Analysis of land use change and its driving forces in Nanjing metropolitan area

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Abstract. As the earliest inter-provincial metropolitan area started to be built in China, the Nanjing metropolitan area has become an important issue worthy of study in this region after 20 years of development. In order to quantify the characteristics of land use change and its driving factors, ArcGIS was used to calculate the land use transfer matrix and analyze the land use change in Nanjing metropolitan area for two time periods from 2000 to 2010 and 2010 to 2020, and the driving factors of land use change in the study area were explored by the method of principal component analysis. The results show that the Nanjing metropolitan area is dominated by arable land, forest land and water bodies, which account for more than 80% of the total area; the area of arable land decreases significantly and the area of construction land continues to increase during the study period, and the area of arable land transformed into construction land is the most numerous among the land use change types. The increase in population, socio-economic development and changes in climatic factors are the main driving factors for land use type conversion in the Nanjing metropolitan area. This study provides a theoretical basis for the sustainable and high-quality development of land resources and the coordinated development of human-land relations in the Nanjing metropolitan area.

Keywords: land use/LUCC, Nanjing metropolitan area change, spatial analysis, remote sensing turnover.

1. Introduction

The development and changes of the natural geographical environment are deeply influenced by human activities, and land use is one of the most direct manifestations of human activities [1]. The spatial and temporal dynamics of land use can visually reflect the transformation of the land surface state by human activities. Since the 1980s, international scientific organizations have turned their attention to global system change and carried out various programs to study it in depth, the most representative ones being the International Geosphere Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP). The study of land use change is a necessary part of these programs, and since then, land use/cover change (LUCC) research has become more and more widespread and has gradually become a core component of global environmental change research [3]. feedback [4-5]. Conducting research on land use change is of great significance to the sustainable use of human land resources and scientific configuration of land use patterns in the future.

Since the reform and opening up, the rapid development of China's economy and society has had a significant impact on the spatial pattern of land use and its changes, so the research on land use change has been a key research project. Based on the land use data of the Yellow River Basin during 1995-2018, Huang Yuqing et al [6] explored the driving forces affecting the changes by analyzing the spatial and temporal characteristics of land use in the Yellow River Basin and found that meteorology, economy and policy were the three main driving forces of land use changes in the study area. Shi Han et al [7] revealed the characteristics and patterns of land use changes in Jilin Province over 40 years from 1980-2017 by analyzing land use data from Jilin Province, providing a basis for land resource use adjustment, ecological environmental protection, and overall development in Jilin Province. Xiao S. et al [8] used land use data of three different time periods from 1980 to 2005 in the Taihu Lake Rim area of Jiangsu Province to obtain the quantitative change characteristics of land use and the spatial transformation characteristics of use types, and compared them to find that the change characteristics

of each time period have obvious regional differences, and some human economic activities bring great challenges to regional agricultural development and sustainable development of land resources. Zhou Guosheng et al [9] and Qin Kangyu et al [10] analyzed the characteristics of land use changes in the study area using remote sensing images of Suqian City Phase 2 and Jiangnan District of Nanning City Phase 3, respectively, in which economic factors were all the main drivers of land use changes.

Nanjing metropolitan area, as the earliest inter-provincial metropolitan area planned and constructed in China, plays an important role in the construction of the Yangtze River Delta city cluster, and has achieved certain results in the development of the regional economic association since it was proposed in 2000, but problems such as the slightly lack of radiation capacity of the central city, the existence of strong administrative barriers within the metropolitan area, the convergence of industrial structures, and the difficulty of coordinating resource allocation are all restricting, to varying degrees, the economic development of the region to varying degrees [11-12]. At present, a large number of studies have focused on the Yangtze River Delta urban agglomeration, but few studies have focused on the Nanjing metropolitan area, an important fulcrum of the Yangtze River Delta urban agglomeration. This study investigates the spatial and temporal changes in land use and its driving forces in the Nanjing metropolitan area during 2000-2020 from the perspective of geography, with the aim of providing theoretical references for economic development, industrial collaboration, and regional planning in the Nanjing metropolitan area.

2. Overview of the study area

Nanjing metropolitan area is located in the core area of the Yangtze River Delta city group on the east coast of China, with Nanjing as the center across Jiangsu and Anhui provinces, including five cities in Jiangsu, Nanjing, Changzhou, Yangzhou and Huai'an, and four cities in Anhui, Maanshan, Chuzhou Xuancheng and Wuhu, a total of nine prefecture-level cities, proposed by Jiangsu Province in 2000 to build. The geographical coordinates of Nanjing metropolitan area range from 117°10′ to 119°58′ east longitude and 30°95′ to 34°06′ north latitude, covering an area of 654,215,400 square kilometers. The climate of the region belongs to the north subtropical monsoon climate, with four distinct seasons, pleasant climate and abundant rainfall, the average annual temperature is about 16.5℃, and the average annual precipitation is 769.63-1008.65mm. As of 2020, the study area has a registered population of 36,202,800 and a regional gross domestic product of 4,749,659 billion yuan. As the first inter-provincial metropolitan area in China officially approved by the National Development and Reform Commission for planning, the Nanjing metropolitan area has formed an economic regional belt with Nanjing as the center and the provinces of Jiangsu and Anhui for joint development since it was proposed. With the rapid development of economic synergy, the urban clusters in the region are closely connected by the developed transportation network, and the land use pattern is changing to diversification while the land use structure is also rapidly adjusting.

