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RESEARCH ARTICLE

Analysis of Urban Spatial Patterns Based on Satellite Remote Sensing and Comparison between Metropolitans - A Case Study of Nanchang, China

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Abstract

The planning of metropolises is a challenging issue, as it guides the high-quality development of developing cities. Providing a development direction through rational planning while avoiding path dependency is a key challenge for developing cities pursuing high-quality development. This issue is discussed in this paper, with the Nanchang Metropolitan Area, China, taken as an example. The solution involves analyzing the urban spatial pattern to reveal the phased characteristics and evolutionary trajectory of the urbanization process, and comparing it with developed cities to provide insights. To this end, satellite remote sensing data and landscape indices are used for the analysis. Data sources are provided by tasks such as satellite image classification at different scales, post-processing of unsupervised segmentation, and statistics of landscape metrics. The research analyzes the current status and changes of Nanchang's spatial pattern from 2017 to 2023, and conducts a comparison with the Sydney Metropolitan Area to explore the future development direction of Nanchang. This provides insights for understanding the current spatial pattern of developing cities and determining their development directions.

Keywords: remote sensing, urban spatial pattern, classification, segmentation, landscape indicators, Nanchang, Sydney.

1 Introduction

As a developing country, China has experienced the world's largest-scale urbanization process over the past 30 years. From 1994 to 2024, China's urbanization rate rose from 28.5% to 67%, with more than 600 million people relocating to live in cities. While rapid urbanization has boosted economic development, it has also transformed the spatial pattern of cities to accommodate a larger population and support more vigorous economic activities. After reaching a certain scale, this high-speed development has given rise to the demand for high-quality development.

Nanchang is the capital of Jiangxi Province in

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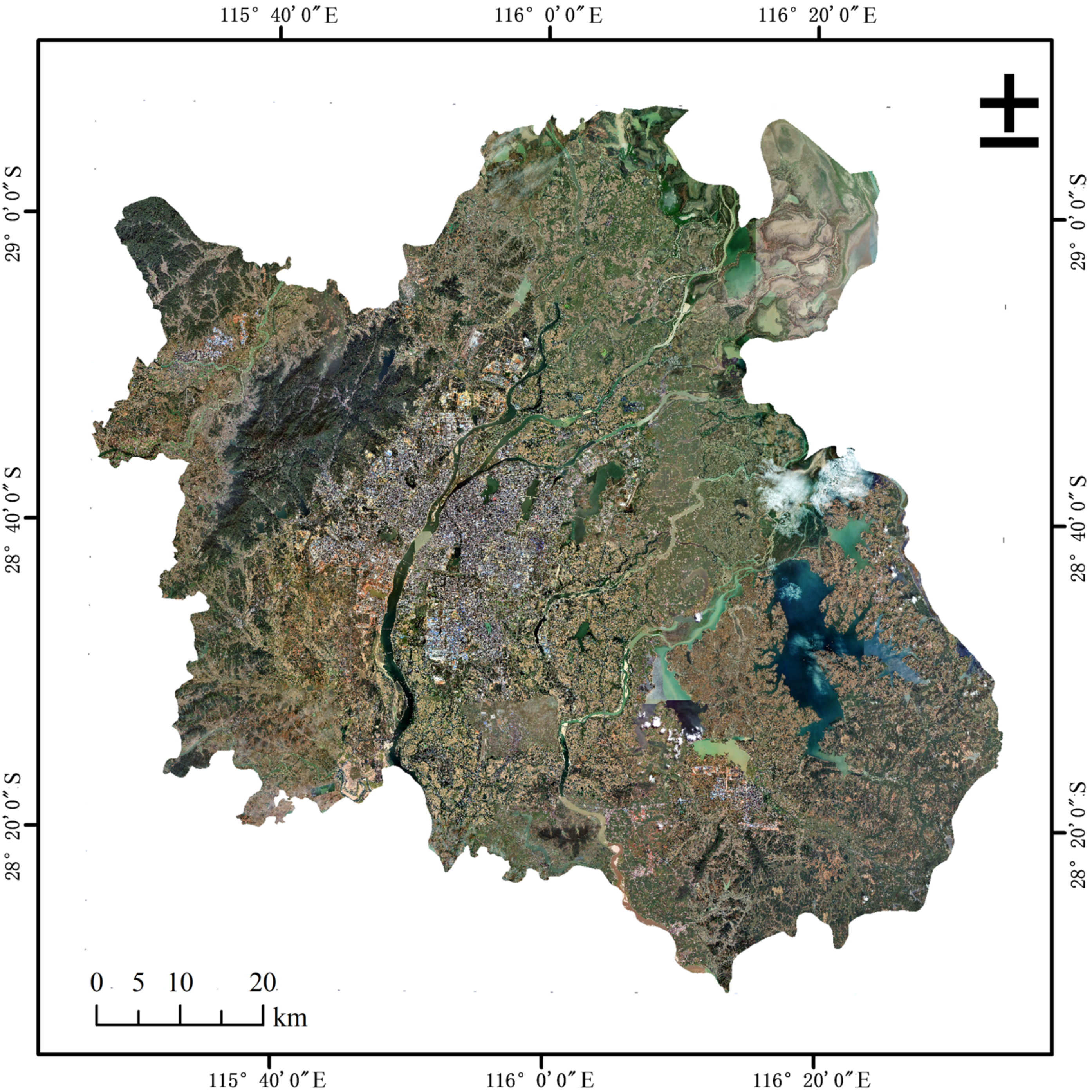


Figure 1. Study area.

central China, which faces uncertainties of long-term development, too. Currently, Nanchang is planning a single-core super metropolitan area, centered on the original Nanchang Metropolitan Area and extending to four adjacent metropolises of Jiujiang, Fuzhou, Yichun, and Shangrao. However, the reasonability is unknown for such a huge metropolitan area, and it is difficult to plan the overall layout. Obtaining such an answer requires comprehensive analysis of social development stages, economic foundations, and macro-policies, data for which are not easily accessible. A top-down comparison approach to metropolitan area analysis may provide development planning. From a goal-driven perspective, we can directly benchmark internationally well-developed cities and use them as templates to determine Nanchang's long-term development direction. The implementation is to explore the current status of the urban pattern and identify gaps through metric comparison, thereby helping decision-makers set development goals. This approach avoids interference from the current development status and reduces evaluation biases caused by differences in social development stages.

