Evaluation of Land Use and Land Cover Change and Spatial Ecological Impacts Using GIS: A Case Study of Urumqi's Primary Urban Area

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Abstract. In this study, GIS technology was used to take the main urban area of Urumqi as an example to conduct an in-depth study of the land use cover change and its spatial ecological effects in the past 30 years. It is found that the rapid urbanization process has led to the gradual reduction of arable land and vacant land, while the area of land designated for construction has witnessed a notable upward trajectory. The alteration in land use has had a profound effect on the ecological environment, changed the original ecological pattern, and has had a non-negligible impact on air quality, soil fertility and biodiversity. Therefore, advocating reasonable land use and proposing and implementing sustainable urban development strategies are very important for the future development of the main urban area of Urumqi.

Keywords: Land use and land cover change, geographic information system, spatial ecological effects, the main urban area of urumqi.

1. Introduction

Land use and land cover change (LUCC) is a direct and important manifestation of the impact of human activities on the natural environment, which has a profound impact on ecosystem structure and function, as well as human socio-economic activities. Especially during rapid urbanization, the fluctuations in urban land use type and spatial structure have a noteworthy impact on the ecological effect of urban space [1,2]. In the process of urbanization, the land use pattern of the main urban area of Urumqi has undergone drastic changes, which have had a profound impact on the urban environment and the lives of urban residents.

Geographic information system (GIS) is a tool for integrating, storing, querying, analyzing, and graphically displaying all types of geographic information. GIS provides an accurate and efficient solution for the evaluation of land use cover change and its spatial ecological effect. Through GIS technology that can intuitively and accurately depict the actual situation on the ground, further analyze the influence of land use alteration on spatial ecology, and provide scientific basis for policy formulation [3,4].

In this study, illustrating with Urumqi's central urban area as a case study, GIS technology was employed to assess the dynamics of land use cover throughout the urbanization process and its implications on the ecological functioning of urban spaces. This is not only a deepening study of the current situation of land use and its impact in the main urban area of Urumqi, but also provides a reference for the formulation of scientific and reasonable land planning and urban development strategies in rapidly urbanizing cities [5].

2. Overview and Data of the Study Area

2.1. Overview of the Study Area

Urumqi, positioned at the northern slopes of the central section of the Tianshan Mountains and the southern periphery of the Junggar Basin, is encompassed by mountains on three sides. It resides at an average elevation of 800 meters and experiences a middle temperate semi-arid continental climate.

As of 2023, Urumqi exercises administrative jurisdiction over 7 urban districts and 1 county, along with 3 national-level development zones and 1 comprehensive bonded zone. The total area spans 13,800 square kilometers, with the built-up areas accounting for 536.2 square kilometers. The permanent population amounts to 4,082,400 and consists of 56 ethnic groups, including Han, Uygur, Kazakh, Hui, and Mongolian, encompassing over 90% of the urban population. Urumqi represents the sole major city in Xinjiang [6].

Its main urban area consists of Shayibake District, Tianshan District, Toutunhe District, Shuimogou District and Xincheng District, which is situated in the hinterland of Urumqi City and is the political, economic, cultural and educational center of Urumqi can be seen in figure 1.