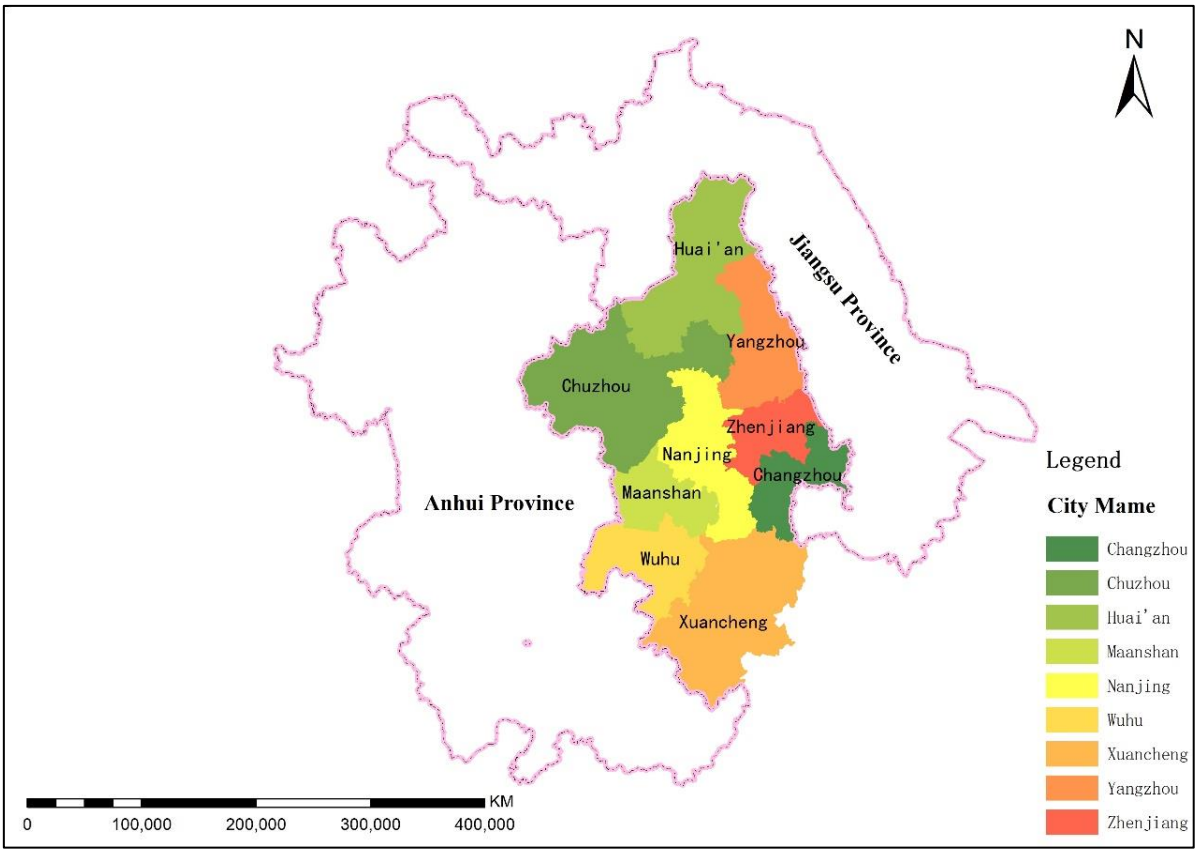


Figure 1. Administrative division of Nanjing metropolitan area

3. Data sources and research methods

3.1. Data sources and classification methods

The land use data of Nanjing metropolitan area were obtained from the GlobeLand30 remote sensing images of 3 issues in 2000, 2010 and 2020, and the boundary vector data of the study area were obtained from the Resource and Environment Science Data Center of Chinese Academy of Sciences (http://www.resdc.cn/), and the statistical data were obtained from the Statistical Yearbook of Jiangsu Province and the Statistical Yearbook of Anhui Province. The images were processed by ArcGIS software to obtain the current land use map of Nanjing metropolitan area. Land use types, including eight classifications of arable land, forest land, grassland, water bodies, shrubs, wetlands, man-made surface, and bare land.

Table 1. Comparison table of land use type classification

Code	10	20	30	40	50	60	80	90
Type of land use	Arable land	Woodland	Grassland	Shrubs	Wetlands	Water bodies	Artificial surface	Bare ground

3.2. Research Methodology

3.2.1 Magnitude of land use change

The magnitude of land use change (Q) refers to the change in the area of land use types at a certain time period. There are various angles to study the types of land use change, and calculating the magnitude of land use change can compare the range of change of each land use type in the same period, reflect the change of different types of land in the total, and help to understand the change of land use structure and the general dynamics of land use change. The expressions are:

$$Q=\frac{V_b-V_a}{V_a}\times 100\% \quad (1)$$

P is the magnitude of land use change, V_a indicates the number of a land use type at the beginning of the studyV_b indicates the amount of the corresponding type of land use at the end of the study.The magnitude of land use change is calculated in a ten-year cycle between 2000 and 2020, and the comparison shows the development of land use type change in different periods.