The urban pattern can be analyzed from both policy and landscape ecology perspectives. Analyzing the urban pattern from the policy perspective involves considering factors such as economy, people's livelihood, and management difficulty, and the required data elements are not easily accessible. For example, Cattivelli [1] investigated the methods of urban classification in Europe over the past 20 years and concluded that the current approaches to classifying the peri-urban area of European cities mostly rely on economic and social indices, population data, travel distance data and settlement data as analytical data. From the landscape pattern perspective, the urban pattern is generally evaluated by analyzing the spatial changes of patches or landscapes based on various landscape indices. In landscape ecology, landscape pattern generally refers to the spatial pattern, which mainly focuses on land-use-related information at the spatial level, such as the size, shape, quantity of land parcels, and their spatial arrangement. In the theory of landscape patch dynamics, the urban landscape is composed of patches of different land-use types, and the evolution of the urban landscape pattern can be reflected by changes in land-use type patches. To study the evolution of the urban landscape pattern, indicators such as land-use type area change and landscape pattern dynamic change are usually used for analysis. Landscape pattern elements can be obtained from remote sensing data.

To analyze the rationality of Nanchang's urban pattern, evaluate the feasibility of Nanchang's metropolitan planning, and provide suggestions for Nanchang to break free from path dependence and achieve high-quality development, this study proposes to conduct a research on the current status and comparative analysis of Nanchang's spatial pattern based on remote sensing observations. Using satellite remote sensing technology and multi-temporal remote sensing images to analyze land-use changes in Nanchang, this study obtains the current status and change trends of Nanchang's spatial pattern in recent years. From the perspective of landscape pattern, this study discusses the landscape layout of urban area and farmland in Nanchang. With the Sydney Metropolitan Area as a reference, some gaps between Nanchang and Sydney are pointed out.

2 Study Area and Methods

2.1 Study Area

The study area in this paper is located in the Nanchang City covering twelve counties or districts. Nanchang City, the capital of Jiangxi Province, is located between $115°27' - 116°35'$ E, and $28°10' - 29°11'$ N. Situated in the middle and lower reaches of the Yangtze River, Nanchang adjoins Poyang Lake, China's largest freshwater lake. The specific location of Nanchang City is shown in Figure 1. Nanchang has a total area of 7,195 km^2 and a permanent population of 6.5381 million [2].

2.2 Data Preparation

Two types of satellite remote sensing data are used in this study: high-resolution satellite remote sensing data with a resolution of 10–30 m, and very-high-resolution satellite remote sensing data with a resolution of less than 5 m. In addition, vector data of Nanchang's administrative divisions are also needed.

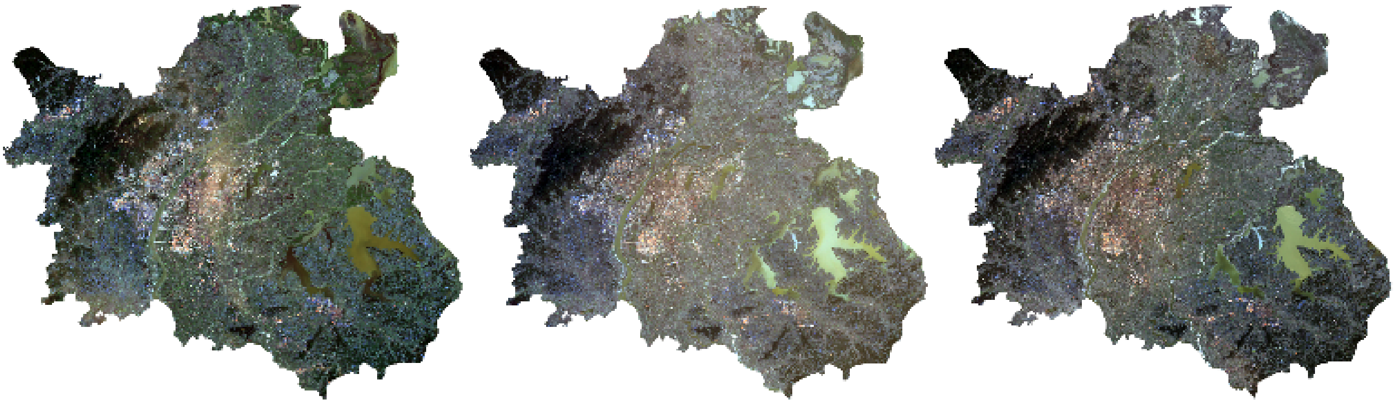
The wide field view (WFV) data of Gaofen-1 satellite covering Nanchang is used as the high-resolution source. The data is downloaded from the China Centre for Resources Satellite Data and Application (https://data.cresda.cn), with a spatial resolution of 16 m, including the blue, green, red, and visible near-infrared (VNIR) bands. The acquisition times of the images are April 30, 2017, February 23, 2020, and March 6, 2023, respectively, as shown in Figure 2.

The very-high-resolution satellite data are obtained from Bing Maps. Using the vector boundary of Nanchang and the ShuiJingZhu software, the satellite remote sensing image of Nanchang was obtained. The extracted data is shown in Figure 1, which was captured in March 2023, with a ground resolution of 2.4 m spanning the red, green, and blue (R/G/B) bands.

2.3 Methods

This study analyzes the spatiotemporal changes of land use, farmland landscape indices, and urban landscape indices in Nanchang from 2017 to 2023. These indicators represent the overall trend, the scale of high-standard farmland, and the quality of urban construction, respectively.

The spatiotemporal change data of land use are obtained through classification and comparison of category changes. The fine-grained multiscale classification network with superpixel postprocessing (FGMCN-SPP) [3] was used. It requires a smaller



April 30, 2017 February 23, 2020 March 6, 2023

Figure 2. Nanchang images captured by 16-m Gaofen-1 WFV.

Table 1. Landscape Indices and Formulas.

Landscape Index	Implications of Landscape Index	Formula
Number of Patches (NP)	Total number of patches of a specific land-use type	$\text{NP}_i = n_i$, where i represents the patch type.
Patch Density (PD)	Number of patches of a specific land-use type per unit land area; smaller values indicate better consolidation	$\text{PD} = n/S$, where n is the number of patches and S is the total area of patches.
Edge Density (ED)	Length of patch edges per unit land area; larger values indicate higher degree of patch division	$\text{ED} = E/S$, where E is the total perimeter of patches and S is the total area of patches.
Mean Patch Size (MPS)	Average area of a specific patch type per unit land area; larger values indicate better consolidation	$\text{MPS} = S/N$, where S is the total area of patches and N is the number of patches.
Mean Shape Index (MSI)	Complexity of patch shape; larger values indicate higher complexity.	$\text{MSI} = \sum_{i=1}^{n} (0.25P_i/\sqrt{a_i})/N$, where a is the patch area, P is the patch perimeter, and N is the number of patches.
Area-Weighted Mean Shape Index (AWMSI)	Complexity of patch shape considering area factors; larger values indicate higher complexity	$\text{AWMSI} = \sum\limits_{i=1}^{n} [(0.25P_i/\sqrt{a_i})(a_i/A)]$, where n is the number of patches, P is the patch perimeter, a is the patch area, and A is the total area of patches.
Fragmentation Index (FS)	Fragmentation degree of a specific land-use type; larger values indicate higher fragmentation	$\text{FS} = 1 - 1/\text{MSI}$, where MSI is the Mean Shape Index.

scale of training data, and the experiments showed more superior performance than that of typical Transformers. These characteristics are highly consistent with the requirements of pixel-wise classification of remote sensing images, as it effectively reduces the workload of data annotation without the demand of continuous block annotation. Since pixel-wise classification may lead to fragmentation and blurred boundaries, an unsupervised segmentation method is used in FGMCN-SPP to merge classification results, which eliminates the salt-and-pepper noise in the classification results as well as improving the classification accuracy. The transfer matrix presents the category change of land cover types. This scheme secures semantic changes with better accuracy than change detection algorithms. The satellite data used for change detection are the Gaofen-1 WFV data.