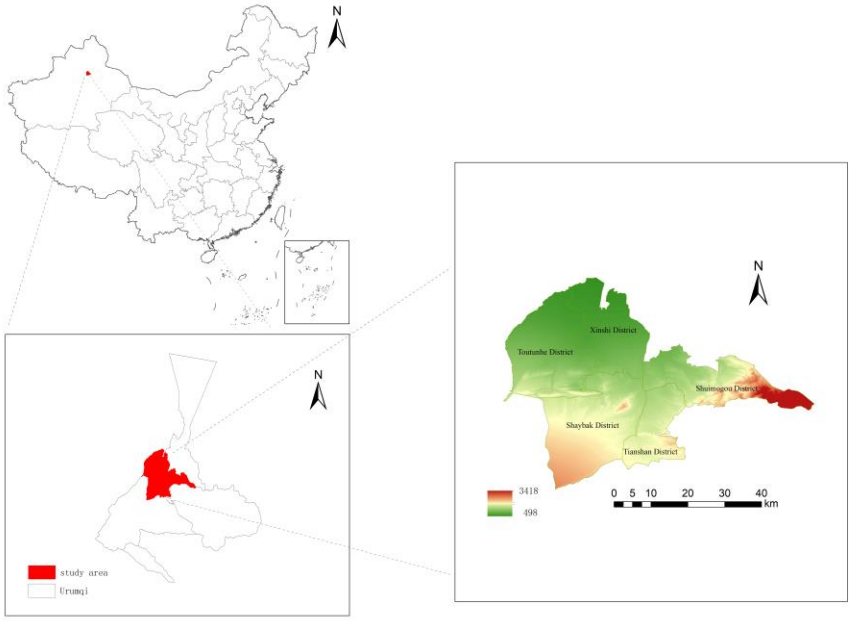

Fig. 1 Overview map of the study area(Photo/Picture credit: Original)

2.2. Study Area Data and Preprocessing

The joystick data collected by this institute comes from a wide range of sources, including remote sensing data such as Landsat-MSS/TM/ETM and Landsat8 images.

First, the obtained image is preprocessed, including radio correction, atmospheric correction, image fusion, cropping, and mosaic. Following the "Classification of Land Use Status" (GB/T 21010-2007) system, the land use status in Urumqi's primary urban area was classified into six categories, namely Cultivated land, Woodland, Grassland, Waters, Construction land, and Unused land. To ensure accuracy, visual correction was implemented through supervised classification. Ultimately, land use images for the main urban area of Urumqi in 1990, 2005, and 2020 were obtained.

3. Research Methods

3.1. Land Use and Land Cover (LUCC) Transfer Matrix

The transfer matrix is a tool used in systems analysis to quantitatively describe the state of the system and state transition, which can be used to comprehensively evaluate the distribution of features from the beginning to the end of the study and reveal the conversion trend between different features during the study period. By constructing a transfer matrix, the sources of land use/cover types and their composition in the overall structure during the study period can be better analyzed. This quantitative description method can accurately observe and analyze the changes in features over time and understand the process of land use/cover type change reflected in it. Through the transfer matrix, the trend and law of land use/cover change can be studied in more depth, which provides a scientific basis for land resource management and planning [7]. The transition matrix mathematical expression:

$$S = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} \quad (1)$$

In equation (1): any element Sij stands as the representative region where the land use type i is transformed into j; The diagonal of the matrix is the area unchanged from the initiation to the culmination of the investigation for land use/cover type i.

3.2. Land Use and Land Cover (LUCC) Dynamics

In addition, The dynamics, denoted as K, reflects the extent of land use transformation within a given time interval, and the dynamic degree calculation formula is [8].

$$K = \frac{a_y - a_x}{a_x} \frac{1}{T} \times 100\% \quad (2)$$

In Equation (2): K represents the dynamic degree of land use change, indicating the rate at which a specific land type undergoes transformation during the study period. A higher absolute value of K implies a more rapid rate of change for that land use type. ax and ay are the area of a land use in the previous and subsequent phases, respectively; T is the time between phases.

3.3. Remote Sensing Ecological Index Model (RSEI)

The RSEI model adopted in this study was proposed by Xu Hanqiu in 2013 based on four natural factors, NDVI, WET, LST and NDBSI, which provided an objective and rapid technique for the evaluation pertaining to the caliber change characteristics relating to the standard or level [9].

$$I_{RSE} = f(I_{NDV}, W_{ET}, T_{LS}, I_{NDBS}) \quad (3)$$

In equation (3), IRSE is the ecological index derived from remote sensing analysis; INDV is the greenness component; WET is the humidity component; TLS is the heat component; INDBS is the dryness component.

4. Results and Analysis

4.1. Land Use Change Analysis

According to the final interpretation results, ArcGIS software was employed to generate the land use classification map for the primary urban area of Urumqi in 1990, 2005 and 2020 can be seen in figure 2, as well as the land use area and percentage of each year can be seen in table 1. It should be noted that the numbers 1, 2, 3, 4, 5 and 6 in the legend are arable land, forest land, grassland, water, construction land and unused land.

