitat degradation, and the spatial clustering of habitat quality indices in Jiaozuo is characterized by hot in the north and south, cold in the middle. From 1990 to 2020, the habitat quality hotspots (99% confidence level) in Jiaozuo were mainly distributed in the northern mountains and around the Yellow River in the south. The northwestern part of the city is hilly, covered mostly with shrubland and grassland, with high vegetation cover and low population, and is a secondary hot spot area (95% or 90% confidence level). During 2000-2010, Jiaozuo City made great efforts to develop its economy, promote the expansion and quality of county-level cities, and promote urban-rural integration. In Jiefang, Shanyang, Zhongzhan, and Macun Districts (under the jurisdiction of the city), which are located in the central part of Jiaozuo, there is a tendency for cold spot areas of habitat quality to spread in the southern direction due to increasing population and the disturbance of human activity, accompanied by industrialization and urbanization effects.

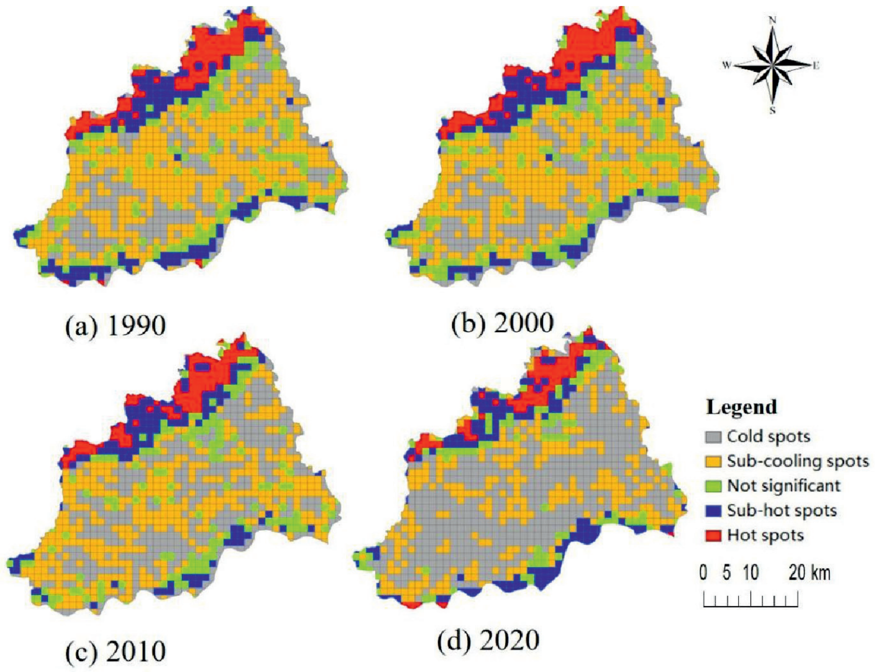

Fig. 6. Hot spots and cold spots of habitat quality in Jiaozuo from 1990 to 2020.