The locations of high-standard farmland were extracted by farmland landscape indices. Seven farmland landscape indices, including Number of Patches (NP), Patch Density (PD), Edge Density (ED), Mean Patch Size (MPS), Mean Shape Index (MSI), Area-Weighted Mean Shape Index (AWMSI), and Fragmentation Index (FS), were used to analyze the quality of farmland. The calculation of these indicators relies on the secondary identification of farmland area. The scope of farmland was determined by the classification results of Gaofen-1 WFV images. Within the farmland area, the BsiNet neural network model [4] was used for semantic segmentation and identification of roads and crops from the Gaofen-1 WFV images. FGMCN-SPP is not used for the secondary classification of farmland area owing to mixed pixels caused by 16-m resolution and the difficulty in labeling sufficient training set. BsiNet is a lightweight segmentation model effective for extracting farmland with irregular shapes and small sizes which was trained on the GID-15 dataset [5] with a spatial resolution of 4 m. Since the 16-m Gaofen-1 WFV images are not clear enough to identify

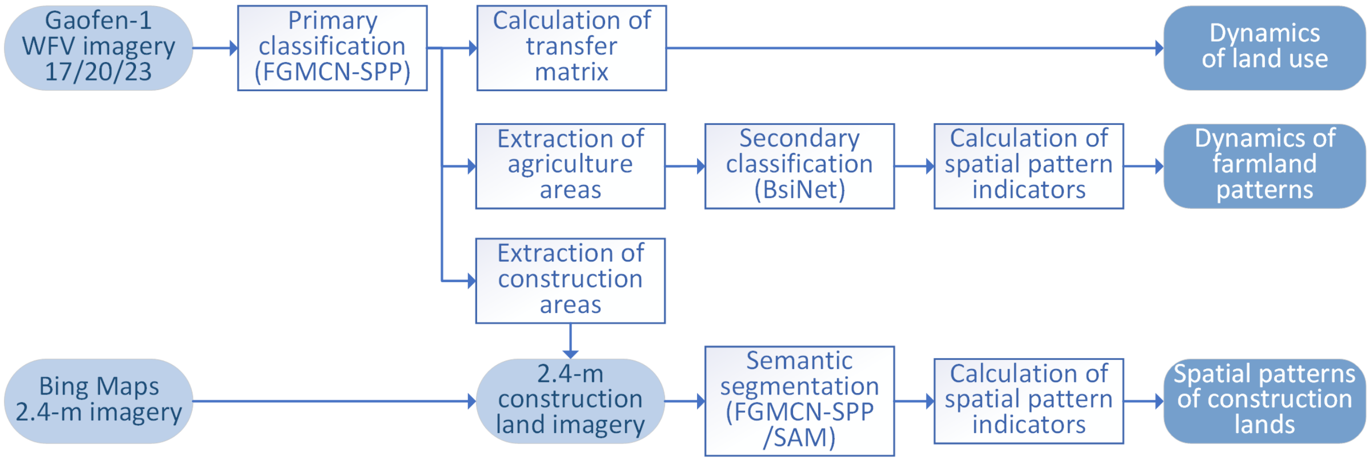


Figure 3. General work flow for the used data and methods.

the agricultural content, the 2.4-m Bing Maps satellite image is necessary for aid.

After obtaining the segmentation results, the above mentioned farmland landscape indices were evaluated by equations in Table 1. The quality of urban construction can be reflected by indicators such as the area, shape, and fragmentation of urban land. Six indices, including Number of Patches (NP), Patch Density (PD), Edge Density (ED), Mean Patch Size (MPS), Mean Shape Index (MSI), and Area-Weighted Mean Shape Index (AWMSI), were used to evaluate the development level of urban land. The calculation of these indicators relies on the segmentation and identification of urban land area, too. Similar to identifying the farmland regions, the urban regions were extracted by the classification results of Gaofen-1 WFV images. Within the urban regions, the 2.4m R/G/B image was also used for secondary identification of urban land. As an alternative choice, the Segment Anything Model (SAM) [6] was used for segmentation. SAM uses prompt engineering to solve different segmentation problems, enabling few-shot learning, reducing the cost of label annotation, and achieving good segmentation results on ultra-high-resolution remote sensing datasets [7].

The general flow is concluded in Figure 3. In the analysis of Nanchang's spatial pattern, Gaofen-1 image data covering Nanchang in 2017, 2020, and 2023 are used. After preprocessing, a context-aware pixel-wise classification algorithm (FGMCN-SPP) is used to obtain the level-1 classification results. Secondly, the spatiotemporal evolution of land use in Nanchang from 2017 to 2023 is systematically analyzed using methods such as transfer matrix, change map, fluctuation map, and change dynamic degree. Thirdly, the BsiNet method is used to perform the level-2 classification in the level-1 classified farmland area, and the results are converted to landscape indices to explore the agricultural trend of flatness and fragmentation in Nanchang during 2017—2023. Fourthly, For the built-up area, level-2 classification and SAM segmentation are conducted on the 2.4-m Bing Maps image, and the results are put to landscape indices to analyze the spatial pattern of built-up land in Nanchang.

3 Results and Analysis

3.1 Results of Land use Classification

On the Gaofen-1 satellite images of Nanchang, 28,090,768 pixels were labeled and divided into five primary categories: water area, farmland, construction land, forest land, and bare land. After training FGMCN-SPP using the labeled data, pixel-wise classification was performed, and the land-use status of Nanchang in 2017, 2020, and 2023 was finally obtained, as shown in Figure 4, in which the land cover types are marked in blue, yellow, red, green, and pink, respectively.

3.2 Spatiotemporal Evolution of Land Use in Nanchang

3.2.1 Spatial Structure Characteristics of Land Use

Table 2. Land use proportions across years.

Category	2017	2020	2023
Water Area	14.33%	10.94%	10.52%
Farmland	48.58%	48.33%	36.12%
Construction Land	17.51%	21.95%	31.99%
Forest Land	12.29%	12.19%	14.60%
Bare Land	7.29%	6.60%	6.77%

Table 3. Land use transfer matrix of Nanchang from 2017 to 2020.

