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Land Use Classification and Spatiotemporal Change Analysis of Nanjing Based on RS and GIS

Jinhong Sun

School of Internet of ThingsNanjing University of Posts and Telecommunications, Nanjing, China
1736435439@qq.com

Abstract. Changes in land use and land cover (LULC) are key factors affecting the ecological environment and economic development of a given area. This study employs remote sensing (RS) and geographic information systems (GIS) techniques to analyze the characteristics of land use change in Nanjing over the past 20 years. The results show that built-up land increased markedly by 148.71%, farmland decreased by 4.85%, forestland increased by 4.34%, and water bodies first increased and then decreased. Urban expansion caused farmland to be converted to built-up land; the policy of returning farmland to forest promoted forest recovery; and climatic factors influenced fluctuations in water bodies. The study reveals the dual impacts of urbanization and ecological policy, providing a scientific basis for land-use planning. This paper aims to investigate the trends of land use change in Nanjing during the past two decades based on RS and GIS, and to analyze the underlying logic of these changes so as to provide a reference for future urban land use.

Keywords: Land Use Change, Remote Sensing, Geographic Information Systems, Nanjing

1. Introduction

In recent years, research on land use change based on remote sensing (RS) and geographic information systems (GIS) has become a hot topic in the fields of geography and environmental science. International scholars have mostly focused on the mechanisms by which urbanization affects land use. For example, Seto et al. (2012) used long-term series of remote sensing data to reveal the spatiotemporal patterns of urban expansion in Asia. In contrast, domestic studies have paid more attention to policy-driven land use transformation. For instance, Liu Jiyuan et al. (2014), using national land survey data, analyzed the regulatory role of China's cultivated land protection policy in land use change. However, multi-period dynamic analyses of land use change in megacities remain insufficient, particularly regarding comprehensive driving mechanisms that integrate ecological policies and urbanization processes [1].

This study applies RS and GIS techniques to classify land use in the Nanjing study area and to analyze the reasonable spatiotemporal characteristics of land use change in Nanjing [2]. It constructs a land use transfer matrix to explore the conversion relationships among different land use types and, through the collection and analysis of remote sensing imagery from 2003, 2013, and 2023, identifies the main driving forces of land use change. The primary data sources used in this study

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include the Resource and Environmental Science Data Center (https://www.resdc.cn/), Google Earth reference data, and data from the Nanjing Statistical Yearbook.

2. Study area and data processing

2.1. Overview of the study area

Nanjing is located in the southwestern corner of Jiangsu Province, with geographic coordinates ranging from 118°22′E to 119°14′E and 31°14′N to 32°37′N. Covering a total area of approximately 6,580 km², the city holds significant urban influence. In the current period of rapid urbanization, research on land use changes in Nanjing is both typical and necessary [3].

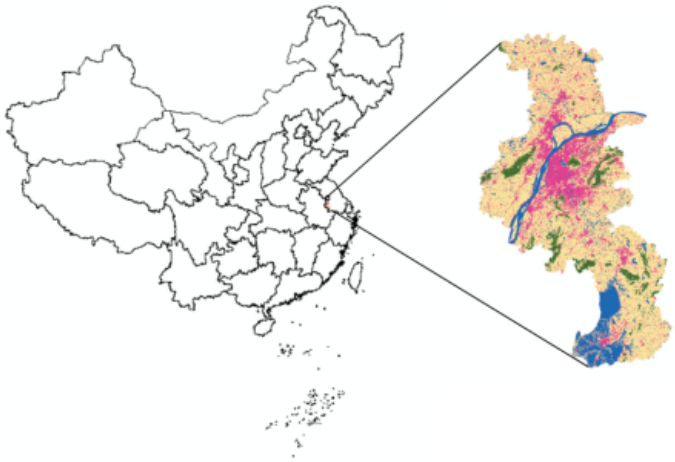


Figure 1. Geographical location of the Nanjing study area

2.2. Data sources and processing

The primary data sources used in this study include the Resource and Environmental Science Data Center (https://www.resdc.cn/), Google Earth reference data [4], and data from the Nanjing Statistical Yearbook.