3.2.2 Land use dynamic attitude

Land use dynamics (K) refers to the change in the quantity of a certain land use type in a certain study area within a certain time frame, reflecting the rate of change of a certain land type within the study time frame of the area, with the formula：

$$\mathrm{K} = \frac{V_b - V_a}{V_a} \times \frac{1}{\mathrm{T}} \times 100\% \quad (2)$$

K is the dynamic attitude of land use types; T is the study duration, and when the period of T is year, the value of K is the annual change rate of a certain land use type in the study area. By calculating the dynamic attitudes of different land use types in the two periods of 2000-2010 and 2010-2020 in Nanjing metropolitan area, the characteristics of quantitative changes and change trends of land use degree in the study area are characterized, reflecting the depth and breadth of different types of land use on the one hand and the comprehensive influence of land use changes by driving factors on the other.

3.2.3 Principal component analysis

There are many factors affecting regional land use change, and although it is difficult to cover all aspects, it is important to select as comprehensive as possible the indicators affecting the driving factors from them. The problem is that all the selected indicators have different degrees of correlation, which is prone to the problem of multivariate covariance and makes the correct results impossible to be analyzed. Based on this, the principal component analysis method can effectively solve this problem.

By combining the indicators reflecting the overall information through linear transformation and using the combined principal components instead of the original variables, the problem of multi-collinearity among variables can be avoided without losing the main information. At the same time, the principal component analysis method does not have strict requirements on sample size, which is ideal for doing land use change driver analysis. The F1 with the largest variance among all linear combinations is selected as the first principal component, and if the first principal component is not sufficient to represent the information of the original n indicators, the second linear combination F2, the second principal component, is selected again, and so on.

$$F_p = a_{1i} * Z_{X1} + a_{2i} * Z_{X2} + \cdots + a_{pi} * Z_{Xp} \quad (3)$$

a_{1i}, a_{2i}, …… a_{pi} (i=1,……,m) is the eigenvector corresponding to the eigenvalues of the covariance array $\sum$ of X, $Z_{X1}, Z_{X2}, \ldots\ldots, Z_{Xp}$ is the normalized value of the original variable.

4. Results and Analysis

4.1. Spatial distribution pattern and transfer characteristics of land use in Nanjing metropolitan area from 2000 to 2020

Using ArcGIS, a spatial distribution map of land use in Nanjing metropolitan area in different periods was produced (Figure 2). It can be seen that the main land uses in Nanjing metropolitan area are arable land, forest land and water bodies, among which the area of arable land occupies the most and is the dominant area of arable land. The arable land is widely distributed in the whole area, and the southern part of the study area is more sparse, with the arable land area accounting for 66.41%, 64.55% and 59.18% of the total area of the study area in 2000, 2010 and 2020, respectively; it can be seen that the arable land area in Nanjing metropolitan area has a decreasing trend from 2000 to 2020, with the arable land area on both sides of the Yangtze River in the study area decreasing more; the

forest land is mainly concentrated The area of forested land is mainly distributed in the southern part of the study area, accounting for 16.25%, 16.29% and 15.97% of the total area of the study area in 2000, 2010 and 2020, respectively, and the overall change of the area and proportion of forested land is not significant and remains at a stable level. The proportion of water bodies was 8.22%, 9.13% and 9.38% in 2000, 2010 and 2020, respectively, and the area of water bodies steadily maintained a small increase during 2000-2020.

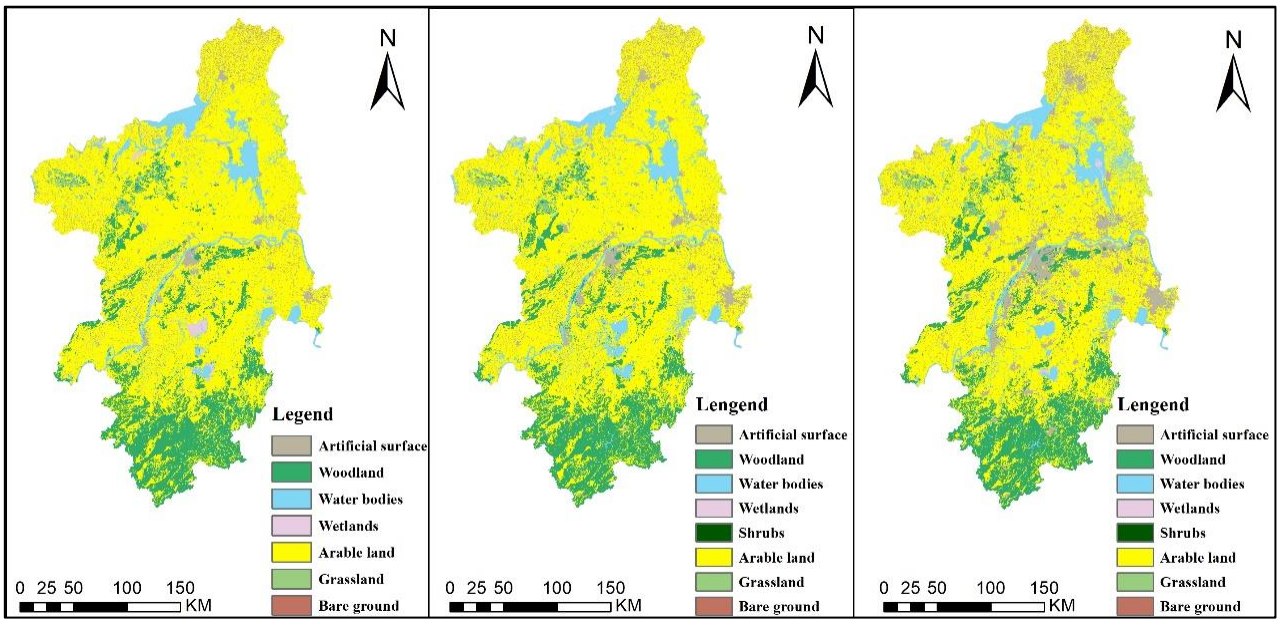


Figure 2. Nanjing Metropolitan Area Land Use

4.2. Land use dynamics in Nanjing metropolitan area from 2000 to 2020

From 2000 to 2020, the land use of Nanjing metropolitan area has undergone obvious changes, and when discussed in two periods before and after ten years, it can be found that the changes in the before and after ten years are also different.