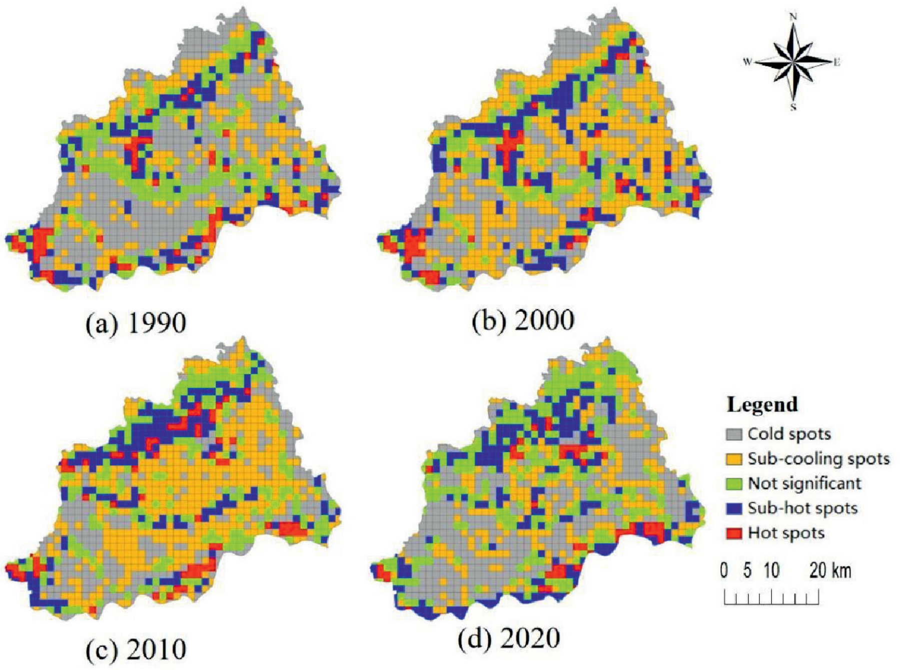

Fig. 7. Hot spots and cold spots of degradation in Jiaozuo City from 1990 to 2020.

From Fig. 7, it can be seen that the spatial clustering of habitat degradation has the characteristic of cold in the north and the south, hot in the middle. Between 1990 and 2020, the hot spots and secondary hot spots of habitat degradation in Jiaozuo mainly spread from the south to the middle and north, and the proportion of area distribution gradually increased, mainly concentrated in the central cultivated land, around the Yellow River basin and in the northern part of the reserve. As Jiaozuo City continued to develop, more cultivated land was converted to construction land, while the change in the watershed area of the Yellow River in the south caused some of the watershed to be converted to cultivated land. There was a clear tendency of low habitat quality clustering during the study period, with habitat quality improving at a local spatial scale. The cold spots and sub-cold spots of habitat degradation in the study area are concentrated in the arable areas of the central plain.

Discussion

Impact of Land Use Change on Habitat Quality

Human activities such as agricultural farming and urbanization are important drivers of habitat quality evolution, and land use change is the most direct reflection of human activities [39-41], so land use transformation is one of the main factors in habitat quality. This study found that land use changes in Jiaozuo City from 1990 to 2020 were relatively drastic, mainly due to the interconversion between cultivated land and other types of land, while the expansion of construction land directly or indirectly led to an overall decline in habitat quality. This is consistent with the findings of other scholars. For example, Teng et al. [3] found that land-use change was the main cause of habitat quality change in Wuhai City. A study by Dou et al. [42] on resource-depleted cities in China found that the extent of habitat quality restoration was mainly dependent on changes in land use structure. Tang et al. [43] found that habitat quality in the Huaihe Economic Zone was significantly negatively correlated with urban development intensity. A study by He et al. [44] on the prediction of different scenarios in Wanzhou District, Chongqing, found that increased urbanization led to a decline in regional habitat quality. Xie et al. [45] studied habitat quality in Beijing during 1990-2013 and produced predictions for the next 20 years. Jiao et al. [46], in a study of the Pearl River Delta, found that habitat quality was lower in central areas with high population density and well-developed industrial areas than in other areas. Wang et al. [47], in a study of Chongqing and Chengdu, found that urban expansion had a negative effect on local habitat quality.

Policy and socioeconomic factors can directly or indirectly influence land use transitions and, hence, changes in habitat quality. In this study, the spatial distribution of habitat quality in Jiaozuo was distinct and closely linked to the distribution of land use. Decreased habitat quality during the study period was mainly around urban construction sites in counties and urban areas, while increased habitat quality was mainly concentrated in the Beishan Mountains and parts of the Yellow River Basin in the south. This indicates, on the one hand, that the expansion of urbanization led to decreased habitat quality. On the other hand, it also shows that the increasing management of the ecological environment in Jiaozuo City, especially the Beishan Ecosystem Protection Zone and the Yellow River Basin, has had a positive effect on the improvement of habitat quality. The specific analysis is as follows.