As of 2025, the land use types in the Nanjing study area are shown in the figure below:

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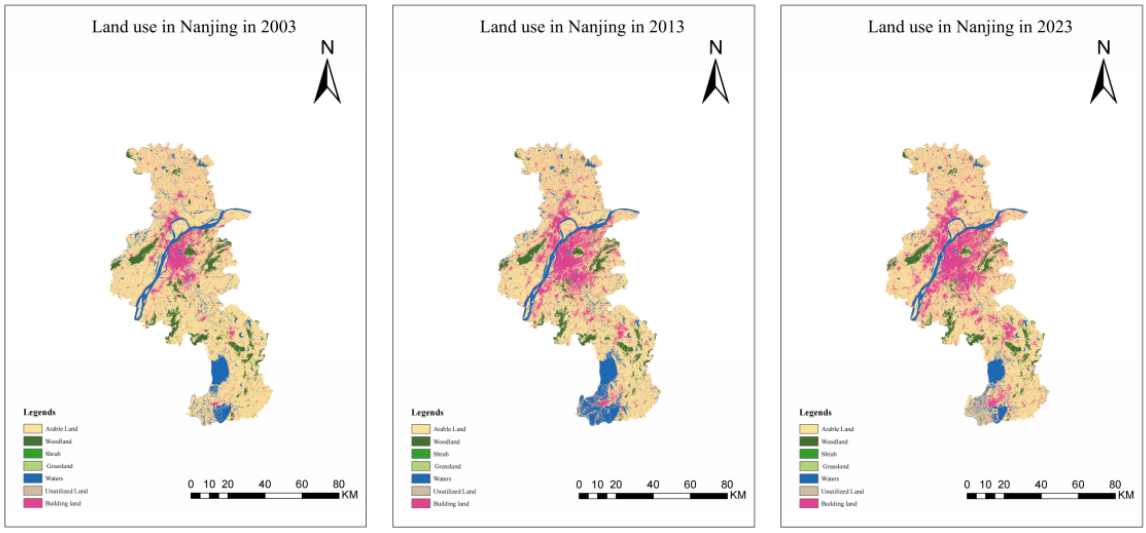


Figure 2. Land use in Nanjing in 2003, 2013, and 2023

3. Land use change analysis in the study area

3.1. Land use change in the study area

This study conducts an in-depth analysis of land use in Nanjing over the 20-year period from 2003 to 2023, selecting six major categories—farmland, forestland, water bodies, grassland, unused land, and built-up land—that encompass the core components of both the natural ecosystem and the human environment, thereby ensuring strong representativeness. In the field of land use change research, changes can be categorized into newly added areas, unchanged areas, and transferred-in areas. Therefore, this paper adopts the indicator of land use dynamic degree to reflect the rate of land use change in Nanjing. The land use dynamic degree can be analyzed in two main categories: (1) single land use dynamic degree, and (2) comprehensive land use dynamic degree [5].

Table 1. Land use changes in Nanjing over the past 20 Years

Land Use Type	Area in 2003 (km²)	Area in 2023 (km²)	Area Change (km²)	Single Land Use Dynamic Degree
Farmland	4671.4872	4219.7724	-451.7118	-0.4835
Forestland	504.2718	411.6285	-92.6443	-5.8906
Grassland	0.774	0.2268	-0.5472	-3.5349
Water bodies	648.999	534.969	-114.03	-0.8785
Unused land	0.0261	0.063	0.0369	7.0690
Built-up land	761.2443	1420.1397	658.8954	4.3278
Total	6586.7994	6586.7994	0	0

3.2. Single land use dynamic degree

The single land use dynamic degree primarily addresses the rate of change of a specific land use type within the study area over the research period (starting point: T1, ending point: T2). Its mathematical expression is as follows:

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$$K_j = \frac{(LA_{(j,t2)} - LA_{(j,t1)})}{LA_{(j,t1)}} \times \frac{1}{t2-t1} \times 100 \quad (1)$$

Where: K_j represents the dynamic degree of the j-th land use type, reflecting the rate of change of that land use type over the 20-year period. $LA_{(j,t1)}$ denotes the area of the j-th land use type in 2003. $LA_{(j,t2)}$ denotes the area of the j-th land use type in 2023.

According to Table 1, during the 20-year period from 2003 to 2023, unused land exhibited the highest single land use dynamic degree at 7.0690, followed in descending order by built-up land, water bodies, farmland, forestland, and grassland. This indicates that built-up land is rapidly increasing, with urban construction areas expanding quickly; the built-up land area increased by approximately 658.8594 km², nearly doubling. The urbanization process is evident, while the relatively stable areas of other land types may be related to national policies such as returning farmland to forest and grassland [6].

In addition to considering the dynamic degree of individual land use types, this study also employs the comprehensive land use dynamic degree to measure and evaluate the overall status, magnitude, and extent of changes across various land use types within a certain period. The comprehensive land use dynamic degree can reveal the conversion relationships and evolutionary trends among different land use categories in the overall land use pattern. Its mathematical expression can be realized by constructing a dynamic degree matrix, with the calculation expressed by the following formula:

$$LC = \left[\frac{\sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \left| \Delta LU_{i \to j} \right|}{\sum_{i=1}^{n} LU_i} \right] \times \frac{1}{T} \times 100\% \quad (2)$$

The comprehensive land use dynamic degree of the Nanjing study area from 2003 to 2023 was calculated to be 0.067.