	2017 → 2020	Water Area	Farmland	Construction Land	Forest Land	Bare Land	Total (km^2)
Water Area	Loss	65.56%	19.36%	2.69%	0.27%	12.13%	354.92
	Gain	85.89%	5.74%	1.75%	0.32%	26.35%	110.99
Farmland	Loss	2.06%	79.76%	11.54%	2.68%	3.95%	706.94
	Gain	9.17%	80.18%	25.55%	10.67%	29.10%	688.66
Construction Land	Loss	0.74%	13.71%	80.37%	2.64%	2.54%	247.15
	Gain	1.18%	4.97%	64.13%	3.79%	6.75%	566.13
Forest Land	Loss	0.35%	10.38%	3.67%	82.93%	2.67%	150.87
	Gain	0.39%	2.64%	2.05%	83.61%	4.98%	143.68
Bare Land	Loss	5.06%	42.92%	19.61%	2.70%	29.72%	368.24
	Gain	3.37%	6.47%	6.51%	1.62%	32.83%	318.65

By counting the pixel values of each category in the classification results of Nanchang, the area of each category was calculated, and the results are shown in Table 2. In this table, the total area of Nanchang is 7,191 km^2, which is very close to the official data.

3.2.2 Land-Use Transfer Matrix

By merging and calculating the land-use type maps of 2017, 2020, and 2023, land-use transfer matrices for different periods (2017→2020, 2020→2023, and 2017→2023) were obtained. The transfer area, gain volume, and loss volume of each land-use category were statistically analyzed, and the results for each period are shown in Table 3, Table 4, and Table 5, respectively.

3.2.3 Overall Change of Land-Use Types in Nanchang (2017→2020→2023)

Table 3 shows the land-use changes in Nanchang from 2017 to 2020. For the water area, 675.58 km^2 remained unchanged, accounting for 65.55%. For the farmland, 2,786.41 km^2 remained unchanged, accounting for 79.76%. The construction land was the main conversion target, indicating that construction land occupied a large area of farmland in Nanchang from 2017 to 2020. A large proportion of construction land (80.37%) remained unchanged, and the main conversion target of its area was farmland, accounting for 13.71%. The proportion of forest land decreased by 10.38%. The development degree of bare land was high as 29.72% remained unchanged. From the perspective of gain volume of land-use types, the main conversion sources for bare land were water area and farmland, accounting for 26.35% and 29.10% respectively. The reason could be explained by the seasonal fluctuation of the Poyang Lake at the upper right of the image and the agricultural crop rotation because of high temperatures and abundant precipitation.

Table 4 shows the land-use changes in Nanchang from 2020 to 2023. 64.57% farmland remained unchanged. Construction land was the main transition target of farmland, accounting for 21.77%. From the perspective of gain volume of land-use types, the main transition

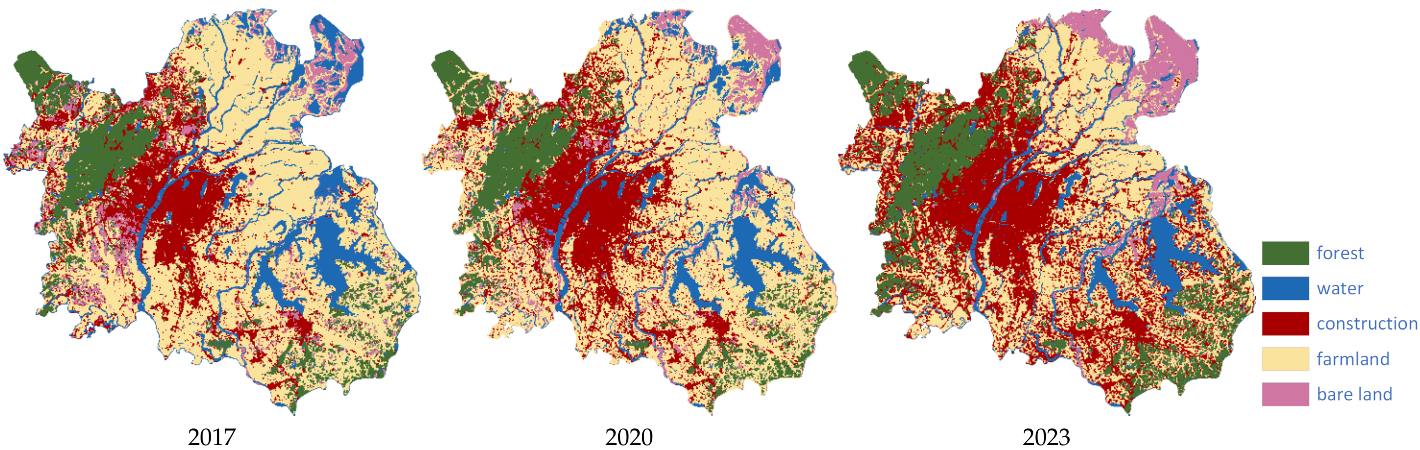


Figure 4. Results of land use classification in different years.

Table 4. Land use transfer matrix of Nanchang from 2020 to 2023.

	2020 → 2023	Water Area	Farmland	Construction Land	Forest Land	Bare Land	Total (km^2)
Water Area	Loss	71.38%	9.67%	3.09%	0.93%	14.93%	225.04
	Gain	74.25%	2.93%	1.06%	0.70%	24.11%	194.62
Farmland	Loss	3.62%	64.57%	21.77%	5.04%	5.00%	1231.08
	Gain	16.63%	86.39%	32.89%	16.67%	35.72%	353.57
Construction Land	Loss	2.27%	9.42%	85.69%	2.34%	0.28%	225.85
	Gain	4.75%	5.72%	58.79%	3.51%	0.92%	947.81
Forest Land	Loss	0.07%	2.41%	5.10%	92.13%	0.30%	69.00
	Gain	0.08%	0.81%	1.94%	76.93%	0.54%	242.13
Bare Land	Loss	6.84%	22.75%	25.82%	4.84%	39.76%	285.57
	Gain	4.29%	4.15%	5.32%	2.18%	38.71%	298.39

Table 5. Land use transfer matrix of Nanchang from 2017 to 2023.

	2017 → 2023	Water Area	Farmland	Construction Land	Forest Land	Bare Land	Total (km^2)
Water Area	Loss	59.93%	12.07%	5.86%	2.23%	19.90%	412.64
	Gain	81.66%	4.79%	2.63%	2.19%	42.11%	138.64
Farmland	Loss	2.89%	63.75%	24.61%	5.06%	3.70%	1266.32
	Gain	13.36%	85.74%	37.37%	16.83%	26.52%	370.43
Construction Land	Loss	1.69%	7.41%	87.18%	3.57%	0.15%	161.39
	Gain	2.82%	3.59%	47.73%	4.28%	0.38%	1202.35
Forest Land	Loss	0.40%	4.03%	7.74%	87.22%	0.60%	112.87
	Gain	0.47%	1.37%	2.97%	73.42%	1.09%	278.94
Bare Land	Loss	2.45%	22.35%	40.84%	6.57%	27.78%	378.40
	Gain	1.70%	4.51%	9.30%	3.28%	29.90%	341.27

Table 6. Farmland landscape indices of Nanchang in 2017, 2020, and 2023.