During 2000-2010, the basic characteristics of land area change in Nanjing metropolitan area are: the area of arable land is obviously decreasing, while the area of forest land, grassland, water bodies and man-made surfaces are increasing in different degrees. The largest changes in the amount of arable land and man-made surfaces were observed, with the area of arable land decreasing by 1257.57 km^2 and the area of man-made surfaces increasing by 941.06 km^2.

During 2010-2020, the basic characteristics of land area changes in Nanjing metropolitan area are: the area of arable land continues to decrease significantly by 3625.83 km^2; the area of forest land and grassland are decreasing but at a smaller rate, decreasing by 221.54 km^2 and 16.16 km^2 respectively, with a change rate of -0.2% and -0.12%; the area of water bodies, man-made surfaces and other land areas increase, with an area The area of water bodies, man-made surface and other land increased by 170.03 km^2, 3553.22 km^2 and 140.66 km^2, respectively, and the area of man-made surface increased significantly, with a change rate of 8.04%.

Table 2. Annual change in land use in Nanjing metropolitan area, 2000-2020

Time	2000		2010		2020		2000-2010	2010-2020
Land type	Area km^2	Proportion	Area km^2	Proportion	Area km^2	Proportion	Rate of change	Rate of change
Arable land	44861.91	66.41%	43604.34	64.55%	39978.51	59.18%	-0.28%	-0.83%
Wood land	10978.97	16.25%	11007.49	16.29%	10785.95	15.97%	0.03%	-0.20%
Grass land	1282.02	1.90%	1313.74	1.94%	1297.58	1.92%	0.25%	-0.12%
Water bodies	5555.67	8.22%	6166.13	9.13%	6336.16	9.38%	1.10%	0.28%
Artificial surface	4346.68	6.43%	5287.74	7.83%	8840.96	13.09%	2.17%	6.72%
Other Sites	529.47	0.78%	174.95	0.26%	315.61	0.47%	-6.70%	8.04%

In general, the basic characteristics of land area changes are: the area of forest land and grassland have shown a trend of first increasing and then decreasing, the area of water bodies and man-made surfaces are steadily increasing, and the man-made surfaces have obviously expanded and increased rapidly during the latter 10 years, corresponding to the continuous decrease of arable land area, and the deceleration is even greater in the latter 10 years, it can be seen that the rapid development of urbanization is positively correlated with the number of man-made surface areas, and negatively correlated with the number of It can be seen that the rapid development of urbanization is positively correlated with the amount of man-made surface area and negatively correlated with the amount of arable land; the small base of other land areas shows a trend of first decrease and then increase; the overall trend of balanced land use is increasing, and the land use structure of Nanjing metropolitan area tends to be homogeneous, and the increase and decrease of man-made surface area and agricultural land area are opposite and of equal magnitude; the degree of land use is increasing and the efficiency of land use is obviously improved.

4.3. Land use dynamic attitude

Based on the land use data of Nanjing metropolitan area in 2000 and 2010, 2010 and 2020, the land use transfer data were obtained and the transfer matrix was produced by overlay analysis with ArcGIS software, as shown in Table 3 and Table 4.

From Table 3, the main types of land use changes in Nanjing metropolitan area from 2000 to 2010 are forest to cropland, water body to cropland, cropland to forest, cropland to water body, and cropland to man-made surface. Among them, the area of cropland to man-made surface is the largest, followed by the area of cropland to water body and the area of water body to cropland. There are transfers in and out of both artificial surface and cropland, and there is a large net difference. The arable land area is shrinking, with a net transfer out value of 1275km^2; the man-made surface area is increasing, with a net value added of 941.35km^2, and is at the stage of urbanization development.

Table 3. Nanjing Metropolitan Area Land Use Transfer Matrix, 2000-2010

2000/2010 (km^2)	Arable land	Woodland	Grassland	Shrubs	Wetlands	water column	Artificial surface	Bare ground	Total	Transfer out
Arable land	41843.40	655.33	191.65	0.19	11.39	878.77	1276.81	1.73	44859.27	3015.87
Woodland	551.52	10201.93	28.76	0.23	12.50	149.21	33.36	0.02	10977.54	775.61
Grassland	33.06	60.67	1044.57		41.29	75.14	26.96	0.22	1281.91	237.34
Shrubs									0.00	
Wetlands	119.00	24.10	8.40		49.83	322.15	1.86	0.05	525.39	475.56
water column	661.26	54.71	35.81		51.97	4720.37	29.72	0.46	5554.29	833.92
Artificial surface	394.03	8.52	4.27	0.22	1.10	19.31	3918.89	0.03	4346.36	427.45
Bare ground	0.05	0.01	0.22			0.02	0.03	3.71	4.04	0.28
Total	43602.33	11005.27	1313.68	0.64	168.07	6164.97	5287.62	6.23		
Switch to	1758.92	803.34	269.11	0.64	118.24	1444.58	1368.70	2.52		

From Table 4, the main types of land use changes in Nanjing metropolitan area from 2010 to 2020 are water bodies to cropland, man-made surface to cropland, cropland to forest land, cropland to water bodies and cropland to man-made surface. Among them, the area of cropland to man-made surface is the largest, followed by the area of cropland to water bodies and the area of water bodies to cropland. The area of cultivated land continues to shrink, with a net transfer out value of 3,626.1 km^2, while the net increase in the area of man-made surface reaches 3,522.9 km^2, which leads to the conclusion that a large amount of cultivated land was converted to man-made surface during the period and is in the expansion phase of urban development.