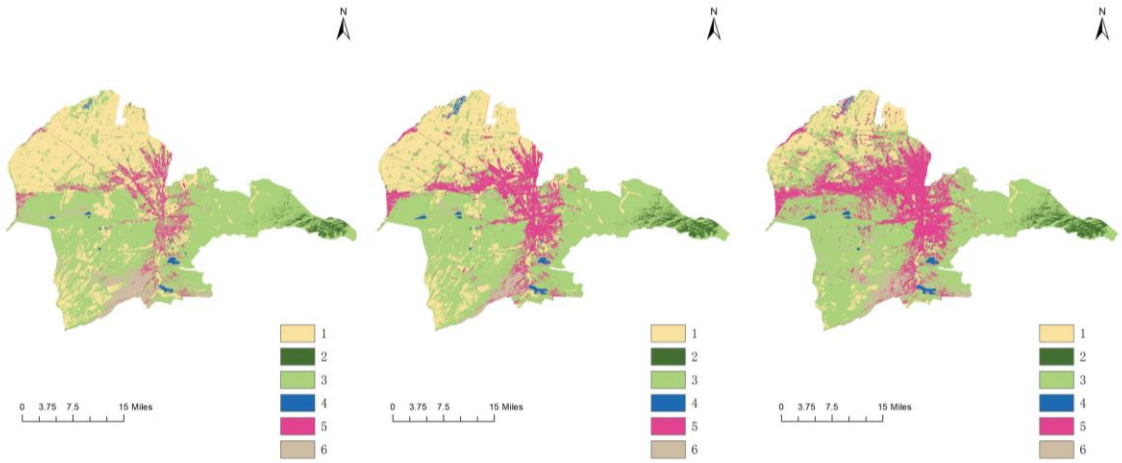

Fig.2 Land use classification map of the study area in 1990, 2005 and 2020
(Picture credit : Original)

Table 1. Area and percentage of land use types in the main urban area of Urumqi City, 1990/2005/2020

Ground class	In 1990		In 2005		In 2020	
	Area/km^2	Percentage/%	Area/km^2	Percentage/%	Area/km^2	Percentage/%
Cultivated land	489.245	33.04	426.965	28.83	237.208	16.02
Woodland	23.727	1.60	31.095	2.10	34.782	2.35
Grassland	776.344	52.42	764.024	51.60	799.434	53.99
Waters	7.844	0.53	12.432	0.84	12.531	0.85
Construction land	99.396	6.71	204.638	13.82	319.546	21.58
Unused land	93.234	6.30	50.637	3.42	86.289	5.83

Derived from the obtained data of land use types in each year, ArcGIS software was utilized to acquire land use data destination maps of the main urban area of Urumqi from 1990 to 2005 and 2005 to 2020 can be seen in figure 3 and figure 4, as well as land use change transfer matrix and dynamic statistical report can be seen in table 2 to table 4.