Year	NP	PD	ED	MPS	MSI	AWMSI	FS
2017	14289	1.9871	26.8258	24.4478	1.1664	29.7475	0.1427
2020	33685	4.6843	42.0622	10.3172	1.1203	35.3701	0.1074
2023	80196	6.8261	35.4779	3.2390	1.1412	21.5079	0.1237

source for water area was farmland, accounting for 16.63%. For construction land, farmland was the largest conversion source, with a proportion of 32.89%, followed by bare land accounting for 5.32%. The main conversion sources for bare land were water area and farmland, accounting for 24.11% and 35.72%, respectively.

Table 5 shows the land-use changes in Nanchang from 2017 to 2023. The loss proportion of water area was 40.07%, with the main conversion targets being farmland and bare land, accounting for 12.07% and 19.90%, respectively. For farmland, 63.75% remained unchanged, and 24.61% was converted to construction land. For construction land, 87.18% remained unchanged. The main conversion targets of bare land are construction land and farmland, accounting for 40.84% and 22.35%, respectively. From the perspective of gain volume of land-use types, the main source converting into water area was farmland, accounting for 13.36%. For construction land, farmland was the largest conversion source, with a proportion of 37.37%. This indicates that Nanchang experienced a high-speed urban expansion during the six years by reducing agricultural land. The main conversion source for forest land was farmland. The main conversion sources for bare land were water area and farmland, accounting for 42.11% and 26.52%, respectively.

Table 7. Changes in farmland landscape indices of Nanchang from 2017 to 2023.

Period	NP	PD	ED	MPS	MSI	AWMSI	FS
2017 → 2020	135.74%	135.74%	56.80%	-57.80%	-3.95%	18.90%	-24.73%
2020 → 2023	138.08%	45.72%	-15.65%	-68.61%	1.87%	-39.19%	15.22%
2017 → 2023	461.24%	243.52%	32.25%	-86.75%	-2.16%	-27.70%	-13.27%

Table 8. Landscape indices of Nanchang's built-up land in 2023 with diverse segmentation methods.

Algorithm	Feature Type	NP	PD	ED	MPS	MSI	AWMSI
FGMCN-SPP	Housing	1704	0.2198	9.7675	78.5383	1.4015	21.6343
	Road	2166	0.2794	4.4329	5.6411	1.5883	3.6589
	Water	60	0.0077	0.0919	3.839	1.4987	1.8082
	Vegetation	953	0.1229	2.3945	9.603	1.5437	4.0046
	Bare Land	35	0.0045	0.0644	3.839	1.4987	1.8082
SAM	Housing	316916	27.1042	44.3518	0.1937	1.2854	3.124
	Road	146100	12.4952	8.9612	0.035	1.2594	3.157
	Water	19865	1.699	1.2226	0.0403	1.2483	2.3573
	Vegetation	87950	7.5219	9.9904	0.1512	1.2803	2.7374
	Bare Land	5424	0.4639	0.241	0.0193	1.2213	2.7069

3.3 Spatiotemporal Change of Agricultural Land Standards in Nanchang

Using ArcGIS tools and Fragstats, landscape index analysis was conducted on the farmland data of Gaofen-1 satellite after primary classification, including Number of Patches (NP), Patch Density (PD), Edge Density (ED), Mean Patch Size (MPS), Mean Shape Index (MSI), Area-Weighted Mean Shape Index (AWMSI), and Fragmentation Index (FS). The values of farmland landscape indices in Nanchang are shown in Table 6. The changes in farmland landscape indices are presented in Table 7.

Conclusions are drawn by analyzing the scores in Table 6 and Table 7.

1) From the perspective of the Number of Patches (NP) of farmland, the number of farmland patches in Nanchang increased year by year, with a total growth proportion of 461.24%. This indicates that the farmland in Nanchang was gradually divided as the number of patches increased and the flatness decreased.

2) From the perspective of Patch Density (PD) of farmland, the number of farmland patches per unit area in Nanchang increased significantly, with a total growth rate of 243.52%, which was consistent with the change trend of the number of farmland patches. This indicates that the fragmentation degree of farmland in Nanchang increased year by year.

3) Edge Density (ED) is also an important indicator of the fragmentation degree of patches. However, the ED of Nanchang showed different change trends between 2017–2020 and 2020–2023, increasing first and then decreasing, with an overall increasing trend from 2017 to 2023.

4) Mean Patch Size (MPS) is a basic indicator for evaluating whether the farmland in the study area is suitable for agricultural mechanization. However, the MPS of farmland in Nanchang gradually decreased, from 24.4478 in 2017 to 3.2390 in 2023, with a change rate of -86.75%. This directly reflects that the fragmentation degree of farmland in Nanchang changed significantly, affecting the level of agricultural mechanization.

5) Both Mean Shape Index (MSI) and Area-Weighted Mean Shape Index (AWMSI) represent the complexity of patch shape, and more complex patch shapes lead to higher farming costs. Between 2017–2020 and 2020–2023, the MSI of farmland in Nanchang did not change significantly, while the AWMSI changed significantly, increasing first and then decreasing from 2017 to 2023, but showing an overall downward trend. The AWMSI of farmland in

Nanchang showed an overall downward trend from 2017 to 2023, indicating that the shape of farmland patches became more regular over time, which may help reduce farming costs.

6) Fragmentation Index (FS) can directly reflect the fragmentation degree of farmland. The FS of farmland in Nanchang showed a trend of first increasing and then decreasing, indicating that the intensity of farmland consolidation increased from 2020 to 2023.

When the indicators are used to evaluate high-standard farmland, the changes indicate that Nanchang has slowed down the construction of high-standard farmland in recent years.

3.4 Pattern Analysis of Construction Land in Nanchang

In this section, secondary classification of construction land in Nanchang was conducted with FGMCN-SPP, and landscape indices were used to analyze the construction land in Nanchang. Fragstats software was used to calculate the landscape indices, and the relevant landscape indices of construction land in Nanchang are shown in Table 8.

An attempt was also made to use the Segment Anything Model (SAM) for segmentation. Although it is easy to use, the results of SAM lack labels. To accomplish the semantic segmentation, the segmentation results of SAM were provided with labels for each patch through additional data labeling and neural network training. Using the final SAM segmentation results, a second landscape index calculation was conducted, which is included in Table 8 for reference. Unfortunately, our findings are consistent with those reported in several studies [7, 8], namely that the original SAM is not well-suited for the segmentation of satellite imagery. The data show that the segmentation by SAM is significantly finer, reflected in more fragments in the image, which is not suitable for the residential environment in China that takes residential communities as the unit. Therefore, the results of secondary FGMCN-SPP classification were used for subsequent analysis.