Table 4. Nanjing Metropolitan Area Land Use Transfer Matrix, 2010-2020

2010/2020 (km^2)	Arable land	Woodland	Grassland	Shrubs	Wetlands	water column	Artificial surface	Bare ground	Total	Transfer out
Arable land	37586.11	546.65	138.04	0.01	32.38	1296.61	4000.33	1.72	43601.85	6015.74
Woodland	475.40	9983.34	187.39	0.10	3.54	125.07	228.23	1.91	11004.97	1021.64
Grassland	85.59	191.77	941.22	0.16	1.64	36.89	51.77	4.61	1313.65	372.43
Shrubs	0.00	0.35	0.10	0.17			0.02		0.64	0.45
Wetlands	30.64	0.51	1.40		74.18	59.62	1.72	0.00	168.07	153.51
water column	1053.70	45.99	18.49		191.28	4784.08	71.38	0.04	6164.96	1380.84
rtificial surface	743.40	15.76	9.72	0.00	0.65	31.41	4486.59	0.00	5287.52	800.93
Bare ground	0.91	0.16	1.13			0.48	0.36	3.18	6.23	3.05
Total	39975.74	10784.53	1297.49	0.44	303.67	6334.17	8840.39	11.46		
Switch to	2389.64	801.19	356.27	0.27	229.49	1550.08	4353.80			

4.4. Correlation analysis

The statistical data of 12 indicators of Nanjing metropolitan area from 2000 to 2020 were selected, and the statistical analysis software SPSS was used to conduct correlation analysis and derive the variable correlation coefficient matrix.

Table 5. Driving force evaluation index system

Target layer	Indicator layer	Variables
Driving force	**Household population (10,000 people)**	X1
	Total GDP (billion yuan)	X2
	GDP per capita (yuan)	X3
	Total industrial output value (billion yuan)	X4
	Total agricultural output value (billion yuan)	X5
	Total forestry output value (billion yuan)	X6
	Total output value of livestock industry (billion yuan)	X7
	Grain production (million tons)	X8
	Average temperature (degrees Celsius)	X9
	Annual precipitation (mm)	X10
	Road mileage (km)	X11
	Total power of agricultural machinery (million kilowatts)	X12

Due to the differences in the order of magnitude of the units of measure of the raw data of the variable factors, in order to make the results accurate and easy to calculate, the data were standardized and factor analyzed using SPSS27 analytical descriptive tool to finally obtain the correlation matrix between the factors.

Table 6. Correlation matrix of independent variable factors

	ZX1	ZX2	ZX3	ZX4	ZX5	ZX6	ZX7	ZX8	ZX9	ZX10	ZX11	ZX12
ZX1	**1.00**	**0.93**	**0.93**	**0.96**	**0.97**	**0.92**	**0.97**	**0.88**	**0.03**	**0.30**	**0.91**	**0.98**
ZX2	**0.93**	**1.00**	**1.00**	**0.99**	**0.98**	**0.98**	**0.94**	**0.79**	**0.22**	**0.35**	**0.85**	**0.96**
ZX3	**0.93**	**1.00**	**1.00**	**0.99**	**0.98**	**0.98**	**0.94**	**0.81**	**0.23**	**0.34**	**0.88**	**0.97**
ZX4	**0.96**	**0.99**	**0.99**	**1.00**	**0.99**	**0.98**	**0.97**	**0.85**	**0.16**	**0.34**	**0.90**	**0.99**
ZX5	**0.97**	**0.98**	**0.98**	**0.99**	**1.00**	**0.98**	**0.98**	**0.86**	**0.13**	**0.38**	**0.88**	**0.99**
ZX6	**0.92**	**0.98**	**0.98**	**0.98**	**0.98**	**1.00**	**0.94**	**0.78**	**0.25**	**0.43**	**0.83**	**0.95**
ZX7	**0.97**	**0.94**	**0.94**	**0.97**	**0.98**	**0.94**	**1.00**	**0.89**	**0.03**	**0.42**	**0.91**	**0.99**
ZX8	**0.88**	**0.79**	**0.81**	**0.85**	**0.86**	**0.78**	**0.89**	**1.00**	**-0.03**	**0.21**	**0.92**	**0.88**
ZX9	**0.03**	**0.22**	**0.23**	**0.16**	**0.13**	**0.25**	**0.03**	**-0.03**	**1.00**	**-0.05**	**0.09**	**0.10**
ZX10	**0.30**	**0.35**	**0.34**	**0.34**	**0.38**	**0.43**	**0.42**	**0.21**	**-0.05**	**1.00**	**0.32**	**0.39**
ZX11	**0.91**	**0.85**	**0.88**	**0.90**	**0.88**	**0.83**	**0.91**	**0.92**	**0.09**	**0.32**	**1.00**	**0.94**
ZX12	**0.98**	**0.96**	**0.97**	**0.99**	**0.99**	**0.95**	**0.99**	**0.88**	**0.10**	**0.39**	**0.94**	**1.00**

4.4.1 Principal component analysis

The KMO coefficient value and Bartlett's sphericity test were used to test whether the selected metrics met the requirements of the study. The results showed that the KMO value was 0.823 and Sig<0.01, both of which passed the one-time test, indicating that the sample size selected in this case met the requirements and was suitable for analysis.