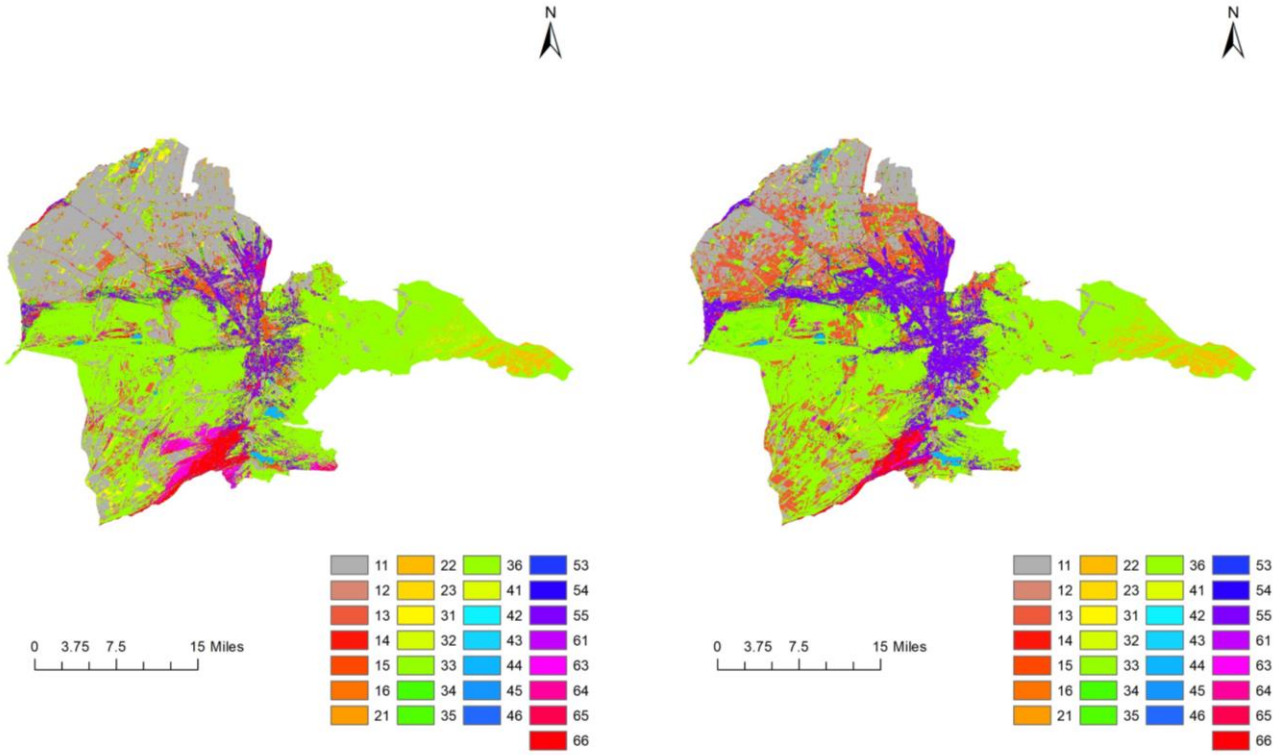

Fig. 3 Land use destination maps for 1990-2005 and 2005-2020(Picture credit: Original)

Table 2. Land use/cover transfer matrix, 1990-2005

2005 1990	Cultivated land	Woodland	Grassland	Waters	Construction land	Unused land	Total
Cultivated land	390.980	0.081	62.760	2.171	33.418	0.437	489.245
Woodland	1.092	22.631	0.005	0	0	0	23.727
Grassland	34.568	8.382	659.509	2.852	56.381	14.651	776.344
waters	0.166	0.002	0.090	7.235	0.093	0.259	7.844
Construction land	0	0	0.001	0.041	99.354	0	99.396
Unused land	0.761	0	41.659	0.132	15.392	35.290	93.234
Total	426.965	31.095	764.024	12.432	204.638	50.637	1489.790

Table 3. Land use/cover transfer matrix, 2005-2020

2020 2005	Cultivated land	Woodland	Grassland	Waters	Construction land	Unused land	Total
Cultivated land	214.638	0.328	161.367	0.401	44.335	5.897	426.965
Woodland	0.144	3.502	0.005	0	0	0	31.095
Grassland	20.942	3.502	622.687	1.235	62.693	52.965	764.024
Waters	0.885	0	0.408	10.205	0.889	0.045	12.432
Construction land	0.011	0	0.037	0.264	204.318	0.008	204.638
Unused land	0.588	0.006	14.931	0.427	7.311	27.374	50.637
Total	237.208	34.782	799.434	12.531	319.546	86.289	1489.790

Table 4. Land use/cover dynamics in the main urban area of Urumqi at different time periods

Ground class	1990-2005		2005-2020	
	Varying area/km^2	Single dynamics/%	Varying area/km^2	Single dynamics/%
Cultivated land	-62.280	-0.85	-189.757	-2.96
Woodland	7.368	2.07	3.687	0.79
Grassland	-12.320	-0.11	35.410	0.31
Waters	4.588	3.90	0.099	0.05
Construction land	105.242	7.06	114.908	3.74
Unused land	-42.597	-3.05	35.652	4.70