To more accurately understand the current development status of Nanchang and provide forward-looking guidance for its long-term development, it is necessary to compare Nanchang with other cities using the same algorithm, which will be presented in the next section.

4 Comparison of Urban Patterns between Nanchang and Sydney Metropolitan Area

Comparing the land-use situation of Nanchang with that of international metropolises from the perspective of landscape pattern can help identify gaps and point out the direction for Nanchang's subsequent development. Considering the area and population, the Sydney Metropolitan Area in Australia was selected as the comparison city. The comparison was conducted through land use and landscape indices, and the development direction of Nanchang was proposed from the perspective of urban construction pattern.

4.1 Basic Information of the Sydney Metropolitan Area

According to data from the Australian Bureau of Statistics (https://www.abs.gov.au), the Sydney Metropolitan Area had a permanent population of 5.2311 million in 2021, covering an area of 12,368.68 km^2, with a per capita gross domestic product (GDP) of approximately 80,000 Australian dollars (about 53,000 US dollars). The scope of the Sydney Metropolitan Area selected in this study includes the surrounding cities centered on Sydney, New South Wales, Australia (excluding sparsely populated areas such as Wollondilly, Blue Mountains, Hawkesbury, Gosford, and Wyong), covering an area of 5,416.58 km^2, as shown in Figure 5. The satellite images covering the Sydney Metropolitan Area have a spatial resolution of 2 m, with data sourced from Google Maps satellite data, obtained through QGIS and Google Tile Maps. The data size is 42019×54348 pixels, with an effective area of 5,377.7 km^2. It can be seen that the Sydney Metropolitan Area and Nanchang are comparable in terms of area and population, but there is a large gap in economic development.

4.2 Comparison between Nanchang and Sydney Metropolitan Area

4.2.1 Land-Use Comparison

The land-use classification results for the Sydney Metropolitan Area are presented in Figure 6, which clearly illustrates the spatial distribution of various land-cover types. In this classification, green space encompasses both forested areas and grasslands. As farmland is absent in the study area, it is not treated as a separate category. Overall, the Sydney Metropolitan Area is predominantly characterized by vegetation and built-up regions, with water bodies occupying a relatively small proportion. The river systems in

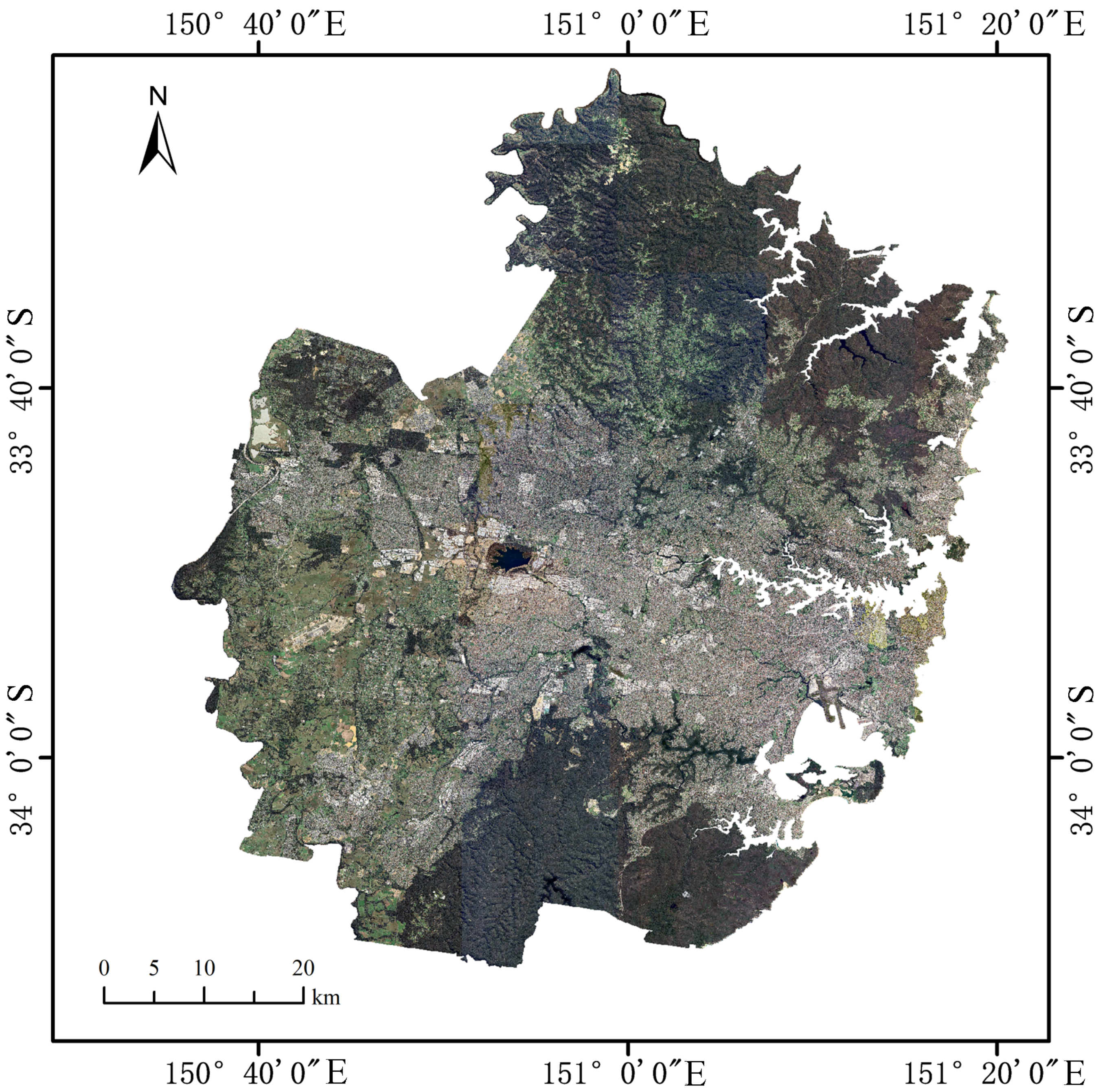


Figure 5. Sydney Metropolitan Area.

the area are primarily extensions of the ocean that penetrate inland.

Based on the land-use classification results and image spatial resolution, the area and proportion of each land type in the Sydney Metropolitan Area were obtained and directly compared with those of Nanchang, as shown in Table 9. Nanchang has higher proportion of industrial land, while the built-up land in Sydney is mainly used for individual housing. Compared with Sydney, Nanchang may improve its pattern by increasing vegetation and reducing unused bare land. The main land use in Sydney is for vegetation, followed by housing construction and roads. This forms a sharp contrast with Nanchang's farmland and water area, and the built-up area of Sydney is much larger than that of Nanchang.