Between 1990 and 2000, areas with low and lower habitat quality increased, probably because Jiaozuo City was in the early stage of transformation, the reliance on coal development had not yet changed significantly during that period, and the overall habitat quality of the region was degraded due to environmental problems caused by overexploitation of coal mines [48]. Between 2000 and 2010, the proportion of low and lower habitat quality was mainly due to the continuous promotion of the development and transformation of Jiaozuo, especially the strategy of building a tourism city in 1999 and the tourism-led strategy in 2009, the economic structure changed, which helped to improve the local habitat quality. During 2010-2020, the trend of habitat quality change was relatively consistent with that of the previous period, but the decrease in habitat quality was much less than that of the previous period. The implementation of policies such as scientific planning, ecological environmental protection in mining areas, and tourism resource development resulted in appropriate adjustments to the land structure, which improved the efficient use of land resources and achieved an optimized economic structure and economic transformation. At the same time, Jiaozuo City implemented ecological protection and restoration of mountains, water, forests, fields, lakes, and grasses; optimized the land use structure; formulated ecological protection plans including the Master Plan for Ecological Environmental Protection and Utilization of Jiaozuo City's Beishan, the Three-Year Enhancement Plan for Jiaozuo City's Forest City, and the Plan for Jiaozuo City's Water Ecological System; and legislated the Regulations on Ecological Environmental Protection of Jiaozuo City's Beishan, all of which helped to further improve the quality of the local environment. Factors such as policy implementation are important in influencing land use transformation and indirectly affect changes in habitat quality by influencing economic development. This is consistent with the findings of Lu et al. [49] that the impact of policies on resource-depleted cities in China is critical. Therefore, policy-led factors are the core drivers of land use transformation and habitat quality enhancement in the region [50-52].

Reliability Analysis of the InVEST Model for Habitat Quality Assessment

This study explored the evolution of habitat quality in Jiaozuo City over a 30-year period based on land use changes, which can reflect the change pattern of habitat quality in the study area on a macro scale and provide a reference for regional habitat conservation policies. However, the assessment results have some limitations due to the criteria for setting parameters; for example, there is no uniform standard for setting the parameters of the habitat module in the InVEST model, and the setting of parameters such as sensitivity and weight is subjective, which could affect the assessment results [53-54]. Therefore, in future studies, we will add the threat factors within the study area, further consider the intrinsic mechanisms of habitat quality, and enhance local parameterization based on field survey data to more accurately evaluate the spatial and temporal variation characteristics of habitat quality. In addition, this study examined the spatial and temporal characteristics of habitat quality only from the perspective of land use change. In the future, we will combine that with other ecosystem modules to consider the ecological effects caused by land use change in an integrated manner, in order to provide a reference basis and scientific support for sustainable and healthy development of the ecosystem in Jiaozuo.

Conclusions

(1) The proportion of cultivated land in the study area decreased from 65.82% to 62.53%; at the same time, the proportions of forestland, grassland, and water area decreased by 1.2, 0.49, and 1.75%, respectively, and the proportions of construction land, Mining land and unused land increased by 4.98, 1.67 and 0.07%, respectively. The land use conversion units showed a trend of first increasing and then stabilizing, mainly distributed around the city, the mountainous area in the north, and the Yellow River basin in the south.

(2) The spatial distribution of habitat quality in Jiaozuo City has obvious characteristics and is closely linked to the distribution of land use, and the spatial and temporal characteristics of habitat quality change significantly during periods of drastic land use changes. The interconversion of cropland, forestland, and construction land is the main reason for the reduction in regional habitat quality, and attention should be paid to protecting cropland and preventing the degradation of forestland.

(3) There is a spatial aggregation of habitat quality and habitat degradation in the study area, with the habitat quality index showing a spatial distribution pattern of hot in the north and south and cold in the center, and the degree of habitat degradation showing a spatial distribution pattern of cold in the north and south and hot in the center.

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Conflict of Interest

The authors declare no conflict of interest.

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