4.2. Land Use and Land Cover (LUCC) Dynamics Analysis

The evolving calculation results of various land use/cover types over time are presented in table 4. As evident from the data in Table 4, between 1990 and 2005, overall, cultivated land and unused land showed a decreasing trend, and other types of area demonstrated an upward trajectory. The evolving degree of each type was sorted by construction land> unused land> woodland> cultivated land > waters > grassland. From different time periods, the construction land was the most dynamic from 1990 to 2005, and the unused land was the most dynamic from 2005 to 2020. This observation highlights the substantial influence of urban construction on land use and coverage within the main urban area of the city.

4.3. Analysis of Spatiotemporal Changes in Ecological Environment Quality

Based on land use change analysis, table 5 shows an RSEI model was developed to assess the ecological condition of Urumqi's primary urban region, and the average values of each index and the ecological quality distribution map in 1990, 2005 and 2020 were obtained can be seen in figure3.

Table 5. Average indicators by year

Year	Index				RSEI
	NDVI	WET	NDBSI	LST	
In 1990	0.15	0.54	0.64	0.18	0.43
In 2005	0.26	0.62	0.67	0.61	0.37
In 2020	0.18	0.42	0.48	0.62	0.44

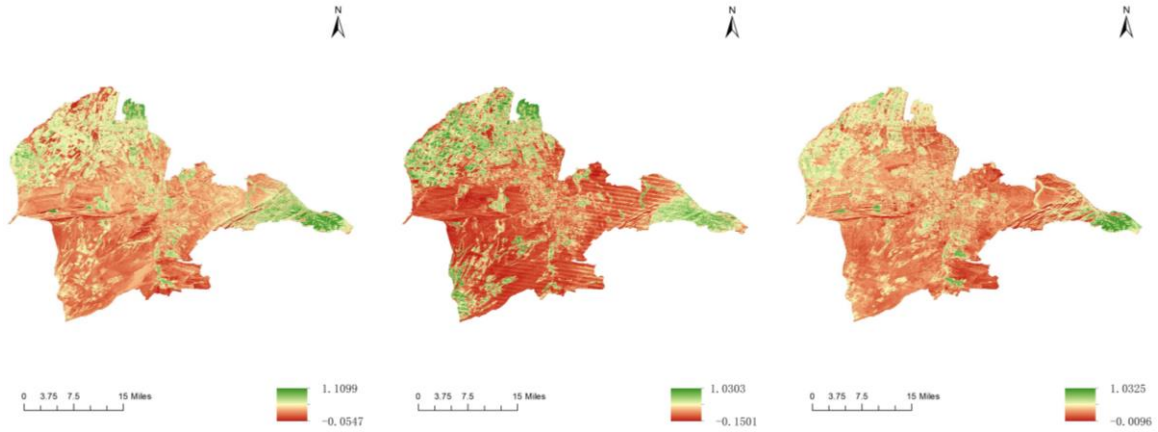

Fig. 4 Ecological quality maps for 1990, 2005 and 2020(Picture credit: Original)

4.4. Ecological Effects of Land Use Change

By comparing land use data and RSEI ecological quality data, monitoring images of ecological quality changes from 1990 to 2005 and from 2005 to 2020 are obtained as shown in figure 5, the results show that there is a positive correlation between regional ecological quality and NDVI. This further confirms the positive contribution of cultivated land, woodland and grassland to the regional ecological environment. Similarly, regional ecological quality shows a negative correlation with NDBSI, suggesting that unused land may have a negative impact on regional ecological environment. By combining land use transfer data and RSEI change monitoring data, comparative analysis shows that there is an inflow of arable land and water in areas with increased RSEI. In areas where RSEI decreased, woodland, grassland and arable land decreased, while large areas of construction land increased significantly. These all indicate that land use pattern transformation has a direct impact on regional ecological quality [10].