4.2.2 Comparison of Landscape Indices

To explore the landscape differences between Nanchang and the Sydney Metropolitan Area, this section uses Fragstats to calculate relevant landscape indices and compares them with the landscape indices of the secondary classification results of Nanchang's

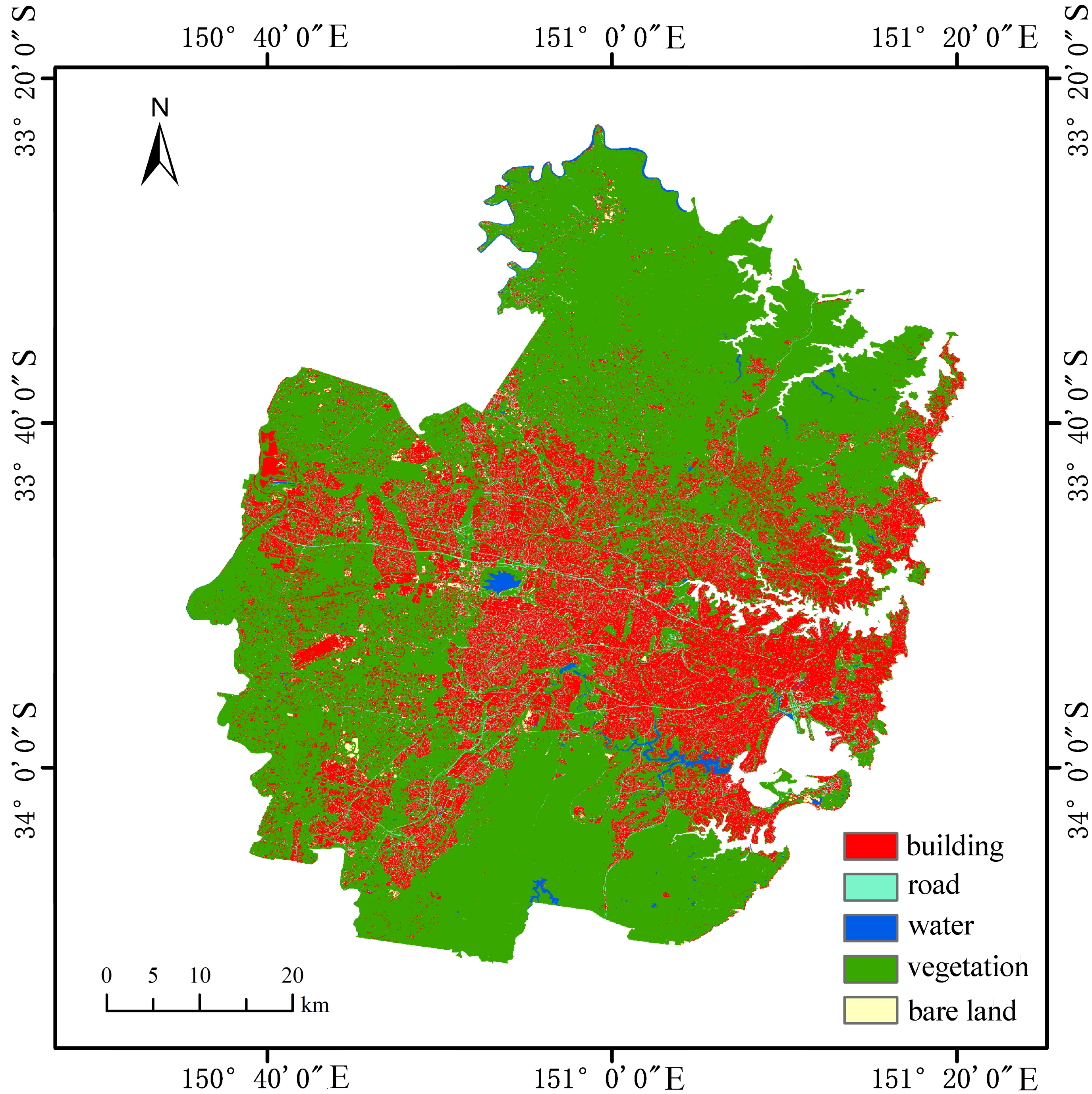


Figure 6. Classification results of land-use features in the Sydney Metropolitan Area.

Table 9. Comparison of land use between Sydney and Nanchang in 2023.

Sydney			Nanchang		
Category	Area (km^2)	Proportion	Category	Area (km^2)	Proportion
Housing	1507.73	28.04%	Construction Land	2300.26	31.99%
Road	337.70	6.28%	Farmland	2597.46	36.12%
Water Area	48.86	0.91%	Water Area	756.23	10.52%
Vegetation	3442.29	64.01%	Forest Land	1050.14	14.60%
Bare Land	41.11	0.76%	Bare Land	486.96	6.77%

construction land. The index comparison is shown in Table 10.

The combination of Number of Patches (NP) and Patch Density (PD) can accurately identify the fragmentation

Table 10. Landscape index comparison of built-up land between Sydney and Nanchang in 2023.

City	Feature Type	NP	PD	ED	MPS	MSI	AWMSI
Sydney	Housing	4348	0.4759	18.9203	35.5931	1.7156	13.1084
	Road	5877	0.6432	12.0805	5.9005	1.6769	10.1166
	Water Area	2974	0.3255	1.3778	1.5896	1.2362	3.4199
	Green Space	716	0.0784	9.9442	477.2052	1.7006	19.8601
	Bare Land	304	0.0333	0.4881	6.2016	1.5235	2.2564
Nanchang	Housing	1704	0.2198	9.7675	78.5383	1.4015	21.6343
	Road	2166	0.2794	4.4329	5.6411	1.5883	3.6589
	Water Area	60	0.0077	0.0919	3.839	1.4987	1.8082
	Green Space	953	0.1229	2.3945	9.603	1.5437	4.0046
	Bare Land	35	0.0045	0.0644	3.839	1.4987	1.8082

types of urban spatial patterns, avoiding the biases that arise from relying on a single indicator. For land use types in Sydney except vegetation, NP and PD are generally significantly higher than those in Nanchang, reflecting that Sydney's urban space is more fragmented, while Nanchang's land use is more contiguous and has higher spatial integration. The high NP and PD values of Sydney's housing and road land reflect the narrow street and dense road network, as well as the decentralized residential pattern formed through historical development. In contrast, Nanchang's construction and road land feature centralized residential clusters and a wide-road network with strong functional aggregation. Overall, Sydney tends to follow a decentralized, small-scale development model, presenting a pattern of natural evolution and functional dispersion. Conversely, Nanchang leans toward centralized, large-scale development, where contiguous residential area, roads, and ecological land have been formed under planning guidance, embodying an intensive urban pattern.