Table 7. Total variance explained by factor analysis

Components	Initial Eigenvalue			Extraction of the sum of squares of loads		
	Total	**Percentage of variance**	**Accumulation %**	**Total**	**Percentage of variance**	**Accumulation %**
1	**9.54**	**79.53**	**79.53**	**9.54**	**79.53**	**79.53**
2	**1.10**	**9.18**	**88.72**	**1.10**	**9.18**	**88.72**
3	**0.89**	**7.39**	**96.11**			
4	**0.30**	**2.47**	**98.58**			
5	**0.08**	**0.63**	**99.21**			
6	**0.06**	**0.51**	**99.71**			
7	**0.02**	**0.14**	**99.86**			
8	**0.01**	**0.08**	**99.94**			
9	**0.01**	**0.04**	**99.98**			
10	**0.00**	**0.02**	**99.99**			
11	**0.00**	**0.01**	**100.00**			
12	**0.00**	**0.00**	**100.00**			

The variable rates that were significantly correlated at the 0.01 level (two-sided) in Table 7 were selected, and the number of principal components was determined by the method of factor minimum eigenvalue greater than one, and the maximum variance method was used for principal component rotation. After SPSS operation, two principal components meeting the extraction requirements were proposed, and their cumulative contribution rate reached 88.72%. After rotation by SPSS, the principal component loading matrices of factor loading on the two principal components were obtained for each variable (Table 8).

Table 8. Principal component loading table

Variables	**Principal component 1**	**Principal component 2**	**Indicator specification**
ZX1	**0.97**	**-0.09**	**Household population**
ZX2	**0.98**	**0.12**	**Total GDP**
ZX3	**0.98**	**0.12**	**GDP per capita**
ZX4	**0.99**	**0.05**	**Total industrial output value**
ZX5	**0.99**	**0.01**	**Total agricultural output value**
ZX6	**0.97**	**0.12**	**Total forestry output value**
ZX7	**0.99**	**-0.12**	**Total output value of livestock industry**
ZX8	**0.88**	**-0.16**	**Grain production**
ZX9	**0.14**	**0.96**	**Average temperature**
ZX10	**0.39**	**-0.30**	**Annual precipitation**
ZX11	**0.93**	**-0.06**	**Road mileage**
ZX12	**0.99**	**-0.03**	**Total power of agricultural machinery**

Among the variables with the first principal component factor loadings above 0.8, GDP, GDP per capita, gross output value of industry, agriculture, forestry and wood, and grain production reflect the degree of economic development, population reflects the demographic status, road mileage reflects the regional accessibility, and total agricultural machinery power reflects the degree of agricultural production intensification. Among the variables with the second principal component factor loading over 0.8, temperature reflects the agricultural production conditions.

4.4.2 Analysis of the main driving factors

(1) Population growth

From 2000 to 2020, the population of Nanjing metropolitan area increased from 31,510,300 to 36,202,800, an increase of 4,692,500 or 14.89%. The increasing population in the area has directly

stimulated the demand for residential land and food. 21 years, the construction land area of Nanjing metropolitan area increased by 4494.28 km^2, but the arable land area decreased from 44861.91 km^2 to 39978.51 km^2. The growth of urban population and the increase of man-made surface area encroached on the agricultural land area, which is the main reason for the decrease of arable land area. During the 10-year period of 2011-2020, the decrease in arable land area led to a decrease in food production in Nanjing metropolitan area during 2016-2020 compared with the usual food production in 2011-2015, and the average food production decreased by 510,500 tons; in terms of land resources, the population growth led to an increase in the demand for construction land expansion, and the rapid expansion of construction land brought continuous decrease in the amount of arable land, so the continuous increase in the number of population has brought serious challenges to the protection of arable land and food security in the Nanjing metropolitan area. The results of the analysis show that the rapid growth of the total household population and the rapid expansion of construction land area in the Nanjing metropolitan area during the study period of 2000-2020 led to a decrease in the amount of arable land, and the number of population was positively correlated with the area of construction land and negatively correlated with the area of arable land.

(2) Socio-economic development

The total GDP of Nanjing metropolitan area in 2000 was 358,007,000,000 Yuan, which increased to 474,959,000,000 Yuan in 2020, more than 13 times that of 2000, which shows that Nanjing metropolitan area is developing very rapidly. 2000-2020 economic factors of Nanjing metropolitan area are shown in Figure 3.