4. Land use transfer matrix and transfer rate analysis in the study area

This study employs the land use transfer matrix analysis method calculated using ArcGIS 10.8 software, a widely used and important approach that intuitively and comprehensively reflects the direction and specific magnitude of land use changes. The specific steps are as follows: Classify the land use categories of the study area's image data according to land type codes and merge them using the Dissolve tool; Use the Intersect tool to perform cross-analysis of data from multiple time periods; Add area intervals to the qualitative table; Finally, export the data to a .DBF file, open it in Excel, and execute the “DataTransface” command under the Data menu twice to obtain the land use transfer matrix between the two time periods for the study area.

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Table 2. Land use transfer matrix of Nanjing from 2003 to 2013 (unit: km²)

2013 2003	Farmland	Forestland	Grassland	Water bodies	Unused land	Built-up land
Farmland	4045.1949	102.1419	0.2223	55.6065	0.0018	0.6039
Forestland	20.0187	393.9264	0.0333	0.3600	0.0000	0.0009
Grassland	0.4770	0.1044	0.1944	0.0045	0.0000	0.0000
Water bodies	195.6762	0.1656	0.0063	577.8504	0.0045	3.9852
Unused land	0.0513	0.0000	0.0594	0.0315	0.0036	0.0000
Built-up land	410.0661	7.9344	0.2583	15.1461	0.0153	756.6543
Total	4671.4842	504.2727	0.7740	648.9990	0.0252	761.2443

Table 3. Land use transfer matrix of Nanjing from 2013 to 2023 (unit: km²)

2023 2013	Farmland	Forestland	Grassland	Water bodies	Unused land	Built-up land
Farmland	3922.1739	50.7987	0.3186	245.7468	0.0621	0.6723
Forestland	49.0023	362.5821	0.0198	0.0189	0.0018	0.0036
Grassland	0.1098	0.0000	0.1116	0.0000	0.0054	0.0000
Water bodies	15.3387	0.0153	0.0018	516.9798	0.0000	2.6334
Unused land	0.0000	0.0000	0.0189	0.0225	0.0216	0.0000
Built-up land	217.1466	0.9432	0.3096	14.9202	0.0549	1186.7652
总计	4203.7713	414.3393	0.7803	777.6882	0.1458	1190.0745

Each parameter in the land use transfer matrix represents the area transferred from land use type I to land use type J. Elements along the diagonal represent the area that remained unchanged in its original land use type during the study period, while off-diagonal elements indicate areas transferred from one type to another.

As shown in Tables 2 and 3, significant land use changes occurred in Nanjing between 2003 and 2013 and between 2013 and 2023. From 2003 to 2013, the area of forestland converted to farmland was 20.0187 km², attributed to urban expansion and increased demand for agricultural land. The area of built-up land transferred out was 0.6039 km², the area transferred in was 1,190.0745 km², and the unchanged area was 756.6543 km², reflecting a substantial expansion of urban built-up areas. Farmland converted to built-up land amounted to 410.0661 km², accounting for 34.42% of the total transferred-in area, indicating that a significant portion of built-up land originated from farmland.

During the period from 2013 to 2023, urbanization in Nanjing continued to advance, with expansion of built-up areas, reduction of farmland, increase in built-up land, an initial increase followed by a decrease in water bodies, growth in forestland, and relatively minor changes in grassland. These changes reflect the combined effects of rapid urbanization and industrialization, policy regulation, economic development, and ecological protection in Nanjing [7].

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5. Conclusion

Land use and land cover, as core topics in the fields of geography and environmental science, have been hotspots of research over the past several decades. After analyzing the land use changes in Nanjing over the past 20 years, several significant trends can be observed. The overall area of farmland has shown a decreasing trend, primarily converting to water bodies and built-up land, reflecting the impacts of urban expansion and agricultural restructuring. The substantial increase in built-up land indicates the expansion of urban construction areas, a typical phenomenon during urbanization. Meanwhile, the increase in forestland area is mainly due to the conversion of farmland to forestland, which may be related to the implementation of the policy of returning farmland to forest, aimed at restoring and increasing forest coverage and improving the ecological environment. The significant increase in built-up land reflects the expansion of construction land during the urbanization process, consistent with the rapid development of urbanization and industrialization. These changes have profoundly affected Nanjing's ecological environment, economic development, and social welfare. At the same time, they remind us that issues such as sustainability and ecological environment protection require further attention in future urban planning and management. Ensuring sustainable urban development and improving the quality of life for the population make the reasonable planning and scientific management of land use highly significant. In the future, Nanjing needs to continue optimizing its land use structure, strengthening ecological environment protection, and promoting green development to achieve coordinated economic, social, and environmental development.

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