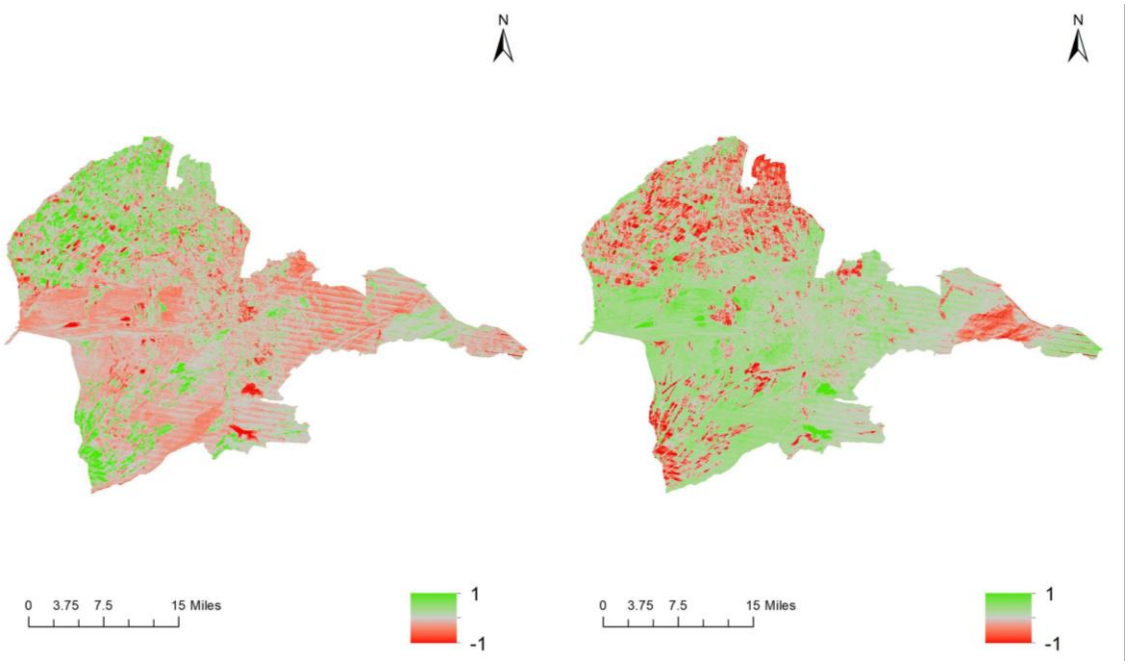

Fig. 5 Detection of ecological quality changes from 1990 to 2005 and 2005 to 2020 (Picture credit: Original)

5. Conclusion

Based on the extensive analysis and observation carried out in this study, it is evident that significant changes have occurred in land use and cover within Urumqi's primary urban area over the

past three decades. The utilization of GIS technology has provided detailed temporal and spatial data, thereby enhancing our understanding and control over this issue. The rapid urbanization of Urumqi's main urban area has resulted in a continuous decrease in arable land, while the expansion of construction land has had a broader impact on ecosystems, significantly influencing the spatial ecological effects of the region.

Due to the rapid urbanization process, not only the category of land use cover has changed, but also the spatial form of land use cover, thereby changing the spatial configuration of the land landscape, which has greatly affected the spatial ecological effect of the main urban area of Urumqi. Such changes have profound implications for ecological factors such as air quality, land fertility and biodiversity. They exacerbate the region's air pollution, reduce soil quality and negatively impact local biodiversity.

To mitigate the impact of urbanization on the spatial ecological environment, it is crucial to incorporate ecological sustainability into land planning for Urumqi's main urban area and implement a sustainable urban development strategy. Further research efforts should focus on monitoring and evaluating the dynamics of land use and cover changes in the region, along with their correlation with ecological effects. This will aid in the formulation of more effective ecological compensation strategies and regulatory measures.

The utilization of GIS technology in monitoring and assessing changes in land use cover and their ecological impact in spatial terms can provide scientific guidance for managing and utilizing urban land resources. This approach holds significant practical value in enhancing the urban ecological environment and facilitating sustainable development.

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