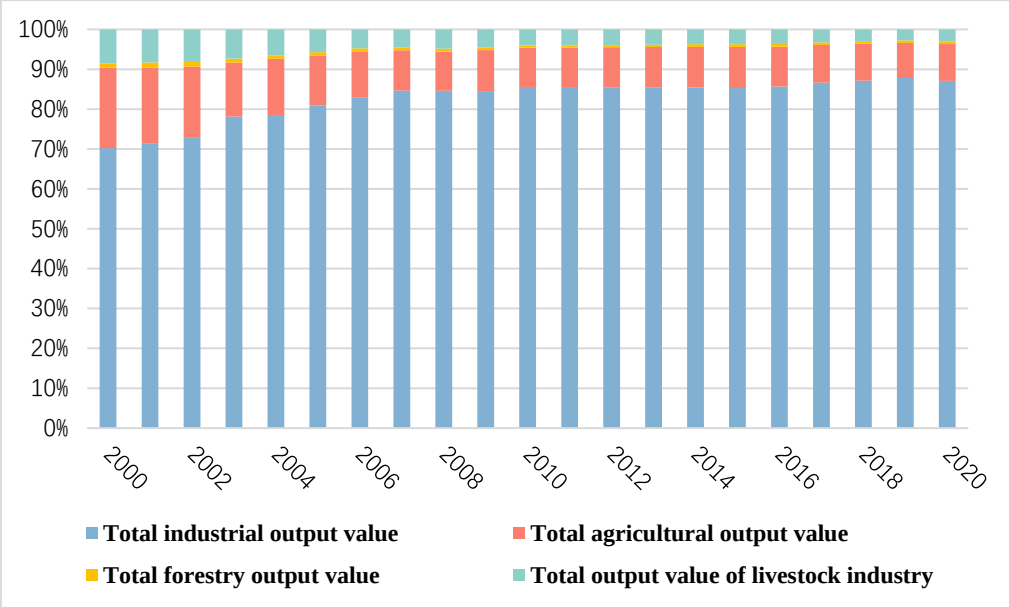


Figure 3. Economic factors of Nanjing metropolitan area, 2000-2020

As can be seen from Figure 3, from 2000 to 2020, the regional GDP, GDP per capita, industrial and agricultural output values of the Nanjing metropolitan area showed a yearly increase, and the output values of forestry and pastoralism showed a fluctuating upward trend. During the study period, industry accounted for the largest share of regional GDP in Nanjing metropolitan area, followed by agriculture and pastoralism, and forestry accounted for the smallest share, where the industrial output value was almost 10 times that of agriculture. Since Jiangsu province proposed to build the Nanjing metropolitan area centered on Nanjing in 2000, the region spans 66,000 square kilometers across the two provinces. To facilitate linkage development, the number of road miles within the jurisdiction has grown rapidly, from 28,300 kilometers in 2000 to 101,000 kilometers in 2020, and the scope of human production and life has been changing and expanding, so the land use structure of the study area is bound to A corresponding shift occurs, so there is a shift from arable land to construction land. However, people's requirements for quality of life are also increasing with economic development, and the construction of ecological civilization has gradually become a focus of attention, so the area

of forest land and water bodies has experienced a change process of decreasing in the first 11 years and increasing in the next 10 years during the study period.

(3) Climate change

Since entering the 21st century, influenced by global warming, the temperature and precipitation across the country have shown large changes, and the climate factors of Nanjing metropolitan area from 2000 to 2020 are shown in Figure 4.