From the perspective of Edge Density (ED), the ED of housing, roads, green space, and bare land in Nanchang's construction land is lower than that in the main region of the Sydney Metropolitan Area. Taking roads as an example, the ED of roads in Nanchang's construction land is 4.4329, while that in the main region of the Sydney Metropolitan Area is 12.0805. This indicates that the road network density in the main region of the Sydney Metropolitan Area is higher than that in Nanchang.

From the perspective of Mean Patch Size (MPS), the MPS of housing and roads in Nanchang's construction land is higher than that in the main region of the Sydney Metropolitan Area, while the MPS of water area and bare land is lower. Taking housing as an example, the MPS of housing in Nanchang's built-up land is 78.5383, while that in the main region of the Sydney Metropolitan Area is 35.5931. Combined with the ED indicator, this reflects that the construction layout of Nanchang is centralized, while that of Sydney is distributed.

From the perspective of Mean Shape Index (MSI), the MSI of housing, roads, water area, and green space in Nanchang's built-up land is not significantly different from that in the Sydney Metropolitan Area. Taking housing as an example, the MSI of housing in Nanchang and the Sydney Metropolitan Area is 1.4015 and 1.7156 respectively.

From the perspective of Area-Weighted Mean Shape Index (AWMSI), the AWMSI of housing, roads, water area, green space, and bare land in Nanchang's built-up land is lower than that in the main region of the Sydney Metropolitan Area. Taking roads as an example, the AWMSI of roads in Nanchang's built-up land is 3.6589, while that in the main region of the Sydney Metropolitan Area is 10.1166. This indicates that the blocks in Nanchang are more regular than those in the core region of the Sydney Metropolitan Area.

4.3 Discussion on Nanchang's Future Development Direction

The significant differences between two cities can be observed through the pattern comparisons of the two cities. Nanchang is an emerging industrial city with well-developed agriculture, abundant freshwater resources such as rivers and lakes, and a high population density. Sydney is a post-industrial city driven by finance, tourism, education, information technology, etc., with a low population density. Considering their respective development stages and urban positioning, the following suggestions for Nanchang's urban construction are put forward based on the urban pattern comparison.

1) Bare land is reduced to avoid soil erosion and waste of land resources.

2) Green vegetation is increased.

3) Land use efficiency of industrial zones is improved.

4) Smart indoor agriculture is developed to reduce the proportion of cultivated land on the premise of food security.

5) High-density housing is restricted to improve residential quality.

The essence of the above suggestions is to improve the livability of the city to attract high-tech talents required by advanced technologies such as aviation, new energy, and electronic information that Nanchang focuses on promoting. Currently, Nanchang University is the only research university in Nanchang. In contrast, the Sydney Metropolitan Area has internationally renowned science and engineering universities such as the University of Sydney, the University of New South Wales, and the University of Technology Sydney. Without inherent advantages in talent and funding, Nanchang can attract spillover talents from China's first-tier cities by offering a higher quality of life through forward-looking urban planning, including well-designed low-density residential areas, abundant green space, and high-quality medical and educational resources.

In addition, it is suggested that the metropolitan area should be divided into layers by function rather than by administrative divisions. The entire Sydney Metropolitan Area is divided into three parts: the eastern part focuses on financial services, the central part focuses on medical care, education, and manufacturing, and the western part focuses on aviation and logistics. The Sydney Metropolitan Area is comparable to Nanchang in terms of area and population. However, the Nanchang metropolitan area planned by government covers a total area of more than 45,000 km^2 and a total population of over 18 million. A huge metropolitan area calls for huge amount of funds and talents, such that the goal of high-quality development cannot be approached. Moreover, from an international perspective, metropolises are more of a regional economic concept rather than an administrative concept. Therefore, this study proposes to divide the metropolitan area into layers according to functional planning, and form an agglomeration effect to reduce the cost of the industrial chain.

4.4 Limitations of the Comparative Framework

This study selected Nanchang and Sydney for cross-regional comparison, with the core objective of revealing the differentiated characteristics of land use pattern evolution under two urban morphologies: the high-density compact type and the low-density sprawling type. In the study, Sydney is a diverse example and should not be treated as a development benchmark or template for inland Chinese cities such as Nanchang. It is important to explicitly note that the direct comparison between the two cities has inherent limitations, stemming from their fundamental differences in urban typology, cultural context, and development stage. As a developing inland city, Nanchang is characterized by a vertical growth model and high-density superblocks, with significant disparities from Sydney in population density (approximately 2,000 people/km^2), urbanization dynamics (primarily policy-driven), and topographic conditions (surrounded by mountains in the periphery). In contrast, Sydney, as a developed city, features low-density detached housing and sprawling expansion, with population density (approximately 400 people/km^2), economic structure (service-dominated), and the shaping effect of coastal terrain on urban spatial patterns being essentially different from those of Nanchang. Without normalization of key variables such as population density, topography, economic structure, and cultural background, the comparison results cannot be directly used to evaluate the differences of the land use patterns of the two cities, nor can they simply lead to the conclusion that Nanchang should align with Sydney's development model.

Despite the limitations, the comparison between the two cities still holds reference significance. Theoretically, from the perspectives of the Compact City Theory and Urban Morphology Theory, the comparison of Nanchang and Sydney can be regarded as a case of urban morphological differentiation driven by the combined effects of institutions, culture, and development stages. It reveals the influence mechanisms of different development models on farmland fragmentation, built-up land intensification, and landscape pattern stability, thereby providing empirical support for understanding the diversity of urban spatial evolution on a global scale. Practically, the comparison results can help Nanchang break through the cognitive limitation of a single development path by drawing on Sydney's experience in landscape ecological maintenance under the low-density morphology. The problems in farmland protection are possibly solved by the quick developing technologies on smart indoor agriculture to conserve land for large-scale production. This provides a diversified reference for Nanchang's future spatial planning featuring predominantly compact development with appropriate decentralization, rather than implying a replicable reference.

5 Conclusions

Using satellite remote sensing data and landscape ecology indices, this study analyzed the current status and changes of Nanchang's spatial pattern in 2017, 2020, and 2023, and compared it with the Sydney Metropolitan Area in Australia. Through methods such as land-use transfer matrix, land-use change map, land-use fluctuation map, and land-use change dynamic, the spatiotemporal evolution process of land use in Nanchang from 2017 to 2023 was systematically analyzed. With the Sydney Metropolitan Area as a reference, the gaps between Nanchang and international metropolises were analyzed from the macro perspective and land-use landscape perspective, providing insights and suggestions for Nanchang's future planning and sustainable development.

Data Availability Statement

Data will be made available on request.

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Conflicts of Interest

The authors declare no conflicts of interest.

AI Use Statement

The authors declare that no generative AI was used in the preparation of this manuscript.

Ethical Approval and Consent to Participate

Not applicable.

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