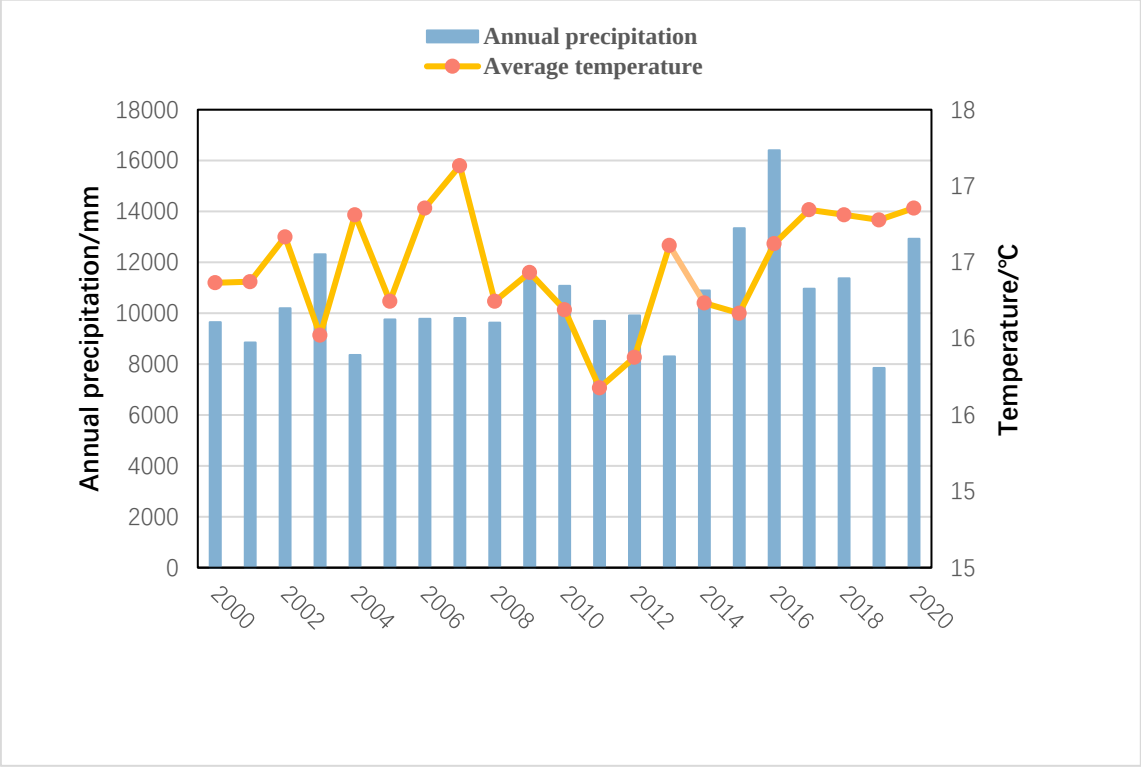


Figure 4. Climate factors in Nanjing metropolitan area, 2000-2020

As can be seen from Figure 4, the overall temperature in the Nanjing metropolitan area has a certain tendency to increase, with the annual average temperature fluctuating between 15.5 and 17.5°C. Precipitation fluctuates significantly, and the climate is characterized by frequent interannual droughts and floods. Comparing climatic factors with grain yield shows that grain yield is low in years with high average annual temperature and low precipitation, such as 2007, when the average annual temperature was the only year exceeding 17°C in 21 years and precipitation was low at 9813.2 mm, and grain yield was the lowest 15,239,900 tons in the upper and lower three years; however, grain yield is also lower in years with abnormally high precipitation (e.g., 2016), due to the Nanjing metropolitan area After 2010, grain yield is negatively correlated with the change in annual average temperature, with an upward trend in temperature fluctuations and a larger reduction in arable land area than during 2000-2010, indicating that frequent droughts and floods due to climatic factors of temperature fluctuations are also a major driver of the transformation of land use patterns in the Nanjing metropolitan area. This indicates that frequent droughts and floods caused by temperature fluctuations are also one of the main factors driving the transformation of land use patterns in Nanjing metropolitan area.

5. Conclusion and Discussion

5.1. Conclusion

The types of land use changes in Nanjing metropolitan area from 2000 to 2020 are complex and diverse. Analyzing the quantitative changes in land use area, spatial conversion characteristics and their driving factors, the following conclusions can be drawn:

(1) In terms of the overall land use structure, the Nanjing metropolitan area is dominated by the area of cultivated land and forest land, which accounts for more than 75% of the total area. During the study period, the quantity of arable land and man-made surface area changed most drastically, with the area of arable land decreasing and the area of man-made surface increasing, while the area of other land use types changed to a lesser extent. Within the Nanjing metropolitan area, the agricultural land use type is absolutely dominant.

(2) From the analysis of the current situation of land use, the spatial changes of each land type occurred to different degrees from 2000 to 2020, among which the area of arable land converted into man-made surface was the most, and the increase of man-made surface was concentrated in the surrounding areas of water areas such as river banks; it can be seen that during the 20 years of rapid economic and social development, the urbanization development of Nanjing metropolitan area dominated by agricultural land was quite effective, and mainly It is clear that the urbanization of Nanjing metropolitan area, which is dominated by agricultural land, has been successful during the 20 years of rapid economic and social development, and is mainly concentrated around rivers with convenient transportation and flat topography. The area of water bodies in the Nanjing metropolitan area, which is located within the Yangtze and Huaihe river basins, increased in 2020 compared to 2000, indicating that water bodies were consciously protected and restored during the urbanization development process.

(3) From the analysis of driving forces, population growth, socio-economic development and changes in climatic conditions are the main factors contributing to land use changes in the Nanjing metropolitan area. The spatial and temporal patterns of land use in the region are changing under the combined effect of socio-economic and natural factors. Population growth and socio-economic development lead to the need for expansion of the man-made surface, which occupies a large amount of arable land, resulting in less arable land area, but because there is a basic demand for the amount of arable land area due to population size, the overall reduction of arable land area at the beginning and end of the study period has a certain limit of 10.89%. The planned establishment of the Nanjing metropolitan area has had a great impact on the inter-provincial cooperation between Jiangsu and Anhui at the socio-economic level. The increase of 101,000 road miles means that the closeness of transportation links is greatly increased and in turn further supports and promotes the economic development and social progress within the metropolitan area, which eventually manifests itself in a large increase of the man-made surface area, which in 2020 compared to the year 2000 increased by 50.83% in 2020 compared to 2000.

5.2. Discussion

(1) The study of changes in land use types and their driving factors is conducive to resolving the contradiction between socio-economic development and the uneven allocation of land resources in various utilization modes, and is of great significance to the sustainable utilization of land resources and the construction of a healthy land pattern in the region. Combining the analysis of the actual situation in the study area with the research findings, it is recommended that in the process of future land resource utilization and management, the conversion and allocation of land for cultivation, forestry, grass and water bodies and the area of man-made surface land needed for economic and social development should be balanced, and the relationship between the expansion of land for urbanization and construction and the protection of arable land area, economic development and ecological protection should be handled, so as to ensure the rational development and scientific allocation of land resources, guarantee food security, and improve the construction and development of ecological civilization.

(2) For cross-provincial metropolitan areas such as Nanjing metropolitan area, land use is not only influenced by socio-economic factors in humanistic drivers, but also greatly interfered by various policies and systems, and even due to belonging to different provincial administrative regions, administrative barriers, different goals and characteristics of urban development, and differences in the degree of technological innovation can also have an impact on the conversion of land use types

brought about by the synergistic development of metropolitan areas, and such effects Although attention has been paid, it is difficult to overcome the difficulties of quantitative research, and the comprehensive consideration of quantitative research on the above-mentioned influencing factors should be strengthened.

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